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CARBON ASSESSMENT OF HOMEGARDENS IN DIGHALIA UPAZILA, KHULNA

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DECLARATION

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DEDICATED

TO

MY BELOVED PARENTS

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ABSTRACT

Tropical homegardens are believed to have an immense prospect in carbon sequestering and Bangladesh has a substantial number of homegardens that may store a great quantity of carbon because of their perceived ability for greater capture and utilization of growth resources than monoculture. However, a vital variable of tropical homegardens is its' species diversity. Thus species diversity may influence the biomass production of a homegarden ecosystem and consequently carbon stocks. The purpose of this study was to determine whether there is a relationship between species diversity and carbon stocks in case of tropical homegardens in Dighalia, Bangladesh. 40 homegardens were selected from two unions (lowest administrative unit) of Dighalia upazill by multistage random sampling. The plot size was 10m × 10m. Diameter at breast height (DBH) and height were measured, species were counted and soil samples were collected from (0.0-0.15) m and (0.15-0.3) m depths. Tree biomass was calculated using equation of Chave et al. (2005) and converted into carbon, soil carbon was analyzed in laboratory and species diversity was calculated. Then, relation between species diversity and carbon stocks was developed. Total carbon stocks in homegardens ranged from 103.96 to 242.32 Mg ha^{-1} with an average ± S.E. of 170.13 ± 5.64 Mg ha^{-1} and was higher than other reported homegardens. Woody species diversity as measured by the Shannon-Wiener index (H') and species richness as measured by the Margalef index (R) were 2.56 ± 0.04 and 2.3 ± 0.06 respectively. A positive and moderate significant relationship ($r = 0.56$, $P = 0.001$) was observed between Shannon-Wiener index and carbon stocks as well as Margalef index (R) ($r = 0.47$, $P = 0.002$). So the conservation of species diversity may stand for an important factor in the mitigation of global warming, through great amounts of carbon storage in traditional smallholder agroforestry systems.

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LIST OF ACRONYMS

C	Carbon
CO_2	Carbon-di-oxide
CDB	Conservation of Biological Diversity
FAO	Food and Agricultural Organization
DBH	Diameter at Breast Height
GHG	Greenhouse Gas
GPS	Global Positioning system
IPCC	International Panel on Climate Change
MGD	Millennium Development Goals
REDD+	Reduced Emissions from Deforestation and Forest Degradation "plus" conservation
UNFCCC	United Nations Framework Conference on Climate Change
USDA	United States Department of Agriculture

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Chapter 1

Introduction

1.1 Background and Justification of the Study

World today, facing major challenges for biodiversity conservation and rising levels of atmospheric CO_2 (Kumar 2011, Zhang et al. 2011) leading to global warming is a worldwide concern at the recent time (Asante 2011). Global warming is resulting mostly because of man-made emissions of greenhouse gases (mainly CO_2) (Sharma et al. 2010). Two main sources of CO_2 emission to the atmosphere are combustion of fossil fuel and deforestation (Detwiler and Hall 1988). At a rate of 3.5 Pg (Pg = 1015 g or billion tons) per annum carbon is accumulating in the atmosphere, the major proportion of which resulting from the burning of fossil fuels and the conversion of tropical forests to agricultural production (Paustian et al. 2000). The current average annual increase of CO_2 is about 1.5 μLL^{-1} (1.5 ppm), with a predicted doubling of the pre-industrial concentration by the end of the 21st century (IPCC 2001). Increasing amount of atmospheric CO_2 from 1906-2005 caused the increase of average global temperature by 0.74^0C (IPCC 2007). There is an estimation that if global warming continue and accelerate, the earth could warm by $(2\text{-}4)^0C$ by 2100. The most substantial processes associated with an increased concentration of CO_2 in the atmosphere are harmful changes in the global climate. Increasing global temperature at this rate could considerably alter the earth's climate, land use and raising sea level up to 5 m by melting polar ice-cap (Detwiler and Hall 1988).

The REDD+ mechanism is primarily about CO_2 emissions reductions. It refers to actions that reduce emissions by sources or increase removals by sinks in various land use sector in developing countries. It is primarily focused on enhancing the role of conservation, Sustainable Management of Forests and Enhancement of forest carbon stocks in Developing Countries (Gardner et al. 2011). Important elements of REDD+ programme include monitoring, reporting, and verification as well as reference emission level which need sufficient records of carbon stock. Moreover, non-carbon benefit of REDD+ programme has also focused on the biodiversity promotion (Mandal et al. 2013). Besides, there is another growing concern that whether working for carbon enhancement through REDD+ programme should include the biodiversity promotion too (Mandal et al. 2013).

Forests, having their long-lived woody character makes them most productive terrestrial ecosystem and attractive for climate change mitigation. Forest play an important role in carbon storing and in the world forest current carbon stock is estimated to be (861 ± 66) Pg C, with (383 ± 30) Pg C (44%) in soil (to 1m depth), (363 ± 28) Pg C (42%) in live biomass (above and below ground), (73 ± 6) Pg C (8%) in deadwood and (43 ± 3) Pg C (5%) in litter. Geologically, 55% is stored in tropical forests, with 32% in boreal and 13% in temperate forests (Pan et al. 2011). Halting deforestation single can contribute to reduce about 18% atmospheric CO_2 emission (IPCC 2007). Enhancing carbon sequestration by increasing forested land area has been suggested as an effective measure to mitigate elevated atmospheric CO_2 concentrations and hence to contribute towards the prevention of global warming (Watson 2000). Under the Kyoto Protocol's Article 3.3, A&R (afforestation and reforestation) with agroforestry as a part of it has been recognized as an option for mitigating greenhouse gases. As a result, there is now increasing awareness on agroforesty's potential for carbon sequestration (Nair et al. 2009a, 2010).

As most agroforestry systems have great potential for carbon sequestration, homegardens are unique in this respect (Kumar 2011). They not only sequester carbon in biomass and soil, but also reduce fossil-fuel burning by promoting fuel wood production, and conserve agro-biodiversity (Kumar and Nair 2004). In addition, they help in the conservation of carbon stocks in existing natural forests by alleviating the pressure on these areas (Kumar 2006). Moreover, there is no complete removal of biomass from the homegardens, representing the permanence of these systems (Kumar 2011). Thus it is an added advantage of homegardens, as lack of stability or permanence of the carbon sequestered is a major concern in carbon sequestration projects (UNFCCC 2007). More than half of the carbon assimilated by woody perennials in this system is also transported belowground via root growth and organic matter turnover processes (e.g., fine root dynamics, rhizodeposition and litter dynamics), expanding the soil organic carbon pool (Kumar 2006).

Environmentalists have also become interested in potential functional relationships between plant diversity and carbon storage (Zhang et al. 2011). There is evidence that plant assemblages with high species diversity may promote a more efficient use of resources and greater net primary production (Vandermeer 1989) and consequently, a higher rate of carbon sequestration (Kirby and Potvin 2007) compared with sites with lower species diversity. Greater species diversity of homegardens also may ensure longer term stability of carbon storage in fluctuating environments (Henry et al. 2009). Again Species diversity of tropical homegardens is quite variable (Kumar and Nair 2004) depending on the geographic location (Kumar 2011). Most of the studies on Bangladesh homegardens remained descriptive on the floristic, structure, uses, and the relation between household and homegardens characters (Alam and Masud 2005, Bardhan et al. 2012, Kabir and Webb 2008a, Millat-e-Mustafa et al. 2002, Webb and Kabir 2009). Kumar (2006) reviewed the countries or places where studies conducted on home gardens potential for carbon sequestration but no studies have yet been documented particularly for Bangladesh. Thus in this study following objectives have been taken.

1.2 Objectives

i. To assess carbon stocks in homegardens of Dighalia upazilla.
ii. To assess woody species diversity in homegardens of Dighalia upazilla.
iii. To quantify relationship between carbon stocks and woody species diversity in homegardens of Dighalia upazilla.

1.3 Scopes

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

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

Chapter 2

Literature Review

2.1 Evolution of homegarden

History of evolution of homegardens is antiquated and not precise. Most probably, next to shifting cultivation, homegardening is the oldest land use activity. Homegardens may have evolved through initiation of cropping intensification to meet demand derived from increasing human pressure and corresponding shortage of cultivable lands (Kumar and Nair 2004). Their existence was observed to 3000 BC and perhaps 7000 BC (Soemarwoto 1987). This is supported by Ramayana and Mahabharata (based on events that have supposedly happened around 7000 BC and 4000 BC respectively) two great Indian epics contain an illustration of Ashok Vatika, an appearance of present homegardens (Puri and Nair 2004). There have existence of village forest gardens, a type of homegarden since the tenth century AD (Michon 1983). Origination of Javanese homegardens is reported as early as the seventh millennium BC (Hutterer 1984) and homegardens in Kerala, India are considered at least 4000 years old (Kumar and Nair 2004). Finally centuries of cultural and biological transformation and the accrued wisdom and insights of farmers' interaction with environment, without access to outer inputs, capital or scientific skills was the essence of homegarden evolution.

2.2 *Concepts of homegarden*

Several authors have tried to describe the term homegarden. None is perhaps universally accepted as the definition but the concept is well understood to us. Homegardens are intensively cultivated agroforestry systems managed within the compounds of individual homes. A complex mixture of trees and agricultural crops in and around the homestead lands is traditionally called the homegarden. They involve the deliberate management of multipurpose trees and shrubs (the woody component), grown in intimate association with herbaceous species (mainly annual, perennial, and seasonal agricultural crops), and livestock (Fernandes and Nair 1986). Torquebiau (2000) further classifies them as agroforestry homegardens in order to avoid possible confusion with domestic vegetable gardens. Homegardens are a common most ancient smallholder agroforestry system. These species-rich tree based systems usually occupy lands immediately surrounding the household and are used to produce a diverse array of food and other products. Traditionally intended to produce goods mainly for home consumption, the initiation of rural infrastructure and market-economies has made homegardens more commercially oriented. Homegardens production now commonly serves household and market demand, providing families with much needed income (Michon and Mary 1994).

