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Quantitative stand structure of woody components of homestead forests and its implications on silvicultural management: a case study in Sylhet Sadar, Bangladesh

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Abstract This study determined existing quantitative stand structure and its implication on silvicultural management of homestead forestry. The results showed that fruit and timber species have importance values of 57% and 43%, respectively, in the study area, which is in contrast to the commonly held view of absolute domination of fruit species. The fruit species were only moderately dominant over timber species in relation to the quantitative stand structure of homestead forests. Two fruit species, *Mangifera indica* and *Artocarpus heterophyllus*, contribute about one third of the stand structure, while amongst the timber species *Samanea saman* and *Albizia spp.* are the most important species. A simulated evaluation of soil expectation value of homestead forest showed that the existing stand structure would not maximize the financial gain perpetually, in contrast, the quantitative stand structure could be effectively regulated to maximize grower benefit without compromising the existing biodiversity. Optimization of the quantitative stand structure of homestead forests could be achieved by changing the species composition, specifically by increasing the percentage of commercially valuable species like *Michelia champaca*, *Tectona grandis*, *Artocarpus chapalasha*, *Gmelina arborea*, *Litchi chinensis*, *Citrus grandis*, *Psidium guajava, Lagerstroemia speciosa, Swietenia mahogany*, etc., reducing the percentage of species like *Mangifera indica*, *Artocarpus heterophyllus*, *Cocos nucifera*, *Samanea saman*, *Spondias pinnata*, *Phoenix sylvestris*, etc., and eradicating species like *Lannea coromandelica* and *Ficus benghalensis*. It was estimated that the optimal relative density of fruit and timber species that would generate optimal financial benefit would be 40.4% and 59.6%, respectively.

Key words Quantitative stand structure · Homestead forests · Fruit and timber species · Importance value · Soil expectation value

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Introduction

The importance of homestead forests in Bangladesh is enormous in the forestry sector, and this recognized in all quarters. Tree husbandry appears to be a universal practice in Bangladesh (Raintree 1991). The choice of tree species by different households varies from family to family, from village to village, and according to location. Sometimes farmers may be interested in planting multipurpose species, rather than planting trees just for fuelwood alone (Arnold 1992). Personal preferences and attitudes, socioeconomic status, and culture often reflect the appearance, structure, and function of the homegardens (Christanty 1985). Abedin et al. (1988) reported that farmers preferred fruit trees because they get both fruit and fuel from those trees. Similarly, Leschner and Khaleque (1987) reported that homestead plantation farmers prefer fruit trees because they provide fruit, fuelwood, fodder, and timber. Fruit trees have a distinct advantage over other woody species in that they can be harvested periodically and/or in a staggered manner, and thus be a source of cash income, in addition to food, to the farmer (Nair 1989). Over the years, there has been a widely held belief that fruit species overwhelmingly dominate the quantitative stand structure of homestead forests; however, there exists almost no scientific evidence to support this common belief. Because the quantitative stand structure determines the quality of the stand, it is very important to acquire clear knowledge of the stand structure of homestead forests for scientific management and sus-

Table 1. Description of the study area (Sylhet Sadar upazila)

Items	Description
Origin	Sylhet Sadar, the most populous upazila of Sylhet Zila, came into existence in 1867
Location	Sylhet Sadar upazila is one of the northeastern upazila of Bangladesh. It is located between 24°43′ and 25°05′ north latitudes and between 91°40′ and 92°01′ east longitudes
Area	Total area: 517.43 km^2 River: 10.05 km^2 Government forest: 19.22 km^2 Agriculture, homesteads, and other: 488.16 km^2
Climate	Mean annual minimum temperature: 17.6°C; minimum (in January): 8.8°C Mean annual maximum temperature: 33.0°C; maximum (in June): 36.1°C Mean annual humidity: 80.2% Mean annual rainfall: 4545 mm Monthly minimum rainfall (in December): 0.0 mm Monthly maximum rainfall (in July): 1172 mm
Population	Total: 554 412; male: 291 141; female 263 271 Rural population: 320 057; urban population: 234 355; population density: 1071/km^2
No. of villages	689
No. of households	Total: 86 074; rural: 50 509; urban: 35 565
Average household size	6.4 persons
Literacy	41.1% for both sexes; Male: 50.0%; Female: 37.6%
Homestead area/head	0.03 ha

Source: Bangladesh Bureau of Statistics (1996) and Government of Bangladesh (1999)

Table 2. Description of the sample villages

Items	PSU 1 (Shekh Para)	PSU 2 (Tilagar)	PSU 3 (Akhaliaghat)
Location	Tuker Bazar Union	Tultikar Union	Tuker Bazar Union
No. of households	141	108	109
Household size (Persons)	7.06	4.97	7.57
Average homestead forest size (ha)	0.09	0.06	0.13
Population	996	537	825
Literacy level (%)	21.60	71.90	47.80
No. of households sampled	30	30	30
Major forest products	Fruit, fuelwood, timber, bamboo	Fruit, fuelwood, timber, bamboo	Fruit, fuelwood, timber, bamboo

Source: analysis of field survey data of 2001 and Bangladesh Bureau of Statistics (1996)
PSU, primary sampling unit

tainable development of the homestead forestry sector of Bangladesh. Hence, in this study we tried to determine the existing quantitative stand structure of homestead forests. We made a soil expectation value analysis to evaluate the performance of existing structure and proposed ways of manipulating stand structure for optimal financial benefit to growers.

