ESTIMATION OF ECOSYSTEM CARBON STOCK AND TREE SPECIES DIVERSITY AT NATIONAL BOTANICAL GARDEN, DHAKA, BANGLADESH

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CERTIFICATE

This is to certify that the thesis entitled ***'ESTIMATION OF ECOSYSTEM CARBON STOCK AND TREE SPECIES DIVERSITY AT NATIONAL BOTANICAL GARDEN, Dhaka, Bangladesh'*** *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 (MS) IN AGROFORESTRY AND ENVIRONMENTAL SCIENCE****, embodies the results of a piece of bona fide research work carried out by* ***MD. DELWAR HOSSAIN, Registration No. 12-04845 under*** *my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

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

Dated: June 2018
Dhaka, Bangladesh

Prof. Dr. Md. Forhad Hossain
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DEDICATED

TO

MY BELOVED PARENTS

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ABSTRACT

Urban botanical garden plays an important role in mitigating hazards evolved due to climate change through sequestering atmospheric carbon dioxide. The study was conducted during the period of January to April 2018 to the estimation of ecosystem carbon stock and tree species diversity at National Botanical Garden, Dhaka, Bangladesh. Using transects line method square plots with a size of 20 m × 20 m were taken. So altogether there were total eighty three sample plot in National Botanical Garden. Above ground carbon (AGC) and below ground carbon (BGC) biomass stock was 192.67 and 31.34, respectively and soil organic carbon mean value of 27.52 Mg ha^{-1}, 21.45 Mg ha^{-1} and 16.23 Mg ha^{-1}, respectively for 0-10 cm depth, 10-20 cm and 20-30 cm depth. The average number of trees in National Botanical Garden (233 tree ha^{-1}), basal area (21.45 m^2 ha^{-1}) and mean DBH (39.86 cm). Tree diversity range from 0.25 to 1.86 and the mean value of (0.93 ± 0.14) in National Botanical Garden. Relationship such as biomass carbon with basal area, mean DBH, stem density and tree diversity were estimated. Among these the relationship between basal area and biomass carbon showed positive significant correlation. Therefore, the results of the study confirmed that the selected botanical garden can serve as a valuable ecological tool in terms of carbon sequestration, diverse tree species and storage of soil organic carbon.

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INTRODUCTION

Climate change, the outcome of anthropogenic global warming is the single biggest environmental crisis facing Earth, which may lead to unfathomable humanitarian disasters (Milfont *et al*., 2017 and Xue *et al*., 2017). In the fifth assessment (AR5) of 2014, the Intergovernmental Panel on Climate Change (IPCC) asserted increasing concentrations of greenhouse gases (GHG) mainly from anthropogenic activities as the cause of global warming (IPCC, 2014). AR5 climate model projected a rise of average global surface temperature by 0.3-1.7^{0}C and 2.6-4.8^{0}C, respectively, under the lowest and the highest emission scenarios (Stocker *et al*., 2013). AR6 expected to limit the global warming within 1.5^{0}C (IPCC, 2018) by keeping GHG emission under check through internationally binding instruments (Weitzman, 2017) including carbon quota, Clean Development Mechanism (CDM).

The Government of Bangladesh is taking initiatives to meet up nation-wide carbon stock data and prepared the REDD+ Readiness Roadmap (BFD, 2018). As a signatory of the Kyoto protocol, Bangladesh needs accurate estimations of existing carbon stocks throughout the country to implement carbon trading CDM projects (Saatchi *et al*., 2011). The reliable quantification of carbon sequestration by vegetation will help the policy makers, researchers, and entrepreneurs to sell Certified Emission Reduction to developed countries (Ahammad *et al*., 2014 and Ahmed and Glaser, 2016) in global carbon markets under REDD+ and CDM as they need to offset their higher per capita carbon emission. Carbon estimation is also necessary for Bangladesh to implement climate change mitigation policies (Saatchi *et al*., 2011). As forests, trees, or vegetation acts as the carbon sink, these can be used in devising mechanisms to cope with the adverse impact of global climate change (Rahman *et al*., 2013). Achievement of full carbon mitigation potential requires estimation of country-level carbon stocks through statistically validated methods (Mahmood *et al*., 2016).

Estimation of above ground biomass (AGB) is an essential aspect for the estimation of carbon stocks and effects of deforestations and carbon sequestration on global carbon balance (Ketterings *et al*. 2001). It is also a useful measure for comparing structural and functional attributes of forest ecosystems across a wide range of environmental condition (Brown, 2001). Carbon stock estimation includes quantification of soil organic carbon, carbon in living trees, understory vegetation, woody debris, and litters of forest floor in form of above-ground carbon and below-ground carbon (Gibbs, *et al*., 2007 and Patra *et al*., 2013). In Bangladesh, researchers have estimated carbon stocks in different forms at different parts of the country and have developed allometric models. However, most of the available estimation is limited to application of few variables that miss the vast pools of ecosystem carbon (Donato *et al*., 2011). Again, most of the works reflect allometric equation of some common tree species, palm, and shrub species (Mahmood *et al*., 2016).

Globally, about 60% of the carbon is stored in forests, with about 12-20% of anthropogenic greenhouse gas emissions being attributable to forest degradation and loss (Baccini *et al*. 2012; Houghton *et al*., 2012 and Paoli *et al*., 2010). Tree species is known to affect soil through the absorption of nutrients and water from and addition of litter to different soil layers (Prescott and Vesterdal, 2013). Some studies have demonstrated that tree species diversity can lead to higher mineral soil carbon stocks and pH (Guckland *et al*., 2009) or increase soil carbon stocks and the C/N ratio (Dawud *et al*., 2016). Other studies have demonstrated that tree species diversity has no effect on plant-available nitrogen in the soil compared to each mono-species with mixed-species stands (Schmidt *et al*., 2015). However, it is still unknown whether species diversity provides a positive impact on the soil nutrient status in a certain forest ecosystem, although previous studies have shown that species diversity promotes productivity and the above ground carbon stock (Paquette and Messier, 2011 and Jucker *et al*., 2014). Plant species identity is an important driver of soil properties, especially in the top soil layer of the forest soil (Augusto *et al*., 2015 and Dawud *et al*., 2016).

Soil contains about three times more organic carbon than vegetation and about twice as much carbon than is present in the atmosphere (Dinakaran *et al*., 2008 and Kumar *et al*., 2006). Terrestrial vegetation and soil currently absorb 40% of global CO_2 emission from human activities (Sheikh and Kumar, 2010). So, soil in the urban park can also play in climate change mitigation. Worldwide, the forests and species biodiversity and number of trees are being degraded. So, in this aspect urban green space can play an important role in conserving tree diversity. Diversity of tree species also increases the efficiency of trees to play their roles in urban environment (Zare *et al*., 2009). Species level tree biomass carbon estimation using diameter at breast height (DBH) with a tree density based allometric model is becoming popular (Pandey *et al*., 2014). Studies have made significant contributions in estimating ecosystem level aboveground carbon stocks using basal biomass (Rahman *et al*., 2014). In spite of having these benefits, there is still lack of quantitative data and available information on urban park in respect of their ecosystem carbon stock and tree species diversity especially in Dhaka city. So, this study focused on estimating the amount of above and below ground carbon stock, soil organic carbon (SOC) and pattern of tree species diversity at National Botanical Garden, Dhaka, Bangladesh.

Objectives:

1. To estimate the amount of ecosystem carbon stock (AGC, BGC and SOC) in National Botanical Garden;
2. To assess the pattern of tree species diversity; and
3. To find out the relationships of biomass carbon, tree species diversity and soil organic carbon.

Chapter II

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

Global climate change is the most severe environmental threat in the 21st century. Today climate change is a global challenge for humankind with having significant effects and is a major threat not only for mankind, but also for life on earth as a whole. Climate change represents one of the most important threats to our planet's biodiversity. Biodiversity is threatened by human-induced climate change and climate change is already forcing biodiversity to adopt either through shifting habitat or changing life cycles. Plants and animals are endangered due to global warming resulting from increasing concentration of carbon dioxide released into atmosphere through different human activities. In climate change perspective some literature reviewed mentioning global climate change scenario, global carbon cycle, carbon sequestration in the ecosystem, urban park in carbon sequestration, importance and carbon stock and measuring biomass in different carbon pools under the following heading:

2.1 Global climate change scenario

Singh (2017) stated that the term climate change is growing in preferred use to 'Global warming' because it helps to convey that there are other changes in addition to rising temperature. Climate change refers to any significant change in measures of climate (such as temperature, precipitation or wind) lasting for an extended period. Climate change may result from: a) Natural factors, such as changes in the sun's intensity or slow changes in the Earth's orbit around the sun. b) Natural process within the climate system c) Human activities that change the atmosphere's condition (such as burning fossil fuels) and deforestation, urbanization and industrialization. Climate change is an intricate problem which although environmental in nature has consequences for all spheres of existence on planet. It either impacts on or is impacted by global issues including poverty economic development population growth sustainable development and resource management.

IPCC (2013) 5th Assessment Report (AR5) that was issued in the year of 2013-14 confirmed the 4th Assessment Report's assertion that global warming of our climate system is unequivocal and is associated with the observed increase in anthropogenic greenhouse gas concentrations and it is necessary to keep the temperature rise less than 2^0C relative to preindustrial levels and that CO_2 emissions should be reduced globally by 41-72% by 2050 and by 78-118% by 2100 with respect to 2010 levels.

Bellard *et al*. (2012) revealed that the principal specificities and caveats of the most common approaches used to estimate future biodiversity at global and sub-continental scales and synthesized results on adverse climate change effects. Their review showed that current estimation of climate change effect on the bio-diversity are very variable, depending on the method, taxonomic group, biodiversity loss metrics, spatial scales and time periods considered. Yet, the majority of models indicate alarming consequences for biodiversity, with the worst-case scenarios leading to extinction rates that would qualify as the sixth mass extinction in the history of the earth.

IPCC (2007) indicated that most of the observed increase in global average temperatures since the mid-20th century is very likely due to observed increases in anthropogenic greenhouse gas concentrations.

IPCC (2007) reported that climate changes and global warming are the largest environmental problems of all time in the world; the level of scientific proof achieved in recent years leaves no doubts that human activity is the primary cause of these processes.

IPCC (2007) stated that average global temperatures already register an increase of 0.7^0C, caused by the growing concentration of atmospheric greenhouse gases (GHG). The increasing frequency of extreme natural phenomena such as hurricanes, cyclones, torrential rains and prolonged droughts has already affected the lives of millions of people around the world.

2.2 Overview of global carbon cycle and forest

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

IPCC (2007) observed that the forest carbon management must be an important element of any international agreement on climate change. Forest carbon flows comprise a significant part of overall global greenhouse gas emissions.

Sedjo and Sohngen (2007) stated that while global forests as a whole may be a net sink global emissions from deforestation contribute between 20 and 25 percent of all greenhouse gas emissions.

Schulze *et al*. (2004) reported that the carbon dioxide in the atmosphere is 2% of the amount in the ocean, only slightly higher than the amount of carbon bound in the biomass plants and only half that stored in soil.

IPCC (2000) reported that the size of the total global carbon pool in forest vegetation is about 359 Gt C (gigatonnes of carbon), compared to annual global carbon emissions from industrial sources that is approximately 6.3 Gt C.

Watson *et al*. (2000) stated that the potential impact on the global carbon cycle of both natural and anthropogenic changes in forests is enormous. In the 1990s, gross deforestation was slightly higher, at 13.1 million ha/yr. Due to afforestation, landscape restoration and natural expansion of forests, it is estimate that net loss of forest is 7.3 million ha/yr. The loss is still largest in South America, Africa and Southeast Asia. There is considerable interest on the role of terrestrial ecosystems in climate change, more specifically on the global carbon cycle. The world's tropical forests covering 17.6 M km^2 contain 428 Gt C in vegetation and soils. It is estimated that about 60 Gt C is exchanged between terrestrial ecosystems and the atmosphere every year. Land Use, Land-Use Change and Forestry (LULUCF) activities, mainly tropical deforestation, are also significant net sources of CO_2, accounting for 1.6 Gt C/yr of anthropogenic emissions.