Homegardens are widely practiced in Latin America, Southeast Asia and Equatorial Africa and are the most sustainable cropping system in the tropics (Herzog 1994), having many different local names in different countries even in different places within a country. Some of the different names are agroforestry homegardens, household or homestead farms, compound farms, mixed garden, house garden, tree garden, kitchen garden, dooryard garden and backyard garden (Kumar and Nair 2004). Some of the local names are pekarangan in Java (Kumar and Nair 2004), kebun in Malaysia, Shamba and Chagga in East Africa, Kampung in Indonesia, jardin creole in West Indies, dooryard gardens in America (Michon 1983), quintal and calmil in tropical, kibanja in North West Tanzania, compound farms in Africa, and bagan bari in Bangladesh (Millat-e-Mustafa et al. 1996). A total of 270,000 ha area i.e., 2% of country's total land area and 10% of country's total primary forests area is under homegarden agroforestry systems in Bangladesh (FAO 2005).

2.3 Carbon Sequestration

Carbon sequestration refers to the capture and long term storage of carbon in forests and soils, so that the build-up of CO_2 (one of the principle greenhouse gases) in the atmosphere will reduce or slow. The UNFCCC defines carbon sequestration as the process of removing carbon from the atmosphere and depositing it in a reservoir. Carbon sequestration can be defined as the amount of carbon that can be additionally stored in an agro-ecosystem (Bernoux et al. 2006). At present, carbon sequestration is valued as a function of credit emission reductions (CERs), based on the difference between the amount of carbon stored in scenario projects and the baseline, current amount of carbon stored in the system (UNFCCC 2004). According to USDA Forest Service, "Carbon sequestration is the process by which atmospheric CO_2 is taken up by trees, grass and other plants through photosynthesis and stored as carbon in biomass (trunks, branches, foliages and roots) and soils."

2.3.1 Types of Carbon Sequestration

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

i. Terrestrial sequestration or vegetative sequestration: Terrestrial sequestration is the natural intake of CO_2 by plants, which incorporate it in their wood, leaves, and roots and also bind it to the underlying soil and much of this CO_2 is not released into the atmosphere until the plant is destroyed (by decay or burning) or the soil is tilled and exposed to the atmosphere. This can be enhanced by increasing the growth of land plants through planting trees, mitigating deforestation or adjusting forest management practices. It is the easiest and most immediate option for carbon sequestration at the present time.

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

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

2.4 Forest as a climate mitigation option

Forest have an important role in the global carbon cycle (Pan et al. 2011) and forestry can contribute to climate change mitigation through three different ways like carbon sequestration, carbon conservation and carbon substitution.

2.4.1 Carbon sequestration

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

2.4.2 Carbon conservation

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

2.4.3 Carbon substitution

Forest products can substitute for products from other sectors that have relatively high GHG emission. Wood-based fuels such as fuel wood, charcoal, black liquor and ethanol can be used as substitutes for fossil fuels in heating, energy generation and transport. When wood is produced in forests under a sustainable forest management (SFM) regime, it is effectively carbon-neutral. The production of goods made of steel, aluminum, concrete and plastic consumes large amount of energy and therefore causes significant GHG emission. The substitution of these products with sustainably produced wood products can therefore help reduce GHG emission (IPCC 2005).

2.5 Carbon cycle in forest

Photosynthesis is the chemical process by which plants use sunlight to convert nutrients into sugars and carbohydrates. CO_2 is essential to building the organic chemicals that comprise leaves, roots and stems.

As more photosynthesis occurs, more CO_2 is converted into biomass, reducing carbon in the atmosphere and sequestering it in plant tissue (vegetation) above and below ground. Plants also respire, using oxygen to maintain life and emitting CO_2 in the process. At times (e. g., at night and during winter seasons in non-tropical climates), living, growing forests are net emitters of CO_2; although they are generally net carbon sinks over the life of the forest.

When vegetation dies, carbon is released to the atmosphere. This can occur quickly, as in a fire or slowly as fallen trees, leaves and other detritus decompose. For herbaceous plants, the above ground biomass dies annually and begins to decompose right away but for woody plants some of the above ground biomass continues to store carbon until the plants dies and decomposes. This is the essence of the carbon cycle in the forests-net carbon accumulation (sequestration) with vegetative growth and release of carbon when the vegetation dies. Thus the amount of carbon sequestered in a forest is constantly changing with growth, death and decomposition of vegetation. In addition to being sequestered in vegetation, carbon is also sequestered in forest soils. Carbon is the organic content of soil, generally in the partially decomposed vegetation (humus) on the surface and in the upper soil layers, in the organisms that decompose vegetation and in the fine roots.

The amount of carbon in soils varies widely, depending on the environment and history of the site. Soil carbon accumulates as dead vegetation is added to the surface and decomposers respond. Carbon is also "injected" into the soil as roots grow (root biomass increases). Soil carbon is also slowly releases to the atmosphere as the vegetation decomposes. Scientific understanding of the rate of soil carbon accumulation and decomposition is currently not sufficient for predicting changes in the amount of carbon sequestered in forest soils.

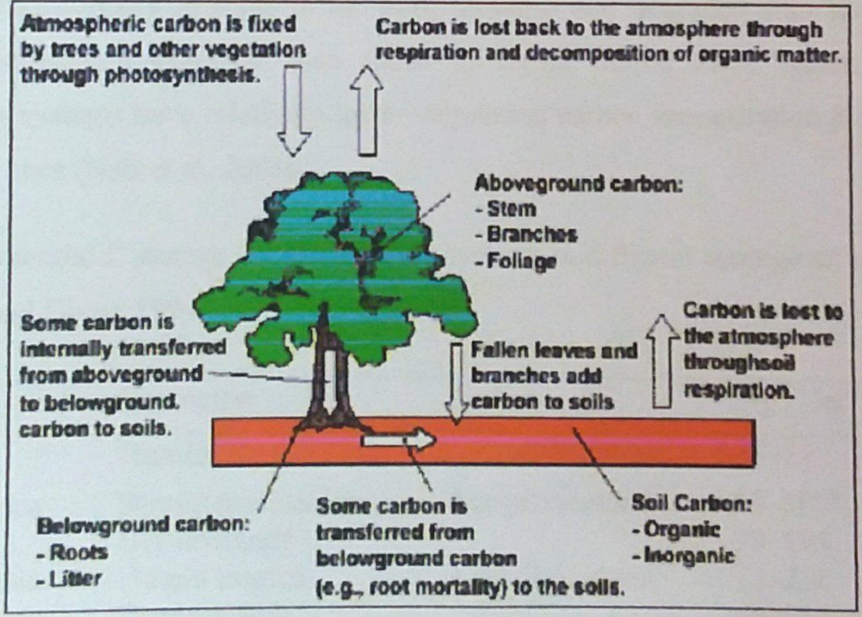

Figure 2.1 An illustrated guide to carbon cycle (Source: USEPA at www.epa.gov/ sequestration/local_scale.html)

2.6 Global forest carbon trends

The total carbon stocks in world's living forest was 277.49 Gt in 2010 with 55.74 Gt in Africa, 44 Gt in Asia and Pacific, 104 Gt in Latin America and the Caribbean, 45 Gt in Europe, 25.25 Gt in North America and 3.5 Gt in the near east. The total gross carbon uptake by the world established and tropical regrowth forests is 4.0 Pg C y^{-1} (Pan et al. 2011), which is equivalent to half of the fossil fuel carbon emissions in 2009. During the period 1990-2007, the cumulative C sink into the worlds established forest is ~43 Pg C and for the established plus re-growing forest was 73 Pg C , the latter equivalent to 60% of cumulative fossil emissions in the period (i.e., 126 Pg C). So it is clear that forests play a critical role in earth's terrestrial C sinks and exert strong control on the evolution of atmospheric CO_2 (Pan et al. 2011).

2.7 Carbon sequestration in homegardens

The above-ground vegetation in natural forests held on average 54% of the total carbon stocks, with the root and soil components each contributing 14% and 32%, respectively. In agroforests, in contrast, the soil component on average included about 66% of the carbon stocks, followed by the aboveground vegetation (26%) and roots (7%) (Kessler et al. 2012). Agroforestry systems in the arid, semiarid and degraded sites have a lower carbon sequestration potential than those in fertile humid sites. Again temperate agroforestry systems have relatively lower vegetation carbon sequestration potential than the tropical ones (Nair et al. 2009b).

Table 2.1 Potential C storage for agroforestry systems in different ecoregions of the world (Krankina and Dixon 1994).

Continent	Ecoregion	System	Mg C ha^{-1}
Africa	Humid tropical high	Agrosilvicutural	29–53
South America	Humid tropical low	Agrosilvicutural	39–102[a]
	Dry lowlands		39–195
Southeast Asia	Humid tropical	Agrosilvicutural	12–228
	Dry lowlands		68–81
Australia	Humid tropical low	Silvopastoral	28–51
North America	Humid tropical high	Silvopastoral	133–154
	Humid tropical low	Silvopastoral	104–198
	Dry lowlands	Silvopastoral	90–175
Northern Asia	Humid tropical low	Silvopastoral	15–18

[a] Carbon storage values were standardized to 50-year rotation.

