



Impact of Household Interventions on Homestead Biodiversity Management and Household Livelihood Resilience: An Intertemporal Analysis from Bangladesh

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Abstract

Household livelihood preferences are crucial determinants of homestead biodiversity. Therefore, we conducted a temporal analysis (harnessing data from three different time points (i.e., 1994, 2004, and 2014) with ten years of interval starting from 1994) on three Bangladeshi subdistricts to trace the effect of managed interventions on homestead biodiversity. Our findings unravel the transformation of a non-profitable untapped homestead agrobiodiversity from 1994 into an intervened and profitable biodiversity in 2014. The domestication of the introduced species in the homesteads increased the earnings by many folds. The observed stand structure of the introduced tree species was also financially profitable in 2014. We noted that tree diversity, richness, and evenness increased in the study areas while dominance decreased. Animal diversity and evenness decreased; however, richness and dominance increased. Management interventions only occurred when households grasped that homestead biodiversity could significantly supplement their family income. Management interventions occurred in the following ways: willingness to dedicate labor for both males and females increased over time, and willingness to pay labor costs significantly increased (i.e., on average, a male and female member in Haluaghat spent 336 labor hours/year and 288 labor hour/year, which is equivalent to an investment of BDT 23,100 (USD 330) and BDT 12,240 (USD 174.9), respectively in 2014), and average annual investment for agrobiodiversity management almost tripled. As the yearly investment soared, management interventions became better planned. Consequently, earnings from agrobiodiversity increased drastically. In 2014, households in Gouripur, Ishwarganj, and Haluaghat received 43.2, 34.5, and 39.3% of their total income from homestead biodiversity, which generated 157.8, 125.7, and 143.2 person-days employment/household. Thus, planned investment in homestead biodiversity management provides upgraded ecosystem services. Therefore, we claim that intervention is not always wrong, and planned interventions can lead to a progressing symbiotic relationship (a win–win situation) between households and homestead biodiversity.

Extended author information available on the last page of the article

Keywords Homestead agrobiodiversity · Ecosystem services · Managed intervention · Shannon diversity index · Species richness · Species dominance

Introduction

Analysis of species diversity across Bangladesh is still insufficient and requires rigorous evaluation to unravel what is going on within its ecosystem. In a natural environment, the evolutions of forests, animals, or even microorganisms are determined mainly by nature. However, we are observing increasing human intervention in nature (Allan et al. 2017; Gang et al. 2014), which damages the natural habitat and accelerates climate change (Mittal et al. 2016). Homestead biodiversity management is determined by the preferences of the households, where they decide which tree or animal species to adopt or not. Most of the time, the preferences are driven by monetary, dietary, or cultural factors. The few studies in Bangladesh dedicated to homestead agroforestry observed similar outcomes, where they found fruit trees dominated timber production (Alam and Sarker 2011; Roy et al. 2013).

Bangladesh, the world's largest delta, is rich in biodiversity and is known as a top global hot spot for biodiversity (Mukul et al. 2016). As time passes, forests and wetlands, which were untouched by humans in Bangladesh, are now widely facing deforestation and degradation (Kibria and Haroon 2017; Murshed et al. 2020). The impact of this deforestation is so severe that other dependent species (animals, birds) are losing their habitat (Symes et al. 2018). The total forest area is decreasing in Bangladesh, and there is currently < 10% forest area (Hussain 2018), lower than the required level (25%). Moreover, even these limited forest areas are not protected, and illegal harvesting of timber is common. Excessive dependence on forest biomass for livelihoods can be minimized through diversification of livelihood enterprises, which will help to mitigate the risk of poverty and will also help in restoring ecological balance (Hossain et al. 2016). Fuelwood consumption is another crucial reason behind deforestation in Bangladesh (Ullah et al. 2022). Against this background, alternative renewable fuel options such as biogas can be a great benefit to natural forests (Hossain 2020, 2021). Moreover, dependence on sustainable fuel options will help mitigate environmental stress and our ecological footprint (Hossain et al. 2022a, b). Therefore, large-scale homestead tree plantations and conservation of the remaining forest lands are imperative to maintaining the balance of Bangladesh's ecosystem.

Homestead agroforestry is a multi-purpose avenue surrounding a household that supports the co-existence of trees, livestock, crops, and other plants and primarily being managed by family labor (Fernandes and Nair 1986), which is becoming popular in Bangladesh across rural and semi-urban areas. Households with large homestead areas are more motivated by commercial agriculture than households with smaller homestead areas. The aims of homestead agriculture somewhat vary worldwide, as these are conditional and driven by geographic, socio-political, economic, and climatic factors

(Kabir and Webb 2009). An increase of homestead agriculture can positively impact the environment and the dwellers' livelihood (Rahman et al. 2017). In this study, our main aim was to assess the impact of household preferences on homestead biodiversity management in a rural setting in Bangladesh. In doing so, we have considered the homestead trees and other plants, animals, and fish species cultured around the homestead areas of 60 households. We hypothesized that homestead biodiversity management solely depends on the households' preferences and their interventions. In other words, we wanted to scrutinize whether the structural livelihood decisions like what to eat and what to sell were the primary determinants of homestead biodiversity management in the studied areas. In doing so, we have asked four critical questions: (1) How, why, and since when have household preferences changed? (2) How, why, and when did the conventional natural agrobiodiversity change into an intervened and managed biodiversity? (3) Which management interventions were adopted by the households and why were these interventions adopted? (4) What were the implications of these management interventions regarding the households' livelihood?

The findings of our study are novel and robust. We claim the originality and novelty for the following reasons: (1) a few studies have tested the significance of the homestead agrobiodiversity on the household in terms of livelihood resilience (Alam 2012; Miah and Hussain 2010; Rahman et al. 2005); however, most of these studies are old and only focused on a specific point of time. There is no temporal research based on homestead agrobiodiversity's impact on households in Bangladesh. We have incorporated the time effect in our paper to address the research gap. We have demonstrated how the management interventions become meticulous as time passes and compared the intervention scenarios in terms of their returns from different time conditions, which is a unique case and fills an existing research gap. (2) Most of the studies in the homestead agrobiodiversity domain have scrutinized the effect of agrobiodiversity management on the food security and livelihood resilience of the households (Powell et al. 2015; Rosenberg et al. 2018; Singh et al. 2016; Tesfamariam et al. 2018). Contrarily, there is so far no study on the management interventions by the households about how the management interventions evolve and get better planned as the returns from the agrobiodiversity escalate. So, there is a missing link between the household's psychology (i.e., willingness to spend labor hours, willingness to pay for annual labor cost) about when to go for better-planned interventions and the return from the agrobiodiversity services. Through this paper, we have also endeavored to fill this research gap. (3) Thirdly, most of the studies on the homestead agrobiodiversity have only incorporated the tree species diversity, their richness, and dominance and ignored the effects on animal, fish, birds, and non-tree plant species on biodiversity (Alam and Sarker 2011; Alcudia-Aguilar et al. 2018; Mellisse et al. 2018). We have incorporated the diversity from all available components (tree and other plants, animal, fish, poultry, and birds) of the homestead agrobiodiversity, which is another novelty of our study. The findings will hopefully assist in designing new policies focused on the better development of homestead biodiversity in Bangladesh.

