

Contribution of Homestead Forests to Rural Economy and Climate Change Mitigation: A Study from the Ecologically Critical Area of Cox's Bazar—Teknaf Peninsula, Bangladesh

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Abstract Homestead forests in the Teknaf Peninsula ecologically critical area of Cox's Bazar in Bangladesh have not been widely studied. This paper explores floristic diversity of homestead forests together with their contribution to the household economy and climate change mitigation. Data were collected from a survey of 140 households and a vegetation survey of 70 homesteads in three sites. Villagers allocated 70 % of their homestead area for homestead forestry and altogether 73 plant species were recorded from the study sites. The average density was 4,000 plants/ha. The above-ground biomass was estimated 235.45 Mg/ha, equivalent to 117.73 Mg C/ha. Villagers maintain sustainability of homestead forests by planting seedlings every year and thus ensure several diameter and height classes. Homestead forests contribute substantially to household income, provide fuelwood and timber for own consumption and sale, and protect villagers during cyclones. Homestead forests thus meet the conditions to be a clean development mechanism forestry project which would provide a win-win strategy for involving small-scale farmers in climate change mitigation and adaptation initiatives, and biodiversity conservation.

Keywords Plant diversity and structure · Carbon sequestration · Household income · Biodiversity conservation

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Introduction

As in many other countries, people in rural and semi-urban areas of Bangladesh plant and maintain a wide variety plants in their homesteads. They have intentionally been growing these plants for generations for meeting household needs including fuelwood, timber, fruit and vegetables, as well as for revenue and environmental amelioration. In the face of rapid degradation of public forests of the country, these homestead forests are considered as major supplier of forest products. It has been reported that over 20 M homestead forests covering about 2 % (0.27Mha) of the total land area of Bangladesh fulfil the country's demand of more than 80 % of timber and 70 % of bamboo (Hammermaster 1981; Leuschner and Khaleque 1987; FMP 1992; Salam et al. 2000). In addition, homestead forests can act as a safety net in providing alternative livelihood sources for the people during crisis periods including natural hazards (Kabir and Webb 2009). These forests are also believed to conserve biodiversity and are often referred to as a 'Biodiversity Island' of the country (Alam and Furukawa 2010).

Tropical homestead forests, often called *home gardens* and *homestead agroforestry*, have potential for carbon sequestration (Verhot et al. 2007; Kumar 2011), and can help to mitigate climate change impacts. Homestead agroforestry, that integrates tree production with crop and animal production, is believed to have a higher potential to sequester carbon than pastures or field crops (Nair et al. 2009). It also helps to reduce carbon emissions from fossil-fuel burning through fuelwood production and conservation of carbon stocks in existing natural forests by alleviating pressure on these forests (Kumar and Nair 2004; Kumar 2006; Mattsson et al. 2013). Overall, homegardens reduce atmospheric carbon dioxide through carbon sequestration, carbon conservation and carbon substitution (Montagnini and Nair 2004). The rich agrobiodiversity of homegardens ensures longer term stability of carbon storage, augments biomass production, enhances nutrient cycling and increases soil organic carbon (Kumar and Nair 2004; Montagnini 2006; Henry et al. 2009).

The well-adapted agroforestry system of homegardens could have potential for achieving multiple goals of climate change adaptation and mitigation as well as poverty reduction and sustainable development (Mattsson et al. 2013). Because homestead agroforestry is mostly practiced by subsistence farmers in developing countries, there is an attractive opportunity for those farmers to benefit financially from these agroforestry if the carbon sequestered through agroforestry activities is sold to developed countries through trading of carbon emission sequestration credits (Nair et al. 2009). There has to date been little research on the role of homegardens in relation to policies and measures to mitigate against and adapt to climatic change (Mattsson et al. 2013).

Research on homestead forests in Bangladesh is less intensive than is desirable based on their importance to the economy, ecology and livelihoods (Kabir and Webb 2009). Notable studies on homestead forests of Bangladesh focus on plant composition and structure (Mustafa et al. 1996, 2000; Van Noordwijk et al. 2002; Ali 2005; Rahman et al. 2005; Kabir and Webb 2008), peoples' perceptions and preferences of growing plants in homesteads (Salam et al. 2000; Alam et al. 2010), biodiversity conservation (Alam and Sarker 2011; Muhammed et al. 2011) and quantitative

analysis of home garden characteristics (Kabir and Webb 2009). Although some of these studies were conducted in the homestead forests of Cox's Bazar-Teknaf peninsula, none examines the potential of homestead forests for carbon sequestration and environmental services including protection against cyclones.