In agroecosystems, although organic carbon stocks in the soil represent often the largest carbon sink (Dixon 1995), aboveground biodiversity may still play an important role in carbon sequestration with consequent positive impacts on belowground carbon sequestration (e.g., through litter fall, root exudation and turnover or soil erosion control). Variability in carbon sequestration and biodiversity can be high within complex agroecosystems, depending on factors such as vegetation age, structure, species involved, management practices, land uses and landscape (Montagnini and Nair 2004).

Table 2.2 *Summary of literature values on aboveground and root C stocks in some tropical homegardens and agroforestry systems.*

Land-use system	Method of estimation	C stock (Mg ha^{-1})		Source
		Aboveground	Root	
Homegardens; Central Kerala, India	Excludes litter, herb, shrub, root and soil C stocks	16-36	×	Kumar 2011
Homegardens; Indonesia	Excludes litter, herb, and soil C stocks	35.3	8.8	Roshetko et al. 2002
Agroforest (Home and outfield gardens), Panama	Excludes, litter, herb, and soil C stocks	93	18	Kirby and Potvin 2007
AF woodlot; Kerala, India	Root excavation; only coarse roots (>1.4 cm in diameter) included	172	8.87	Kumar et al. 1998a

The literature on soil carbon sequestration potential of homegarden and agroforestry system is scanty although rather plentiful reports are available on the potential role of agricultural soils to sequester carbon. Reviewing the soil carbon sequestration in homegarden and agroforestry system in comparison with other land-use systems, Nair et al. (2009b) noted a general trend of increasing soil organic carbon (SOC), an indicator of soil carbon sequestration, in agroforestry and ranked the land-use systems in terms of their soil organic carbon content in the order: forests > agroforests > tree plantations > arable crops.

Table 2.3 Summary of literature values on soil C stocks under tropical homegardens and agroforestry systems (Nair et al. 2009b)

Agroecological zones	Major landuse system	System characteristics- E:existing; N: new plantings; TD: tree density (trees ha^{-1}); age: years (yr)	C Stock to 50 cm soil depth (Mg ha^{-1})
Humid Lowlands	Homegardens	Low TD < 750 trees/ha	60–90
		Medium TD > 750 trees/ha	70–120
	Silvopasture (Grazing systems)	TD Low, <25/ha	80-100
		E, TD High > 25/ha	80-120
	Shaded perennial systems	E > 15 yr	100–200
		N/young, <5-yr-old	70–150
Tropical Highlands	Homegardens	Low TD < 250 trees/ha	50–80
		Medium TD >250 trees /ha	70–150
	Silvopasture (Grazing systems)	E, TD Low, >20/ha	70–120
		E, TD High	80–150
	Shaded perennial systems	E > 15 yr old	100–200
		N or young, <5 yr	70–150

In general term, there have some factors that influence on the soil carbon stock (Nair et al. 2009b). A list of those factors with their impact on soil carbon is given below.

Table 2.4 List of factors with their impact on soil carbon (Nair et al. 2009b)

Factor	Effect on soil C
Age of system	More age indicates more C storage
Tree density	More trees indicates more C storage
Species attributes	Fast growing tree indicates high biomass production, higher shoot: root ratio as a result more C storage
Rainfall	Higher and evenly distributed rainfall indicates more C storage
Soil properties	Higher clay + silt indicates more C storage, sandy soil indicates less C storage, clayey soil indicates more C storage, better soil conditions that support tree growth! more C storage

2.8 Studies on plant diversity

Species diversity of the tropical homegardens is generally believed to be very high (Babu et al. 1982) and may have species different from those found in neighbouring natural systems. In addition, species diversity and plant density also vary from place to place depending on cultural ecological and socioeconomic factors (Soemarwoto 1987). In Bangladesh, homegardens represent a well established traditional land-use system where natural forest cover is less than 10 percent, which are maintained by at least 20 million households, represent one possible strategy for biodiversity conservation (Kabir and Webb 2008a). Since the natural forest of Bangladesh is shrinking at an alarming rate due to unprecedented anthropogenic pressure, researchers from across the world have demonstrated homestead gardens' dynamic role in the conservation of biodiversity (Roy et al. 2013)

Several studies showed that species diversity in a homegarden can range from less than five (Coomes and Ban 2004) to more than 100 species. Summary of literature on values of Shanon Index (diversity index) and Margalif Index (species richness index) of homegardens of different part of Bangladesh is given below.

Table 2.5 Values of Shanon Index (diversity index) and Margalif Index (species richness index) of homegardens of different part of Bangladesh based on literature

Location	Value of Shanon Index	Value of Margalef Index	Source
Sylhet Sadar, Bangladesh	3.1	7.7	Rahman et al. 2005
Kishoreganj Sadar, Bangladesh	3.37	4.78	Roy et al. 2013
Sandwip upazila, Bangladesh	3.4	20.65	Alam and Masud 2005

2.9 Relationship between carbon stocks and woody species diversity

REDD+ has focused on carbon stocks enhancement but simultaneously it should focus on biodiversity promotion too (Mandal et al. 2013). Environmentalists have also shown interest in potential relationships between plant diversity and carbon storage (Zhang et al. 2011). There is evidence that plant assemblages with high species diversity may promote more efficient use of resources and greater net primary production (Vandermeer 1989) and consequently, a higher rate of carbon sequestration (Kirby and Potvin 2007) compared with sites with a lower species diversity. So far, only few investigations have indicated a positive impact of plant diversity on carbon sequestration in soils (Fornara and Tilman 2008).

Any published articles were found with particular reference to relationship between carbon stocks and woody species diversity in homegardens in any part of the world. However, Mandal et al. (2013) found a positive but very weak relationship between carbon stock and species richness in collaborative forests in Terai, Nepal and Karna (2012) also found positive but weak relationship between carbon stock and tree diversity. Again Martinez-Sanchez and Cabrales (2009) found strong positive relationship between floristic diversity and carbon stocks in tropical vegetation in Mexico. But Zhang et al. (2011) found a significant negative relationship between plant diversity and carbon stock.

CHAPTER 3

MATERIALS AND METHOD

3.1 Study area

3.1.1 Location

The study was conducted in Dighalia upazilla of Khulna district of Bangladesh. Dighalia upazilla is situated at the southwestern part of Bangladesh. The study area is primarily a flood plain landmass lying between 22.50° and 22.60° N latitude and 89.31° and 89.37° E longitude. Dighalia upazilla lies north of Ovoynagor upazilla of Jessore and Kalia upazilla of Narail, east of Terokhada and Rupsha upazilla of Khulna, west of Dumuria upazilla of Khulna and south of river Bhairob and Khulna metropolitan area. The deltaic landscape of this region is a primarily low (<10 m above asl), flat, and fertile plain (BBS 2012). The average area of a homegarden across the study site is 0.05 ha (Kabir and Webb 2008a). Almost every household in Dighalia a upazilla has been maintaining a home garden mainly for family subsistence use with subsequent commercial use from the sale of surplus homegarden products.

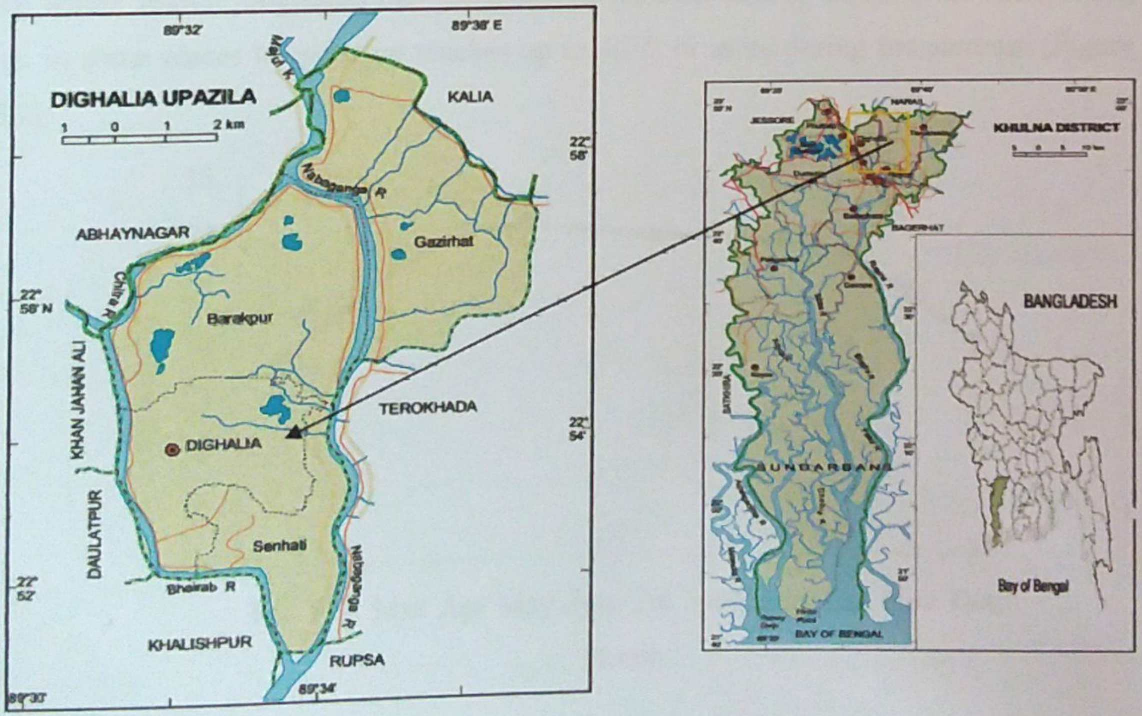

Figure 3.1 Study area, Dighalia upazilla of Khulna district of Bangladesh.