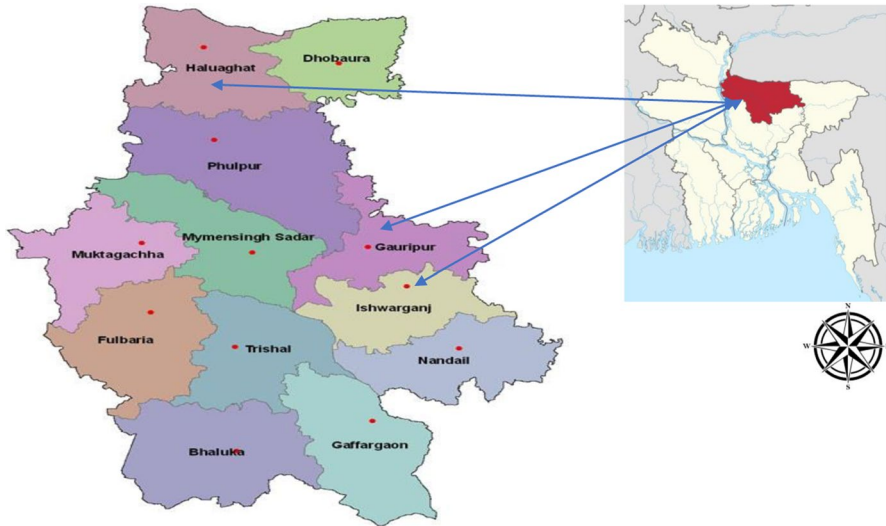


Fig. 1 Location map of the study areas (Source: Rahman et al. 2021)

Methodology

Study Area

To conduct the study, based on our research objectives, we selected three sub-districts (Gouripur, Ishwarganj, and Haluaghat) of the Mymensingh district (Fig. 1) of Bangladesh. Three villages from Gouripur, namely Dapunia, Yousufabad, and Satuti, four villages from Ishwarganj, namely Matikhola, Morichar Char, Charal Bil, and Char Pubail, and three villages from Haluaghat, namely Norail, Sumonia Para, Hadiser Mor were selected. The district has an area of 4394 km², and the geolocation is between 24°02'31" and 25°25'56" N latitudes and between 89°39' and 91°15'35" E longitude. The study areas are under Agro-ecological Zone (AEZ) eight, called Young Brahmaputra and Jamuna Floodplain. The regions have a more relaxed winter and moderate summer than the northern and western zones of the country. The monsoon starts in mid-May and continues until late September. The mean temperatures during the hottest and coolest months are 35.7 °C and 9.4 °C. The mean annual precipitation is 2212 mm (Bangladesh Bureau of Statistics 2013). We chose Mymensingh district for this study for the following reasons: (1) This district is one of the crucial biodiversity hotspots in Bangladesh, rich in terms of both fauna and flora species. Moreover, the study area has a mix of plain lands and the hilly regions, which makes it unique compared to other areas of Bangladesh. (2) Mymensingh district produces the highest amount of rice in Bangladesh (Bangladesh Bureau of Statistics 2019), which means that during peak times of rice

production (Aus, Aman, and Boro),¹ it is challenging to find fallow lands as most of them remain occupied for rice production. Most of the farmers use their homestead areas to complete the post-harvest activities (i.e., rice threshing, drying, cleaning, grading, storing, and weighing), which means households in the study areas have sizeable homestead areas that can be rich in agrobiodiversity (i.e., biodiversity that supports agricultural activities).

Agriculture is the primary profession of the respondents in the study areas, followed by business, shopkeeping, teaching, and other non-farm activities. Rice, wheat, maize, potato, jute, pulses, and seasonal vegetables are the primary agricultural products. The study area is also known for several horticultural, timber, medicinal and aesthetic crops. The average literacy rate was 39.1% (Bangladesh Bureau of Statistics 2013). Regional manufacturing, like sawmilling and pickles processing, is highly dependent on the raw materials produced from the homestead biodiversity in the study areas.

Field Methods and Analysis

For data collection, 60 households were surveyed (20 from each subdistrict). The data were collected through random sampling and focus group discussion (FGD). Data on the tree, domestic animals, fish, and vegetable (summer and winter) species were collected using a pre-tested questionnaire. The data were collected considering three-time phases, spanning from 1994 to 2014. The first phase of data covered the information of the species during 1994 (20 years before the base year of 2014), the second phase data focused on 2004 (10 years before the base year of 2014), and the third phase focused on 2014. The data on the various species were collected according to the abundance of each species for each respondent for each subdistrict for each period. The data collection method was complicated as there was no baseline survey on the exact number of total species. Therefore, we had to use the recall method to collect the number of different species for 1994 and 2004. To increase the reliability of our collected data, we applied the "Aided Recall" method. Under the "Aided Recall" method, the respondents received assistance from their elder family members to determine the number of total species in 1994 and 2004. Although there are downfalls in the recall method, this can still be an option in agricultural data collection (Beegle et al. 2012; Bell et al. 2019). This study has featured the species households commonly produce within their homestead areas. Therefore, the respondents had good information about what their families had.

Regarding the land area, we only used the homestead areas of the respondents. We deducted the areas that comprised the respondents' living spaces (house, bathroom, and kitchen) from the total homestead areas. We included the areas of cattle sheds and ponds. We did not include any land area beyond the homestead areas so that we do not face any issues related to the change in land areas between the study

¹ Bangladesh has three rice cultivation seasons: Aus, Aman, and Boro. These varieties are cultivated and harvested as follows: Aus (July–August), broadcast Aman (November–December), transplanted Aman (November–January), local boro (April–May), and high-yielding boro (May–June).

periods. Regarding the quantity change in the homestead land areas, we observed no change in the total quantity of land areas as there was no river erosion or land fragmentation among the selected respondents. It is worth mentioning that we found a few families that experienced homestead land distribution among their offspring; however, as the father remained the primary decision-maker, we did not consider these changes.

The selection of the species of trees, vegetables, livestock, and fish was not a randomized process. We did some prior research to determine the most practiced species in the mentioned categories in the study areas. Regarding the number of the surveyed species (25 tree species, 7 animal species, 22 endemic and introduced fish species, and 11 and 14 winter and summer vegetable species, respectively), we focused on the most common species that had a connection with the lifestyle of the respondents and geophysical attributes of the study areas. The methods that were used to calculate species indices are presented in Table 1.

Results and Discussion

Social Status Determinants of the Respondents

The outcomes of the determinants of social status are listed in Table 2. The mean schooling of the respondents was 10.5 years and the mean family size was 4.9. On average, in terms of landholdings, the respondents had 21 decimals homestead land (roughly 0.08 ha) in their possession, of which most was dedicated to agroforestry, a mean of 12.1 decimal. In contrast, the least amount (1.6 decimals) was allocated for fish and vegetable cultivation. It is notable that regardless of the amount of total homestead area, all of the respondents tended to utilize the space for small-scale agroforestry to supplement family requirements. In the study areas, 66.6% of respondents were engaged with farming, whereas 16.6, 8.4, 5, and 3.3% were involved with the business, shopkeeping, teaching, and non-farm activities, respectively.