Considering the above backdrop, this study explores the floristic diversity and stock of homestead forests, contribution of homestead forests to the household economy and villagers' perception on the role of homestead forests in mitigation of cyclone damage. It also assesses above-ground carbon stocks of homestead forests and examines the potential of carbon sequestration for trading in carbon (sequestration) credits.

The Study Area

The ECA in Cox's Bazar and Teknaf Peninsula is located along the beach of the Bay of Bengal, the western coastal zone of the Teknaf Peninsula from Cox's Bazar to Shahparir Dwip (Island) with coordinates of 20°–21° N and 92° E, and includes both the beach and adjacent hinterland extending back to the foot of hill (Fig. 1). Teknaf Peninsula is one of the longest sandy beach ecosystems (about 80 km) in the world. The local inhabitants are predominantly dependent on local natural resources for their livelihoods. However, overexploitation of the resources has caused abrupt decline of biological diversity in the area. Past land use that has had the greatest impact on the present condition of the ECA includes deforestation, hill cutting (for land levelling) and settlement, conversion of forest land to agriculture, conversion of mangrove forests to aquaculture and salt pans, and urbanization and associated infrastructure development. Deforestation, afforestation and the conversion of natural forest into plantations have not only destroyed wildlife habitat but also changed plant species composition (CWBMP 2006).

The climate in Cox's Bazar-Teknaf peninsula is classed as moist tropical maritime with high rainfall concentrated during monsoon (usually June–September) and a dry period of 4–5 months (December–April). Annual rainfall for Cox's Bazar for 1987–1996 ranged from 2,867 to 4,684 mm, and the ranges of mean annual maximum and minimum temperatures recorded at Cox's Bazar for 1987–1996 were 30–33 and 19–22 °C respectively (CWBMP 2006). Humidity remains relatively high throughout the year with an average of about 80 %. The region is particularly susceptible to cyclones and tidal surges. Cyclonic storms develop in the Bay of Bengal, generally in April–May and October–November, occasionally coming to shore and causing severe damage to human settlements and vegetation. Historical tidal data for the last 22 years at the Cox's Bazar coastal station exhibit a sea level rise of 7.8 mm/annum (MoEF 2005).

Research Method

At the beginning of the study the researchers visited Cox's Bazar towards Teknaf Peninsula along the sea beach, hillside and the Shahparir Dwip to observe the



Fig. 1 Map of study area showing the locations of sampled villages (*green circles*). (Color figure online)

general condition of homestead forests. It was noticed that homestead forests exist along both the beachside and the hillside along Cox's Bazar-Teknaf Peninsula. Therefore, it was decided for sampling to divide homesteads into three strata, viz. hillside (1), beachside (2) and Shahparir Dwip (3). Six villages at approximately equal distances along Cox's Bazar-Teknaf Peninsula were selected, from where a total of 120 households, 60 from hillside and 60 from beachside were selected randomly. The Shahparir Dwip is a compact settlement and 20 households were selected randomly for there.

Household and vegetation surveys were carried out during October 2012–March 2013. Semi-structured household interviews were conducted for the 140 selected households. A semi-structured questionnaire was designed to obtain data on the respondents' household size, education status, landholding, professions, income sources and mean monthly income, livestock ownership, and contribution of

homestead forests to household economy. Respondents were asked about species preferences together with reasons for selection, and planting pattern. They were asked which plants they prefer for mitigating cyclone damage. Characteristics of these plants and how they reduce cyclone damage were explored.

Of the sampled households, 70 homestead forests (30 hillside, 30 beachside and 10 from Shahparir Dwip) were surveyed for plant composition, plant density, biomass production and spatial distribution. The area of each selected homestead forest was measured and divided into four quadrats based on direction from the dwelling. Each quadrat was further divided into 1–5 sub-quadrats at 5 m intervals from the dwelling. All woody plants (trees, palms, shrubs and herbs) in the sampled homestead forests were identified and numbers of each species were counted. Specimens of unidentified plants were collected and identified by a plant taxonomist. The height (m) and diameter at breast height (dbh, cm) was of all trees and shrubs was assessed. Ages of coconut palms were noted based on respondent's recall. Plant species, and numbers of each species, diameters and heights were recorded in respect to direction and distance intervals (0–5, 5.1–10, 10.1–15, 15.1–20 m) from dwelling.

A total of seven focus group discussions (FGDs) were held in seven sampled villages with villagers in three study sites. The discussion focused on choice of species, villagers' knowledge about climate change, problems they are facing due to climate change, and contribution of homestead forests in reducing climate impacts.

Household data were compiled and summarized and frequency distributions obtained for selected variables. For describing ecological attributes, homestead forest vegetation in various sites was analyzed based on functions, horizontal and vertical structure, and in terms of diversity indices. For analyzing horizontal and vertical structures of plants data were pooled for three sites. Several diversity indices (including Simpson's diversity index, Shannon–Wiener's Diversity Index, Evenness index, Richness index, Similarity index, and Sørensen similarity index) were determined.