3.1.2 Climatic condition

Dighalia upazilla enjoys generally a tropical to subtropical monsoon climate. While there are six seasons (changes every two months) in a year, three namely summer (March to May), monsoon or rainy (June to October) and winter (November to February) are prominent. These three seasons are characteristic of Khulna region. Winds are mostly from the north and northwest in the winter, blowing gently at 1 to 3 km/h in northern and central areas and 3 to 6 km/h near the coast. From March to May, violent thunderstorms produce winds of up to 60 km/h. During the intense storms of the early summer and late monsoon season, southerly winds of more than 160 km/h cause waves to crest as high as 6 meters in the Bay of Bengal, which brings disastrous flooding to coastal areas of this region.

3.1.2.1 Temperature

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

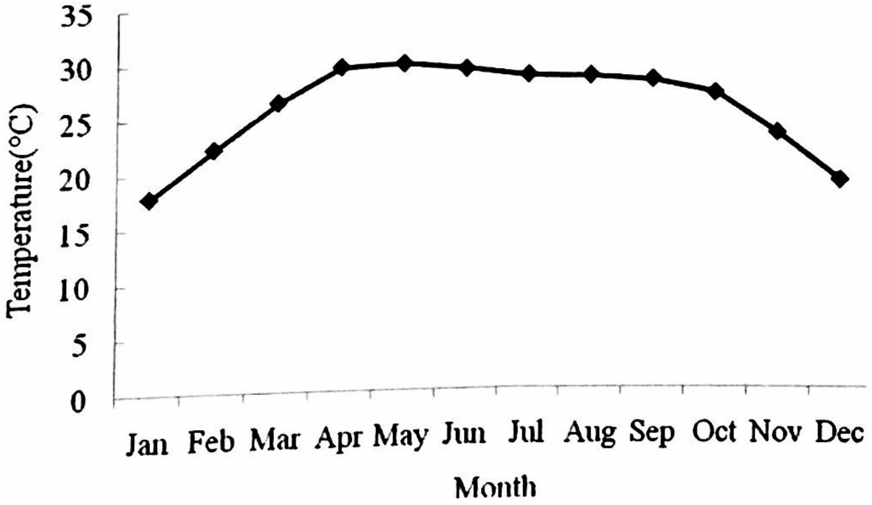

Figure 3.2 Mean monthly temperatures of Dighalia upazilla. Source: BBS 2012.

3.1.2.2 Rainfall

Annual average rainfall of Dighalia upazilla of Khulna is 1986 mm ranging from 1400 to 2600 mm. Approximately 87% of the annual average rainfall occurs between May and October (Figure 3.3). The monsoons result from the contrasts between low and high air pressure areas that result from differential heating of land and water. During the hot months of April and May hot air raises over the Indian subcontinent, creating low-pressure areas into which rush cooler, moisture-bearing winds from the Indian Ocean. This is the southwest monsoon, commencing in June and usually lasting through September.

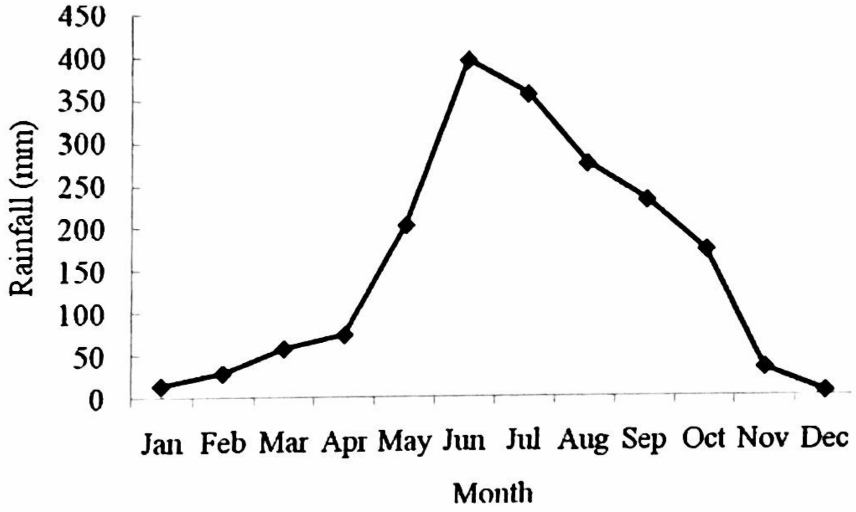

Figure 3.3 Mean monthly rainfall of Dighalia upazilla. Source: BBS 2012.

3.1.2.3 Humidity

The annual average relative humidity of the region is 73%. March is the least humid month (62%). The relative humidity is 84% during monsoon (June to September) because of heavy rainfall but in summer season humidity becomes low.

3.1.2.4 Hydrology

Three main rivers have enclosed this upazilla like Bhairab, Citra and Naboganga (BBS 2012). Because of this reason, seasonal flooding near the river is a prominent characteristic in this region. Most of the area belongs to above river flood level where small area like coastal part of this region usually subjected to flood deeply. Some level terrace areas are also subjected to shallow rainwater flooding.

3.1.3 Geology and Soil

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

According to the report of Bureau of Bangladesh Statistics 2012, Bangladesh has three broad types of soil; flood plain soils (79%), brown hill soils (12.7%) and terrace soils (8.3%). Flood plain soils are of fourteen sub-types like non-calcareous alluvium soil, calcareous alluvium, acid sulphate soil, peat soil, non-calcareous grey floodplain soil, calcareous grey floodplain soil, grey piedmont soil, acid basin soil, non-calcareous dark grey floodplain soil, calcareous dark grey floodplain soil, calcareous brown floodplain soil, non-calcareous brown floodplain soil, brown piedmont soil and black terai soil extended over the floodplain area of the country. Calcareous floodplain is the basic soil types under this study area (Table 3.1).

Table 3.1 Soil Types Different Part of Khulna District

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

Source: BBS 2012

3.2 Methodology

3.2.1 Sampling Design

This study was conducted in Dighalia upazila (administrative unit) of Khulna District. This upazila consists of a number of unions (administrative unit). Each union again is composed of a number of villages and each village is composed of a number of a number of households. Almost each household planted with multistory-species plants is called homegarden. First two unions named Senhati and Barakpur were selected randomly among six unions of Dighalia upazila. Next four villages from every union, total eight villages were selected randomly. Finally five households from each village, total forty households were selected purposively for primary data collection. One 10 m x 10 m (100 m^2) plot was established in each selected household or homegarden for primary data collection.

3.2.2 Field Data Collection

3.2.2.1 Tree Survey

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

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

- All live woody stems having a diameter at breast height $\geq$ 3 cm. Diameter at breast height (DBH) is the stem diameter at 1.3 m above the ground.

3.2.2.2 Measurements

Every individual of woody species was counted. Diameter having 3 cm or greater of every individual of woody species at breast height was measured using a diameter tape and huga-altimeter was used for height measurement. For the sapling of palms those have not form any diameter only height was taken for them. Wood density of every species was collected from secondary data such as FAO's list of wood densities for tree species from tropical Asia and Zanne et al. (2009), Global wood density database.

3.2.2.3 Soil Sampling

Five centimeter long steel cores were used for soil sample collection. Two samples were taken from the center of each plot. First one was taken from the midpoint of 0-15 cm depth and second one from the midpoint of 15-30 cm depth. Two open side of cores immediately covered with rubber cover to resist the moisture going out from the soil samples. Finally these samples were taken to laboratory to measure bulk density and organic carbon content.

3.2.3 Data analysis

3.2.3.1 Allometric computations for aboveground biomass

3.2.3.1.1 Live Tree

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

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

AGB = Aboveground biomass, ρ = Wood density (g cm^{-3}), DBH = Diameter at breast height, ln = Natural logarithm, 1.499 = Constant, 2.148 = Constant, 0.207 = Constant 0.0281= Constant

3.2.3.1.2 Live Sapling

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

3.2.3.1.3 Palms

Palm, coconut and date are common in southwestern part of Bangladesh. Brown et al. (2001) developed equation for palms that was used for aboveground biomass calculation.

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

6.666 = Constant, 12.826 = Constant, 0.5 = Constant, ht = Height, ln = Natural logarithm

3.2.3.2 Allometric computation for root or belowground biomass

To determine the below ground biomass and carbon, the regression model developed by Cairns et al. (1997) which is based on knowledge of above ground biomass was employed. It is the most cost effective and practical methods of determining root biomass.

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

BGB = Belowground Biomass, ln = natural logarithm, AGB = aboveground biomass
-1.0587 = constant, 0.8836 = constant

3.2.3.3 Conversion of aboveground biomass to carbon

Estimated biomass from allometric relationship was multiplied by the wood carbon content (50%). As almost all carbon measurement projects in the tropical forest assume all tissues (i.e. wood, leaves and roots) consist of 50% carbon on a dry mass basis (Chave et al. 2005).

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

3.2.3.4 Soil carbon calculation

Soil carbon storage was calculated as the product of soil carbon concentration (% of dry mass determined by wet oxidation techniques), soil bulk density and soil depth range. First we obtained the bulk density of each soil layer within each plot. This is determined by dividing the oven-dry soil sample mass by the volume of the sample. The bulk density equation is given below.

$$\text{Soil bulk density } (\text{gm}^{-3}) = \frac{\text{Oven dry sample mass(g)}}{\text{Sample volume}(\text{m}^3)}$$

Determination of organic carbon content of soil by loss on ignition method:

Loss on ignition (LOI) is a common and widely used method to estimate the organic carbon content of soil (Dean 1974). Soil samples were oven dried at 105^0 C for 3 days and ground past a 0.5 mm sieve before analysis. Porcelain crucibles' were weighed and these were the cup weights. 1 g of each sieved soil samples were weighed in individual porcelain crucibles with marking of sample identification number at the bottom side of crucibles. Porcelain crucibles with soil samples were oven dried at 105^0 C again for two hours. Again those porcelain crucibles with soil samples were weighed and those weights were the cup plus sample weight at 105^0 C. Next samples were transported to the muffle furnace (Wisetherm muffle furnace) with digital temperature display and thermostatic temperature control, made in Germany) and placed those crucibles into the furnace. Porcelain crucibles with soil samples were kept into muffle furnace for 5 hours at 450^0 C to combust organic matter to ash. After that final weights were taken and those weights were the cup plus sample weight at 450^0 C. The LOI was then calculated using the following equation:

Loss on ignition (LOI_{450}) = $((DW_{105}-DW_{450})/DW_{105})*100$

Finally, soil carbon storage was calculated by the following equation for each plot.