IPCC (2000) said that to overcome the conditions, sustainable management strategies are mandatory; therefore, it is necessary to make the forest carbon sinker rather than source. Currently, the biosphere constitutes a carbon sink that absorbs about represents about 30 percent of fossil-fuel emissions.

2.3 Carbon sequestration in the ecosystem

FAO (2010) observed that the Carbon sequestration means, carbon dioxide is captured from the atmosphere through photosynthesis by the tree or plant to store it in its trunk, branches, twigs, leaves and fruit and oxygen is released to the air in return. Also the roots of the trees and plants take up carbon dioxide. Decomposing organic materials increase the amount of carbon stored in the soil, which is higher than the total amount in the vegetation and the atmosphere. Animals breathe in oxygen and breathe out CO_2 and through their feces carbon and N_2O is released to the soil.

Watson (2008) reported that the main components of terrestrial carbon storage are above ground and below ground biomass dead litter and soil organic matter.

Eric *et al*. (2008) stated that geologic carbon sequestration is a mechanism of injecting carbon dioxide directly into underground geological formations.

Sundquist *et al*. (2008) reported that Oceans are natural CO_2 sinks and represent the largest active carbon sink on Earth. Among the global net sequestrated CO_2 about 2 Gts of carbon released as a result of anthropogenic activities.

IPCC (2007) reported that the phenomenon for the storage of CO_2 or other forms of carbon to mitigate global warming and its one of the important clause of

Kyoto Protocol, through biological, chemical or physical processes; CO_2 is captured from the atmosphere.

Mathews and Robertson (2002) stated that terrestrial carbon sequestration is the process through which CO_2 from the atmosphere is sequestered by trees, plants and crops through photosynthesis, and stored as carbon in biomass and soils. Therefore, a carbon sink occurs when carbon sequestration is greater than carbon releases over some time period.

2.4 Urban park in carbon sequestration

Nero *et al*. (2018) sated that urban forestry has the potential to address many urban environmental and sustainability challenges. The vegetation inventory included a survey of 470,100 m^2 plots based on a stratified random sampling technique and six streets ranging from 50 m to 1 km. A total of 3757 trees, comprising 176 species and 46 families, were enumerated. Tree abundance and species richness were left skewed and unimodally distributed based on diameter at breast height (DBH). Trees in the diameter classes >60 cm together had the lowest species richness (17%) and abundance (9%), yet contributed more than 50% of the total carbon that stored in trees within the city. Overall, about 1.2 million tonnes of carbon is captured in aboveground components of trees in Kumasi, with a mean of 228 t C ha^{-1}.

Tenkir (2011) reported that the urban forestry refers to any re-vegetation effort including the planting of trees and shrubs whose design is intended to improve the environmental quality, economic opportunity, or aesthetic value associated with a city's landscape. The perception that comes to mind regarding urban forest is street trees and ornamental woody plants. However, the urban forest is a complex system of trees and smaller plants, wildlife, associated organisms, soil, water and air quality in and around a city.

Grimm *et al*. (2008) reported that in 1900 just 10% of the global population was living in urban areas which now exceeds 50% and is expected to further rise to 67% in the next 50 years.

Pataki *et al*. (2006) observed that in urbanizing regions, organic carbon is stored within and cycled through the air, soils, waters, plants, and the built environment itself. Although it is abundantly clear that cities and urbanizing areas affect local and global sinks and sources of CO_2, the exact magnitude of and mechanisms for carbon exchange remain highly uncertain for urbanizing regions.

IPCC (2007) reported that the amount of carbon dioxide in the atmosphere has increased from 280 ppm in the pre-industrial era (1750) to 379 ppm in 2005, and is increasing by 1.5 ppm per year.

Chiari and Seeland (2004) have highlighted the role of urban forests as a place of social integration as they provide recreation and relief to the urban population from their hectic life.

2.5 Urban forest contribution to climate change mitigation

Daniel *et al*. (2010) reported that rapid urbanization increased motorization and economic activity, which leads to increased air pollution. Emissions from mobile sources are said to be the principal contributors to urban air pollution and it is becoming a serious health and environmental threat.

Lasco *et al*. (2008) stated that tropical forests have the largest potential to mitigate climate change amongst the world's forests through conservation of existing carbon pools by reduced impact logging expansion of carbon sinks through reforestation, agroforestry.

Gill *et al*. (2007) showed a statistics that include 40 trees will sequester one ton of CO_2 each year; and that one million tree covering 1,667 acres could capture 25,000 ton of CO_2 annually, and have pollution mitigation and carbon sequestration potential. Standing from this point, urban trees help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue, by altering energy use in buildings, there by altering carbon dioxide emissions from fossil fuel based power plants and also by protecting soils, one of the largest terrestrial sinks of carbon. They also be useful in adapting to climate change through evaporative cooling of the urban environment.

IPCC (2007) stated that forest mitigation options include reducing emissions from deforestation and forest degradation, enhancing the sequestration rate in existing and new forests. Properly designed and implemented forestry mitigation options have substantial co-benefits in terms of employment and income generation opportunities, biodiversity and watershed conservation, provision of timber and fiber, as well as aesthetic and recreational services.

Nowak and Crane (2002) reported that forestland such as urban park can play for climate change mitigation. It is estimated that total carbon stored by the urban trees is 23.8 million tons from an estimated 7.79 million ha urban area, i.e. 3.01 tones of carbon/ha. Urban forests contribute only 2.21% of the carbon stock against 17.11 tons carbon/ha from overall forest and tree cover. Thus, there is an ample scope to increase contribution of urban forests to overall carbon stocks. Urban trees in the USA store 700 million tons of carbon with a gross carbon sequestration rate of 22.8million t C/yr. The national average urban forest carbon storage density is 25.1 t C ha^{-1}, compared with 53.5 t C ha^{-1} in forests stands, model estimated that Torbey's trees store 98100 ton of carbon (15tons of carbon ha^{-1}) and sequester a further 4279 tons per year (0.7 tons of carbon ha^{-1}).

2.6 Factor that affect carbon stock in forest

Mukul *et al*. (2014) stated that in tropical developing countries, reducing emissions from deforestation and forest degradation is becoming an important mechanism for conserving forests and protecting biodiversity. Using available information they provided a new and more reliable estimate of carbon in Bangladesh forest ecosystems, along with their geo-spatial distribution. Our study reveals great variability in carbon density in different forests and higher carbon stock in the mangrove ecosystems, followed by in hill forests and in inland Sal (*Shorea robusta*) forests in the country.

Gissen (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.

FAO (2006) 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.

MEA (2005) scenarios showed that forest area in industrialized regions will increase between 2000 and 2050 by about 60 to 230 million ha. At the same time, the forest area in the developing regions will decrease by about 200 to 490 million ha. The lack of consensus on factors that control the carbon balance is an obstacle to development of effective mitigations strategies.

Asner *et al*. (2005) reported that the deforestation and conversion of forest to no forestland uses is typically associated with large immediate reductions in forest carbon stock through land clearing. 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.

Warn and Patwardhan (2001) stated that the development of sustainable green cities is the need of today’s fast urbanizing world. More number of populations will soon be living in urban areas and urbanization is vigorously promoted both politically and socially as a means to enhance average living standards. However, the ever growing urbanization threatens escalating of carbon emission due to higher consumption of goods and services compared to the rural sector.

Nowak and Crane (2002) 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.

2.7 Tree species diversity in garden

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. In total 1671 trees were sampled and 32 different tree species were identified and recorded. The Shannon Wiener index was used to evaluate the tree diversity per home garden and it ranged from 1.00 to 2.2 with a mean value of 1.64.

Fard *et al*. (2015) stated that the tree diversity of two urban parks of Kio and Shariati in Khorramabad Country were (SWI = 1.5) and (SWI = 0.88) respectively.

Jayakumar *et al*. (2009) reported that the floristic inventory and diversity studies of evergreen forest in the Eastern Ghats of Tamil Nadu, India using various sampling methods viz. (a) ad hoc (AH) vegetation survey, (b) stratified random plot (SRP) and (c) bigger plot (BP). The mean stand density and mean basal areas was found to be 547 (SRP) and 478 (BP) stems ha^{-1}, and 46.74 (SRP) and 43.6 m^2 ha^{-1}(BP), respectively on the study sites. Shannon Index (H') was found to be 3.140 (SRP) and 3.340 (BP).

Gupta *et al*. (2008) reported that urban forest in 43 ha of NEERI campus at Nagpur; Maharashtra has 135 vascular plants including 16 monocots and 119 dicots, belonging to 115 genera and 53 families. The taxa included 4 types of grasses, 55 herbs, 30 shrubs and 46 trees. The large number of species within very small area indicates rich biodiversity in this urban forest.

Nowak and Crane (2002) reported that urban trees in the Coterminous USA, store 700 million tons of carbon with a gross carbon sequestration rate of 22.8 million t C/yr. The national average urban forest carbon storage density is 25.1 t C/ha, compared with 53.5 t C ha^{-1} in forest stands.

2.8 Measuring biomass in different carbon pools

Nero *et al*. (2018) sated that urban forestry has the potential to address many urban environmental and sustainability challenges. They also observed that tree density, DBH, height, basal area, aboveground carbon storage, and species richness were significantly different among green spaces. The diversity was also significantly different among urban zones. The DBH distribution of trees followed a modified reverse J-shaped model. The urban forest structure and composition is quite unique. The practice of urban forestry has the potential to conserve biological diversity and combat climate change. The introduction of policies and actions to support the expansion of urban forest cover and diversity is widely encouraged.

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. Liu *et al*. (2014) estimated that the AGC and BGC of Lesio-louna tropical rainforest of Congo were 168.60 Mg ha^{-1} and 39.55 Mg ha^{-1}, respectively.

Liu *et al*. (2014) estimated that the AGC and BGC of Lesio-louna tropical rainforest of Congo were 168.60 Mg ha^{-1} and 39.55 Mg ha^{-1}, respectively.

Averti *et al*. (2014) reported that the AGC of humid tropical wetland forests of the Republic of Congo was 223 Mg ha^{-1}.

Wondimu (2013) stated that the AGC and BGC of Biheretsige park in Addis Ababa were 21.7 Mg ha^{-1} and 4.3 Mg ha^{-1}, respectively. He also added that also the AGC of Central park in Addis Ababa was 29.12 Mg ha^{-1}.

A study was carried out by Borah *et al*. (2013) in ten tropical forests of Cachar district to estimate AGB, carbon stocks and their relationship with density, basal area and diversity indices. The AGB was ranged from 32.47 Mg ha^{-1} to 261.64 Mg ha^{-1} and C-stocks ranged from 16.24 Mg ha^{-1} to 130.82 Mg ha^{-1}. The small to medium trees contributed more AGB and C-stocks than the large trees. *Cynometra polyandra*, *Artocarpus chama*, *Sapium baccatum*, *Ficus bengalensis*, *Trewia nudiflora*, *Xerospermum glabratum*, *Pterygota alata* and *Semecarpus anacardium* were top contributor of AGB and C-stocks in different tropical forests of Cachar district of Assam. AGB showed significant relationship with basal area and diversity indices. The AGB, however, did not show significant relationship with tree densities.

Dwivedi *et al*. (2009) reported the case of Kerwa urban forest area in Bhopal is another Indian case that supports several threatened and endangered plant, animal, and bird species. It also plays a critical role as a carbon sink with a total storage of about 19.5 thousand tonnes of above ground carbon.