Tree Species Diversity, Richness, Evenness and Dominance

We surveyed 25 homestead tree species. Of these species, 12 are fruit species, 4 are timber species, and 9 are fuelwood, medicinal or bamboo species. The numbers and percentages of the tree species of the study areas based on categories are presented in Table 3, and the averages are shown in Table 4. It is evident that the total number of fruit trees declined in the study areas over time (i.e., respondents in Gouripur had a total of 535 fruit trees in 1994; however, the number dropped to 481 in 2004 and to 475 in 2014) and the same goes for fuelwoods, medicinal trees and bamboos. However, the total number of timber trees increased across the study area over time. It is also notable that mango (*Mangifera indica*) is the most abundant and dominant tree species in the region (i.e., in 2014, 38.1, 48, and 48.7% of the total fruit trees in Gouripur, Ishwarganj and Haluaghat, respectively were mango

Table 1 Specification and indication of biodiversity indices for different species in Mymensingh, Bangladesh

Biodiversity attributes	Equation	References
Shannon diversity index (H')	$H' = -\sum p \ln p$ <p>where H' is the Shannon diversity index, p is the importance probability calculated as $\frac{n}{N}$. Here n stands for number of individuals within each species and N stands for total number of individuals</p>	Shannon and Weaver (1949)
Margalef's richness index (D)	$D = \frac{S-1}{\ln S}$ <p>where D is the species richness index, S is the number of species and N is the total number of individuals</p>	Margalef (1958)
Evenness index (E)	$E = \frac{H'}{\ln S}$ <p>where H' is the Shannon diversity index, S is the number of species and E is the evenness index</p>	Pielou (1966)
Dominance index (C)	$C = \sum \left(\frac{n_i}{N} \right)^2$ <p>where C is the species dominance index, n_i is the number of each species and N is the total number of individuals within each species</p>	Magurran (1988)

Table 2 Social status characteristics of the households. *Source* Field survey

Categories	Unit (decimal)	Subdistricts					
		Gouripur		Ishwanganj		Haluaghat	
		In 2014	In 2014	In 2014	In 2014	In 2014	In 2014
Average land holdings		21.1 (100)	20.1 (100)	21.8 (100)	21 (100)	21 (100)	21 (100)
Total Homestead Land (THL)		12.3 (58.3)	11.3 (56.2)	12.8 (58.5)	12.1 (57.6)	12.1 (57.6)	12.1 (57.6)
Total Agroforestry Land (TAL)		2.4 (11.1)	2.7 (13.2)	2.1 (9.6)	2.4 (11.37)	2.4 (11.37)	2.4 (11.37)
Land for Livestock Sheds (LLS)		1.7 (7.8)	1.3 (6.2)	1.7 (7.6)	1.6 (7.2)	1.6 (7.2)	1.6 (7.2)
Land for Pond and/or Vegetables (LPV)		4.8 (22.7)	4.9 (24.4)	5.3 (24.3)	5 (23.8)	5 (23.8)	5 (23.8)
Land Dedicated for Living Spaces (LDLS)		11.7	10.2	9.6	10.5	10.5	10.5
Average schooling years		5.3	4.8	4.7	4.9	4.9	4.9
Average family size		98,567.8	108,567.6	102,344.8	103,106	103,106	103,106
Average annual income (in BDT)							

Values within parentheses ‘()’ are the percentages

Table 3 Numbers and percentages of tree species based on categories. *Source* Field survey

Categories	Tree species	Subdistricts								
		Gouripur			Ishwarganj			Haluaghat		
		1994	2004	2014	1994	2004	2014	1994	2004	2014
Fruits	Mango	123 (23)	123 (25.5)	181 (38.1)	181 (33.1)	213 (42.4)	242 (48)	114 (27)	142 (34.5)	205 (48.7)
	Wood apple	18 (3.3)	20 (4.1)	16 (3.3)	22 (4)	11 (2.2)	13 (2.6)	34 (8)	16 (3.9)	13 (3.1)
	Pomegranate	9 (1.6)	6 (1.2)	3 (0.6)	9 (1.6)	3 (0.6)	4 (0.8)	13 (3)	14 (3.4)	4 (0.9)
	Banana	157 (29.3)	173 (36)	112 (23.5)	32 (5.8)	64 (12.7)	43 (8.5)	50 (11.8)	66 (16)	54 (12.8)
	Lime	41 (7.6)	32 (6.6)	31 (6.5)	66 (12)	46 (9.2)	36 (7.1)	37 (8.8)	34 (8.3)	20 (4.8)
	Jackfruit	50 (9.3)	34 (7)	33 (6.9)	57 (10.4)	41 (8.2)	35 (7)	46 (11)	42 (10.2)	28 (6.7)
	Coconut	30 (5.6)	16 (3.3)	19 (4)	36 (6.6)	12 (2.2)	16 (3.2)	24 (5.7)	8 (2)	15 (3.6)
	Papaya	4 (0.7)	6 (1.2)	9 (1.8)	6 (1.1)	17 (3.4)	19 (3.8)	1 (0.2)	6 (1.5)	16 (3.8)
	Guava	43 (8)	32 (6.6)	31 (6.5)	45 (8.2)	37 (7.4)	45 (9)	44 (10.5)	34 (8.3)	27 (6.4)
	Betel nut	29 (5.4)	21 (4.3)	25 (5.2)	49 (9)	35 (7)	38 (7.5)	10 (2.4)	18 (4.4)	20 (4.8)
Timber	Tamarind	22 (4.1)	10 (2)	10 (2.1)	29 (5.3)	9 (1.8)	8 (1.6)	26 (6.2)	15 (3.7)	15 (3.6)
	Date palm	9 (1.6)	8 (1.66)	5 (1)	14 (2.5)	15 (3)	5 (0.9)	22 (5.2)	16 (3.9)	4 (0.9)
	Total	535 (100)	481 (100)	475 (100)	546 (100)	503 (100)	504 (100)	421 (100)	411 (100)	421 (100)
	Earleaf acacia	33 (32.3)	47 (29)	77 (28.8)	16 (19.7)	92 (47.7)	70 (28.2)	35 (36.1)	35 (23)	67 (23.6)
	Mahogany	36 (35.2)	69 (42.5)	113 (42.3)	41 (50.6)	62 (32.1)	109 (44)	28 (28.9)	63 (41.5)	137 (48.2)
	Rain tree	32 (31.3)	42 (25.9)	75 (28)	20 (24.7)	33 (17.1)	67 (27)	26 (26.8)	49 (32.2)	76 (26.8)
	Siris tree	1 (0.9)	4 (2.4)	2 (0.7)	4 (5)	6 (3.1)	2 (0.8)	8 (8.3)	5 (3.3)	4 (1.4)
	Total	102 (100)	162 (100)	267 (100)	81 (100)	193 (100)	248 (100)	97 (100)	152 (100)	284 (100)