The Shannon–Weiner diversity Index (H) was calculated according to Shannon and Wiener (1963):

$$H = - \sum (n_i/N) \times \text{Ln}(n_i/N)$$

where n_i = Number of individuals of one species in a site, N = total number of individuals of all species in a site.

The Species Diversity Index (SDI) was calculated based on the formula of Kohli et al. (1996):

$$\text{SDI} = \sum_{i=1}^s \log(n_i/N) / \log(1/S)$$

where n_i is the number of individuals of each species, N is the total number of individuals of all species and S is the total number of species.

The Indices of Species Richness (R) and Evenness (E) were estimated using the formula of Margalef (1958) as cited by Kohli et al. (1996):

$$R = (S - 1)/\text{Ln}N$$

$$E = H/\text{Ln}S$$

where S = total number of species, N = the individuals of all the species, and H = the Shannon–Weiner Index of Diversity.

The Index of Dominance (ID) was measured by Simpson's Index (Simpson 1949):

$$\text{ID} = \sum_{i=1}^s (n_i/N)^2$$

where n_i = the number of individuals of each species, S = the number of species and N = total number of individuals of all species.

Sorensen's Similarity Index (of similarity in species composition at two sites) was assessed by the equation of Magurran (2004):

$$C_s = 2c/(a + b)$$

where a = number of species found in site 1, b = number of species in site 2, and c = number of species common in two sites.

For biomass estimation of woody plants (trees, palms and shrubs) following equations were used:

For coconut palms the formula of Kumar (2011) was applied:

$$Y = 5.5209X + 89.355$$

where Y = dry weight (kg) and X = tree age (years).

For *supari* palm (*Areca catechu*) the equation of Frangi and Lugo (1985), cited in Brown (1997), was used:

$$Y = 10 + 6.4H$$

where Y = biomass (kg) and H = Total height (m).

An equation from Brown (1997) was used for all other woody trees and shrubs:

$$Y = 42.69 - 12.8D + 1.24D^2$$

where Y = biomass per tree in (kg) and D = diameter at breast height (cm).

Results and Discussion

Extent, Diversity, Density and Distribution of Plants in the Homestead Forests

The average homestead area is 0.15 ha (range 0.08–1.25 ha) of which villagers allocate 67 % of the area (typically about 0.1 ha) for homestead forest. Alam and

Sarker (2011) reported from a study in north-west Bangladesh that households in the villages allocate 32 % of their homestead area for homestead forests (mean area 0.12 ha) and in south-western parts of country, the average landholding was reported by Kabir and Webb (2009) as 0.35 ha and homestead size was 0.08 ha. These figures indicate that villagers in the study area allocate more land for homestead forests than those in the northern and south-western parts of the country. Respondents commented that although they have limited land they utilize the available land for maximum production.

A total of 42 plant species were identified in the beachside, 39 in Shahparir Dwip and 34 in hillside, respectively (Table 1). A total of 73 species were identified over all three sites (“Appendix”), more than 50 % being trees, followed by shrubs and herbs (Fig. 2). A meta-analysis of Bangladesh homestead forests in five distinct locations throughout the country reported 91 individual plant species (Bardhan et al. 2012). Muhammed et al. (2011) mentioned the presence of 43 woody perennials in some homesteads of central Bangladesh. In neighbouring countries, in India, Das and Das (2005) reported 122 species from 15 ha of homestead forests in Tripura state while Shastri et al. (2002) identified 68 from 1.28 ha of home garden in Karnataka state. Kehlenbeck and Maass (2004) identified 149 plant species including vegetables from 2.1 ha of homestead forests in Central Sulawesi, Indonesia. Unlike the studies reviewed above, this study considered woody perennials only and therefore the 73 species across the study sites can be regarded as reasonably rich plant composition. Functionally, more than 20 species in each site have horticultural values for edible fruits followed by timber and other uses including medicinal uses (Fig. 3). Das and Das (2005) noted that an important characteristic of home gardens is the dominance of indigenous fruit trees.