Montagu *et al*. (2005) reported the assessment of biomass that provides information on the structure and functional attributes of trees. With approximately 50% of dry biomass comprises of carbon biomass assessments illustrate the amount of carbon that may be sequestered by trees.

Pearson *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.

Zheng *et al*. (2004) estimated the above ground biomass of Chequamegon National Forest of Wisconsin USA using Landsat 7 ETM data. Total above ground biomass of the study area was estimated to be 3.3 M tons, of that 76.5% was hard wood and mixed hardwood/pine forest. Above ground biomass ranged from 1 to 358 Mg ha^{-1}.

Cairns *et al*. (2003) reported that two methods of measuring sample tree biomass are available: (1) destructive and (2) non-destructive. Direct or destructive method of tree biomass involves felling an appropriate number of trees and estimating their field- and oven-dry weights, a method that is accurate however it is impractical. Rather than performing destructive sampling all the time in the field, an alternative method (non- destructive) can be used that predicts biomass given some easily measurable predictor variable, such as “tree diameter” and “height” can be used.

Haripriya (2000) reported that the above ground biomass density and carbon storage in biomass of major forest strata (21) of India for data collected from 1,70,000 sampling units distributed all over the country in 1993. Biomass densities ranged from 14 to 210 Mg ha^{-1} with a mean of 67.4 Mg ha^{-1}, which equals around 34 Mg C ha^{-1}.

2.9 Soil organic carbon

Zheng *et al*. (2017) carried out a study in how tree species identity and diversity affect soil properties. Forest soil profiles were sampled at a fixed depth (0–10, 10–20, 20-40, and 40-60 cm). The abovementioned soil properties were compared by species to demonstrate the influence of tree species identity. They calculated the true Shannon diversity index and evaluated tree species diversity effects on soil properties. They found that tree species diversity only showed a negative effect on soil carbon stock; in contrast, a positive effect on soil nitrogen stock in the 0- to 10-cm soil layer was found. High diversity could lead to a change in the soil nutrient conditions in the form of C/N ratio decreases.

Swai *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.

Sakin (2012) reported that the Bulk density depends on several factors such as compaction, consolidation and amount of SOC present in the soil but it is highly correlated to the organic carbon content, soil organic carbon (SOC), soil organic matter (SOM) and the correlation between bulk densities.

Reum *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}.

Watson (2008) observed that SOM is influenced through land use and management activities that affect the litter input. In SOM accounting, factors affecting the estimates include the depth to which carbon is accounted, commonly 30 cm, and the time lag until the equilibrium stock is reached after a land use change, commonly 20 years.

Grossman and Reins (2002) stated that bulk density values are also used as a measure of soil quality, indicating the ease of root penetration, water movement, and soil strength.

Chapter III

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

The study was conducted to the estimation of ecosystem carbon stock and tree species diversity at National Botanical Garden, Bangladesh. The materials and methods that were used for conducting the study have been presented in this chapter under the following headings-

3.1 Description of the study site

3.1.1 Experimental period

The study was conducted during the period of January to April 2018.

3.1.2 Location of the study area

The study was located at $23^{0}50^{/}$N latitude and $90^{0}40^{/}$E longitude with an elevation of 8.6 meter above sea level. It is situated in Chiriakhana Road, Mirpur-1, Dhaka, Bangladesh. The National Botanical Garden was established in the year of 1962-63. The total area of is 87.13 hectare with surrounding area 5.00 kilometer and internal road. There were around 68 thousand trees with a scientific collection of approximately 100,000 preserved specimens (Anonymous, 2015). It is managed by Department of Forest under Ministry of Environment and Forests and Climate Change, Government of Bangladesh (DoF, 2019).

3.1.3 Climatic and soil

The climatic condition of Dhaka city is characteristics by a hot, wet and humid tropical climate. The city has a distinct monsoonal season, with an annual average temperature for the year in Dhaka is 26.1^{0}C. The warmest month, is June with an average temperature of 29.1^{0}C and the coolest month is January, with an average temperature of 19.1^{0}C and the average amount of precipitation for this year in Dhaka is 2148.8 mm (Weatherbase, 2019). The soil of Dhaka city is belongs to the Tejgaon series under the Agro-ecological Zone, Madhupur Tract (AEZ-28) and the general soil type is Deep Red Brown Terrace Soils with pH 5.8-6.5, ECE-25.28 (Haider, 1991).

3.2 Sampling procedure

Considering the arrangement of National Botanical Garden, Dhaka, Bangladesh, the sampling procedure for this study was determined as the sample plot transects line method were used.

Plate 1. Measuring sampling plot for the study

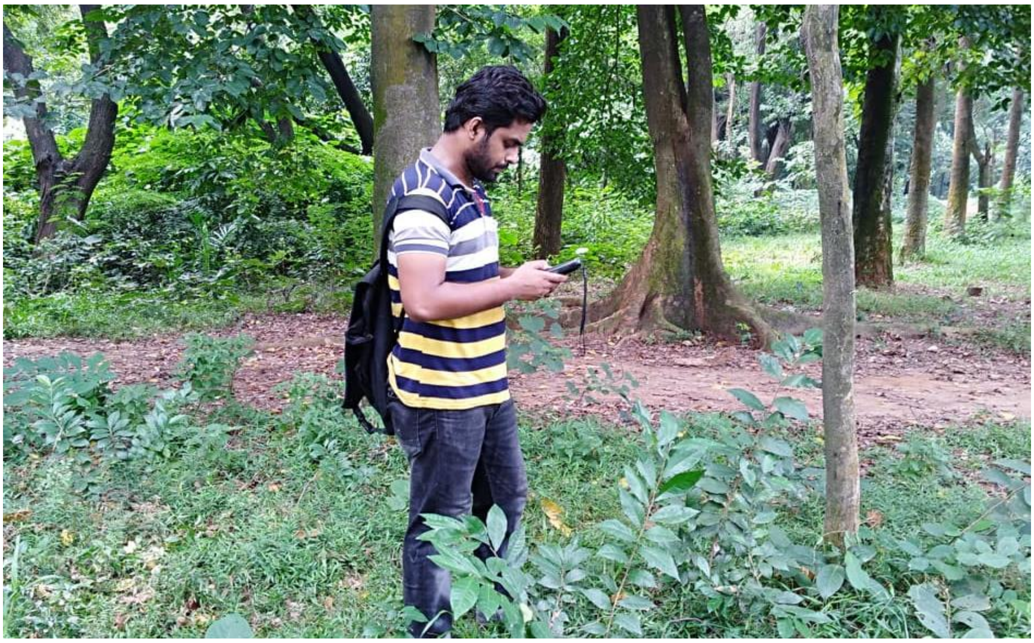

Plate 2. Measuring center point co-ordinates with GPS

3.3 Selection and description of the study area

Using transects line method square plots with a size of 20 m × 20 m were taken. So, altogether there were total eighty three sample plot in National Botanical Garden. Among each plot 50 meter interval from plot to plot was maintained for the feasibility of determining the sample plot. Plot No. 4, 9, 17, 21, 25, 29, 30, 34, 38, 43, 49 and 62 were avoided due to presence of pond, residence, very low land, office and lake and altogether there were 12 plots accordingly.

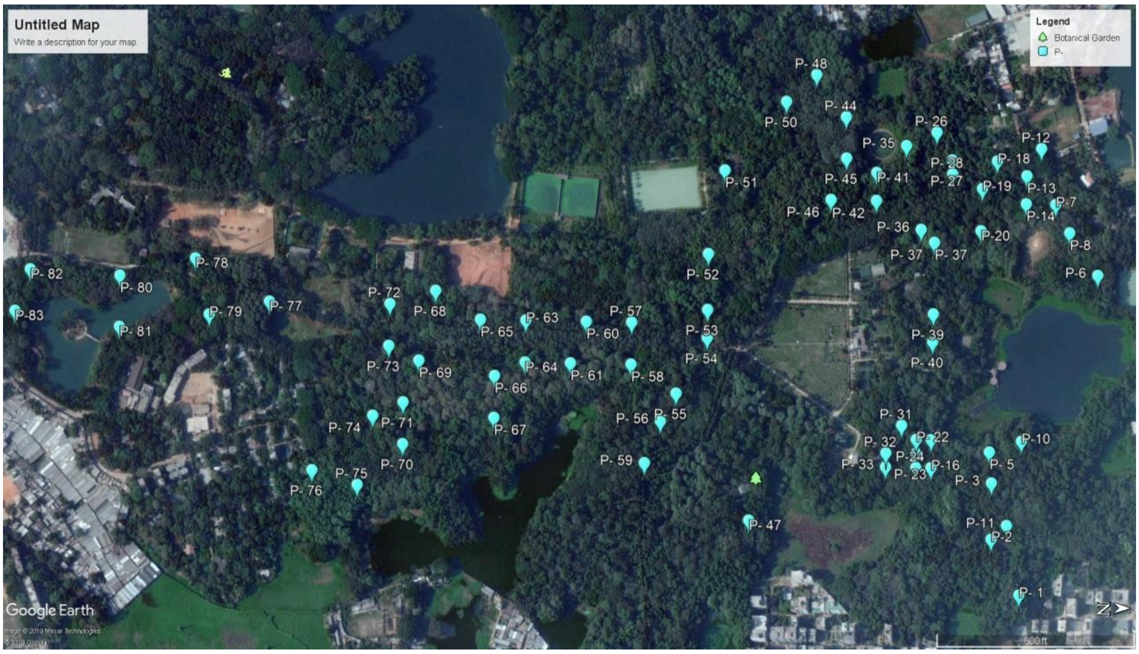

Plate 3. Sample plot co-ordinates of National Botanical Garden

3.4 Soil sampling and analysis

There were total 83 sample plots in National Botanical Garden. But Soil samples were collected from 71 selected sample plots. In each sample plot, three sampling sites were selected randomly and soil samples were collected at three depths measuring 0-10 cm, 10-20 cm and 20-30 cm from each sites using Auger. A composite sample for each depth interval was prepared by mixing soil from three sampling sites resulting one sample per depth level from National Botanical Garden. There were in total 213 (71 ×3) soil samples were collected. Bulk density of sampled soil was measured using the formula stated below. Carbon content in the sample soil was analyzed by Walkley and Black (1934) method and it was done in Soil Resource Development Institute (SRDI), Dhaka, Bangladesh.

Plate 4. Inserting Auger in the soil for collecting soil sample

$$\text{Bulk Density-BD (g/cc)} = \frac{\text{Oven dry weight of sample soil}}{\text{Volume of soil in the core}}$$

Percentages of organic carbon content of the sample soil were also calculated by using following formula:

$$\text{Bulk Density-BD (g/cc)} = \frac{(B\text{-}T) \times N \times 0.003 \times 1.3 \times 100}{ODW}$$

Where,

ODW = Oven dry weight

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

Soil organic carbon (SOC) was measured by Walkly and Black (1934) formula:

SOC = Depth (cm) × Bulk density (g/cc) × Organic carbon (%)

3.5 Allometric equation for above and below ground biomass

3.5.1 Tree biomass

Biomass equations relate to diameter at breast height (DBH) of tree biomass and biomass may differ among species. It is because trees in similar functional group can differ greatly in their growth forms between different geographical areas (Pearson *et al*., 2007). Considering these factors Chave *et al*. (2005) developed allometric equations for tropical trees that can be used for wide geographical and diameter range.

3.5.2 Above ground biomass

To measure the above ground plant biomass of the study plot, following equation was used (Chave *et al*., 2005):

$$AGB = \rho \times \exp\left(-1.499 + 2.148 \times Ln(DBH) + 0.207 \times (Ln(DBH))^2 - 0.0281\{Ln(DBH)\}^3\right)$$

Where,

ρ = Wood density ($g\ cm^{-3}$): - 1.499, 2.148…………0.207 and 0.0281= Constant.