Description of the study area

Sylhet Sadar, the most populous upazila (subdistrict) of Sylhet zila, came into existence in 1867. The upazila occupies an area of 517.43 km^2, including 10.05 km^2 of river area and 19.22 km^2 of government forest area. It is located between 24°43′ and 25°05′ north latitudes and between 91°40′ and 92°01′ east longitudes. The upazila is bounded on the north by Companiganj and Gowainghat upazilas, on the east by Golapganj and Kanighat upazilas, on the south by Balaganj and Fenchuganj upazilas, and on the west by Bishwanath upazila and Chhatak upazila of Sunamganj zila (Fig. 1). Tables 1 and 2 describe the main features of the study area.

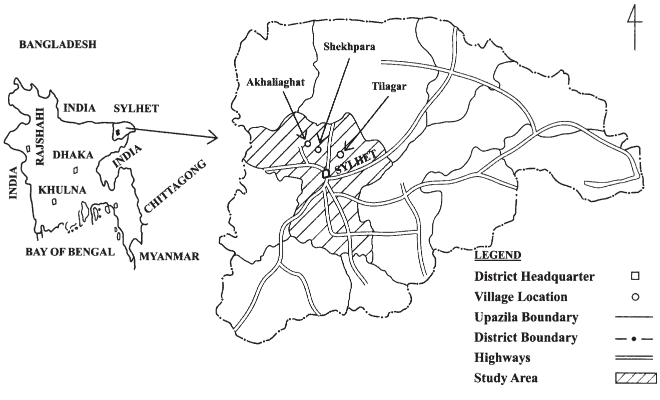

Fig. 1. Location of the study area, Sylhet Sadar upazila, Bangladesh

Research method

The structure of sociological order in any plant community cannot be studied by observing each and every individual of plant species growing in a habitat. Therefore, rough estimates of species content in a habitat can be made by observing the plant species at different places or sample areas, in the habitat (Shukla and Chandel 1998). Because homestead forests are clusters of trees around homesteads that are packed together in sparsely distributed villages, a two-stage sampling design was employed to collect data from the population. Three villages (primary units; PUs) were randomly selected from a list of 689 villages in the first stage. In each PU, 30 households (secondary units; SUs) were selected and by given proportionate weights for their landholding size classes. All trees with diameter at breast height (DBH) of 20 cm or greater that were under the possession of the household were enumerated for parameters of interest like DBH, species name, and number. Trees with DBH less than 20 cm were counted with species name. Management information and producers' prices for different forest produce were recorded by interviewing the stakeholders. It is necessary to define some terminologies that were used in this study to allow a proper understanding of the interpretation of the research. Fruit species, timber species, fuelwood species, and multipurpose species were used in this research quite often. However, in Bangladesh these terms have rather loose meanings because most fruit trees yield timber and fuelwood at the end of their rotation, and all timber trees yield fuelwood at different stages of silvicultural management. It is also common for homestead forest users to use fuelwood species for timber. Strictly speaking, most trees in the homesteads are multipurpose in nature. Therefore, in this study, these terms are used to describe the main purpose of use, for instance, a woody species mainly planted for fruit, irrespective of whether it is a major or minor species, is defined as a fruit species, excluding agricultural fruit crops like banana (*Musa pudica*), pineapple (*Ananas comosus)*, papaya (*Carica papaya*), lemon (*Citrus aurantifolia*), etc. that are beyond the scope of this study. Trees like betel nut (*Areca ctechu*) and bay leaf (*Cinnamomum tamala*) are also not included in the quantitative analysis because they fall below the 20-cm DBH class at maturity. Because it is rather difficult to isolate timber species from fuelwood species due to their intimate nature of intermingled uses, timber and fuelwood species are treated together as one entity as timber species. Any tree that has more than one known use can be described as a multipurpose tree (Government of Bangladesh 1992). Although bamboos are the most commonly used homestead product, because they cannot be treated as a tree class (rather they are a woody herb) and because they fall below the 20-cm DBH class, they were also excluded from the quantitative stand structure analysis of homestead forests. Finally, evaluation of soil expectation values for different existing species was made to simulate a model to determine the optimum percentage of species for the study area. In calculating soil expectation values, a financial analysis was carried out using producers' prices for all forest produce in 2001.

Data analysis

Quantitative analysis of the different stand characteristics were carried out to obtain a better understanding of the homestead forests of the area. The characteristics considered were: species count and species diversity, relative density, relative frequency, abundance, relative dominance, and importance value. The formula used for calculating these characteristics are given below.

Total count of number of species and different indices

All the woody plants found in the sample areas were identified and the individuals of each species were counted to determine the species richness/variety index (d), Shannon biodiversity index (H), evenness index (e), and index of dominance (c). As described by Odum (1971), the following equations were used:

$$d = (S-1)/\ln N \tag{1}$$

$$H = -\sum P_i \ln P_i \tag{2}$$

$$e = H/\ln S \tag{3}$$

$$c = \sum (n_i/N)^2 \tag{4}$$

where S is the number of species, n_i is the number of individuals of each species, N is the total number of individuals of all species, and P_i is the importance probability for each species (n_i/N).