The species diversity index (SDI) is lowest in Shahparir Dwip (1.21) while in beachside and hillside areas it is 1.47 and 1.53, respectively (Table 1). The higher value (3.16) of Shannon-Wiener index in Shahparir Dwip indicates that the plant community is diverse and not dominated by a few species. This is consistent with the index of dominance where the value (0.09) is lowest in Shahparir Dwip. In Shahparir dwip the species are more uniformly distributed (evenness index 0.84) than at the other sites. Species richness is the highest in Shahparir Dwip (6.67). In an 11.52 ha area of homestead forests in northwest Bangladesh an H value was reported in a range of 1.31–2.10 (Alam and Sarker 2011) and in a 5.4 ha homestead forest area in central Bangladesh an H value of 2.62–3.33 was reported by Muhammed et al. (2011). Chandrashekara and Baiju (2010) estimated a diversity index of 1.02–2.97 in 32 ha of home gardens in Kerala, India. The higher Sørensen similarity index values between hillside and Shahparir Dwip, and beachside and Shahparir Dwip, indicate greater similarity in species composition while in beachside and hillside the composition is less uniform.

Villagers plant seedlings of *supari* (*Areca catechu*) very closely, not following any regular spacing, and the average spacing was measured as 1.5 m × 1.5 m. The average plant density across the study sites is about 4,000 plants/ha with the highest (4,537/ha) in the hillside area and the lowest (3,337/ha) in Shahparir Dwip. In hillside *supari* is dominant (57 % of plant density) followed by bamboo (*Bambusa* spp., 23 %), mango (*Mangifera indica*, 6 %) and banana (2 %). In beachside areas

Table 1 Species composition, diversity and stock of homestead forests in the study sites

Variable	Study site		
	Hillside	Beachside	Shahparir Dwip
No. of species	34	42	39
Density (no./ha)	4,537	4,140	3,337
<i>Diversity indices</i>			
Species diversity index	1.53	1.47	1.21
Species richness	4.52	5.98	6.67
Shannon-Wiener's Diversity Index	1.73	1.76	3.16
Evenness	0.48	0.46	0.84
Index of dominance	0.37	0.42	0.09
Sorensen's similarity index	1.44 ^a	1.53 ^b	1.58 ^c
Biomass (Mg/ha)	251.08	318.56	330.24

^a Similarity between beachside and hillside (Cs B–H)

^b Similarity between beachside and Shahparir Dwip (Cs B–S)

^c Similarity between hillside and Shahparir Dwip (Cs H–S)

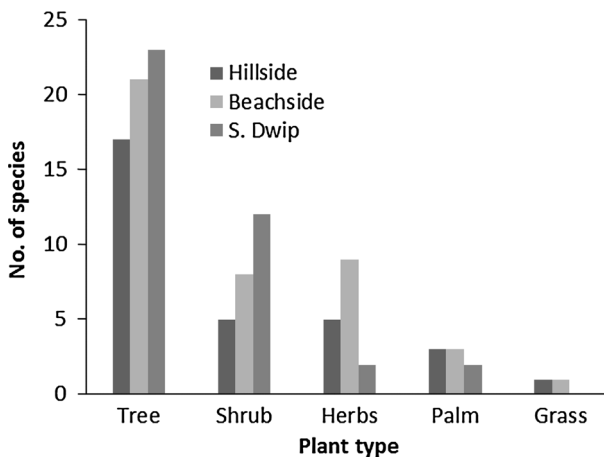


Fig. 2 Number of species of various plant forms found in three study sites in Cox's Bazar—Teknaf Peninsula

supari is dominant (63 %) followed by coconut (*Cocos nucifera*, 7 %), mango (2 %) and *dumur* (*Ficus* spp.). By contrast, mango is dominant (22 %) in Shahparir Dwip followed by *Acacia auriculiformis* (11 %), *Eucalyptus* sp. (9 %), *supari* (8 %) and banana (7 %). Kabir and Webb (2009) reported that tree and shrub density in south-eastern Bangladesh was 1,327/ha. Saikia et al. (2012) reported a density of 3,843/ha in Assam in India.

The dominance of *supari* in hillside and beachside locations in the current study was due to the high economic value of this species. Respondents of Shahparir Dwip

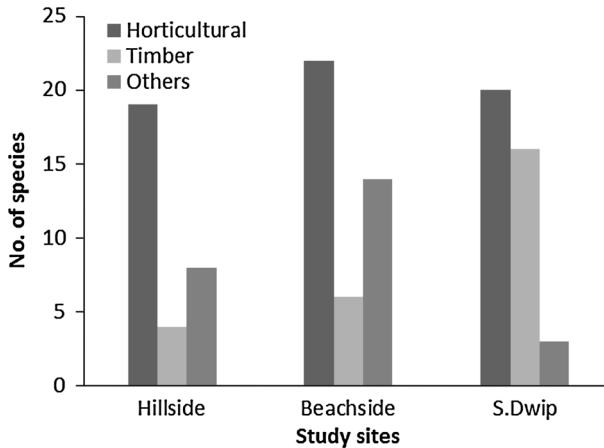


Fig. 3 Number of species found under various utilization categories

Table 2 Household incomes of the three study strata and contribution of homestead forests in 2012