3.5.3 Below ground biomass:

To determine the below ground biomass and carbon, the model equation developed by Cairns *et al*. (1997) was employed. It was the most cost effective and practical methods of determining root biomass.

$$BGB = \exp(-1.0587 + 0.8836 \times Ln\ AGB)$$

Where,

BGB = Belowground biomass

Ln = Natural logarithm

AGB = Aboveground biomass, -1.0587 and 0.8836 are constant.

3.5.4 Palm species biomass

The following equation that was developed by Brown *et al*. (2001) for palms was used for AGB calculation:

$$AGB = 6.666 + 12.826 \times ht0.5 \times Ln(ht)$$

Where,

AGB = Above Ground Biomass

Ln = Natural logarithm

ht = Height

Plate 5. Measuring GBH of tree in the study sites

Plate 6. Measuring height of tree in the study sites

3.5.5 Conversion of biomass to carbon

After estimating the biomass from allometric relationship, it was multiplied by wood carbon content (50%). 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).

Carbon (Mg) = Biomass estimated by allometric equation × Wood carbon content % = Biomass estimated by allometric equation × 0.5

3.6 Tree species diversity

Tree species diversity was determined from the each sample plot acquiring common names that subsequently converted into botanical names. An index was setup based on the number of species and their frequency in sample plot. For this study Shannon-Wiener diversity index (SWI) was used due to its suitability for evaluating diversity of tree species. The Shannon-Wiener diversity characterizes the proportion of species abundance in the population being at maximum when all species are equally abundant and the lowest when the sample contained one species. The proportion of species (i) relative to total number of species (P*i*) was calculated and then multiplied by the natural logarithm of the same proportion (Ln P*i*). The resulting product is summed across species, and multiplied by -1.

$$H = \sum_{I=1}^{n} P_i \,\mathrm{Ln}\, P_i$$

Where,

Σ= Summation.

p*i* = Proportion of total sample represented by species *i*. Total no. of individual species i , divided by total no. of plant species found in a sample plot.

H = Shannon index and n = No. of species

3.7 Data analysis

After the collection of field data the information was processed and compiled by MS Excel 2007 and SPSS-16 software. Aboveground C pools were computed using international standard common tree allometries combined with local tables of wood density by tree species. Regression analyses were used to test the relationship among different variables.

Chapter IV

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

The study was conducted to the estimation of ecosystem carbon stock and tree species diversity at National Botanical Garden, Dhaka, Bangladesh. Data were recorded on ecosystem carbon stock i.e., above ground carbon, below ground carbon and soil organic carbon of National Botanical Garden. The findings of the study were presented under the following headings:

4.1 Ecosystem carbon stock

4.1.1 Above and below ground biomass carbon (AGC and BGC)

For the estimation of above and below ground biomass carbon stock of the plantation sites of the selected experimental site was measured on the basis of diameter at breast height (DBH) and height and also calculated by using the desired equations. For measuring biomass carbon stock total plantation of 71 plots of National Botanical garden were used. So the total number of sample plot was n = 71. The data revealed that the biomass carbon stock of National botanical garden ranged from 3.08 to 265.74 Mg C ha^{-1}. The average value of the biomass carbon stock was 144.46 Mg C ha^{-1} (Table 1). In earlier study Averti *et al*. (2014) found that the AGC in humid tropical wetland forests of the Republic of Congo was 223 Mg ha^{-1}. Gibbs *et al.* (2007) found that the mean biomass carbon in Bangladesh was 65-158 Mg ha^{-1}. Borah *et al*. (2013) reported that AGB was ranged from 32.47 Mg ha^{-1} to 261.64 Mg ha^{-1} and C-stocks ranged from 16.24 Mg ha^{-1} to 130.82 Mg ha^{-1} in ten tropical forests of Cachar district. In Bangladesh Kundu (2015) recorded carbon stock ranged from 2.25 to 222.72 Mg C ha^{-1} with a mean value of 122.19 Mg C ha^{-1} in Chandrima Uddan, Dhaka and also for Ramna Park ranged from 2.71 to 918.46 Mg C ha^{-1}; Mean, 247.90 Mg C ha^{-1} which was similar of the findings of this study. Islam (2013) estimated average biomass carbon stock of the roadside, woodlot and home garden were 159.18 ± 36 Mg C ha^{-1}, 206.19 ± 42 Mg C ha^{-1} and 169.37 ± 34 Mg C ha^{-1}, respectively which was also support the findings of this study.

Table 1. Carbon stock in National Botanical Garden

Number of sample plot	Carbon stock range (mg ha$^{-1)}$		Average ± CI*
	Lowest	Highest	
71	3.08	265.74	144.46±26.38

* CI: 95% confidence interval

Data also revealed that the above ground carbon (AGC) and below ground carbon (BGC) biomass stock was 192.67 and 31.34, respectively (Figure 1). Jaman *et al*. (2016) recorded mean above and below ground biomass carbon stocks (AGB+BGB) 53.53 Mg ha^{-1} in home garden around four villages of two Upazilas of Rangpur district. Liu *et al*. (2014) also recorded that the AGC and BGC of Lesio-louna tropical rainforest of Congo were 168.60 Mg ha^{-1} and 39.55 Mg ha^{-1}, respectively. Wondimu (2013) stated that the AGC and BGC of Biheretsige park in Addis Ababa were 21.7 Mg ha^{-1} and 4.3 Mg ha^{-1}, respectively.

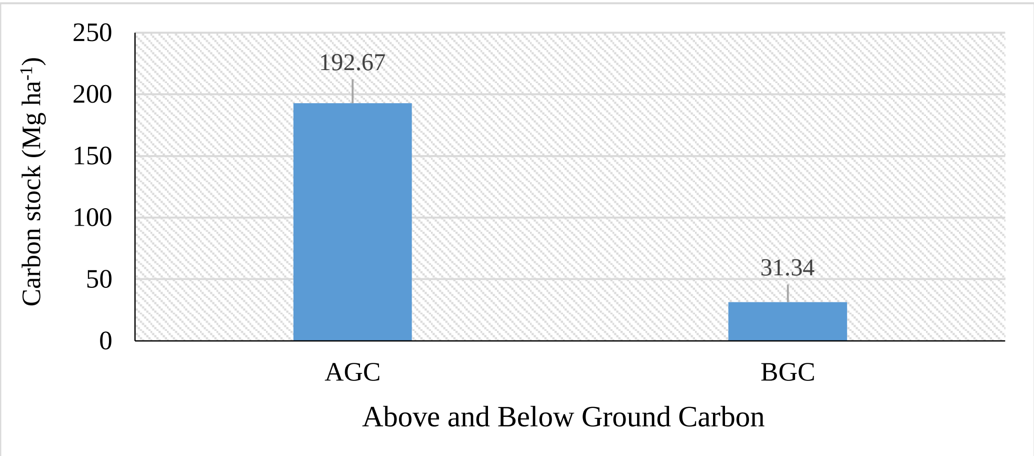

Figure 1. Above and below ground carbon stocks in National Botanical Garden

4.2 Soil organic carbon

Soil organic carbon (SOC) was comparatively higher in the study area. Soil organic carbon ranged from 10.20 to 18.24 Mg ha^{-1} at 0-10 cm depth, 19.00 to 32.56 Mg ha^{-1} at 10-20 cm depth and 17.64 to 26.32 Mg ha^{-1} at 20-30 cm depth with a mean value of 16.23 Mg ha^{-1}, 27.52 Mg ha^{-1} and 21.45 Mg ha^{-1}, respectively in National Botanical garden (Table 2).

Table 2. Soil organic carbon in National Botanical Garden

Depth (cm)	Range SOC (Mg ha^{-1})		Average ± CI*
	Maximum	Minimum	
0-10	32.56	19.00	27.52 ± 1.98
10-20	26.32	17.64	21.45 ± 1.74
20-30	18.24	10.20	16.23 ± 1.68

* CI: 95% confidence interval

It was observed that soil organic carbon was always higher at 0-10 cm depth in comparison to 10-20 cm and 20-30 cm depth (Figure 2). The soil carbon stock measured in the forest was 43.73 Mg ha^{-1} were found the soil carbon stock for a *Pinus densiflora* forest at Gwangneung, central Korea was estimated using the soil carbon model, Yasso. The average soil organic carbon of the National Botanical Garden (65.20 Mg ha^{-1}) is lower than in Hanang forest, Tanzania (Swai *et al.*, 2014). Kundu (2015) revealed that soil organic carbon ranged from 8.86 to 21.27 Mg ha^{-1} at 5-10 cm depth and 6.20 to 16.92 Mg ha^{-1} at 20-25 cm depth with a mean value of 16.52 Mg ha^{-1} and 12.29 Mg ha^{-1}, respectively in Chandrima Uddan and for Ramna Park SOC ranged from 5.46 to 23.75 Mg ha^{-1} at 5-10 cm depth and 0.90 to 35.04 Mg ha^{-1} at 20-25 cm depth with a mean value of 13.64 Mg ha^{-1} and 11.88 Mg ha^{-1}, respectively which also support that findings of this study.

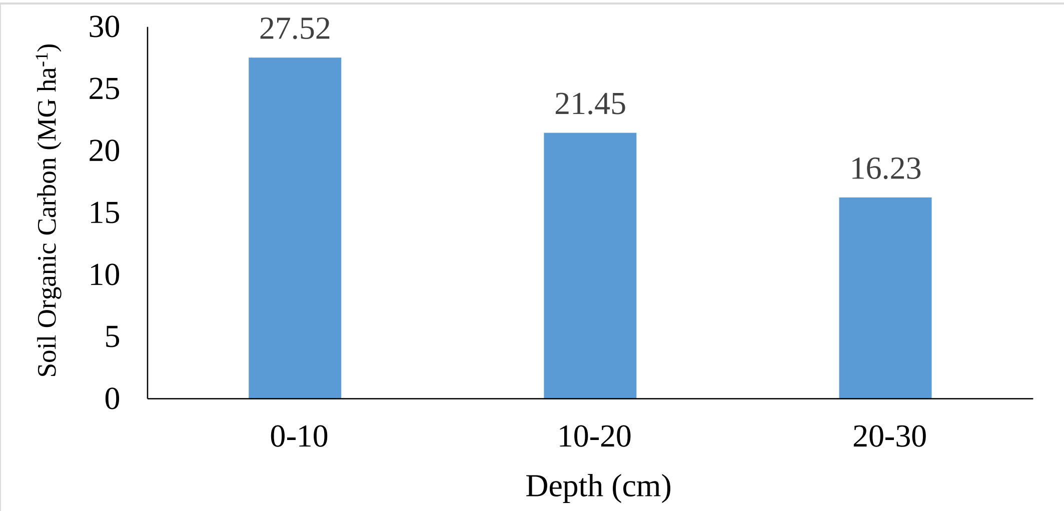

Figure 2. Soil organic carbon (Mg ha^{-1}) in National Botanical garden

4.3 Amount of different carbon pool

Ecosystem carbon stock e.g. Above ground carbon (AGC), Below ground carbon (BGC) and Soil organic carbon (SOC) were 192.67 Mg ha^{-1}, 31.34 Mg ha^{-1} and 65.2 Mg ha^{-1}, respectively in National Botanical Garden (Figure 3).