Relative density (RD)

The numerical strength of a species in relation to a definite unit space is called its density. The proportion of the density of a species to that of a stand as a whole is referred to as the relative density, and it was calculated as:

$$\mathrm{RD} = (\text{Total number of individuals of a species})/(\text{Total number of individuals of all species}) \times 100 \tag{5}$$

Relative frequency (RF)

Frequency refers to the degree of dispersion in terms of percentage occurrence. Relative frequency is defined as the dispersion of a species in relation to that of all the species. Frequency (F) and relative frequency (RF) were calculated making use of the following formula:

$$\mathrm{F} = (\text{Total number of samples in which the spceies occur})/(\text{Total number of samples enumerated}) \times 100 \tag{6}$$

$$\mathrm{RF} = (\text{Frequency of the species in the stand})/(\text{Sum of the frequencies of all species in the stand}) \times 100 \tag{7}$$

Abundance (A)

The estimated number of individuals of a species per unit area is referred to as abundance of the species (A), and is calculated as:

$$A = (\text{Total number of individuals of the species in all the samples})/(\text{Total number of samples in which the species occurred}) \tag{8}$$

Relative dominance (RDo)

Relative dominance (RDo) is the proportion of the basal area of a species to the sum of the basal coverage of all the species in the area. This was calculated as:

$$\text{RDo} = (\text{Total basal area of the species in all the samples})/(\text{Total basal area of all the species in all samples}) \times 100 \tag{9}$$

Importance value (IV)

In any highly heterogeneous plant community, data of frequency, density, abundance, and dominance of species do not yield a total picture of ecological importance independently. Although each has its own importance, frequency gives an indication of how a species is dispersed in the area, but it does not depict the number of individuals or the area covered; density gives the numerical strength but gives information regarding spread or cover; dominance gives the cover but not the spread and number. Therefore, the overall picture of ecological importance of a species in relation to the community structure can be obtained by adding the values of relative density, relative dominance, and relative frequency. This total value (i.e., the added value of RD, RDo, and RF) out of a possible maximum of 300 is called the importance value index (IVI). Importance value (IV) is the average of these three entities calculated as:

$$\text{IV} = (\text{RD} + \text{RDo} + \text{RF})/3 \tag{10}$$

Soil expectation value

Homestead forestland was evaluated using 2001 market prices, a guiding interest rate, a real rate of return, and inflation rate to find the soil expectation value (SEV) under different hypothetical scenarios to optimize the financial benefit from the same piece of land. Because infrequent species may offer high economic return, all the species were evaluated in the soil expectation value analysis. It was assumed that all of the land considered would be suitable for each species to grow. To make the process simple and straightforward, it was further assumed that all of the land would be available for homestead forestry for long rotation (40 years). As such, the hypothetical scenarios was that the land was planted with each species and harvested after the end of the rotation period. Present net value (PNV = N_R) was calculated for each species and was used to calculate the soil expectation value for the species. The soil expectation value equation was deployed to simulate scenarios for land use with infinite rotations. The equations as described by Davis et al. (2001) were used to calculate SEV:

$$N_R = \left\{\left[R_t(1+p)^t\right]\Big/\left[(1+r)^t(1+k)^t\right]\right\} - \left\{\left[C_t(1+p)^t\right]\Big/\left[(1+r)^t(1+k)^t\right]\right\} \tag{11}$$

$$R_t \text{ or } C_t = P\left[(1+i)^t - 1\right]\Big/i \tag{12}$$

$$\text{SEV} = N_R\Big/\left[(1+i)^R - 1\right] \tag{13}$$

where R_t is the expected revenue after the rotation year, C_t is the cost incurred at the end of rotation, r is the real rate of return (5%), k is the average inflation rate of all prices (3%), p is the price inflation rate of forest produce (5%), P is the annual payment of revenue or cost during the rotation period, i is the guiding interest rate (8%) (Bangladish Bureau of Statistics 2003), t is the time elapsed between receipt of a revenue or payment of a cost till the end of the rotation, SEV is the soil expectation value, N_R is the net return at rotation age (R = 40 years).

Optimization of the species percentage was established by allocating land proportionate to the SEV for each species. The optimized number of individuals for each species was ascertained by dividing the allocated land area by the square of the standard planting spacing for each species.

Results and discussion

Stand structure

The complete list of the species is presented in Table 3 and different stand characteristics for frequently occurring species are given in Table 4. Total count of the number of woody species in all the sample households showed that, out of the 149 homestead tree species recorded so far in Bangladesh (Das 1990), the study area has 60 different species. However, out of these 60 species, 5 species of bamboos (*Bambusa balcoa*, *Bambusa tulda*, *Bambusa vulgaris*, *Bambusa polymorpha*, and *Neohouzeaua dulloa*), and betel nut and bay leaf were not included in the analysis because their DBH values were below 20 cm. Out of the remaining 53 species, 24 species constituted 86.8% (in terms of relative density) of the total vegetation and these are presented in detail in Table 4. The remaining 29 species, which constituted only 13.2% (in terms of relative density) of the vegetation, are collectively presented under the heading

Table 3. Complete list of species found in study area with their characteristics and usage