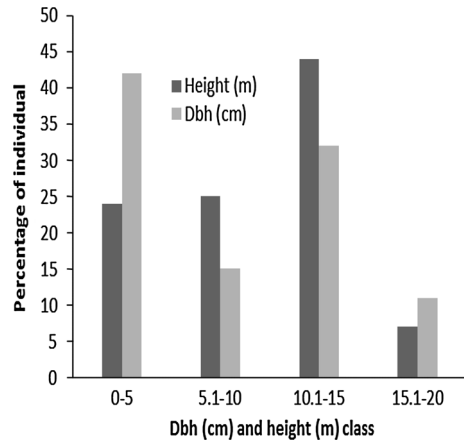
Variable	Study site		
	Beachside	Hillside	Shahparir Dwip
<i>Income from forest products (Tk)</i>			
Timber	–	–	2,222
Fuel wood	–	–	5,208
Bamboo	–	125	–
Fruits	150	8,979	–
Betel nuts	42,960	45,000	4,500
Coconut	2,417	2,958	870
Income from other products (Tk)	2,917	166	–
Mean income from homestead forest (Tk)	48,444 (36)	57,228 (49)	12,800 (6)
Mean annual household income (Tk)	133,704	116,208	202,236

Figures in parentheses indicate percentage contribution of homestead forests to mean annual household income

commented that they were also growing *supari*, but due to frequent tidal inundation, saline water intrusion and waterlogging most of their *supari* palms along with other trees had died. Access to markets can also influence species diversity and density, and studies show that proximity to market has negative influence on diversity and density (Kaya et al. 2002). However, findings of this study reveal that density is relatively high even though there is a strong market for some homestead products, including *supari*.

Home gardens exhibit complex structure, both vertically and horizontally (Das and Das 2005). The vertical structure of home gardens is typically composed of 3–4 canopy layers (Fernandez and Nair 1986). In more than 90 % of the homesteads

Fig. 4 Diameter and height class distribution of plants in the study sites



across the three strata the dwelling is centrally located and surrounded by plants in all directions. Plant species composition (23 species) and number of plants (40 %) were found to be highest at 5–10 m from the dwelling. Relatively taller trees (e.g. *Albizia* spp., *Bombax* spp, coconut and eucalypts) are observed along the boundary of homesteads. Although mean height of plants (11.33 m) is highest towards periphery (15–20 m from dwellings), the number of individuals (3 %) is lowest in that position. Mean height of plants is seen to increase from dwelling towards the boundary which indicates that villagers intentionally grow taller trees at the margin of their homesteads. These tall trees at the margins act as barriers against storm wind, do not fall down on houses during storms, and do not have shade effect on fruit trees growing near houses.

Species composition is relatively similar in all four directions. Plants density is lowest in the west and highest in the north. Diameter distribution (Fig. 4) of plants shows that 42 % of total individuals belong to the 0–5 cm dbh class which might indicate that most of the plants are shrubs. Nearly 60 % individuals belong to the 5–15 m height class, and the number of individuals is lowest in the uppermost dbh and height classes indicating there are few large trees in the studied homesteads. Existence of plants of varying heights and diameters indicates that farmers have been planting these plants continuously and hence maintain a sustainable village forest. Farmers also mentioned that they plant seedlings of various plants every year.

Economic Contribution of Homestead Forests

Respondents across the three strata reported that villagers obtain a variety of products from their homestead forests, not only for their own consumption but also for sale in local markets. All of them almost depend heavily on homestead forests for their fuelwood. Most often they use timber and bamboo for house construction. Although they consume seasonal fruit species (e.g. mango, jackfruit, blackberry and guava), some also sell these fruits. Some respondents reported that they grow

vegetables and sell the surplus in markets. In emergency situations they sell some trees for timber. All respondents commented that they sell betel nut and green coconut every year. The researchers estimated household income from homestead forests in the last year of the study (2012) and found that more than 80 % of the income from homestead forests in the hillside and beachside strata is derived from sale of betel nut. In Shahparir Dwp betel nut contributes about 35 % of income (Table 2). Considering all products it was found that households earn on average an income of Tk 57,228 in hillside forests, Tk 48,444 from beachside forests and Tk 12,800 from Shahparir Dwp. The mean annual income from homestead forests across the whole study area is Tk 39,490, which is about 10 times as much as that of south-western parts of country, where Kabir and Webb (2009) estimated that villagers could make an annual income of Tk 3,850 from their homestead forests. This is probably due to commercial cultivation of betel nut in the homesteads of hillside and beachside sites of the study area. Homestead forests in hillsides contribute 49 % to mean annual income followed by 36 % for beachsides and 6 % for Shahparir dwp.