Table 3 (continued)

Categories	Tree species	Subdistricts								
		Gouripur			Ishwarganj			Haluaghat		
		1994	2004	2014	1994	2004	2014	1994	2004	2014
Fuelwoods	Cluster fig	3 (0.04)	2 (0.03)	2 (0.05)	3 (0.1)	2 (0.1)	7 (0.6)	9 (0.2)	4 (0.1)	4 (0.2)
	River ebony	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	4 (0.4)	0 (0)	0 (0)	0 (0)
	Throny acacia	0 (0)	8 (0.1)	8 (0.2)	36 (1.7)	7 (0.4)	7 (0.6)	47 (0.8)	12 (0.4)	9 (0.4)
	Ajrun	5 (0.06)	17 (0.2)	17 (0.4)	29 (1.4)	22 (1.2)	20 (1.7)	40 (0.7)	27 (0.9)	27 (1.3)
	Indian lilac	11 (0.1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.03)	0 (0)
	Bahera	23 (0.2)	3 (0.05)	3 (0.07)	8 (0.4)	13 (0.7)	2 (0.2)	4 (0.1)	4 (0.1)	2 (0.1)
	Sal	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	4 (0.4)	0 (0)	0 (0)	13 (0.6)
	Burflower tree	5 (0.06)	6 (0.1)	6 (0.1)	9 (0.4)	13 (0.7)	11 (1)	3 (0.1)	3 (0.1)	6 (0.3)
	Bamboo	8300 (99.4)	5800 (99.3)	4300 (99)	2000 (96)	1700 (96.8)	1100 (95.2)	6000 (98.3)	3000 (98.3)	2000 (97)
	Total	8347 (100)	5836 (100)	4336 (100)	2085 (100)	1757 (100)	1155 (100)	6103 (100)	3051 (100)	2061 (100)

Values within the parentheses ‘()’ are the percentages. The scientific names of all the species listed in this manuscript are attached in the supplemental file

Table 4 Analysis of most dominant tree species

Tree names	Average number of trees per households											
	Gouripur			Ishwarganj			Haluaaghat					
	1994	2004	2014	Trend	1994	2004	2014	Trend	1994	2004	2014	Trend
Mango	6.2	6.2**	9.1*	↑	9.1	10.7**	12.1*	↑	5.7	7.1**	10.3*	↑
Wood Apple	0.9	1.0	0.8	↓	1.1	0.6	0.7	↓	1.7	0.8	0.7	↓
Pomegranate	0.5	0.3	0.2	↓	0.5	0.2	0.2	↓	0.7	0.7	0.2	↓
Cluster Fig	0.2	0.1	0.1	↓	0.2	0.1	0.4	↑	0.5	0.2	0.2	↓
River ebony	0.0	0.0	0.0	-	0.0	0.0	0.2	↑	0.0	0.0	0.0	-
Indian Lilac	0.6	0.4	0.4	↓	1.8	0.4	0.4	↓	2.4	0.6	0.5	↓
Banana	8.3	8.7**	5.6	↓	1.8	3.2**	2.2	↓	2.6	3.3**	2.7	↑
Lime	2.1	1.6	1.6	↓	3.3	2.3	1.8	↓	1.9	1.7	1.0	↓
Jackfruit	2.5	1.7	1.7	↓	2.9	2.1	1.8	↓	2.3	2.1	1.4	↓
Bahera	1.2	0.9	0.9	↓	1.5	1.1	1.0	↓	2.0	1.4	1.4	↓
Coconut	1.5	0.8	1.0	↓	1.8	0.6	0.8	↓	1.2	0.4	0.8	↓
Papaya	0.2	0.3	0.5*	↑	0.3	0.9	1.0*	↑	0.1	0.3	0.8*	↑
Guava	2.2	1.6	1.6	↓	2.3	1.9	2.3	↑	2.2	1.7	1.4	↓
Betel Nut	1.5	1.1	1.3	↓	2.6	1.8	1.9	↓	0.5	0.9	1.0	↑
Tamarind	1.1	0.5	0.5	-	1.5	0.5	0.4	↓	1.3	0.8	0.8	↓
Sal	0.0	0.0	0.0	-	0.0	0.0	0.0	-	0.0	0.1	0.0	↓
Arjun	0.2	0.2	0.2	-	0.4	0.7	0.1	↓	0.2	0.2	0.1	↓
Thorny Acacia	0.0	0.0	0.0	-	0.0	0.0	0.2	↑	0.0	0.0	0.7	↑
Burflower tree	0.3	0.3	0.3	-	0.5	0.7	0.6	↑	0.2	0.2	0.3	↑
Bamboo	415.0	290**	215*	↓	100	85**	55*	↓	300	150**	100*	↓
Date palm	0.5	0.4	0.3	↓	0.7	0.8	0.3	↓	1.1	0.8	0.2	↓
Earleaf Acacia	1.7	2.4**	3.9*	↑	0.8	4.6**	3.5	↑	1.8	1.8	3.4*	↑

Table 4 (continued)

Tree names	Average number of trees per households											
	Subdistricts											
	Gouripur			Ishwarganj			Haluaghat					
	1994	2004	2014	Trend	1994	2004	2014	Trend	1994	2004	2014	Trend
Mahogani	1.8	3.5**	5.7*	↑	2.1	3.1**	5.5*	↑	1.4	3.2**	6.9*	↑
Rain Tree	1.6	2.1**	3.8*	↑	1.0	1.7	3.4*	↑	1.3	2.5**	3.8*	↑
Siris Tree	0.1	0.2	0.1	↓	0.2	0.3	0.1	↓	0.4	0.3	0.2	↓

Values with ** and * represent the most preferred (dominant) tree species reported by the respondents in 2004 and 2014, respectively. ↑ refers increasing trend, ↓ refers decreasing trend and – refers no change

trees) (also see Table 4 for detailed trend analysis of the tree species). Our findings are in line with that of Alam and Sarker (2011); Baul et al. (2021a), Hanif et al. (2018), Muhammed et al. (2011), and Rahman et al. (2017), who noted similar patterns across other study areas of Bangladesh. Results also show that papaya (*Carica papaya*) is another dominant fruit species in the region. Some other fruit tree species like banana (*Musa acuminata*), lime (*Citrus aurantiifolia*), jackfruit (*Artocarpus heterophyllus*), guava (*Psidium guajava*), and betel nut (*Areca catechu*) were also abundant in the region.

It was also noted that households with larger agroforestry areas are highly motivated to plant timber species as these species require a large canopy area (we claim this based on the number of total timber trees in 2014 (Table 3) and comparing this number with the total agroforestry land in the study areas. In Ishwarganj, respondents have the lowest total average agroforestry land in 2014 (Table 2) compared to the other two regions. The number of total timber trees in the case of Ishwarganj is also the lowest in 2014). We also observed that large fruit trees (mostly available in 1994) that spread too much and have bulky trunks but produce fewer fruit values (i.e., local mango trees) are more like to be cut, in order to create space for more high-yielding varieties of fruit trees. These hybrid mango trees require less canopy area, do not have bulky trunks, and produce high fruit values. Because of these changes, we discovered a new stand structure of tree species over time, completely different from the natural stand structure in the study area. This process required proper domestication of the introduced species. Tamang et al. (2019) reported a parallel outcome in West Bengal, India.