Soil C (Mg ha^{-1}) = bulk density (g m^{-3}) × soil depth interval (m) × %OC × 0.01

Soil depth interval = 0.15 for both 0-15 cm depth interval and 15-30 cm depth interval

%OC = Organic carbon percentage, expressed as a decimal fraction (e.g., 5% is expressed as 0.05),

0.01 = a conversion factor to convert units to Mg ha^{-1}

3.2.3.5 Total Carbon Stock

Equation for total C stock is given below

Total C stock = $C_{AG} + C_{BG} + C_{Soil}$

Here, C_{AG} = Aboveground carbon content, C_{BG} = Belowground carbon content
C_{Soil} = Soil carbon content

3.2.3.6 Woody species diversity calculation

Shannon-Wiener index (*H'*) for species diversity and Margalef index (*R*) for species richness were calculated using following formulae.

Shannon-Wiener index (*H'*): $H' = -\sum_{i=1}^{s} P_i ln(P_i)$

Margalef index (*R*): $R = S - 1/\ln N$

Where $P_i = n_i / N$, n_i = number of individual trees for species *i*, N =total number of individuals, S = total number of species
(Margalef 1972, Shannon 1948)

The Shannon-Wiener index measures rarity and commonness of species within a sampled community. (*H'*) = 0 when only one species is present in a population with no uncertainty of what species each individual can be in a population. (*H'*) usually ranges 1.5 to 3.5 and often does not exceed 4 (Margalef 1972). The Shannon index has been widely used in vegetation studies (Shirima et al. 2011).

3.2.3.7 Relationship between carbon stocks and woody species diversity

Correlation analysis was carried out to find the relationship between carbon stock and woody species diversity. For this, a total Carbon stock was used. The relationship between carbon and species diversity as well as carbon and species richness was developed.

3.2.3.8 Density, frequency, basal area and importance value calculation

For describing floristic composition species of study area the basal area, relative density, relative dominance, relative frequency and importance value index (IVI) were calculated.. Following the formulas of Moore and Chapman 1986, quantitative structure parameters of investigated trees were calculated:

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

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

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

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

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

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

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

3.2.3.9 Statistical analysis

The normality of distribution of the species diversity indices, aboveground, root and soil carbon stock for the entire data sets were tested using the Shapiro-Wilk test. When and if distributions were approximately normally distributed, Pearson's correlation tests were performed to explore whether there is correlation between woody species diversity and species richness and carbon stocks. Regression analysis was used to examine the relationship between tree basal area, tree density and carbon stocks. Analyses were performed using SPSS-16 and Microsoft Excel 2007. To assess differences plant communities of two unions, the results of species richness (Margalef index), plant diversity (Shannon-Wiener index), and soil and above-ground carbon stocks were analyzed using t test.

Chapter 4

Results and Discussion

4.1 Results

4.1.1 Species composition

A total of 422 individuals of 48 species were enumerated from 40 sample plots of homegardens (Appendix 1). *Swietenia macrophylla* King, *Mangifera indica* L., *Cocos nucifera* L., *Artocarpus heterophyllus* Lam., *Areca catechu* L. are the top five most-densest species in this study (Table 4.1). These five species comprise 67% of total population. But according to relative frequency five most occurring species are *Mangifera indica* L., *Artocarpus heterophyllus* Lam., *Cocos nucifera* L., *Swietenia macrophylla* King and *Areca catechu* L. which contribute 51% relative frequency of total population. Considering relative dominance 66% of total population is composed by *Cocos nucifera* L., *Swietenia macrophylla* King, *Samanea saman* (Jacq.) Merr., *Artocarpus heterophyllus* Lam. and *Mangifera indica* L. Rank one position changes with species according to relative density, relative frequency and relative dominance (Table 4.1).

Table 4.1 Eight most important species list.

Species Rank	Relative Density (RD %)	Relative Frequency (RF %)	Relative Dominance (RDo %)
1	*Swietenia macrophylla* King	*Mangifera indica* L.	*Cocos nucifera* L.
2	*Mangifera indica* L.	*Artocarpus heterophyllus* Lam.	*Swietenia macrophylla* King
3	*Cocos nucifera* L.	*Cocos nucifera* L.	*Samanea saman* Merr.
4	*Artocarpus heterophyllus* Lam.	*Swietenia macrophylla* King	*Artocarpus heterophyllus* Lam.
5	*Areca catechu* L.	*Areca catechu* L.	*Mangifera indica* L.
6	*Samanea saman* Merr.	*Samanea saman* Merr.	*Areca catechu* L.
7	*Manilkara zapota* L.	*Spondias pinnata* Kurz.	*Phoenix sylvestris* Roxb.
8	*Litchi chinensis* Sonn.	*Litchi chinensis* Sonn.	*Spondias pinnata* Kurz.

4.1.2 Family composition

A total of 26 families were encountered from the study area (Appendix 1). Palmae family was the leading family with 103 numbers of individuals of the total counted population. The family Palmae is predominant with 24% of total population, followed by Meliaceae (20%), Anacardiaceae (15%), Moraceae (13%), Leguminosae (7%), Myrtaceae (3.3%), Rutaceae (2.8%), Sapindaceae (2.1%), Euphorbiaceae (1.7%), Sapotaceae (1.7%). Among 26 families, only five families (Palmae, Meliaceae, Anacardiaceae, Moraceae and Leguminosae) comprise 79% of total population.

4.1.3 Carbon stocks

Measurements were made on a total of 40 homegardens for carbon stocks estimation. Total carbon stocks in homegardens ranged from 103.96 to 242.32 Mg $ha^{-1}$with an average±S.E. of 170.13 ± 5.64 Mg ha^{-1} (Figure 4.1). Aboveground biomass, belowground root biomass and soil accounted for 35%, 8% and 57% of these carbon stocks respectively. Aboveground carbon in the homegardens varied from 23.67 to 109.71 Mg ha^{-1}, with an average of 60.42 Mg ha^{-1} with a standard error (S.E.) of 3.88 Mg ha^{-1}. Belowground root carbon in the homegardens varied from 5.68 to 22.03 Mg ha^{-1}, with an average of 12.89±1.15 Mg ha^{-1}. Soil carbon stocks varied from 57.23 to 128.57 Mg ha^{-1}, with a mean of 96.82 ± 2.91 Mg ha^{-1}. Again there was variation in mean carbon stocks of homegardens between two union named Senhati and Baracpur. Result of T test showed that there was no significant variation in carbon stocks in homegardens between Senhati union and Baracpur union at 5% significant level as *P* value was greater than 0.05.

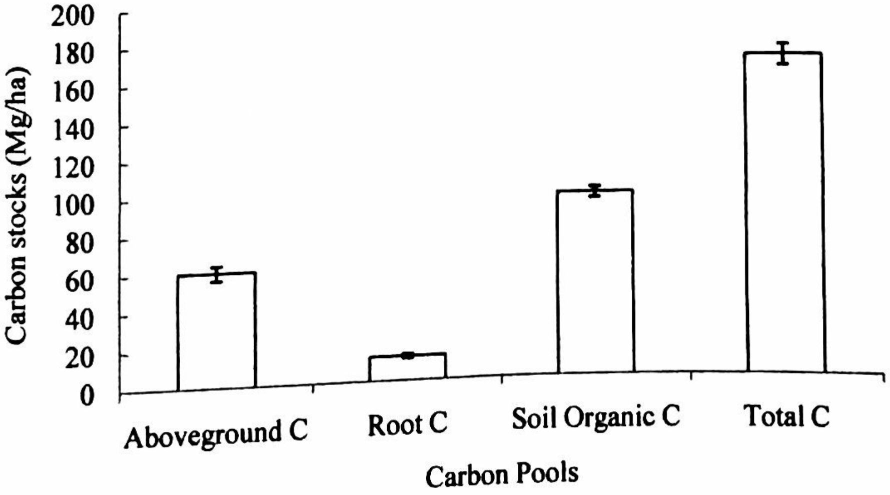

Figure 4.1: Aboveground C, root C, soil organic C and total C stocks in the study area

4.1.4 Descriptive statistics

All investigated properties exhibited great spatial variation across the sampling sites. Vegetation characteristics like stem density and mean DBH; soil bulk density; woody species diversity like Shannon-Wiener index and Margalef index at 40 plots with minimum, maximum and mean values with their standard deviations (SD) and standard error (SE) are presented in table 4.2 where mean stem density, DBH and soil bulk density were 1055 stem/ha, 14.49 cm and 0.33 respectively.

Table 4.2 Descriptive statistics (minimum, maximum, means, standard deviations (SD) and standard error (SE)) of vegetation characteristics, soil bulk density and woody species diversity of the 40 investigated homegardens.