Choice of Species for Mitigation of Natural Hazards

The study sites are prone to frequent natural hazards including seasonal cyclones, tidal storms and sea water surges. Respondents mentioned that these events are increasing in frequency and cause damage to houses, soil erosion, salinity intrusion and vegetation damage. Respondents of Shahparir dwp commented that they have been experiencing frequent tidal inundation during recent years. Many homesteads have become permanently inundated and villagers suspect that in future it would be very difficult for them to survive. Considering the protective role of plants against cyclones, respondents of hillside and beachside locations mentioned that they prefer coconuts (53 %) followed by *supari* (45 %), mango (42 %) and jackfruit (25 %) for planting at their homesteads. The reasons they cited include high survival rate of these species (85 %), strong root system that protects plants from uprooting during cyclones (72 %), strong stems which do not break easily (68 %), and low weight associated with light canopy which reduces wind load on trees (55 %) thus prevents houses from wind damage. The wind speed is reduced when wind hits the trees and hence the destructive force of strong wind declines. Respondents said they plant *supari* palm and other fruit trees near to their dwellings and big trees on property boundaries. *Supari* palm has a very small crown and the stem does not often break during cyclones. Even when the trees do break they do not damage the house because of the low stem weight. However, in Shahparir dwp respondents prefer *Acacia* (50 %), raintree (*Samanea saman*, 40 %), *jhau* (*Casuarina equisetifolia*, 33 %) and mahogany (28 %). They mentioned that these species have strong and spreading root systems (78 %) and can withstand cyclones (65 %). Trees with a taproot or sufficient branch roots retain upright growth and can survive well against heavy wind (Haq et al. 2012). People living near the coast of Sri Lanka reported the role of home gardens as

protection against natural hazards, and suggested maintaining home gardens as measure for future protection (Mattsson et al. 2013).

When asked about species preference for future planting in homestead forests in both hillside and beachside locations, most respondents (75 %) commented that they would like to plant *supari* at their homesteads followed by mango (65 %), coconut (35 %), *segun* (*Tectona grandis*, 35 %) and jackfruit (20 %). They added that they have been cultivating these species for generations because these plants provide economic gain (100 %), grow well (95 %), and protect houses during cyclones (80 %). However, in Shahparir Dwip 72 % of respondents favour *Acacia auriculiformis* followed by mango (55 %), mahogany (*Swietenia macrophylla*, 50 %) and coconuts (28 %). They said these species provide fuelwood (100 %), timber (76 %) and fruit (72 %), and grow well (70 %) in their homesteads even if the area is intermittently inundated with saline water.

Villagers' opinions on choice of species reveal that they choose plants for multiple purposes, including economic and environmental values. Their local knowledge on planting light canopy fruit species near dwelling and large canopy taller trees on boundaries has productive and protective functions. Boundary trees act as a wind barrier and protect trees and houses downwind. Villagers can take intensive and regular care of trees near to houses and can protect fruit from pilferage. In order to reduce the extent of cyclone damage, villagers build houses at the centre of homestead land, surrounded by trees.

Aboveground Biomass and Carbon Sequestration

Aboveground biomass (AGB) production of woody perennials was found to be highest (330.24 Mg/ha) in Shahparir dwip and lowest (251.08 Mg/ha) in hillside homesteads (Table 2). Contributions to AGB across the species of mango (13.27 %), *Acacia* (8.4 %), eucalypts (6.5 %) and *supari* (3.6 %) account for a substantial portion of biomass in the homestead forests of Shahparir dwip. In hillsides, *supari* produces 71 % of total AGB while in the beachside *supari* (56 %) and coconuts (16 %) are the main contributors. The AGB across the three study sites is estimated at 235.45 Mg/ha, of which *supari* and coconut contributes 71.46 %. It was also observed that biomass productivity per tree is highest for mango (186.93 kg/tree, mean dbh 10.9 cm) followed by acacias (170.13 kg/tree, mean dbh 14.9 cm), coconuts (72.78 kg/tree, mean age 12 years) and *supari* (72.62 kg/tree, mean dbh 7.7 cm).

It has been reported that forest carbon stock can be estimated as 50 % (dry mass basis) of AGB (Brown 1997). Using this approximation it can be assumed that mean carbon stock across the three study sites is 117.73 Mg C/ha, which is nearly twice as much as the mean AGB carbon stock (61 Mg C/ha) reported in homestead forests of Sri Lanka by Mattsson et al. (2013). The average aboveground standing stocks of carbon in home gardens of Kerala, India ranged from 16 to 36 Mg/ha (Kumar 2011). In Javanese and Sumatran home gardens the average carbon stock was reported to be 35.3–58.6 Mg C/ha (Jensen 1993; Roshtenko et al. 2002). The higher carbon stock in the study sites is probably due to higher plant density.