Species No.	Scientific name	Family	Characteristics and usage
1	*Mangifera indica* L.	Anacardiaceae	Big evergreen tree, F, CT, Fo, Me, MPT
2	*Spondias pinnata* Kurz.	Anacardiaceae	Medium-size tree, F, LGFu
3	*Lannea coromandelica* (Hout) Mer.	Anacardiaceae	Medium-size deciduous tree, CT, Fo
4	*Annoa reticulata* L.	Annonaceae	Small deciduous tree, F, GFu, Me, MPT
5	*Polyalthia longifolia* (Sonn.) Hook. f. & Thomson	Annonaceae	Medium-size ornamental tree, LGFu
6	*Alstonia scholaris* Br.	Apocynaceae	Big evergreen tree, SW, match stick
7	*Averrhoa carambola* L.	Averrhoaceae	Medium-size evergreen tree, F, LGFu
8	*Bombax ceiba* L.	Bombacaceae	Big deciduous tree, SW, GFu, Me, MPT
9	*Caesalpinia pulcherima* Sw.	Caesalpinoidae	Big evergreen tree, avenue plant, SW, MPT
10	*Bauhinia acuminata* L.	Caesalpinoidae	Small evergreen tree, ornamental, GFu
11	*Terminalia arjuna* Bedd.	Compretaceae	Big evergreen tree, GT, Me, MPT
12	*Dillenia indica* L.	Dilleniaceae	Medium-size evergreen tree, F, T, MPT
13	*Diospyros peregrina* (Gaer.) Gur.	Ebenaceae	Medium-size evergreen tree, GT
14	*Elaeocarpus robustus* Roxb.	Elaeocarpaceae	Medium-size evergreen tree, F, Fu
15	*Phyllanthus embelica* L.	Euphorbiaceae	Small deciduous tree, F, Me, MPT
16	*Quercus spicata* Sm.	Fagaceae	Big evergreen tree, GT, Fr
17	*Flacourtia indica* (Burm.)Menr.	Flacourtiaceae	Small ornamental tree, F, GFu
18	*Flacourtia jangomas* (Laour)Raeus.	Flacourtiaceae	Small tree, GFu, CT
19	*Bambusa balcooa* Roxb.	Graminae	Tall, strong bamboo, beam, tools, house post, Fo
20	*Neohouzeaua dulloa* (Gam). Camp.	Graminae	Medium-size bamboo, house wall, thatching, Fo
21	*Bambusa tulda* Roxb.	Graminae	Long, slender bamboo, house wall, tools, Fo
22	*Bambusa vulgaris* Schrad.	Graminae	Medium-size bamboo, thatching, house post, Fo
23	*Bambusa polymorpha* Munro	Graminae	Small bamboo, house material, mound, Fo
24	*Cinnamomum tamala* Nees.	Lauraceae	Medium-size tree, spice, oils
25	*Tamarindus indica* L.	Leguminosae	Big evergreen tree, F, GFu, CT
26	*Albizia spp.*	Leguminosae	Big tree, GT, Fr, MPT
27	*Samanea saman* (Jaq.) Merr.	Leguminosae	Big evergreen tree, MT, GFu, MPT
28	*Delonix regia* (Boj) Raf.	Leguminosae	Big tree, avenue tree, MT, MPT
29	*Erythrina orientalis* (Linn.)Murr.	Leguminosae	Medium-size deciduous tree, GFu, Fo, MPT
30	*Acacia auricoliformis* A.Cunnex Be.	Leguminosae	Medium evergreen tree, GT, GFu, MPT
31	*Lagerstroemia speciosa* (L.)Pers.	Lythraceae	Medium-to-big evergreen tree, avenue tree, GT
32	*Michelia champaca* L.	Magnoliaceae	Big evergreen tree, avenue tree, GT, Fr, MPT
33	*Swietenia mahogany* (L.) Jacq.	Meliaceae	Big evergreen tree, avenue tree, GT, Fr, MPT
34	*Aphanamixis polystachya* (Wall) Par.	Meliaceae	Medium-size evergreen tree, GT
35	*Azadiracta indica* A. Juss.	Meliaceae	Medium-size deciduous tree, MT, Me, MPT
36	*Toona ciliata* J. Roem.	Meliaceae	Big deciduous tree, MT
37	*Melia azaderach* L.	Meliaceae	Medium-size tree, LGFu, CT
38	*Artocarpus heterophyllus* Lamk.	Moraceae	Big evergreen tree, F, GT, Fo, MPT
39	*Artocarpus lacucha* Buch-Ham.	Moraceae	Medium-size evergreen tree, F, GFu, MT, MPT
40	*Ficus benghalensis* Linn.	Moraceae	Big evergreen tree, religious value, GFu
41	*Artocarpus chaplasha* Roxb.	Moraceae	Big evergreen tree, boat, frame, GT
42	*Syzygium cumini* (L.) Skeel.	Myrtaceae	Big evergreen tree, F, GT, Me, MPT
43	*Barrintonia acutangula* (L.) Gaertn.	Myrtaceae	Medium evergreen tree, MT, GFu
44	*Psidium guajava* (L.) Bat.	Nyrtaceae	Small evergreen tree, F, GFu, MPT
45	*Cocos nucifera* L.	Palmae	Tall palm tree, drink, mats, brooms, F, MPT
46	*Areca catechu* L.	Palmae	Medium-size slender palm tree, F
47	*Phoenix sylvestris* Roxb.	Palmae	Medium-size palm tree, juice, mats, F
48	*Borassus flabellifer* L.	Palmae	Tall palm tree, beam, boat, sweet, F, MPT
49	*Caryota rumphiana*	Palmae	Tall palm tree, ornamental plant
50	*Zizyphus mauritiana* Lamk.	Rhamnaceae	Medium-size tree, F, GFu, Fo, Me, MPT
51	*Anthocephalus chinensis* (Lam.) Rich	Rubiaceae	Big evergreen tree, avenue tree, SW, CT
52	*Aegle marmelos* (L.) Correa.	Rutaceae	Medium-size tree, F, Me, GFu, MPT
53	*Citrus grandis* (L.) Osb.	Rutaceae	Medium-size evergreen tree, F, GFu, CT, MPT
54	*Citrus hystrix* L.	Rutaceae	Medium-size tree, F, GFu, CT, MPT
55	*Litchi chinensis* Sonner	Sapindaceae	Medium-size tree, F, LGFu, MT, MPT
56	*Manilkara sapota* (L.) P.Van.	Sapotaceae	Small tree, F, CFu
57	*Mimusops elengi* L.	Sapotaceae	Big evergreen tree, GT
58	*Streblus asper* Lour.	Urticaceae	Medium-size evergreen tree, Fo, GFu
59	*Gmelina arborea* L.	Verbenaceae	Medium-size evergreen tree, pulp, GT, MPT
60	*Tectona grandis* L.f.	Verbenaceae	Big deciduous tree, GT