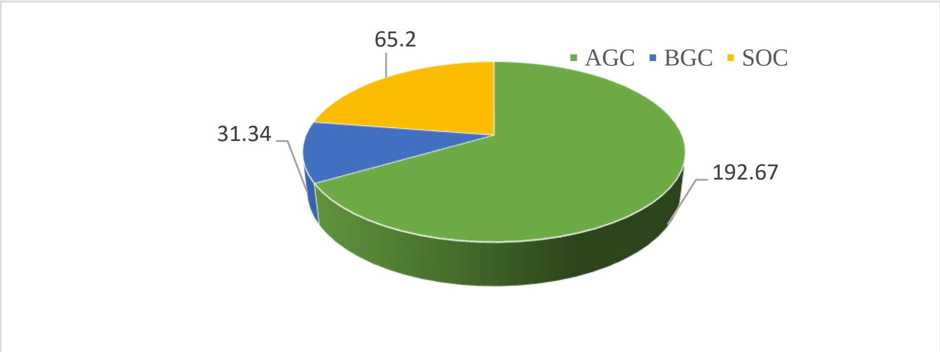

Figure 3. Total mean ecosystem carbon stock (Mg ha^{-1}) (AGC, BGC, SOC) in National Botanical garden

4.4 Tree diversity

Tree diversity of National Botanical Garden were measured by using the Shannon Wiener Index (SWI). SWI showed that the tree diversity range from 0.25 to 1.86 and the mean value of (0.93 ± 0.14) in National Botanical Garden (Table 3). The average number of tree species per hectare was recorded 233 with a mean value of each plot 3.00 to 9.00 species (Table 3). Kundu (2015) observed the tree diversity ranged from 0 to 1.7 with a mean value of (0.87 ± 0.09) in Ramna Park and in Chandrima Uddan tree diversity ranged from 0 to 1.33 with a mean value of (0.58 ± 0.12) which was similar to the findings of this study.

Table 3. Tree diversity in National Botanical Garden

Mean number of trees/ha	Species recorded		Shannon wiener Index (SWI)
	Maximum	Minimum	
233	9.00	3.00	0.93 ± 0.14

4.5 Vegetation characteristics

Vegetation characteristics such as average number of trees per hectare, basal area and mean DBH of total 71 plots were estimated including their standard error (Table 4). From this table it was revealed that the average number of trees in National Botanical Garden (233 tree ha^{-1}), basal area (21.45 m^2 ha^{-1}) and mean DBH (39.86 cm).

Table 4. Average number of trees (ha^{-1}), basal area (ha^{-1}) and mean DBH (cm) in National Botanical Garden

Parameters	Value (± SE)
Average trees (ha)	233.00 (3.67)
Basal area (ha)	21.45 (1.98)
Mean DBH	39.86 (5.03)

*Parenthesis is the standard errors

4.6 Tree density characteristics

Tree density ranged from 48 to 662 trees ha^{-1} with a mean value of 233 trees ha^{-1} in National Botanical Garden (Table 5).

Table 5. Tree density in National Botanical Garden

Minimum tree density value	Maximum tree density value (ha^{-1})	Mean (± SE)
48	662	233 (± 3.67)

4.7 Occurrence of major tree species

From the experimental area it was found that the occurrence of major trees in National Botanical Garden were *Terminalia chebula* and *Mohua longifolia* (6.04%) in same percentage which was followed by *Mangifera indica* (4.83%), *Artocarpus heterophyllus and Tamarix gallica* (4.08%), *Terminalia bellirica* (3.78%), *Acacia auriculiformis* (3.63%) and *Eucalyptus camaldulensis* (2.87%) and *Swietenia macrophylla* (2.72%) (Figure 4). Data revealed that the occurrences of the major were more or less eventually distribution. There were no specific tree species with a major number. Kundu (2015) found that the occurrence of major trees were *Acacia auriculiformis* (47.58%) followed by *Eucalyptus camaldulensis* (8.87%), *Lagerstroemia speciosa* (5.64%), *Artocarpus heterophyllus* (4.83%), *Albizia richadiana* (4.83%) and *Mangifera indica* (4.03%) in case of Chandrima Uddan which differ the findings of this study.

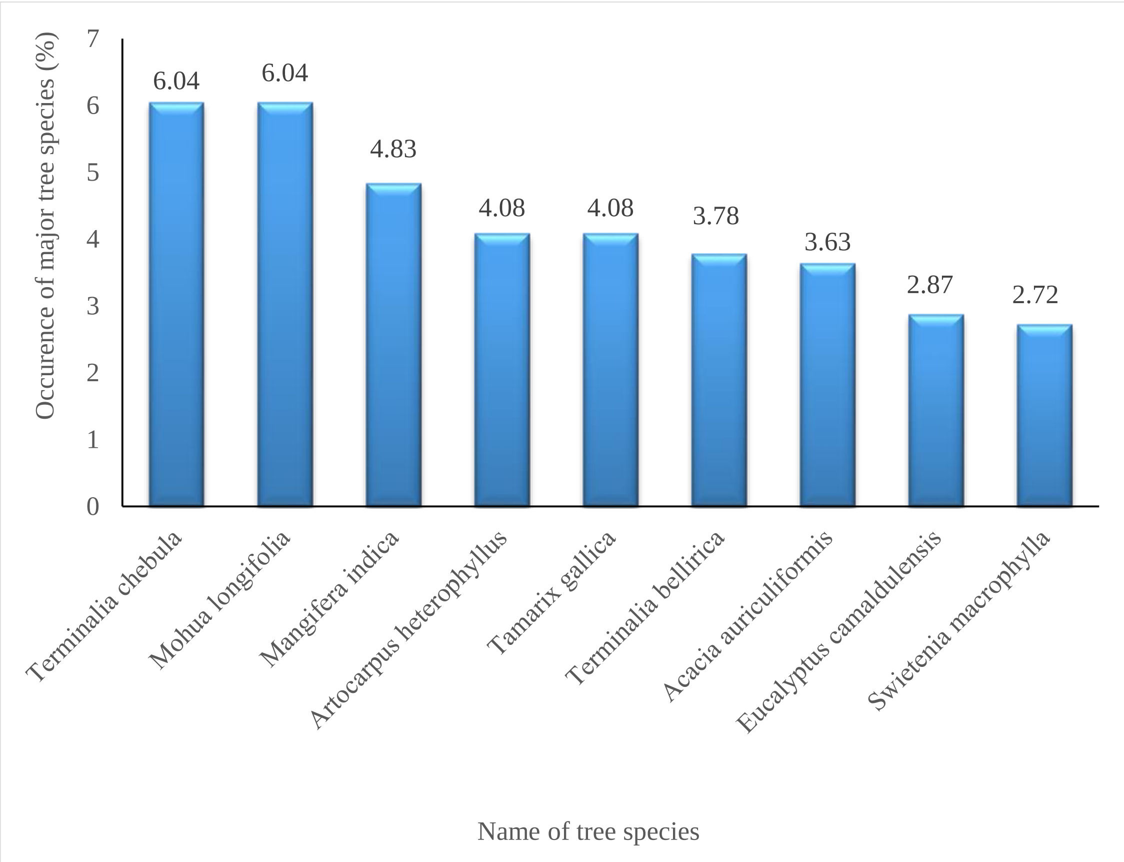

Figure 4. Occurrence of major tree species (%) among the recorded tree species in National Botanical garden

4.8 Major carbon containing tree species

Estimated data revealed that the major carbon containing trees were *Mangifera indica* (52.12 Mg) followed by *Artocarpus heterophyllus* (34.67 Mg), *Tamarix gallica* (27.55 Mg), *Mohua longifolia* (15.32 Mg), *Tamarix gallica* (12.89 Mg), *Acacia auriculiformis* (11.45 mg), *Terminalia chebula* (9.33), whereas the lowest was observed from *Eucalyptus camaldulensis* (9.01 mg) (Figure 5) in National botanical garden.

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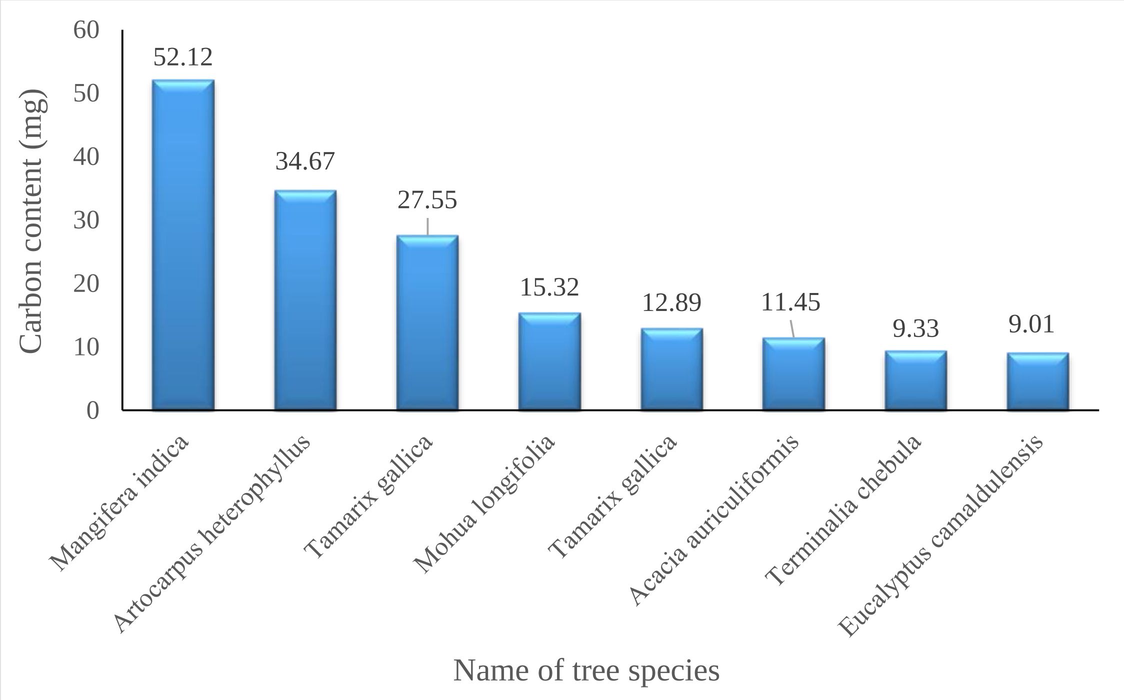

Figure 5. Major carbon containing tree species in National Botanical garden

4.9 Relationship between different stand structure of tree species and its carbon stock

Correlation and Regression analysis were computed to determine the relationship among the different mean value of DBH, basal area and stem density with biomass carbon stock of tree species.

4.9.1 Basal area

The relationship between mean basal area and biomass carbon stock of National Botanical Garden was measured and presented in shown Figure 6. The linear equation as: Y = 10.728 x + 4.7823 ($R^2 = 0.862$), where R^2 value was positive, $r = 0.928$ and $p < 0.01$. So the estimated value indicated that there was a significant and strongly positive correlation between basal area and biomass carbon stock and with the increase of basal area the biomass carbon stock also increases. Similar trend was results also observed by several earlier study (Murali *et al*., 2005 and Vieilledent *et al*., 2012). A number of earlier studies also reported a high significant correlation of biomass carbon stock with basal area (Chaturvedi *et al*., 2011; Kale *et al*., 2004 and Slik *et al*., 2010).