The number of timber species in the study area is limited ($n=4$). We noticed that all three species are found abundant except for the siris tree (*Albizia lebbek*) (in which case the timber is generally of poor quality). Mahogany (*Swietenia macrophylla*) is the most dominant among the four species (i.e., in Haluaghat in 2014, almost 50% of all timber trees are mahogany) (see the trend analysis in Table 4), and it produces the highest quality timber and requires less canopy area compared to the other timber species. Similar outcomes are reported by Ahammad et al. (2021) in the Chittagong Hill Tracts region of Bangladesh and by Alam and Sarker (2011) in the northwestern region of Bangladesh. Under the fuelwood category, the stand structure of the trees is perfectly natural, and bamboo (*Bambusa vulgaris*) is the most dominant species there. We included medicinal tree species like arjun (*Terminalia arjuna*), Indian lilac (*Azadirachta indica*), and bahera (*Terminalia bellirica*) in the fuelwood category as these species are mainly used for fuelwood purposes. We recorded more than 40 uses of bamboo from the study areas apart from its usage as fuelwood, which is compatible with earlier research conducted in Bangladesh (see Ahammad et al. 2019; Mukul and Rana 2013; Rudra et al. 2021). Results show that bamboo declined rapidly in the study area (Tables 3 and 4). We found that in most cases, the owners cut down bamboo to avoid a clash with their neighbors as bamboo creates shade problems; dry leaves from bamboo can cover the yards of the neighboring houses and dampens the adjacent yards after rainfall.

The diversity indices are presented in Table 5. The tree species diversity, richness, and evenness in the study area increased over time. The diversity index was higher in Ishwarganj in 2014 (1.62) than in other areas (i.e., for 2014,

Table 5 Tree species diversity indices in the study areas. *Source:* Author’s calculation

Tree species diversity	Subdistricts								
	Gouripur			Ishwarganj			Haluaghat		
	1994	2004	2014	1994	2004	2014	1994	2004	2014
Shannon diversity index	0.46	0.59	0.74	1.30	1.35	1.62	0.57	0.87	1.15
Margalef’s richness index	2.31	2.39	2.47	2.53	2.57	2.68	2.39	2.69	2.67
Evenness index	0.15	0.19	0.24	0.41	0.44	0.53	0.18	0.28	0.37
Dominance index	0.85	0.80	0.75	0.55	0.51	0.40	0.82	0.71	0.60

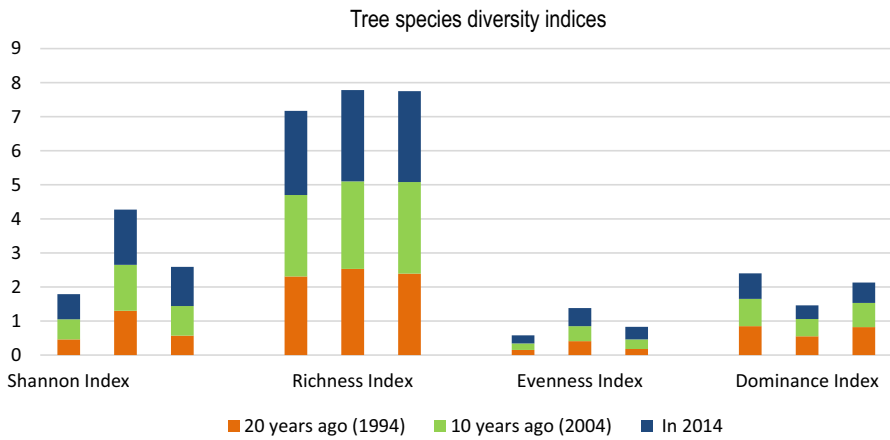


Fig. 2 Graphical representation of tree diversity in the study areas

1.62 > 1.15 > 0.74) as we observed 24 out of 25 tree species there. In contrast, we found 23 and 22 species in Haluaghat and Gouripur, respectively. The increasing richness indices in the study areas reveal that the total number of trees within some species is growing. We observed this behavior in mango, papaya, ear leaf acacia, rain tree, and mahogany, which increased the richness index. The evenness shows even distribution between two or more species. Although the values of the evenness indices (Table 5) are poor, they are increasing, meaning that the gap between the total number of trees between two or more species is not vast (i.e., we observed 31 lime and guava, 33 jackfruit, 25 betel nut, and 16 wood apple trees in Gouripur in 2014). We also noted an inverse relationship between evenness and dominance as dominance declined. The declining dominance also means high diversity and high competition between tree species, required for a balanced ecosystem. Subdistrict Ishwarganj holds the highest evenness, the lowest dominance, and the highest diversity among the study areas. The tree species indices are depicted in Fig. 2.

Table 6 Numbers and percentages of animal species based on categories

Categories	Animal species	Subdistricts								
		Gouripur		Ishwarganj		Haltughat				
		1994	2004	2014	1994	2004	2014	1994	2004	2014
Livestock	Cattle	58 (38.2)	71 (49.3)	99 (77.3)	73 (43.2)	131 (74.4)	136 (75.1)	68 (34)	107 (54.6)	129 (71.3)
	Goat	46 (30.3)	44 (30.6)	29 (22.7)	43 (25.4)	43 (24.4)	45 (24.9)	33 (16.5)	30 (15.3)	35 (19.3)
	Sheep	17 (11.2)	7 (4.9)	0 (0)	22 (13)	0 (0)	0 (0)	58 (29)	37 (18.9)	6 (3.3)
	Horse	0 (0)	0 (0)	0 (0)	5 (3)	0 (0)	0 (0)	8 (4)	4 (2)	2 (1.1)
	Buffalo	31 (20.2)	22 (15.3)	0 (0)	26 (15.4)	2 (1.1)	0 (0)	33 (16.5)	18 (9.2)	9 (4.9)
	Total	152 (100)	143 (100)	128 (100)	169 (100)	176 (100)	181 (100)	200 (100)	196 (100)	181 (100)
Poultry	Hen	175 (60.6)	184 (66.7)	194 (83.9)	152 (50.5)	153 (58.6)	157 (58.6)	214 (53.9)	232 (60.4)	236 (60)
	Duck	114 (39.4)	92 (33.3)	37 (16.1)	149 (49.5)	108 (41.4)	111 (41.4)	183 (46.1)	152 (39.6)	157 (40)
	Total	289 (100)	276 (100)	231 (100)	301 (100)	261 (100)	268 (100)	397 (100)	384 (100)	393 (100)