Source: 2001 field data

F, fruit; CT, cheap timber; MT, medium timber; GT, good timber; GFu, good fuelwood; Me, medicine; MPT, multipurpose tree species; LGFu, low-grade fuelwood; Fr, furniture; SW, soft wood; Fo, Fodder

Table 4. Abundance, relative density, relative frequency, relative dominance index, and importance value of different species

Species name	*A*	RD (%)	RF (%)	RDo (%)	*c*	IV (%)
Mangifera indica[a]	2.53	22.2	16.4	20.2	0.01219	19.6
Artocarpus heterophyllus[a]	1.56	11.8	14.0	11.0	0.01243	12.3
Samanea saman[b]	1.71	8.1	8.9	11.2	0.01434	9.4
Cocos nucifera[a]	2.70	9.2	6.4	12.0	0.00096	9.2
Syzygium cumini[a]	1.19	3.3	5.5	3.1	0.00139	4.0
Albizia spp.[b]	2.50	4.6	3.4	3.7	0.00060	3.9
Swietenia mahogany[b]	2.75	3.2	2.6	2.5	0.00034	2.7
Spondias pinnata[a]	1.18	2.3	3.6	1.9	0.00049	2.6
Phoenix sylvestris[a]	2.00	2.5	2.3	2.2	0.00045	2.3
Bombax ceiba[b]	1.15	1.8	2.8	2.1	0.00032	2.2
Zizyphus mauritiana[a]	1.23	2.1	2.8	1.8	0.00079	2.2
Borassus flabellifer[a]	1.40	1.6	2.1	2.8	0.00033	2.2
Anthocephalus chinensis[b]	1.64	2.1	2.3	1.8	0.00027	2.1
Alstonia scholaris[b]	1.15	1.7	2.8	1.7	0.00028	2.0
Lannea coromandelica[b]	1.67	1.8	1.9	1.7	0.00017	1.8
Aphanamixis polystachya[b]	1.50	1.7	2.1	1.3	0.00015	1.7
Psidium guajava[a]	1.20	1.4	2.1	1.2	0.00025	1.6
Tamarindus indica[a]	1.29	1.6	1.5	1.6	0.00009	1.6
Lagerstroemia speciosa[b]	1.43	1.1	1.5	1.0	0.00005	1.2
Delonix regia[b]	1.50	0.9	1.3	0.7	0.00004	1.0
Caesalpinia pulcherima[b]	1.20	0.7	1.1	0.7	0.00003	0.8
Averrhoa carambola[a]	1.00	0.5	0.9	0.5	0.00001	0.6
Tectona grandis[b]	1.00	0.5	0.9	0.4	0.00001	0.6
Aegle marmelos[a]	1.00	0.3	0.4	0.3	0.01219	0.3
Subtotal	–	86.8	89.6	87.1	0.08669	87.8
Other species	2.41	13.2	10.4	12.9	0.01675	12.2
Total	–	100	100	100	0.10345	100
All fruit	4.81	60.7	51.2	60.2	–	57.4
All timber	4.10	39.3	48.8	39.8	–	42.6
Total	–	100	100	100	–	100

Source: Analysis of field data of 2001
A, Abundance; RD, relative density; RF, relative frequency; *c*, index of dominance; IV, importance value
[a] Fruit species
[b] Timber species

"others" in Table 4. The results show that the homestead forest of the area has a species richness index value (*d*) of 7.7 (Table 7), which is fairly high for a highly disturbed man-made ecosystem and indicates the stability and greater productivity potential of homestead forests. Again, the presence of a large number (29) of less significant species is also an indication of the species richness in the study area. The Shannon general index of diversity (*H*) for the homestead forest of the area is 3.1 (Table 7), which is moderately high, indicates symbiosis, i.e., mutualism, parasitism, commensalism, and so forth (Odum 1971), amongst different homestead species, which depicts a sustaining and stabilizing homestead forest community. A high value of 0.8 for evenness index (*e*) well supports the fact of richness of biodiversity (Table 7). From the tabulated list (Table 3) and the description of the different species encountered in the study, it is evident that amongst the tree species, more than half are multipurpose in nature, which is characteristic of homestead forests.