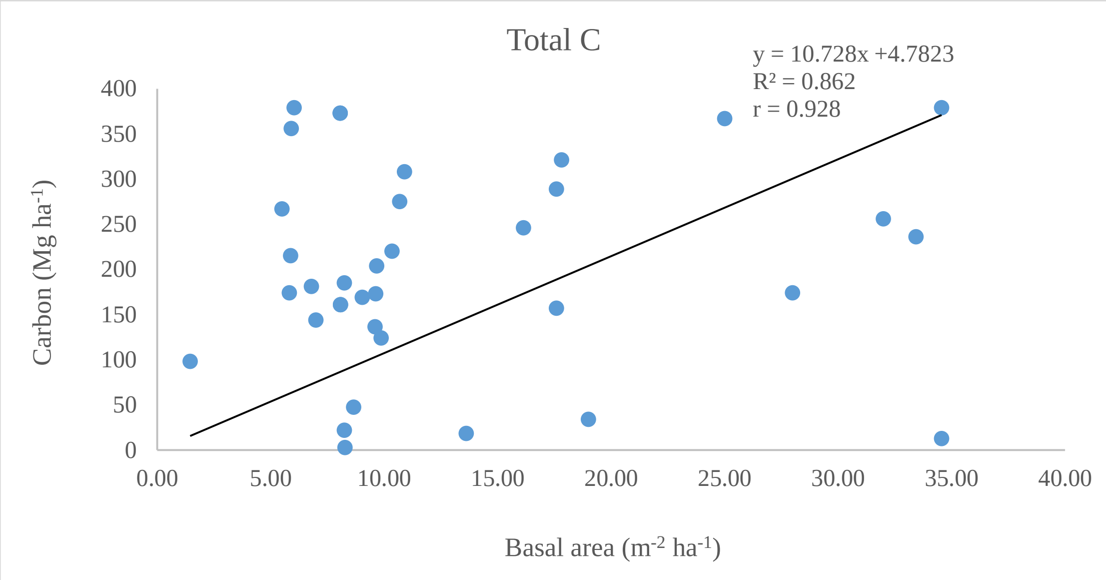

Figure 6. Relationship between basal area (m^2 ha^{-1}) and carbon stock (Mg ha^{-1}) in National Botanical Garden

4.9.2 Mean DBH

The relationship between mean basal area and biomass carbon stock of National Botanical Garden was measured and presented in shown Figure 7. The linear equation as: $Y = 4.779 x + 121.67$ ($R^2 = 0.042$), where R^2 value was positive, $r = 0.205$ and $p > 0.05$. So the estimated value indicated that there was a non-significant and positive correlation between mean DBH and biomass carbon stock and with the increase of mean DBH the biomass carbon stock also increases. But Mani and Parthasarathy (2007) reported that a significant positive correlation between mean DBH and carbon stock as well as between basal area and total woody C also showed a high correlation of biomass with diameter at breast height. Similar trend has been observed by several workers in tropical forests (Murali *et al.*, 2005). In this present study there were no significant correlation was found between mean DBH and biomass carbon stock of National Botanical Garden.

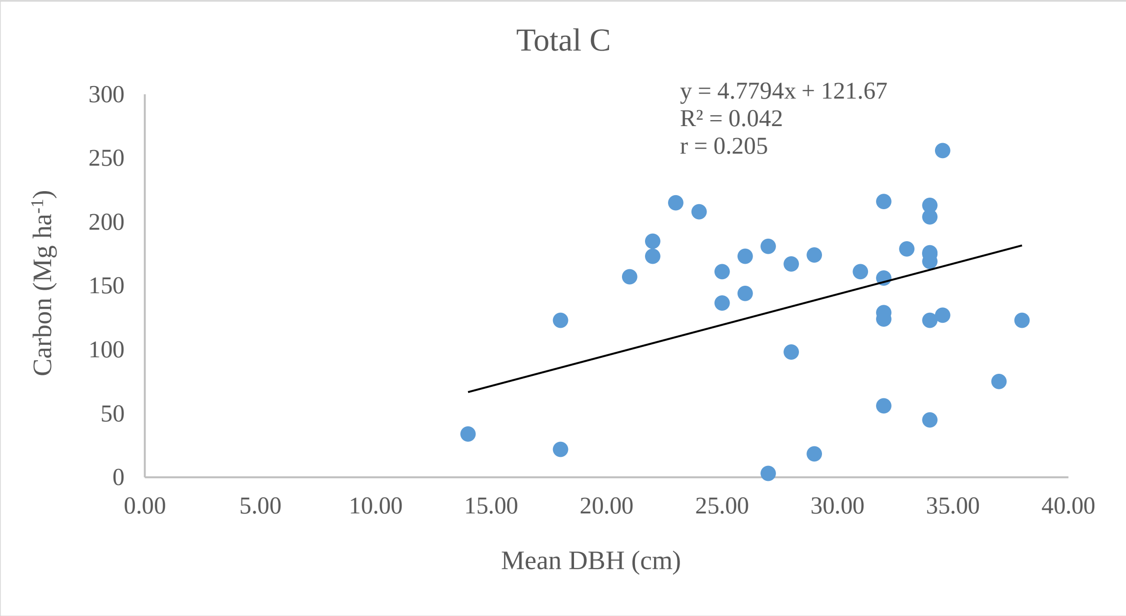

Figure 7. Relationship between mean DBH (cm) and carbon stock (Mg ha^{-1}) in National Botanical Garden

4.9.3 Stem density

The relationship between stem density and biomass carbon stock of National Botanical Garden was measured and presented in shown Figure 8. The linear equation as: $y = 0.9063x + 3.982$ ($R^2 = 0.798$), where R^2 value was positive, $r = 0.893$ and $p < 0.01$. So the estimated value indicated that there was a significant and strongly positive correlation between stem density and biomass carbon stock and with the increase of stem density the biomass carbon stock also increases. Roshetko *et al.* (2007) stated that stem density is important to store carbon as it directly related to the carbon sequestration. In one study that was carried out in an old growth forest of Costa Rica, Central America, found two plots with a stem density 462 to 504 per ha where the AGC was 139 to 138 Mg ha^{-1} respectively (Clark, 2000).

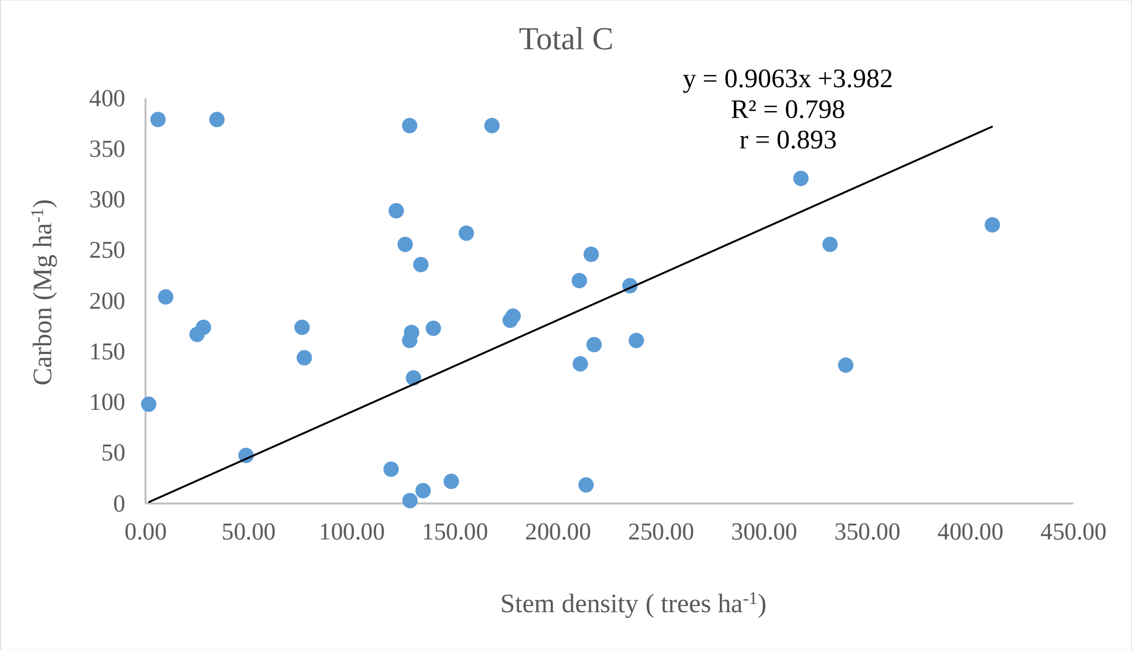

Figure 8. Relationship between stem density (trees ha^{-1}) and carbon stock (Mg ha^{-1}) in National Botanical Garden

4.9.4 Tree diversity

The relationship between tree diversity and biomass carbon stock of National Botanical Garden was measured and presented in shown Figure 9. The linear equation as: $y = 131.81x + 1.342$ ($R^2 = 0.585$), where R^2 value was positive, $r = 0.765$ and $p < 0.01$. So the estimated value indicated that there was a significant and strongly positive correlation between tree diversity and biomass carbon stock and with the increase of tree diversity the biomass carbon stock also increases. In an earlier experiment that was conducted by Day *et al*. (2013) and found that the relationship between tree species diversity and tree carbon stock was significant but weakly correlated with each other in central African rainforest where $r = 0.21$ and $p = 0.03$.

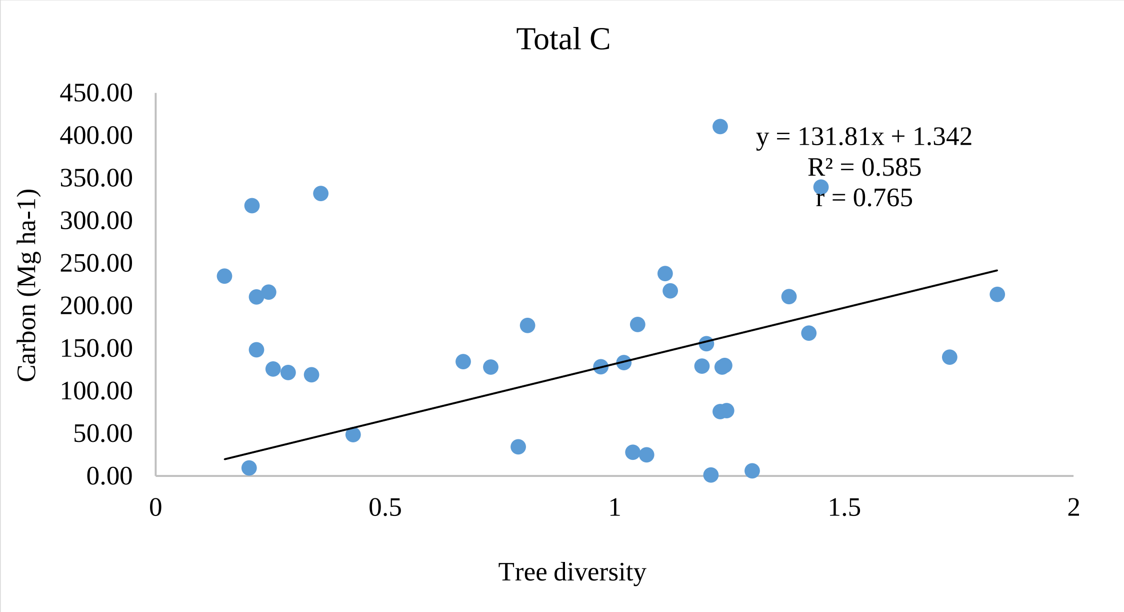

Figure 9. Relationship between tree diversity and carbon stock (Mg ha^{-1}) in National Botanical Garden

4.10 Overall tree species at National Botanical Garden

From the recorded data it was revealed that a total 127 species where available in the National Botanical Garden and there were some unknown species and their local name, botanical name, family, total number of individuals and % of total were shown in Table 6. Kundu (2015) recorded there were a total 19 species in case of Chandrima Uddan and in Ramna park there were a total 41 species.