Values within the parentheses ‘()’ are the percentages

Table 7 Analysis of the most dominant animal species

Animals	Average number of animals per household											
	Subdistricts											
	Gouripur				Ishwarganj				Haluaghat			
	1994	2004	2014	Trend	1994	2004	2014	Trend	1994	2004	2014	Trend
Cattle	2.9	3.6**	5.0*	↑	3.7	6.6**	6.8*	↑	3.4	5.4**	6.5*	↑
Goat	2.3	2.2	1.5	↓	2.2	2.2	2.3*	↑	1.7	1.5	1.8*	↑
Sheep	0.9	0.4	0.0	↓	1.1	0.0	0.0	↓	2.9	1.9	0.3	↓
Horse	0.0	0.0	0.0	–	0.3	0.0	0.0	↓	0.4	0.2	0.1	↓
Hen	8.8	9.2**	9.7*	↑	7.6	7.7**	7.9*	↑	10.7	11.6**	11.8*	↑
Duck	5.7	4.6	1.9	↓	7.5	5.4	5.6	↓	9.2	7.6	7.9	↓
Buffalo	1.6	1.1	0.0	↓	1.3	0.1	0.0	↓	1.7	0.9	0.5	↓

Values with ** and * represent the most practiced (dominant) animal species in the study areas in 2004 and 2014 respectively. ↑ refers increasing trend, ↓ refers decreasing trend and – refers no change

Animal Species Diversity, Richness, Evenness and Dominance

We surveyed 7 domestic animal species. Of them, 5 are domestic livestock species and two are poultry species. The numbers and percentages of the animal species are summarized in Table 6 and the averages are in Table 7. It is conspicuous from the results that the total number of livestock is declining over time in the study areas (except for Ishwarganj), and so does the population of poultry birds. Notably, cattle (*Bos taurus*) and goats (*Capra hircus*) are the most dominant livestock species in the study area (i.e., out of all the livestock species that we observed in 2014, we found 77.3, 75.1, and 71.3% of all of those species are cattle in Gouripur, Ishwarganj and Haluaghat, respectively) (see Table 6). Moreover, Rosin et al. (2016) and Šálek et al. (2018) found comparable observations in Poland and Czech Republic, respectively.

Although we found a few sheep (*Ovis aries*), horses (*Equus caballus*), and water buffalos (*Bubalus bubalis*) in the study area, their numbers are trivial. Due to rapid mechanization in agriculture, farmers do not use the indigenous plough (i.e., an animal drawn plough). Therefore, the use of buffalos to plough the land has declined, and so has their population. The scarcity of small-scale water bodies in rural areas is also responsible for reducing the number of water buffalos. Regarding the poultry species, the local hen (*Gallus gallus domesticus*) is found to be the most dominant species and the population of local ducks (*Anas platyrhynchos*) declined. The local hen population is increasing as they can graze around the respondents' homestead areas and do not require intensive care (i.e., they can feed on the leftover food of the households), and they are less susceptible to diseases than other poultry birds.

Regarding the animal species diversity, richness, evenness, and dominance (results shown in Table 8), it is noteworthy that the animal diversity is decreasing over time. We found only two livestock species (cattle and goats) in Gouripur and Ishwarganj in 2014 (Table 6). Conversely, we found all animal species in Haluaghat, which helped keep the diversity index constant between 2004 and 2014, where the

Table 8 Animal, fish and vegetable species diversity in the study areas

Categories	Indices	Subdistricts						
		Gouripur		Ishwarganj		Haluaghat		
		1994	2004	1994	2004	1994	2004	
Animal species diversity	Shannon diversity index	1.37	1.28	1.24	1.36	1.37	1.30	1.17
	Margalef's richness index	0.56	0.55	0.58	0.57	0.56	0.56	0.62
	Evenness index	0.99	0.92	0.89	0.98	0.99	0.94	0.84
	Dominance index	0.26	0.31	0.30	0.26	0.26	0.29	0.36
Fish species diversity	Richness index	1.94	1.29	2.59	0.65	0.97	1.62	1.62
	Richness index (WV*)	3.75	3.75	4.17	3.34	4.17	4.17	4.17
Vegetable species diversity	Richness index (SV**)	3.79	4.55	3.79	3.21	3.03	3.79	4.55
	Richness index (SV**)	3.79	4.55	3.79	3.21	3.03	3.79	4.55

*:** indicates winter vegetables; **:* indicates summer vegetables

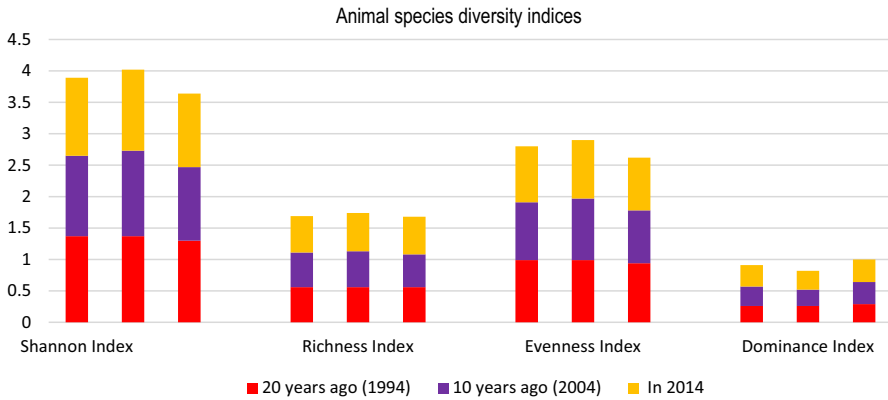


Fig. 3 Graphical representation of animal diversity indices in the study areas

index value is 1.17. The richness increased slightly every ten years as we observed that the number of cattle and hen population is growing, although the total livestock or poultry population is decreasing. A handful of studies has also highlighted the contrast among the indices (see Tews et al. 2004; Yashmita-Ulman et al. 2021).

The evenness index is also decreasing across the region as we noticed an appreciable gap between two species (i.e., we found 136 cattle in Ishwarganj in 2014, but no horses or no buffalos, and we found 194 hens and 37 ducks in 2014 in Gouripur (see Table 6)). Furthermore, as evenness and dominance indices are inversely related, the dominance index increased as evenness declined. We observed that household's food habit is an important determinant of which animal to keep or not. The dominant animal species are directly related to the respondents' food supplements (eggs, milk, and meat). Similar studies support this evidence (e.g., Ferdous et al. 2016; Herrero et al. 2013; Tesfamariam et al. 2018). Animal diversity indices are depicted in Fig. 3.