Determination of the relative density of the different species revealed that mango (*Mangifera indica*) constitutes 22.2% of homestead vegetation of the area followed by jackfruit (*Artocarpus heterophyllus*), which occupies 11.8% (Table 4). Amongst the timber-yielding species, rain tree (*Samanea saman*) and silk tree (*Albizia* spp.) top the list and occupy 8.1% and 4.6%, respectively. All fruit species occupy 60.7%, while all timber species occupy 39.3% of the total homestead vegetation in the study area. These findings show a moderate predominance of fruit species over timber species. The study revealed that the two fruit species of mango and jackfruit are the most frequently occurring species with relative frequencies of 16.4% and 14.0%, followed by the timber species rain tree with a relative frequency of 8.9%. The total of the relative frequencies of the 24 major species constituted 89.6% while that of the remaining 29 species constituted 10.4%. The total relative frequency of all fruit species (51.2%) was slightly larger than the total relative frequency of all timber-yielding species (48.8%), indicating that the dispersion of homestead species is not concentrated on fruit or timber species, but rather is equally distributed between the two types.

This study revealed that mahogany (*Swietenia mahogany*) has the highest abundance value of 2.75 followed by coconut (*Cocos nucifera*) and mango with abundance values of 2.70 and 2.53, respectively. The total abundance value of all fruit species (4.81) was only marginally higher than the total abundance value (4.10) of timber-yielding species, which implies that fruit and timber species are almost equally abundant in the homestead forests of the study area. The fact that timber-yielding species like mahogany, silk tree, etc. have attained high abundance values is an indication that a few stakeholders might have opted to plant

Table 5. Management information of homestead forests in Sylhet area

Items	Total no. of stakeholders interviewed	Total No. of positive respondents	Positive respondents (%)
Soil working	90	88	97.8
Watering	90	90	100.0
Fertilizer	90	53	58.9
Fencing	90	36	40.0
Pesticide	90	35	38.9
Thinning	90	28	31.1
Selection felling	90	82	91.1
Medium rotation	90	82	91.1[a]
Long rotation	90	87	96.7[a]

Source: analysis of field survey data 2001
[a] In homestead forestry, the same household uses different rotations for different species based on objectives, i.e., respondents had more than one answer for rotation (medium rotation = 12–18 years, long rotation ≥ 40 years)

more commercial timber species rather than some traditional fruit species.

For forestry purposes, basal area represents the real extent of domination of a species in the community. Determination of relative dominance based on basal area revealed that mango is the most dominant species with a relative dominance value of 20.2%, which is followed by coconut and rain tree with relative dominance values 12.0% and 11.2%, respectively. Twenty-four frequently occurring species showed a total relative dominance value of 87.1% while the remaining 29 species had a combined relative dominance value of 12.9%. The combined relative dominance of all fruit trees (60.2%) was 20% more than that of the timber-yielding species (39.8%), implying that the domination of fruit trees over timber-yielding species in the homestead forest structure was moderate rather than comprehensive. With the index of dominance (c) showing a low value of 0.10 for the study area, it appears that although mango, coconut, and rain tree have comparatively high relative dominance levels, dominance was not concentrated toward any single species, but rather was shared by many species in the homestead forests. This helps to enhance species diversity and ecosystem stability.

The ecological importance of a community cannot be visualized by the quantitative value of any of the single stand characteristics determinants like frequency, density, abundance, and dominance. Importance value represents the importance of species holistically more so than any other single stand determinants. The importance values of different species in the study area revealed that mango and jackfruit are the most important fruit species with importance values of 19.6% and 12.3%, respectively. These two trees are followed by the timber-yielding rain tree with an importance value of 9.4%. The total of importance values of the 24 frequently occurring species was 87.8%, while the remaining 29 species had a combined importance value of 12.2%. The total of importance values of all fruit trees was 57.4%, which is moderately higher than that of the timber-yielding species (42.6%). This implies that fruit trees are moderately more important than timber trees with regard to the quantitative stand structure of homestead forests (Table 4).

Management

Table 5 shows the results of the analysis of respondent answers regarding different aspects of the existing management systems of homestead forests based on descriptive statistics. The results indicate that almost all stakeholders carried out soil work and watering, but only around 59% of them used fertilizer or manure. On the other hand, most farmers do not care for using fences, pesticides, and thinning practices. Selection felling and medium and long rotations are existing practices in homestead forest management. The percentage of medium and long rotations indicate that almost all stakeholders practice both rotations, which reveals that growers have different management objectives based on the different species they grow. The analysis of the management information reflects the fact that the farmers manage their forests based on traditional knowledge and they lack scientific information to take management decisions.

Soil expectation value

Table 6 gives the soil expectation values together with results of the optimization model discussed later. It was revealed that the maximum soil expectation value would be derived from jackfruit SEV 1926942.0 taka, followed by mango SEV 982901.1 taka, coconut SEV 599591.1 taka, and litchi (*Litchi chinensis*) SEV 559695.6 taka. Amongst the timber species, mahogany tops the list with SEV 238881.2 taka followed by rain tree SEV 232534.9 taka. Species like lannea (*Lannea coromandelica*), mast tree (*Polyalthia longifolia*), white cedar (*Azadiracta indica*), fishtail palm (*Caryopta rumphiana*), banyan tree (*Ficus benghalensis*) would generate very poor SEV. In general, fruit species tend to generate higher SEV than timber species. The relative percentage of SEV for all fruit species is 74% whereas that of the timber species is 26%. It is noteworthy that species with relatively high soil expectation values were found amongst infrequently occurring species of fruit and timber species (Table 6).