Table 6. Major tree species identified at 71 sample plots in National Botanical Garden

Sl. No.	Common Name	Scientific Name	Family	Total No.	% of total
1	Hartaki	*Terminalia chebula*	Combretaceae	40	6.04
2	Mohua	*Mohua longifolia*	Sapotaceae	40	6.04
3	Mango	*Mangifera indica*	Anacardiaceae	32	4.83
4	Jackfruit	*Artocarpus heterophyllus*	Moraceae	27	4.08
5	Jhau	*Tamarix gallica*	Tamaricaceae	27	4.08
6	Bohera	*Terminalia bellirica*	Combretaceae	25	3.78

Sl. No.	Common Name	Scientific Name	Family	Total No.	% of total
7	Akashmoni	*Acacia auriculiformis*	Fabaceae	24	3.63
8	Eucalyptus	*Eucalyptus camaldulensis*	Myrtaceae	19	2.87
9	Mahogoni	*Swietenia macrophylla*	Meliaceae	18	2.72
10	Unknown	--	--	17	2.57
11	Chickrashi	*Chukrasia tabularis*	Meliaceae	15	2.27
12	Debdaru	*Polyalthia longifolia*	Annonaceae	15	2.27
13	Hijol	*Barringtonia acutangula*	Lecythidaceae	14	2.11
14	Minjiri	*Senna siamea*	Caesalpiniaceae	13	1.96
15	Neem	*Azadirachta indica*	Meliaceae	13	1.96
16	Raintree	*Albizia saman*	Fabaceae	11	1.66
17	Kath Badam	*Terminalia catappa*	Combretaceae	10	1.51
18	Radhachura	*Peltophorum pterocarpum*	Fabaceae	10	1.51
19	Arjun	*Terminalia arjuna*	Terminalaceae	9	1.36
20	Lohakath	*Xylia xylocarpa*	Fabaceae	8	1.21
21	Raktan	*Mimosa pudica*	Fabaceae	8	1.21
22	Bakul	*Mimusops elengi*	Spotaceae	7	1.06
23	Date/Khejur	*Phoenix sylvestris*	Palmaceae	7	1.06
24	Piayala	*Flacourtia jangomus*	Flacourtiaceae	7	1.06
25	Sada Garjan	*Dipterocarpus turbinatus*	Dipterocarpaceae	7	1.06
26	Segun	*Tectona grandis*	Lamiaceae	7	1.06
27	Korodia	*Viburnum Lentago*	Lamiaceae	6	0.15
28	Krishnachura	*Delonix regia*	Fabaceae	6	0.91
29	Nageshshor	*Mesua nagessarium*	Guttiferae	6	0.91
30	Titpai	*Millettia peguensis*	Elaeocarpaceae	6	0.91
31	Bel	*Aegle marmelos*	Rutaceae	5	0.76
32	Bottle brush	*Callistemon sp.*	Myrtaceae	5	0.76

Sl. No.	Common Name	Scientific Name	Family	Total No.	% of total
33	Kala Koroi	*Albizia lebbeck*	Fabaceae	5	0.76
34	Megaranga	*Caryophyllales plantae*	Cactaceae	5	0.76
35	Shal	*Shorea robusta*	Dipterocarpaceae	5	0.76
36	Teliya Garjan	*Dipterocarpus turbinatus*	Dipterocarpaceae	5	0.76
37	Bajna	*Zanthoxylum rhetsa*	Rutaceae	4	0.60
38	Gutgutta	*Mimosa pudica*	Fabaceae	4	0.60
39	Japani's Jarul	*Lagerstroemia speciosa*	ythraceae	4	0.60
40	Jarul	*Lagerstroemia speciosa*	Lythraceae	4	0.60
41	Kanak Chura	*Caesalpinia pulcherrima*	Fabaceae	4	0.60
42	Kanjal	*Terminalia paniculata*	Combretaceae	4	0.60
43	Minjium	*Acalypha wilkesiana*	Euphorbiaceae	4	0.60
44	Shimul	*Bombax ceiba*	Malvaceae	4	0.60
45	Ashfall	*Fraxinus americana*	Oleaceae	3	0.45
46	Belati gab	*Diospyros discolor Willd*	Ebenaceae	3	0.45
47	Chapalish	*Artocarpus chaplasha*	Moraceae	3	0.45
48	Coconut	*Cocos nucifera*	Palmaceae	3	0.45
49	Gab	*Diospyros blancoi*	Ebenaceae	3	0.45
50	Goda Harina	*Vitex peduncularis*	Verbenaceae	3	0.45

Chapter V

Summary and Conclusion

CHAPTER V

SUMMARY, CONCLUSION AND RECOMMENDATION

Summary

The study was conducted during the period of January to April 2018 to the estimation of ecosystem carbon stock and tree species diversity at National Botanical Garden, Bangladesh. Using transects line method square plots with a size of 20 m × 20 m were taken. So altogether there were total eighty three plot in National Botanical Garden. Among each plot 50 meter interval from plot to plot was maintained for the feasibility of determining the sample plot. Total 12 were avoided due to presence of pond, residence, very low land, office and lake and there were 12 plots accordingly. Ecosystem carbon stock i.e., above ground carbon, below ground carbon and soil organic carbon were estimated from National Botanical Garden.

In consideration of above ground carbon (AGC) and below ground carbon (BGC) biomass stock was 192.67 and 31.34, respectively. In case of soil organic carbon mean value of 27.52 Mg ha^{-1}, 21.45 Mg ha^{-1} and 16.23 Mg ha^{-1}, respectively for 0-10 cm depth in comparison to 10-20 cm and 20-30 cm depth.

Tree diversity of National Botanical Garden were measured by using the Shannon Wiener Index (SWI). SWI showed that the mean value of (0.93 ± 0.14) in National Botanical Garden. The average number of trees in National Botanical Garden (233 tree ha^{-1}), basal area (21.45 m^2 ha^{-1}) and mean DBH (39.86 cm). Tree density ranged from 48 to 662 trees ha^{-1} with a mean value of 233 trees ha^{-1} in National Botanical Garden.

The occurrence of major trees in National Botanical Garden were *Terminalia chebula* and *Mohua longifolia* (6.04%) in same percentage which was followed by *Mangifera indica* (4.83%), *Artocarpus heterophyllus and Tamarix gallica* (4.08%), *Terminalia bellirica* (3.78%), *Acacia auriculiformis* (3.63%) and *Eucalyptus camaldulensis* (2.87%) and *Swietenia macrophylla* (2.72%)

Relationship such as biomass carbon with basal area, mean DBH, stem density and tree diversity were estimated. Among these the relationship between basal area and biomass carbon showed positive significant correlation. The relationship among different parameters varied from place to place due to structure and composition of tree species as well as soil structure and management of gardens. This type of research findings will be helpful to facilitate similar research in other botanical garden area of Bangladesh. In this way if all the green area carried out under similar research then it will represent the overall carbon sequestration potential as well as pattern of tree species of Bangladesh.

Conclusions:

From the result of this study, it can be concluded that

- In consideration of above ground carbon (AGC) and below ground carbon (BGC) biomass and stock was 192.67 and 31.34, respectively. On the other hand, in case of soil organic carbon mean value of 27.52 Mg ha^{-1}, 21.45 Mg ha^{-1} and 16.23 Mg ha^{-1}, respectively for 0-10 cm depth in comparison to 10-20 cm and 20-30 cm depth.
- Shannon Wiener Index (SWI) showed that the mean value of Tree diversity of (0.93 ± 0.14) in National Botanical Garden. Tree density ranged from 48 to 662 trees ha^{-1} with a mean value of 233 trees ha^{-1} in National Botanical Garden.
- Relationship between basal area and biomass carbon showed positive significant correlation. The relationship among different parameters varied from place to place due to structure and composition of tree species as well as soil structure and management of gardens.

Recommendation:

1. This study has profound influence in terms of climate change mitigation strategy as for similar research works need to be carried out in other botanical garden areas of Bangladesh to estimation of ecosystem carbon stock and tree species diversity as well as enlarging the knowledge of global issues of carbon sequestration in terrestrial area.

2. The allometric equation applied in the present study is not free of errors in calculating carbon levels in different trees. Such errors are caused by approximation of wood densities of trees, slight deviations of biological make up of species in different sites that are not equal to where the allometric equation was developed, and site specific environmental conditions.

3. As a solution, the allometric equation formulated for other countries should be calibrated to suit local situations through field research, and then use them to determine the carbon levels in different trees exactly and accurately.

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Appendices

APPENDICES

Appendix I. Center point co-ordinates of plots in National Botanical Garden

Plot No.	Coordinates		Plot No.	Coordinates	
	N	E		N	E
1	$23^{0}49.43^{/}$	$90^{0}21.10^{/}$	43	--	--
2	$23^{0}49.41^{/}$	$90^{0}21.06^{/}$	44	$23^{0}49.31^{/}$	$90^{0}20.76^{/}$
3	$23^{0}49.41^{/}$	$90^{0}21.02^{/}$	45	$23^{0}49.31^{/}$	$90^{0}20.79^{/}$
4	--	--	46	$23^{0}49.30^{/}$	$90^{0}20.82^{/}$
5	$23^{0}49.41^{/}$	$90^{0}21.02^{/}$	47	$23^{0}49.25^{/}$	$90^{0}21.05^{/}$
6	$23^{0}49.48^{/}$	$90^{0}20.87^{/}$	48	$23^{0}49.29^{/}$	$90^{0}20.73^{/}$
7	$23^{0}49.45^{/}$	$90^{0}20.82^{/}$	49	--	--
8	$23^{0}49.46^{/}$	$90^{0}20.84^{/}$	50	$23^{0}49.27^{/}$	$90^{0}20.75^{/}$
9	--	--	51	$23^{0}49.23^{/}$	$90^{0}20.80^{/}$
10	$23^{0}49.43^{/}$	$90^{0}20.99^{/}$	52	$23^{0}49.22^{/}$	$90^{0}20.86^{/}$
11	$23^{0}49.42^{/}$	$90^{0}21.05^{/}$	53	$23^{0}49.22^{/}$	$90^{0}20.90^{/}$
12	$23^{0}49.44^{/}$	$90^{0}20.78^{/}$	54	$23^{0}49.22^{/}$	$90^{0}20.92^{/}$
13	$23^{0}49.43^{/}$	$90^{0}20.80^{/}$	55	$23^{0}49.20^{/}$	$90^{0}20.96^{/}$
14	$23^{0}49.43^{/}$	$90^{0}20.82^{/}$	56	$23^{0}49.19^{/}$	$90^{0}20.98^{/}$
15	$23^{0}49.37^{/}$	$90^{0}20.99^{/}$	57	$23^{0}49.17^{/}$	$90^{0}20.91^{/}$
16	$23^{0}49.37^{/}$	$90^{0}21.01^{/}$	58	$23^{0}49.17^{/}$	$90^{0}20.94^{/}$
17	--	--	59	$23^{0}49.18^{/}$	$90^{0}21.01^{/}$
18	$23^{0}49.41^{/}$	$90^{0}20.79^{/}$	60	$23^{0}49.14^{/}$	$90^{0}20.91^{/}$
19	$23^{0}49.40^{/}$	$90^{0}20.81^{/}$	61	$23^{0}49.13^{/}$	$90^{0}20.94^{/}$
20	$23^{0}49.40^{/}$	$90^{0}20.84^{/}$	62	--	--
21	--	--	63	$23^{0}49.10^{/}$	$90^{0}20.91^{/}$
22	$23^{0}49.36^{/}$	$90^{0}20.99^{/}$	64	$23^{0}49.10^{/}$	$90^{0}20.94^{/}$