Fish and Vegetable Species Richness Analysis

The richness indices of the fish and vegetable (summer and winter) species are listed in Table 8. We surveyed 22 fish species (local and introduced), 11 winter vegetables, and 14 summer vegetable species. Results show that the richness of fish species increased in 1994 and 2014; however, a shock in the growth rate is visible in 2004 when the richness across the region declined. The most crucial reason for this sudden fall is that the local water bodies are out of indigenous fish species as the households moved towards introduced fish species. However, the culture system of the introduced fishes like bighead carp (*Hypophthalmichthys nobilis*), grass carp (*Ctenopharyngodon idella*), common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*), and Nile tilapia (*Oreochromis niloticus*) was not properly known. Consequently, competition for food in the ponds between several exotic species reduced the overall production. However, gradually indigenous fish species like rohu (*Labeo rohita*), catla (*Catla catla*), gozar (*Channa marulius*), bhetki (*Lates*

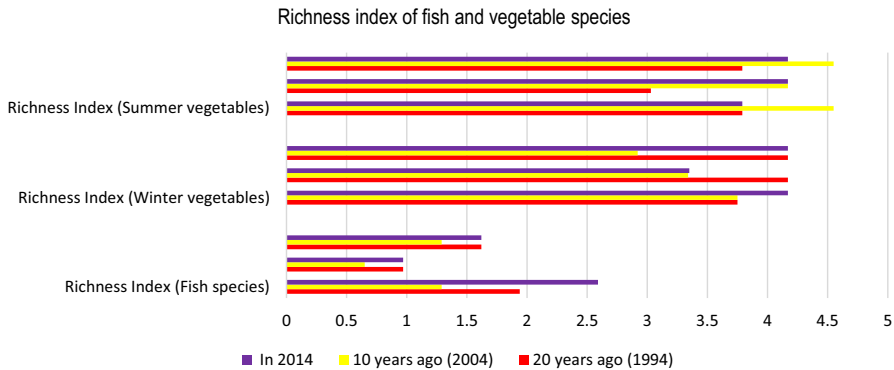


Fig. 4 Graphical view of fish and vegetable species richness

calcarifer) came back, and the respondents learned the culture of introduced fish species which increased the richness in 2014. However, we noted that several native fish species like Indian river shad (*Gudusia chapra*), Indian flying barb (*Esomus danrica*), silver needlefish (*Xenentodon cancila*), and longfin snake-eel (*Pisodonophis cancrivorus*) were scarce in the study areas. The following studies have also noted the reduction in numbers of native fish species in Bangladesh (Alam et al. 2017; Aziz et al. 2021; Mukul et al. 2018).

Results on the richness of both summer and winter vegetable species debunk that the region enjoyed an abundance of vegetables as the richness indices are very high (see Table 8). We observed a few fluctuations in the indices due to weather issues. During the winter season, the fog hampers successful pollination of species like cabbage (*Brassica oleracea*), cauliflower (*Brassica oleracea*), and cucumber (*Cucumis sativus*), which forces the households to omit these species in some years. In addition, during the summer, excessive drought hampers the production of common bean (*Phaseolus vulgaris*), pumpkin (*Cucurbita moschata*), and some other squash vegetables that often get omitted from the cultivation lists. Recent development in the literature has also unveiled the climate change-induced negative externalities on agricultural productivity and livelihood resilience in Bangladesh (see Hossain et al. 2019; Khan et al. 2022). Overall, we found brinjal (*Solanum melongena*), bitter melon (*Momordica charantia*), snake gourd (*Trichosanthes cucumerina*), radish (*Raphanus sativus*), bottle gourd (*Lagenaria siceraria*), tomato (*Solanum lycopersicum*), common bean (*Phaseolus vulgaris*), and taro (*Colocasia esculenta*) abundantly in the study area. The graphical view of the richness indices of fish and vegetable species is portrayed in Fig. 4.

Analysis of the Adopted Management Interventions

The above discussion has revealed that the respondents preferred some species over others. However, to introduce the preferred species in the homestead areas, the respondents had to adopt some management interventions which changed the natural agrobiodiversity of 1994 into a managed agrobiodiversity in 2014. However,

this process did not take place overnight. Initially (in 1994), the respondents were satisfied with what an untapped natural agrobiodiversity offered. However, the tension of feeding more family members and the search for alternative and supplementary income sources using their homestead land motivated them to introduce a few preferred species (at this stage, households cut down trees with large canopy areas and bulky trunks and replaced them with hybrid tree varieties that required smaller canopy areas). Later, as the outcome became more reliable and profitable, households started to invest more time, money, labor and effort, and gradually a managed intervention took place. In ecosystem-based research, several studies highlighted that compensation and provision of ecosystem services can produce more incredible long-term monetary and ecological benefits (see Johns et al. 2013; Krishna et al. 2013; Villamor et al. 2014). The components of the controlled interventions that took place in the study area are shown in Table 9. We considered the following components: willingness to spend labor hours to help with the homestead agroforestry and agrobiodiversity (calculated as average men and women labor hours/week), willingness to pay for annual labor cost (no hired labor was considered, and we converted the labor work provided by the male and female members into monetary units as if they are selling their labor), average annual investment for biodiversity management (the cost for purchasing inputs, cost of raw materials, cost of livestock purchase, cost of hired labor and others).

It is evident from the results (Table 9) that the willingness to spend labor hours for both men and women members in the study area increased over time. It is also notable that male participation in labor hours increased more than their female counterparts (i.e., the male labor hours/week almost tripled in the region in 2014). Therefore, it can be commented that as homestead biodiversity management became a more profitable enterprise, family members (especially men) devoted more time to fine-tuning their homestead biodiversity. This involved planting more high-yielding fruit trees and getting rid of less productive local varieties, applying pesticides during flowering times, collecting grass and other solid foods for livestock, visiting the nearest veterinary surgeon if needed, watering and fertilizing the vegetables and other plants, collecting vegetables, eggs, and milk, pruning the side branches of timber trees, collecting fuelwoods for cooking, building fences around the vegetable gardens and visiting markets for purchasing/selling the homegrown outputs. It is also apparent that the willingness to pay for male and female labor increased over time, indicating a high level of management intervention in homestead biodiversity. For instance, on an average a male and female member in Haluaghat spent 336 labor hours/year and 288 labor hours/year which are equal to an investment of BDT 23,100 (USD 330)² and BDT 12,240 (USD 174.9), respectively, in 2014. These are undoubtedly significant investments for these rural farmers, although they did not directly invest money. Similar outcomes have been found by Das and Mahanta (2013) in the north-eastern region of India and by Cheng et al. (2022) in the Beibu Gulf of China.

² 1 United States Dollar (USD)=BDT 70 (2014 measurement).