Table 6. Results of soil expectation value (SEV) and optimization model

Species	N_R (*taka)[a]	SEV (taka)	%SEV	Area (m^2)[b]	No. of Trees[c]	ORD%	ERD %
Albizia spp.	176 399.7	184 911.4	1.6	7.2	0.96	6.1	4.6
Artocarpus heterophyllus	1 838 243.1	1 926 942.0	16.3	74.9	0.93	6.0	11.8
Swietenia mahogany	227 885.3	238 881.2	2.0	9.3	0.69	4.4	3.2
Samanea saman	221 831.1	232 534.9	2.0	9.0	0.67	4.3	8.1
Cocos nucifera	571 991.4	599 591.1	5.1	23.3	0.65	4.2	9.2
Gmelina arborea	193 152.2	202 472.2	1.7	7.9	0.59	3.8	1.3
Tectona grandis	186 913.1	195 932.0	1.7	7.6	0.57	3.6	0.5
Michelia champaca	176 570.2	185 090.1	1.6	7.2	0.54	3.4	0.2
Artocarpus chaplasha	176 570.2	185 090.1	1.6	7.2	0.54	3.4	0.7
Mangifera indica	937 657.3	982 901.1	8.3	38.2	0.47	3.0	22.2
Syzygium cumini	402 274.6	421 685.2	3.6	16.4	0.46	2.9	3.3
Psidium guajava	364 844.9	382 449.4	3.2	14.9	0.41	2.6	1.4
Lagerstroemia speciosa	125 893.8	131 968.4	1.1	5.1	0.38	2.5	1.1
Citrus grandis	321 221.1	336 720.6	2.8	13.1	0.36	2.3	0.3
Toona ciliata	113 689.9	119 175.7	1.0	4.6	0.35	2.2	0.7
Quercus spicata	110 716.3	116 058.6	1.0	4.5	0.34	2.2	0.8
Acacia auricoliformis	107 352.5	112 532.5	1.0	4.4	0.33	2.1	0.9
Elaeocarpus robusta	273 851.4	287 065.3	2.4	11.2	0.31	2.0	0.6
Bombax ceiba	100 293.1	105 132.4	0.9	4.1	0.30	2.0	1.8
Anthocephalus chinensis	100 293.1	105 132.4	0.9	4.1	0.30	2.0	2.1
Borassus flabellifer	248 966.0	260 979.1	2.2	10.1	0.28	1.8	1.6
Citrus hystrix	241 601.0	253 258.7	2.1	9.8	0.27	1.8	0.1
Litchi chinensis	533 932.3	559 695.6	4.7	21.8	0.27	1.7	0.1
Falcourtia jangomas	89 282.2	93 590.2	0.8	3.6	0.27	1.7	0.8
Diospyros peregrina	85 487.8	89 612.8	0.8	3.5	0.26	1.7	1.0
Barringtonia acutangulata	85 487.8	89 612.8	0.8	3.5	0.26	1.7	0.6
Terminalia arjuna	84 009.2	88 062.8	0.7	3.4	0.26	1.6	0.6
Phoenix sylvestris	155 890.1	163 412.1	1.4	6.4	0.25	1.6	2.5
Phyllanthus embelica	204 183.9	214 036.1	1.8	8.3	0.23	1.5	0.2
Annona reticulata	210 090.4	220 227.7	1.9	8.6	0.24	1.5	0.2
Mimusops elengi	73 586.0	77 136.7	0.7	3.0	0.22	1.4	0.3
Alstonia scholaris	73 586.0	77 136.7	0.7	3.0	0.22	1.4	1.7
Zizyphus mauritiana	398 780.8	418 022.7	3.5	16.3	0.20	1.3	2.1
Aphanamixis polystachya	66 953.2	70 183.8	0.6	2.7	0.20	1.3	1.6
Delonix regia	67 456.6	70 711.6	0.6	2.7	0.21	1.3	0.9
Caesalpinia pulcherima	67 456.6	70 711.6	0.6	2.7	0.21	1.3	0.7
Bauhinia acuminata	62 575.1	65 594.5	0.6	2.6	0.19	1.2	0.7
Aegle marmelos	325 287.6	340 983.4	2.9	13.3	0.16	1.1	0.3
Erythrina orentalis	53 490.6	56 071.6	0.5	2.2	0.16	1.0	0.2
Streblus asper	53 490.6	56 071.6	0.5	2.2	0.16	1.0	0.5
Tamarindus indica	291 911.3	305 996.6	2.6	11.9	0.15	0.9	1.6
Dillenia indica	269 906.1	282 929.7	2.4	11.0	0.14	0.9	0.1
Averrhoa carambola	119 254.6	125 008.9	1.1	4.9	0.14	0.9	0.5
Manilkara sapota	242 009.3	253 686.7	2.1	9.9	0.12	0.8	0.1
Falcourtia indica	92 826.0	97 305.0	0.8	3.8	0.11	0.7	0.1
Artocarpus lacucha	147 635.7	154 759.4	1.3	6.0	0.07	0.5	0.1
Spondias pinnata	145 408.9	152 425.2	1.3	5.9	0.07	0.5	2.3
Melia azaderach	14 042.5	14 720.0	0.1	0.6	0.04	0.3	0.1
Azadiracta indica	13 776.0	14 440.8	0.1	0.6	0.04	0.3	0.7
Polyalthia longifolia	4 279.4	4 485.9	0.0	0.2	0.01	0.1	0.2
Caryopta rumphiana	18 771.0	19 676.8	0.2	0.8	0.02	0.1	0.7
Lannea coromandelica	2 002.7	2 099.4	0.0	0.1	0.01	0.0	1.8
Ficus benghalensis	20 103.6	21 073.6	0.2	0.8	0.00	0.0	0.3
All Fruit	8 337 767.7	8 740 081.8	73.8	340.0	6.30	40.4	30.7
All Timber	2 953 397.3	3 095 904.7	26.2	120.0	9.30	59.6	69.3
All	11 291 164.9	11 835 986.5	100	460.0	15.60	100	100