Plot No.	Coordinates		Plot No.	Coordinates	
	N	E		N	E
23	$23^{0}49.36^{/}$	$90^{0}21.00^{/}$	65	$23^{0}49.07^{/}$	$90^{0}20.91^{/}$
24	$23^{0}49.36^{/}$	$90^{0}21.01^{/}$	66	$23^{0}49.88^{/}$	$90^{0}20.95^{/}$
25	--	--	67	$23^{0}49.08^{/}$	$90^{0}20.98^{/}$
26	$23^{0}49.37^{/}$	$90^{0}20.77^{/}$	68	$23^{0}49.04^{/}$	$90^{0}20.89^{/}$
27	$23^{0}49.38^{/}$	$90^{0}20.79^{/}$	69	$23^{0}49.03^{/}$	$90^{0}20.94^{/}$
28	$23^{0}49.38^{/}$	$90^{0}20.80^{/}$	70	$23^{0}49.02^{/}$	$90^{0}21.00^{/}$
29	--	--	71	$23^{0}49.02^{/}$	$90^{0}20.97^{/}$
30	--	--	72	$23^{0}49.01^{/}$	$90^{0}20.90^{/}$
31	$23^{0}49.35^{/}$	$90^{0}20.98^{/}$	73	$23^{0}49.01^{/}$	$90^{0}20.93^{/}$
32	$23^{0}49.34^{/}$	$90^{0}21.00^{/}$	74	$23^{0}49.00^{/}$	$90^{0}20.98^{/}$
33	$23^{0}49.34^{/}$	$90^{0}21.01^{/}$	75	$23^{0}48.99^{/}$	$90^{0}21.03^{/}$
34	--	--	76	$23^{0}48.96^{/}$	$90^{0}21.02^{/}$
35	$23^{0}49.35^{/}$	$90^{0}20.78^{/}$	77	$23^{0}48.93^{/}$	$90^{0}20.90^{/}$
36	$23^{0}49.36^{/}$	$90^{0}20.84^{/}$	78	$23^{0}48.88^{/}$	$90^{0}20.87^{/}$
37	$23^{0}49.43^{/}$	$90^{0}21.10^{/}$	79	$23^{0}48.89^{/}$	$90^{0}20.91^{/}$
38	--	--	80	$23^{0}48.83^{/}$	$90^{0}20.89^{/}$
39	$23^{0}49.37^{/}$	$90^{0}20.90^{/}$	81	$23^{0}48.83^{/}$	$90^{0}20.92^{/}$
40	$23^{0}49.37^{/}$	$90^{0}20.92^{/}$	82	$23^{0}48.77^{/}$	$90^{0}20.88^{/}$
41	$23^{0}49.33^{/}$	$90^{0}20.80^{/}$	83	$23^{0}48.76^{/}$	$90^{0}20.91^{/}$
42	$23^{0}49.33^{/}$	$90^{0}20.82^{/}$			

Appendix II. Above and below ground biomass carbon stock in 83 sample plots of National Botanical Garden

Plot No.	AGC ($Mg\ ha^{-1}$)	BGC ($Mg\ ha^{-1}$)	Total C ($Mg\ ha^{-1}$)	Average C ($Mg\ ha^{-1}$)	Standard Deviation	Standard Error
1	163.32	26.19	189.51	144.46	64.26	13.19
2	125.96	26.71	152.66			
3	84.88	22.15	107.02			
4	0.00	0.00	0.00			
5	109.50	32.19	141.69			
6	168.21	43.63	211.84			
7	72.80	23.52	96.32			
8	92.56	23.59	116.15			
9	0.00	0.00	0.00			
10	52.74	16.73	69.48			
11	46.62	14.48	61.10			
12	100.56	33.34	133.91			
13	59.22	18.52	77.74			
14	145.66	27.22	172.88			
15	38.58	11.98	50.56			
16	39.87	14.77	54.64			
17	0.00	0.00	0.00			
18	56.26	14.26	70.52			
19	72.27	19.80	92.07			
20	90.90	19.75	110.65			
21	0.00	0.00	0.00			
22	84.79	20.21	105.00			
23	153.42	43.10	196.52			
24	55.92	17.13	73.05			
25	0.00	0.00	0.00			
26	136.46	20.26	156.72			
27	70.23	14.41	84.64			
28	0.26	2.82	3.08			
29	0.00	0.00	0.00			
30	0.00	0.00	0.00			
31	67.99	24.18	92.17			
32	86.74	30.60	117.34			
33	68.28	16.64	84.91			
34	0.00	0.00	0.00			
35	109.59	23.69	133.28			
36	126.50	25.36	151.86			
37	220.58	39.54	260.12			
38	0.00	0.00	0.00			
39	39.91	15.04	54.95			
40	172.97	32.88	205.85			
41	130.65	25.38	156.03			

Plot No.	AGC (Mg ha^{-1})	BGC (Mg ha^{-1})	Total C (Mg ha^{-1})	Average C (Mg ha^{-1})	Standard Deviation	Standard Error
42	134.27	27.93	162.20			
43	0.00	0.00	0.00			
44	26.58	13.48	40.06			
45	79.04	16.76	95.80			
46	108.92	27.29	136.22			
47	82.54	16.93	99.47			
48	43.38	11.12	54.51			
49	0.00	0.00	0.00			
50	161.93	28.00	189.93			
51	231.88	33.86	265.74			
52	144.35	25.46	169.81			
53	170.64	32.02	202.66			
54	154.58	25.73	180.31			
55	90.30	17.54	107.84			
56	198.28	26.34	224.62			
57	65.32	15.83	81.14			
58	41.67	13.03	54.71			
59	205.33	32.34	237.67			
60	73.45	24.92	98.37			
61	52.67	16.83	69.50			
62	0.00	0.00	0.00			
63	213.37	30.16	243.53			
64	102.13	20.95	123.07			
65	94.08	21.61	115.69			
66	131.14	26.29	157.43			
67	106.78	30.38	137.16			
68	234.98	27.86	262.84			
69	93.75	18.38	112.13			
70	192.95	33.37	226.32			
71	212.90	32.49	245.38			
72	164.80	30.28	195.08			
73	176.00	28.22	204.22			
74	141.24	24.43	165.67			
75	216.82	28.54	245.36			
76	99.41	16.73	116.15			
77	202.45	28.62	231.07			
78	153.00	27.32	180.32			
79	219.38	36.19	255.56			
80	136.03	20.34	156.36			
81	213.84	28.15	241.99			
82	194.37	34.99	229.35			
83	139.53	17.84	157.37			

Appendix III. Soil Organic Carbon (SOC) stock at three different depth classes in 83 sample plots in National Botanical Garden

Plot No.	SOC (Mg ha^{-1}) (0-10 cm)	SOC (Mg ha^{-1}) (10-20 cm)	SOC (Mg ha^{-1}) (20-30 cm)	Total SOC (Mg ha^{-1})	Mean	Standard Deviation	Error
1	22.45	21.34	16.45	60.24	21.73	7.43	1.80
2	27.68	20.34	16.22	64.24			
3	29.45	23.34	17.45	70.24			
4	0	0	0	0			
5	27.56	19.89	14.34	61.79			
6	29.34	22.12	15.78	67.24			
7	26.12	21.34	17.46	64.92			
8	28.56	24.55	18.24	71.35			
9	0	0	0.00	0			
10	29.44	25.13	17.56	72.13			
11	26.12	23.12	18.05	67.29			
12	19.00	18.45	14.12	51.57			
13	23.23	21.12	16.34	60.69			
14	29.86	19.12	15.45	64.43			
15	29.21	23.56	15.67	68.44			
16	32.56	25.34	17.23	75.13			
17	0	0	0	0			
18	31.34	23.12	17.67	72.13			
19	28.56	20.09	16.67	65.32			
20	27.22	22.67	15.45	65.34			
21	0	0	0.00	0.00			
22	30.67	24.78	17.34	72.79			
23	27.86	21.56	17.33	66.75			
24	25.12	20.13	15.45	60.70			
25	0		0	0			
26	23.45	18.45	10.89	52.79			
27	22.67	17.64	11.21	51.52			
28	29.56	23.56	17.56	70.68			
29	0	0	0.00	0.00			
30	0	0	0.00	0.00			
31	23.57	17.91	10.20	51.68			
32	28.94	23.23	16.45	68.62			
33	30.12	26.32	17.45	73.89			
34	0	0	0	0			
35	25.56	20.13	16.78	62.47			
36	23.67	19.96	15.34	58.97			
37	22.87	18.45	14.56	55.88			
38	0	0	0	0			
39	25.56	21.18	17.45	64.19			
40	0	0	0	0			
41	29.78	23.67	16.45	69.90			
42	23.78	18.56	15.78	58.12			

Plot No.	SOC (Mg ha^{-1}) (0-10 cm)	SOC (Mg ha^{-1}) (10-20 cm)	SOC (Mg ha^{-1}) (20-30 cm)	Total SOC (Mg ha^{-1})	Mean	Standard Deviation	Error
43	0	0	0	0			
44	28.34	23.46	17.78	69.58			
45	32.21	24.16	16.89	73.26			
46	28.56	23.67	17.56	69.79			
47	28.12	21.67	18.09	67.88			
48	31.89	25.67	17.67	75.23			
49	0	0	0	0			
50	25.67	21.12	17.56	64.35			
51	27.56	23.40	17.89	68.85			
52	23.56	19.95	14.67	58.18			
53	29.34	21.01	17.65	68.00			
54	29.23	23.67	16.89	69.79			
55	30.34	25.78	17.45	73.57			
56	28.24	19.67	15.32	63.23			
57	31.45	24.78	17.89	74.12			
58	27.22	23.66	17.45	68.33			
59	32.12	25.68	18.05	75.85			
60	29.96	22.09	17.78	69.83			
61	28.56	23.56	17.56	69.68			
62	0	0	0	0			
63	30.18	23.34	17.45	70.97			
64	31.98	22.49	16.34	70.81			
65	25.56	21.45	17.89	64.90			
66	29.45	22.67	16.34	68.46			
67	28.78	21.12	15.87	65.77			
68	30.18	19.34	16.67	66.19			
69	31.00	20.89	17.79	69.68			
70	24.56	19.56	16.56	60.68			
71	28.45	24.98	17.45	70.88			
72	29.56	20.56	16.90	67.02			
73	30.90	21.12	17.45	69.47			
74	27.85	20.56	16.66	65.07			
75	29.33	22.78	17.78	69.89			
76	25.74	20.44	17.67	63.85			
77	29.67	23.12	17.83	70.62			
78	27.12	19.04	14.23	60.39			
79	28.07	18.14	15.67	61.88			
80	29.45	20.23	14.67	64.35			
81	26.84	19.45	15.09	61.38			
82	28.65	18.45	13.67	60.77			
83	27.32	20.14	17.96	65.42			

Appendix IV. Tree diversity characteristics in 83 sample plots of National Botanical Garden

Plot No.	Tree diversity value	Mean	Standard deviation	Standard Error
1	1.12	0.93	0.52	0.14
2	1.9			
3	0.93			
4	0			
5	1.14			
6	1.28			
7	0.96			
8	0.67			
9	0			
10	0.68			
11	0.57			
12	0.84			
13	1.45			
14	1.11			
15	1.12			
16	1.32			
17	0			
18	1.34			
19	0.56			
20	0.89			
21	0			
22	0.34			
23	0.67			
24	0.78			
25	0			
26	1.86			
27	0.45			
28	1.15			
29	0			
30	0			
31	0.25			
32	0.76			
33	0.67			
34	0			
35	1.03			
36	1.02			
37	0.78			
38	0			
39	1.14			
40	0.44			
41	1.09			

Plot No.	Tree diversity value	Mean	Standard deviation	Standard Error
42	0.67			
43	0			
44	1.16			
45	0.26			
46	1.23			
47	0.95			
48	1.34			
49	0			
50	1.06			
51	1.56			
52	1.45			
53	0.56			
54	1.15			
55	1.05			
56	1.33			
57	0.69			
58	0.63			
59	1.08			
60	1.32			
61	0.62			
62	0			
63	0.58			
64	0.65			
65	0.89			
66	0.56			
67	1.12			
68	1.24			
69	0.64			
70	0.92			
71	0.45			
72	1.11			
73	1.07			
74	0.58			
75	0.74			
76	1.22			
77	1.06			
78	0.85			
79	0.58			
80	1.02			
81	0.52			
82	1.05			
83	0.82			