Variables	Minimum	Maximum	Mean	SD	SE
Stem density ha^{-1}	600	1600	1055	225.26	35.61
Mean DBH (cm)	9.22	24.45	14.49	3.11	0.49
Soil bulk density (g/cm^3)	0.18	0.42	0.33	0.03	0.003
Shannon-Wiener index (H')	1.91	3.01	2.56	0.25	0.04
Margalef index (R)	1.44	3.03	2.31	0.4	0.06

4.1.5 Woody species diversity

Results on woody species diversity as measured by the Shannon-Wiener index (H') in plots of homegardens ranged from 1.91 to 3.01 with an average ± S.E. of 2.56 ± 0.04 (Table 4.2). There were no statistically significant differences in mean species diversity between homegardens of Senhati and Baracpur ($P = 0.089$). Species richness as measured by the Margalef index (R) in plots of homegardens ranged from 1.44 to 3.03 with an average ± S.E. of 2.31 ± 0.06 (Table 4.2). There were no statistically significant differences in mean species richness between homegardens of Senhati and Baracpur union as calculated P value was greater than 0.05.

4.1.6 Relationship between stand structure, woody species diversity and carbon stocks

Pearson correlation analysis was used to determine the relationship between aboveground carbon stocks and stand structure like mean DBH, stem density; woody species diversity like Shannon-Wiener index, Margalef index. The results of the correlation analysis revealed that there was significant positive ($P < 0.05$) relationship between woody species diversity (Shannon-Wiener index) and carbon stocks (AGC, RC, SOC and TC) (Table 4.3). Homegardens with high species diversity (Shannon-Wiener index) had relatively higher total carbon storage. Species diversity (Shannon-Wiener index) and total carbon stocks (TC) had highest correlation ($r = 0.557$, $P = 0.001$) (Table 4.3). Again there was a positive relationship between species richness (Margalef index) and carbon stocks (AGC, RC, SOC and TC) (Table 4.3). Relationships between species richness (Margalef index) and carbon stocks (AGC, RC) were not statistically significant ($P > 0.05$) but relationships between species richness (Margalef index) and carbon stocks (SOC, TC) were statistically significant ($P < 0.05$).

Table 4.3 Pearson correlation coefficients among different variables. *P*-value is given in parenthesis.

Variables	AGC	RC	SOC	TC
Mean DBH	0.512^{**} (0.001)	0.594^{**} (0.001)	0.058 (0.72)	0.453^{**} (0.003)
Stem density	0.369^{*} (0.013)	0.372^{*}(0.018)	0.12^{*} (0.02)	0.364^{*} (0.021)
Shannon-Wiener index	0.407^{**} (0.009)	0.403^{**} (0.01)	0.438^{**} (0.005)	0.557^{**} (0.001)
Margalef index	0.17 (0.29)	0.3 (0.06)	0.440^{**}(0.005)	0.473^{**} (0.002)

Here AGC = Aboveground C, RC = Root C, SOC = Soil Organic C, TC = Total C

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The total carbon stocks varied with tree density. Homegarden with highest tree density (16 trees/100 m^2) had the higher total carbon stocks than the average value but with lowest tree density (6 trees 100/m^2) had the total carbon stocks near the average value. The results of the correlation and regression analysis exposed a statistically significant positive but weak relationship between tree density and total carbon stocks ($r = 0.364$, $R^2 = 0.132$, $P < 0.05$) (Table 4.3, Figure 4.2). Again there was a statistically significant positive ($P > 0.05$) and moderate relationship between mean DBH and total carbon stock. The values of r and R^2 of linear regression represent 0.45 and 0.21 respectively (Table 4.3, Figure 4.3).

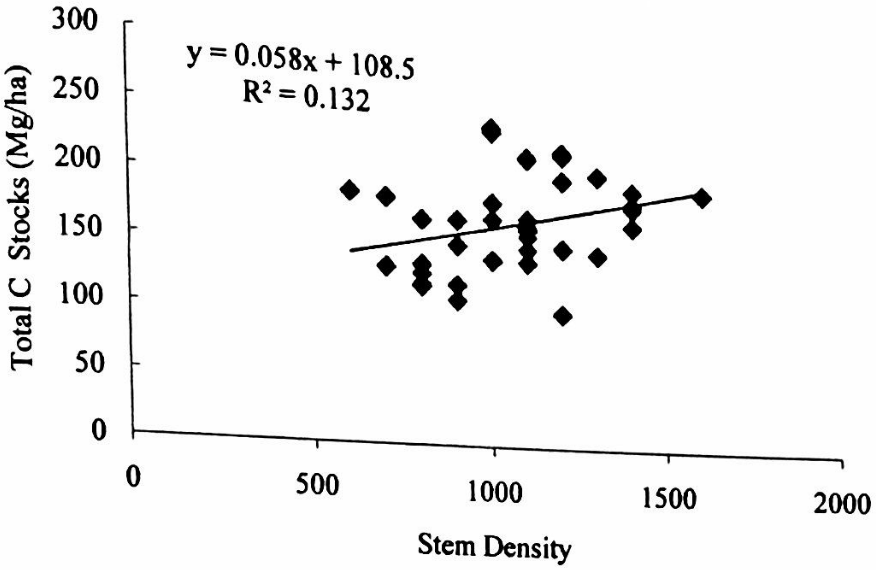

Figure 4.2 Relationship between stem density and total C stocks

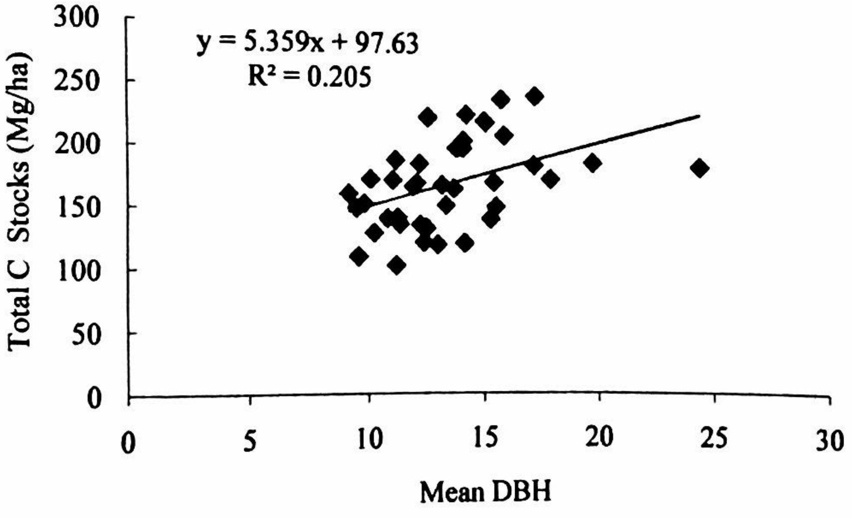

Figure 4.3 Relationship between mean DBH and Total C stocks

4.2 Discussion

4.2.1 Species composition

Homegardens around the world show notable variability in composition and structure. A total of 48 species of trees more than 3cm DBH from 26 families was found in the homestead agroforestry system of Dighalia Upazilla. However, the number of plant species was relatively high and consistent with those found in other homegardens of Bangladesh by Alam and Masud (2005) found 52 species in Tangail, Motiur et al. (2006) found 58 species in South-western Bangladesh, Roy et al. (2013) 62 species in Kishoregong Sadar Upazilla and Islam et al (2014) 30 species in Sylhet Sadar Upazila. But ours findings was inconsistent with the findings of Kabir and Webb (2008a) who recorded a total of 419 plant species from south-western Bangladesh and Masum et al. (2008) who recorded 142 species in Sandwip Island of Bangladesh. This difference was due to the difference in intensity of sampling plots and species selection criteria as our sample plot was 40 and recorded only woody species having DBH ≥ 3 cm. Number of identified families was also consistent with Motiur et al. (2005) and Roy et al. (2013). Out of 48 species 20 species constituted 88.15% (in terms of relative density) that was consistent with Motiur et al. (2005) where out of 53 species, 24 species represent 86.8% of the total vegetation.

4.2.2 Carbon stocks

Total carbon stocks in homegardens of Dighalia in this study (170.13 ± 5.64 Mg ha^{-1}) was higher than that reported in Indonesian homegardens by Roshetko et al. (2002). Roshetko et al. (2002) suggested total carbon stocks per homegarden ranged from 56 to 174 Mg ha^{-1} with an average of 107 Mg ha^{-1}. This difference may be for higher stem density (1055 stem/ha) in homegardens of Dighalia than Indonesian homegardens (624.4 stem/ha), as stem density is positively correlated with carbon stocks (Table 4.3). Again Roshetko et al. (2002) stated that tree biomass (aboveground plus roots) and soil accounted for 41% and 59% of total carbon respectively which are consistent with this study with 43.09% and 56.91% of total carbon stocks respectively in tree biomass (aboveground plus roots) and soil.

The average aboveground carbon stocks (60.42 ± 3.88 Mg ha^{-1}) presently reported was higher than homegardens of Central Kerala, India (16-36 Mg ha^{-1}, Kumar 2011) as well as Indonesian homegardens (35.3 Mg ha^{-1}, Roshetko et al. 2002) but lower than agroforest (home and outfield gardens) in Panama (93 Mg ha^{-1}, Kirby and Potvin 2007) and agroforestry woodlots of Kerala, India (172 Mg ha^{-1}, Kumar et al. 1998a). Root carbons also followed similar type of variation mentioned above. This variation indicates that profound species related variations are possible in homegardens (Nair 2009a). This variation may be result of variation in mean DBH or stem density per hectare or both, as these vegetative characteristics are positively correlated with carbon stocks (Table 4.3)

An exact estimation of above-ground tree biomass is one of the challenges of carbon stock estimation not only in homegarden systems but also in other agroforestry systems. A general regression equation developed for tropical moist forests was used in this study to estimate above-ground biomass and belowground biomass. The size of individual tree canopies in a forest could be smaller than those found in an open homestead agroforestry setting, as the trees in some agroforestry systems have more space and access to light. The difference in structure could result in errors in our estimates. Similarly, trees found in homegardens could be misshapen if branches are cut for fuel wood or other uses. This could also lead to errors in our estimates. At the time of this study, local biomass equations were not available but will need to be developed in the future to reduce possible error in aboveground biomass estimation.