Source: field data 2001, Bangladesh Burean of Statistics (2003), Bangladesh Bank (2002)
N_R, Present net value after first rotation; ORD%, optimal relative density; ERD%, existing relative density
[a] 1 US$ = 57.43 taka in 2001–2002
[b] Total area 460 m^2, lower than average land available for homestead forestry in the area as equated from existing homestead structure
[c] Optimal stem number/460 m^2

Discussion

Analysis of the existing quantitative stand structure revealed that homestead forest in the study area has moderately high biodiversity and species richness. Fruit species were moderately dominant, but none showed absolute dominance as reflected by the very low index of dominance (c = 0.1). The moderate domination of fruit species over timber species may be attributed to the growers' general perception that fruit species would bring early return as well

Table 7. Comparison between different indices of existing homestead and optimal structure

Indices	Existing homestead	Optimal homestead[a]	Change
Species richness $d = (S - 1)/\ln N$	7.7	6.9	–0.8
Shannon diversity $H = -\Sigma P_i \ln P_i$	3.1	3.7	0.6
Evenness $e = H/\ln S$	0.8	0.9	0.2
Dominance $c = \Sigma(n_i/N)^2$	0.10	0.03	–0.07

Source: field data 2001
[a] Because optimization would eradicate two species, $S = 51$ was used to calculate indices

as the multipurpose nature of fruit species. Analysis of existing management regime indicates that the growers lack scientific information. However, analysis of existing stand structure does not depict whether the existing quantitative structure would generate the optimal financial benefit. Hence, a soil expectation value analysis was carried out to simulate different scenarios and the SEV was predicted under different hypothetical regimes. Optimization of species percentage was done by allocating proportionate land according to the relative weight of SEV for each species and taking into consideration the standard spacing required for planting of respective species. Each species was considered in a hypothetical model to optimize growers' financial benefit without significantly compromising the existing overall biodiversity of homestead forests. The optimization model suggested that to optimize financial benefit, it is necessary to modify the existing quantitative stand structure of homestead forest by increasing the percentage of more economically valuable, poorly known, rarely occurring species and reducing other thickly grown species in the area. Major increases should take place for species like iron wood (*Michelia champaca*) to 3.4% (1378.3% increase), mahogany to 5.6% (105% increase), teak (*Tectona grandis*) to 3.6% (682% increase), chapalish (*Artocarpus chaplasha*) to 4.2% (890.6% increase), malay beechwood (*Gmelina arborea*) to 3.4% (204% increase), pummelo (*Citrus grandis*) to 2.3% (576.5% increase), litchi to 1.7% (1445.5% increase), amongst others. Major reductions should be done for dominating species such as mango, to 3.0% (86.5% reduction), jackfruit, to 6.0% (49.30% reduction), hog plum (*Spondias pinnata*) to 0.5% (78.1% reduction), date palm (*Phoenix sylvestris*), to 1.6% (36.0% reduction), amongst others. Species like lannea and banyan should be eradicated, as they would generate very poor financial return. From the results, it is evident that the optimal percentage of fruit and timber species that would generate the maximum financial benefit would be 40.4% fruit trees (33.5% reduction) and 59.6% timber-yielding species (51.8% increase) (Table 6). Thus, the findings of this research should help forest managers to make critical decisions regarding which species to plant and how many. These findings might seem to be unusual to some extent in that the treasured fruit species should be reduced by around 33.5% and the timber species should be increased by 51.8% from the existing structure. In fact, this is, firstly, attributed to the fact that fruit species need more growing space to develop a well-grown crown than timber species for bearing desired quantities of quality fruits; secondly, by the fact that even though fruit species in general generate high soil expectation values, the existing percentage of some fruit species is too high. Actually, even in the optimization model, much of the land parcel (74%) would be required to support fruit species. Table 7 compares the various indices between the existing and optimal structures. From the comparison, it is evident that although under optimization model there will be a small loss (0.8) in species richness, nonetheless, there would be a gain (0.6) in biodiversity as the value of the Shannon general diversity index (H) increases to 3.7 from 3.1 and evenness will be further enhanced, while dominance be further distributed amongst the different species of the stand. Such affirmative renovation would happen due to a more balanced distribution of stem numbers amongst different potential species including those that exist rarely amongst the occurring species and due to an increase in the number of tree species per unit land base ensuing from optimal allocation of land according to SEV.

It should be made clear that this optimization model is based on very simple management regime in which homestead forests are managed under a unique long rotation and all the land parcel available for plantation is suitable for each species for their optimal potential growth. In reality, these assumptions might not be true because the homestead landscape of Bangladesh has different inundation levels that might compel forest growers to plant a group of less economic plants to certain percentages. Rotations may also differ based on different management objectives. Another basic assumption was that the interest rate, inflation, and prices of forest produce would be consistent over a long period of time. In reality, these may fluctuate significantly, especially in an unstable economy like that of Bangladesh. Hence, the optimization model proposed in this study may be regarded as a first approximation in manipulating stand structure of homestead forest for optimal financial return and ecological diversity and stability. Further complex optimization model research under different constraints would obviously improve the applicability of such a model.

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