Homestead Forest and Forest Carbon Financing

Sequestration of atmospheric carbon by forests is well recognised as a low-cost mitigation measure for greenhouse gas. A number of carbon-sink-related clean development mechanism (CDM) forestry projects have been promoted around the globe for the promotion of sustainable development, conservation of forests and mitigation of climate change. However, none of these CDM forestry projects include homestead forests, implying that the potential of these forests as a strategy for carbon sequestration has not yet been fully recognized even though they offer considerable scope to improve biomass accumulation and economic efficiency of climate change mitigation (Kumar 2011). Agroforestry became recognized as a carbon sequestration activity especially under the afforestation and reforestation activities that have been approved as GHG-mitigating strategies under the Kyoto Protocol (Nair et al. 2009). Globally, carbon emission reduction (CERs) trading is rapidly expanding, and the CDM of the Kyoto Protocol offers an attractive financial opportunity for subsistence farmers in developing countries, the major practitioners of agroforestry, for trading the CERs to industrialized countries.

Homestead forests of the study area in particular and Bangladesh as a whole have the potential to capture considerable quantity of atmospheric CO₂ (117.73 Mg C/ha in the study area). Villagers have managed these forests sustainably for generations and there are no land property rights problems because they established forests on their personal land. There is scope to increase tree numbers by planting woody trees along boundaries to increase carbon sequestration. Overall, it seems that homestead forests are permanent, do not face land tenure conflicts and have potential for increased carbon sequestration. These are essential principles for qualifying to participate in CDM forestry projects.

There are several obstacles to participate in CDM forestry projects. First, homestead forests are small in size and it would not be easy to motivate all villagers. Mattsson et al. (2013) suggested incorporating all regional homegardens as “bundled homegardens” to overcome the small size of unit to participate in CDM projects. However, this requires extensive coordination, collaboration and consensus (Thomas et al. 2010). Shin et al. (2007) argued that the most important constraint to Bangladesh’s participation in carbon trading is lack of capacity to manage the application requirements for the CDM projects. However, nowadays there are many trained personnel in Bangladesh who can deal well with CDM activities. A private–public–partnership company can be formed which will provide funding and expertise for initiating, negotiating and implementing CDM activities in the country. There is the possibility of some leakage of captured carbon due to use of homestead forests for household fuel and selling trees in emergency situation. Villagers meet their household fuelwood demand from homestead forests.

If villagers were able to participate in CDM projects the financial benefits they would gain would help them to meet emergency needs thereby reducing selling of trees. Also, introduction of improved cooking stoves can reduce fuelwood demand and these stoves can in turn be incorporated into CDM projects. Improved cooking stoves are eco-friendly, require less biomass to cook food, save forests and thus reduce the amount of CO₂ emission from burning. It has been estimated that by

installing 1,000 improved biomass cooking stoves CO₂ emissions can be reduced by 805 tons in their 5 years life-span and credits for these CO₂ emissions can be traded under CDM and be worth about US\$15,947 (Panwar et al. 2009).

Concluding Comments

The natural hill and mangrove forests in Cox's Bazar-Teknaf Peninsula have been degraded severely due to illegal felling of trees and landuse changes. Due to continuous over-exploitation these forests have lost their regenerative capacity. Once the region was rich in *Dipterocarpus* spp., *Hopea odorata*, *Swintonia* spp. and *Anisoptera* spp., but nowadays these species are rarely seen in natural forests although a few sporadic patches of dipterocarps have been conserved in protected areas. Under this situation homestead forests play an important role not only to conserve biodiversity and but also for other environmental and economic services. Even though the floristic composition and diversity of the study sites is comparable to other parts of the country as well as in other sub-tropical countries, villagers need to be motivated to plant some of the native timber species mentioned above. Along with consumable products, villagers obtain cash income from their homestead forests' products. These forests provide them with protection during cyclones. These ecological and economic attributes and above all awareness of the villagers about importance of homestead forests inspire them to manage sustainably their homestead forest resources. Mattsson et al. (2013) commented that direct supply of necessary goods and services is one of important reasons for the survival of ancient system of home gardens.

The homestead forests sequester and store atmospheric carbon in the form of woody biomass and thus help to mitigate negative impacts of climate change. These forests could potentially be a source of carbon credits through an appropriate carbon financing mechanism. The carbon sequestration can be considered permanent because complete biomass removal does not occur from home gardens (Mattsson et al. 2013). Home gardens thus not only meets the conditions of a CDM project but also provide a win-win strategy for involving small-scale farmers in climate change mitigation and adaptation initiatives and agro biodiversity conservation (Kumar 2011). The concerned agencies including the Department of Environment, Forest Department and Climate Trust of Bangladesh need to take initiatives to incorporate the homestead forests of Bangladesh into carbon financing mechanisms such as the CDM.