Soil organic carbon varied from 57.23 to 128.57 Mg ha^{-1} with a mean of 96.82 ± 2.91 Mg ha^{-1} in this study is higher than soil organic carbon of Indonesian homegardens' varied from 10.4 to 103.7 Mg ha^{-1} , with an average of 60.8 Mg ha^{-1}. But it compares favourably with soil carbon stocks in tropical homegardens reported by Nair et al. (2009b) ranging 70-150 Mg ha^{-1} up to 50 cm soil depth with more than 250 trees /ha as in this study soil samples were collected up to 30 cm. Again there are several factors like age of system, tree density, species attributes, rainfall and soil properties (Table 2.4) which affect soil organic carbon stocks. Variation in result may be the consequence of these factors.

4.2.3 Woody species diversity

Shannon-Wiener index (*H'*) showed that the homegardens in the study area (Dighalia upazilla, Khulna) had high woody species diversity. A high diversity was showed by Shannon-Wiener index (2.56 ± 0.04) as Shannon-Wiener index values greater than 2 are indicative of medium to high diversity. This result showed a lower diversity than other studies conducted in different Upazilla of Bangladesh such as in Sylhet Sadar 3.1 (Rahman et al. 2005), Kishoreganj Sadar 3.37 (Roy et al. 2013) and Sandwip upazila 3.4

(Alam and Masud 2005) (Table 2.5). This variation was the result of considering only woody species in this study while species diversity of the tropical homegardens is generally believed to be very high with wide range of woody and non-woody species. Species richness as measured by the Margalef index (*R*) in homegardens (2.30 ± 0.06) compares favourably with species richness (2.87) of Sylhet Sadar Upazilla (Islam et al 2014). The average species richness presently reported are lower than than homegardens of Kishoreganj Sadar, Bangladesh (4.78, Roy et al. 2013) (Table 2.5).

4.2.4 Relationship between woody species diversity and carbon stocks

Significant positive correlation was found between woody species diversity and carbon stocks in the homegardens of this study. There was an evidence that plant assemblages with high species diversity may promote more efficient use of resources and greater net primary production (Vandermeer 1989) and consequently, a higher rate of carbon sequestration (Kirby and Potvin 2007) compared with sites with a lower species diversity. But the relationship between species diversity and carbon stocks is complicated and depends on the nature of the production system. Besides there have discordance about the understanding of the relationship among the researchers and still it is not clear to all.

Any published articles were found with particular reference to relationship between carbon stocks and woody species diversity in homegardens in any part of the world. But the research done by Karna (2012), Mandal et al. (2013) in collaborative forests in Terai, Nepal, Martinez-Sanchez and Cabrales (2009) in tropical vegetation in Mexico also support this idea. But Zhang et al. (2011) found a significant negative relationship between plant diversity and carbon stocks.

Chapter 5

Conclusion

Homegarden as a traditional land use system has the potential to maintain high species diversity and to move climate change mitigation one step forward by sequestrating carbon from environment in the form of CO_2 in aboveground biomass, root biomass and soil. Overall this study showed that carbon stocks and woody species diversity are quite substantial that is consistent with other reports. It confirms that woody species diversity exhibited a positive and moderate relationship with carbon stocks. So the conservation of species diversity may stand for an important factor in the mitigation of global warming, through great amounts of carbon storage. Carbon sequestration projects that contribute to enhance biodiversity should be considered as more ethical and stable in the long-term than conventional afforestation/reforestation projects that do not consider biodiversity or ecosystem function. Therefore, the REDD+ programme should have parallel focus on biodiversity conservation and promotion. Application of universal biomass allometric equations to calculate aboveground carbon stocks for woody species is an important limitation of this study. Precision of these estimations could be improved by developing species specific local biomass allometric models. But such allometric equations are not available. However, in a wider context, these findings have implications on the function of traditional smallholder agroforestry systems in climate change mitigation through vegetation and soil carbon storage.

Reference

Alam M S and Masud K M, 2005. Status of homestead biodiversity in the offshore island of Bangladesh. Research Journal of Agriculture and Biological Sciences 1(3): 246-253.

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

Babu K S, Jose D and Gokulapalan C, 1982. Species diversity in a Kerala homegarden. Agroforestry Today 4(3): 15.

Bardhan S, Jose S, Biswas S, Kabir K and Rogers W, 2012. Homegarden agroforestry systems: an intermediary for biodiversity conservation in Bangladesh. Agroforestry Systems 85: 29-34.

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

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

Brown S, Masera O, Sathaye J, Andrasko K, Brown P, Frumhoff P, Lasco R, Leach G, Moura-Costa P, Mwakifwamba S, Phillips G, Read P, Sudha P and Tipper R, 2001. Project-based activities. pp. 285-338. In: Watson B, Noble I, Bolin B, Ravindranath N R, Verardo D J and Dokken D J (eds). Land Use, Land-use Change and Forestry, A Special Report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge, Cambridge University Press.

Cairns M A, Brown S,Helmer E H and Baumgardner G A, 1997. Root biomass allocation in the world's upland forests. Oecologia 111: 1-11.

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

Coomes O T and Ban N, 2004. Cultivated plant species diversity in home gardens of an amazonian peasant village in northeastern Peru. Economic Botany 58(3): 420-434.

Dean W E Jr, 1974. Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: Comparison with other methods. J. Sed. Petrol. 44: 242-248.

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

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

FAO, 2005. The State of World's Forest 2005. Food and Agriculture Organization of the United Nations.

Fernandes E C M and Nair P K R, 1986. An Evaluation of the Structure and Function of Tropical Homegardens. Agricultural Systems 21:279-310.

Fornara D A and Tilman D, 2008. Plant functional composition influences rates of soil carbon and nitrogen accumulation. J. Ecol. 96: 314-322.

Gardner T A, Burgess N D, Aguilar-Amuchastegui N, Barlow J, Berenguer E, Clements T, Danielsen F, Ferreira J, Foden,W, Kapos V, Khan S M, Leesm A C, Parry L, Roman-Cuesta R M, Schmitt C B, Strange N, Theilade I and Vieiram I C G, 2011. A framework for integrating biodiversity concerns into national REDD+ programmes. Biol. Conserv. In press, doi:10.1016/j.biocon.2011.11.018.

Henry M, Tittonell P, Manlay R J, Bernoux M, Albrecht A and Vanlauwe B, 2009. Biodiversity, carbon stocks and sequestration potential in aboveground biomass in smallholder farming systems of western Kenya. Agric. Ecosyst. Environ. 129: 238-252.

Herzog F, 1994. Multipurpose shade trees in coffee and plantations in Cˆote d'Ivoire. Agrofor. Syst. 27: 259-268.

Hutterer K L, 1984. Ecology and evolution of agriculture in Southeast Asia. In: Rambo A T and Sajise P E (eds). An Introduction to Human Ecology Research on Agricultural Systems in Southeast Asia. University of Philippines, Los Banos.

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

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

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

Islam M, Dey A and Rahman M, 2014. Effect of tree diversity on soil organic carbon content in the homegarden agroforestry system of north-eastern Bangladesh. Small-scale Forestry DOI 10.1007/s11842-014-9275-5.

Kabir M E and Webb E L, 2008a. Can Home gardens Conserve Biodiversity in Bangladesh? Biotropica 40(1): 95-103.

Karna Y K, 2012. Mapping aboveground carbon using world view satellite image and lidar data in relationship with tree diversity and forests. M. Sc. thesis, University of Twente, Enschede, Netherlands.

Kessler M, Hertel D, Jungkunst H F, Kluge J, Abrahamczyk S, et al. 2012. Can Joint Carbon and Biodiversity Management in Tropical Agroforestry Landscapes Be Optimized? PLoS ONE, 7(10): 47192. doi:10.1371/journal.pone.0047192

Kirby K R and Potvin C, 2007. Variation in carbon storage among tree species: implications for the management of a small scale carbon sink project. For. Ecol. Manage. 246: 208-221.

Krankina O N and Dixon R K, 1994. Forest management options to conserve and sequester terrestrial carbon in the Russian Federation. World Resour. Rev. 6: 88-101.

Kumar B M, 2006. Carbon sequestration potential of tropical home gardens. pp.185-204. In Kumar B M and Nair P K R (eds.). Tropical Home gardens: A Time-Tested Example of Sustainable Agroforestry. Advances in Agroforestry 3. Springer, Netherlands.

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

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

Kumar B M and Nair P K R, 2004. The enigma of tropical homegardens. Agroforestry Systems 61: 135-152.

Mandal R A, Dutta I C, Jha P K and Karmacharya S, 2013. Relationship between Carbon Stock and Plant Biodiversity in Collaborative Forests in Terai, Nepal. ISRN

Botany, Volume 2013, Article ID 625767, 7 pages. http://dx.doi.org/10.1155/2013/625767.

Margalef, R. 1972. Homage to evelyn hutchinson or why there is an upper limit to diversity. Transactions Connecticut Academy of Arts and Sciences 44: 211-235.

Martinez-Sanchez J L and Cabrales L C, 2009. Is there a relationship between floristic diversity and carbon stocks in tropical vegetation in Mexico? African Journal of Agricultural Research 7(17): 2584-2591.

Masum K M, Alam M S and Abdullah-Al-Mamun M M, 2008. "Ecological and economical significance of homestead forest to the household of the offshore island in Bangladesh." Journal of Forestry Research 19(4): 307-310.

Michon G, 1983. Village forest gardens in West Java. pp 13-24. In: Huxley P A (eds). Plant Research and Agroforestry. ICRAF, Nairobi, Kenya.

Michon G and Mary F, 1994. Conversion of traditional village gardens and new economic strategies of rural households in the area of Bogor, Indonesia. Agroforestry Systems 25: 31-58.

Millat-e-Mustafa M, Hall J B and Teklehaimanot Z, 1996. Structure and floristics of Bangladesh homegardens. Agroforestry Systems 33: 263-280.

Millat-e-Mustafa M, Teklehaimanot Z and Haruni A K O, 2002. Traditional use of perennial homestead garden plants in Bangladesh. Forests Trees Livelihoods 12: 235-256.

Montagnini F and Nair P K R, 2004. Carbon sequestration: an underexploited environmental benefit of agroforestry systems. Agroforestry Systems 61: 281-295.

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

Motiur R M, Furukawa Y, Kawata I, Rahman M M And Alam M, 2006. "Role of homestead forests in household economy and factors affecting forest production: a case study in southwest Bangladesh." Journal of Forest Research 11(2): 89-97.

Motiur R M, Tsukamoto J, Furukawa Y, Shibayama Z and Kawata I, 2005. "Quantitative stand structure of woody components of homestead forests and its implications on silvicultural manage-ment: a case study in Sylhet Sadar, Bangladesh." Journal of Forest Research 10(4): 285-294.

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

Nair P K R, Nair V D, Kumar B M and Haile S G, 2009b. Soil carbon sequestration in tropical agroforestry systems: a feasibility appraisal. Environmental Science and Policy 12: 1099-1111.

Nair P K R, Nair V D, Kumar B M and Showalter J M, 2010. Carbon sequestration in agroforestry systems. Adv. Agron. 108: 237-307.

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

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

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

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

Puri S and Nair P K R, 2004. Agroforestry research for development in India: 25 years of experiences of a national program. Agroforestry Systems 61: 437-452.

Rahman M M, Jiro T, Yasushi F, Zenichiro S and Isao K, 2005 . Quantitative stand structure of woody components of homestead forests and its implications on silvicultural management: a case study in Sylhet Sadar, Bangladesh. Journal of Forestry Ressearch 10: 285-294.

Roshetko M, Delaney M, Hairiah K, Purnomosidhi P, 2002. Carbon stocks in Indonesian homegarden systems: can smallholder systems be targeted for increased carbon storage? Am. J. Alt. Agric. 17: 125-137.

Roy B, Rahman M H and Fardusi M J, 2013. Status, Diversity, and Traditional Uses of Homestead Gardens in Northern Bangladesh: A Means of Sustainable Biodiversity Conservation. ISRN Biodiversity,Volume 2013, Article ID 124103, 11 pages. http://dx.doi.org/10.1155/2013/124103

Shannon C E, 1948. A mathematical theory of communication. Bell System Technical Journal 27: 379-423.

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

Shirima D D, Munishi P K T, Lewis S L, Burgess N D, Marshall A R, Balmford A, Swetnam R D and Zahabu E M, 2011. Carbon storage, structure and composition of miombo woodlands in Tanzania's Eastern Arc Mountains. African Journal of Ecology 49: 332-342.

Soemarwoto O, 1987. Homegardens: A traditional agroforestry system with a promising future. pp 157-172. In Steppler H A and Nair P K R (eds). Agroforestry: A Decade of Development, International Centre for Research in Agroforestry, Nairobi, Kenya.

Torquebiau E F, 2000. A renewed perspective on agroforestry concepts and classification. Life Sciences 323: 1009-1017.

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

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

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

Vandermeer J, 1989. The Ecology of Intercropping. Cambridge University Press, Cambridge. 249pp.

Watson R T, 2000. Land Use, Land-Use Change, and Forestry: A Special Report of the IPCC. Cambridge University Press, Cambridge. 377pp.

Webb E L and Kabir M E, 2009. Home gardening for tropical biodiversity conservation? Conservation Biology 23(6): 1641-1644.

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

Zhang Y, Duan B, Xian J, Korpelainen H and Li C, 2011. Links between plant diversity, carbon stocks and environmental factors along a successional gradient in a subalpine coniferous forest in Southwest China. Forest Ecology and Management 262: 361-369.

APPENDIX 1

Plant species list from Dighalia Upazilla, Bangladesh homegardens. F is the frequency of homegardens from where species was recorded. A is the abundance of each species.

Sl. No	Scientific Name	Local Name	Family	F	A
1	*Artocarpus lakoocha* Roxb.	Dewa	Moraceae	1	1
2	*Trewia polycarpa* Benth. & Hook.f.	Pitali	Euphorbiaceae	4	6
3	*Phyllanthus emblica* L.	Amloki	Euphorbiaceae	1	1
4	*Spondias pinnata* (L.f.) Kurz	Amra	Anacardiaceae	6	6
5	*Terminalia arjuna* Wight & Arn.	Aarjun	Combretaceae	1	1
6	*Annona reticulata* L.	Ata	Annonaceae	2	3
7	*Mangifera indica* L.	Aum	Anacardiaceae	32	58
8	*Lepisanthes senegalensis* (Poir.) Leenh.	Aumjum	Sapindaceae	3	3
9	*Aegle marmelos* (L.) Correa	Bel	Rutaceae	5	6
10	*Cordia dichotoma* G.Forst.	Boll Gach	Boraginaceae	1	1
11	*Ziziphus nummularia* (Burm.f.) W. & A.	Boroi	Rhamnaceae	3	3
12	*Cinnamomum verum* J. Presl	Darucini	Lauraceae	1	1
13	*Polyalthia longifolia* (Sonn.) Hook.f. & Thomson	Debdaru	Annonaceae	3	4
14	*Diospyros phillipensis* (Desr.) M.R. Almeida	Gub	Ebenaceae	5	6
15	*Gmelina arborea* Roxb.	Gamar	Verbenaceae	1	1
16	*Trema orientalis* (L.) Blume	Gibonsora	Ulmaceae	1	1
17	*Calophyllum inophyllum* L.	Golob	Guttiferae (Clusiaceae)	1	1
18	*Leucaena leucocephala* (Lam.) de Wit	Ipil-ipil	Leguminosae, Mimosoideae	1	1
19	*Syzygium cumini* (L.) Skeels	Jam	Myrtaceae	4	4
20	*Syzygium samarangense* (Blume) Merr. & L.M.Perry	Jamrul	Myrtaceae	6	6

Sl. No	Scientific Name	Local Name	Family	F	A
21	*Elaeocarpus floribundus* Blume	Jolpai	Elaeocarpaceae	2	2
22	*Anthocephalus chinensis* (Lmk.) A. Rich. ex Walp.	Kadam	Rubiaceae	3	3
23	*Limonia acidissima* L.	Kadbel	Rutaceae	1	1
24	*Citrus limon* (L.) Burm.f.	Kagojee Lebu	Rutaceae	4	4
25	*Albizia lebbeck* (L.) Benth.	Kala Koroi	Leguminosae, Mimosoideae	2	2
26	*Murraya paniculata* (L.) Jack	Kamini	Rutaceae	1	1
27	*Averrhoa carambola* L.	kamranga	Oxalidaceae	3	3
28	*Terminalia catappa* L.	Kat Badam	Combretaceae	1	1
29	*Artocarpus heterophyllus* Lam.	kathal	Moraceae	32	51
30	*Phoenix sylvestris* Roxb.	khejur	Palmae (Arecaceae)	4	4
31	*Litchi chinensis* Sonn.	Lichu	Sapindaceae	6	6
32	*Swietenia macrophylla* King	Mehogoni	Meliaceae	24	74
33	*Lawsonia inermis* L.	Mendi	Lythraceae	3	3
34	*Cocos nucifera* L.	Narkel	Palmae (Arecaceae)	25	53
35	*Azadirachta indica* A.Juss.	Nim	Meliaceae	5	5
36	*Psidium guajava* L.	Peara	Myrtaceae	4	4
37	*Toona ciliata* J. Roem.	Pua	Meliaceae	3	4
38	*Samanea saman* (Jacq.) Merr.	Raintree	Legumonosae, Mimosoideae	10	19
39	*Albizia richardiana* King & Prain	Raj Koroi	Leguminosae, Mimosoideae	4	4
40	*Moringa oleifera* Lam.	Sajna	Moringaceae	1	1
41	*Streblus asper* Lour.	Sheora	Moraceae	1	1
42	*Bombax ceiba* L.	Simul tula	Bombacaceae	2	3
43	*Manilkara zapota* (L.) P. Royen	sofeda	Sapotaceae	4	7
44	*Areca catechu* L.	Supari	Palmae (Arecaceae)	14	45
45	*Borassus flabellifer* L.	Tal	Palmae (Arecaceae)	1	1
46	*Cinnamomum tamala* F. Nees ex T.Nees & Eberm.	Tejpata	Lauraceae	2	2
47	*Tamarindus indica* L.	Tetul	Leguminosae, Caesalpinioideae	3	3
48	*Ambroma augusta* (L.) L. f.	Ulotkomb	Sterculiaceae	1	1

APPENDIX 2

Homegarden Botanical Inventory Form

Plot Code ☐ Longitude ☐ Latitude ☐

Date ☐ Place ☐ Data Collectors ☐

Sl. No.	Local Name	Scientific Name	DBH(cm)	Height(m)	Remarks
1					
2					
3					
4					
5					
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