Appendix

See Table 3.

Table 3 Names of plants found in the study sites

Local name	Scientific name	Study site
Acacia	<i>Acacia auriculiformis</i>	1, 2, 3
Akonda	<i>Calotropis procera</i>	1
Am	<i>Mangifera indica</i>	1, 2, 3
Amloki	<i>Phyllanthus emblica</i>	2
Amra	<i>Spondias pinnata</i>	1, 2, 3
Anarash	<i>Ananas cosmosus</i>	1
Apple	<i>Malus domestica</i>	3
Arshol	<i>Vitex peduncularis</i>	2
Arjun	<i>Terminalia arjuna</i>	2, 3
Asamlata	<i>Chromolaena odorata</i>	1, 2
Asargula	<i>Microcos paniculata</i>	2, 3
Ata	<i>Annona reticulata</i>	1, 2
Badam	<i>Anacardium sp.</i>	3
Baijja	<i>Bambusa vulgaris</i>	1
Banana	<i>Musa sp.</i>	1, 2
Bel	<i>Aegle marmelos</i>	2, 3
Bilambo	<i>Averrhoa bilimbi</i>	2, 3
Boroi	<i>Zizyphus mauritiana</i>	1, 2, 3
Boruna/Batna	<i>Castanopsis sp.</i>	1
Chalta	<i>Dillenia indica</i>	1, 3
Debdaro	<i>Polyalthia longifolia</i>	3
Dumur	<i>Ficus spp.</i>	1, 2
Eucalyptus	<i>Eucalyptus sp.</i>	3
Gamar	<i>Gmelina arborea</i>	1, 2, 3
Guava	<i>Psidium guajava</i>	1, 2, 3
Gub	<i>Diospyros peregrina</i>	3
Horinagodha	<i>Vitex peduncularis</i>	3
Jalpai	<i>Elaocarpus robustus</i>	1
Jam	<i>Syzygium spp.</i>	1, 2, 3
Jambura	<i>Citrus grandis</i>	1, 2
Jhau	<i>Casuarina equisetifolia</i>	3
Joba	<i>Hibiscus rosa sinensis</i>	2
Kaju badam	<i>Anacardium occidentale</i>	3
Kamranga	<i>Averrhoa arambola</i>	1, 2, 3
Kanthal	<i>Artocarpus heterophyllus</i>	1, 2, 3
Katbadam	<i>Terminalia catappa</i>	3
Kathmalati	<i>Tabernaemontana divaricata</i>	2
Keron	<i>Derris indica</i>	3
Khejur	<i>Phoenix sylvestris</i>	1, 2
Krishnachura	<i>Delonix regia</i>	2
Kuruk	<i>Holarrhena antidysenterica</i>	2

Table 3 continued

Local name	Scientific name	Study site
Lantana	<i>Lantana sp</i>	2
Lebu	<i>Citrus limon</i>	1, 2
Liliguta	unknown	3
Litchi	<i>Litchi chinensis</i>	2
Mahagoni	<i>Swietenia mahogani</i>	3
Mandar	<i>Erythrina indica</i>	1, 2
Mangium	<i>Acacia mangium</i>	3
Narikel	<i>Cocos nucifera</i>	2, 3
Neem	<i>Azadirachta indica</i>	2
Nita	<i>Bambusa sp.</i>	1
Orange	<i>Citrus sinensis</i>	1
Painnagula	<i>Flacourtia indica</i>	2
Painnamandar	<i>Erythrina variegata</i>	1
Papya	<i>Carica papya</i>	1, 2, 3
Patabahar	<i>Codiaeum variegatum</i>	2
Raintree	<i>Samanea saman</i>	1, 3
Sada koroï	<i>Albizia procera</i>	3
Sajna	<i>Moringa pterygosperma</i>	1, 2, 3
Sheora	<i>Streblus asper</i>	3
Shiba	<i>Bambusa sp.</i>	1
Shimul tula	<i>Bombax ceiba</i>	3
Sofeda	<i>Annona squamosa</i>	2
Supari	<i>Areca catechu</i>	1, 2, 3
Telsur	<i>Hopea odorata</i>	1, 3
Tentul	<i>Tamarindus indica</i>	1
Titbegun	<i>Solanum sp.</i>	2
Tula	<i>Bombax sp.</i>	1, 2
Vadi	<i>Garunga pinnata</i>	2
Vhat	<i>Clerodendron viscosum</i>	1, 2
Verenda	<i>Jatropha curcas</i>	2

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