Table 9 Components of management interventions in the study areas. *Source:* Field survey and calculation by authors

Categories	Items	Subdistricts											
		Gouripur			Ishwarganj			Haluaghat					
		1994	2004	2014	1994	2004	2014	1994	2004	2014			
Willingness to spend labor hour	Average men (hours/week)	1.5	3	5	2	3	6	3	4	7			
	Average women (hours/week)	3	5	6.5	4	4.5	5	3	3.5	6			
Willingness to pay for annual labor cost	Male (8 h/day basis)	1800	7200	15,000	2640	7740	18,720	4500	9600	23,100			
	Female (8 h/day basis)	3240	9000	14,820	4320	8640	11,400	2880	6090	12,240			
Annual average investment	Cost for seed/fertilizer/insecticide/ nursery plant	1860	4321	8213	2223	5380	7123	2310	4300	8543			
	Cost for fingerlings/calf/poultry bird purchase	5342	7986	14,352	6754	9765	15,900	5480	11,650	16,981			
	Miscellaneous (hired labor or other expenses)	250	320	370	160	210	300	190	220	270			

All cost amounts here are mentioned in Bangladeshi Taka (BDT) (1 USD = BDT 70, 2014 rate). The male and female labor costs in Gouripur have been calculated based on 200, 400, and 500 BDT/8 h/day and 180, 300, and 380 BDT/8 h/day respectively in 1994, 2004, and 2014. The male and female labor costs in Ishwarganj were 220, 430, and 520 BDT/8 h/day and 180, 320, and 380 BDT/8 h/day respectively in 1994, 2004, and 2014. The male and female labor costs in Haluaghat were 250, 400, and 550 BDT/8 h/day and 160, 290 and 340 BDT/8 h/day respectively in 1994, 2004, and 2014

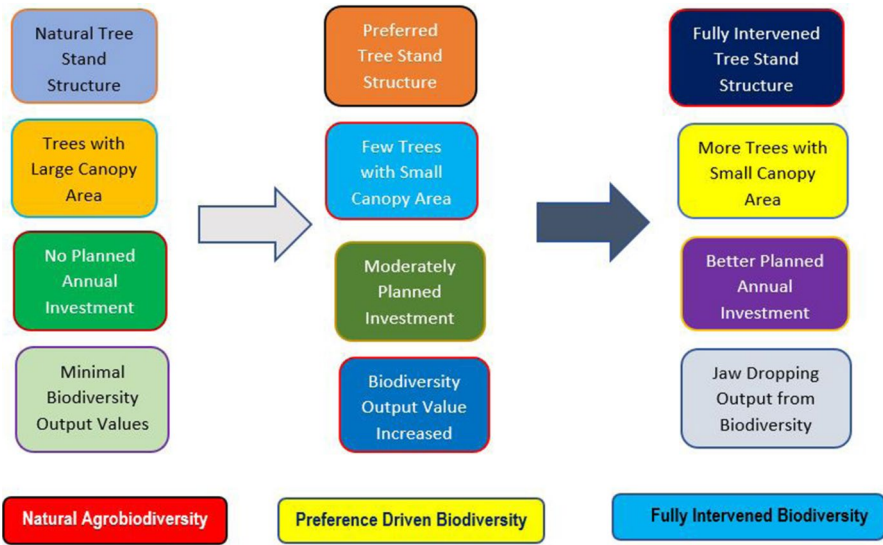


Fig. 5 Flowchart of the intervened homestead biodiversity

Furthermore, the last management intervention we came across is the average annual investment in real BDT. Results (Table 9) confirm that the average yearly investment increased over time, and respondents in Haluaghat invested the highest amount in 2014, BDT 25,794 (USD 368.4). In contrast, respondents in Gouripur and Ishwarganj invested BDT 22,935 (USD 327.6) and BDT 23,323 (USD 333.2), respectively. We observed more than a threefold increase in the annual investment in Gouripur, more than a twofold and threefold increases in the cases of Ishwarganj and Haluaghat, respectively. It is notable that as the investment increased, the intervention became more managed and better planned. Consequently, management intervention in the form of annual investment reshaped the stand structure of the horticultural and timber tree species and motivated the households to buy healthy calves, poultry birds, HYV seedlings, and fingerlings of fast-growing introduced fish species. Figure 5 shows the components of the intervened homestead biodiversity in the study areas.

Effect of Managed Intervention on the Livelihood

It is evident that as the investment increased, homestead biodiversity management became more of a profitable venture and household members spontaneously participated in it. Table 10 shows the total average annual income and income from various sources. Our findings reveal that the share of earnings from homestead agrobiodiversity to the total household income increased presumably related to efficient management intervention. For instance, the average annual income of the respondents of

Gouripur was BDT 67,678.9 (USD 1691.9),³ 85,340.6 (USD 1446.5) and 98,567.8 (USD 1408.1) during 1994, 2004 and 2014, respectively. The combined income from the ten categories below in Table 10 shows that respondents in Gouripur earned 38.8, 41.9, and 43.2% of their total income from homestead agrobiodiversity in 1994, 2004, and 2014, respectively. At the same time, households in Ishwarganj obtained 30.7, 31.1, and 34.5% of their total income from homestead biodiversity. In contrast, respondents in Haluaghat received 37.9, 43, and 39.3% of their total income from homestead agroforestry in 1994, 2004, and 2014, respectively. Similar findings are noted by Ferdous et al. (2016) in Fatikchari, Bangladesh, Meaza and Demssie (2015) in the northern highlands of Ethiopia, and Yeasmin et al. (2021).in Rangpur, Bangladesh.

It is also notable that as the investment increased, the percentage share of the homestead agrobiodiversity income to the total income is also growing. Income from homestead agroforestry (i.e., fruit, fuelwood, and timber production) increased across the study area, indicating that the tree species' present stand structure is financially profitable. Income from livestock decreased in all three study areas (i.e., respondents in Ishwarganj earned 9.7% income from livestock in 1994, which slipped to 6.9 and 5.2%, respectively in 2004 and 2014), and income from bamboo production is also declining in Gouripur and Ishwarganj. However, livestock, fruit production, and bamboo production are the three central homestead biodiversity-related earning sources in the study areas. Apart from these, income from eggs, poultry, and fish also contributed to the final payment from biodiversity management. It is also mentionable that homestead biodiversity management created employment opportunities in the study areas. We calculated that homestead biodiversity created a maximum of 157.8 people-days employment/household in Gouripur in 2014, whereas it generated 125.7 and 143.2 people-days of employment/household in Ishwarganj and Haluaghat in 2014. Similar outcomes have also been found by Islam et al. (2021) and Ray et al. (2020) in India, Baul et al. (2021b) in Bangladesh, and Baul et al. (2013) in Nepal. These figures reveal that preferred species and their richness, dominance, and evenness through an intervened and managed homestead biodiversity have succeeded in the study areas.

Overall, the above observations suggest that ameliorating ecosystem services can be a boon for the participating households and the environment. Our selected households are heterogeneous in terms of socio-economic characteristics, intervention techniques, allocation of labor hours, and profit earning through ecosystem services. Similarly, our study areas varied regarding the capacity of ecosystem services, biodiversity richness, evenness, and dominance. The holistic analysis unearthed that it is a win-win for both households and ecological balance. However, the following points can be made in terms of spatial differences and heterogeneities among the households and study areas. Firstly, socio-economic characteristics play a crucial role in how households deal with and manage ecosystem services. From Table 2 above, households in Gouripur have better schooling, larger family sizes, and a more significant share of land dedicated to agroforestry services compared to the other

³ 1 USD = BDT 40 (1994 measurement) and 1 USD = BDT 59 (2004) measurement.

two study areas. Due to larger family sizes, respondents in Gouripur managed to provide maximum people-days employment in 2014 and earned greater returns from their efforts. Secondly, education is another crucial factor determining how the respondents harnessed the ecosystem services through managed interventions. Schooling boosts practical skills and experience that help to craft sustainable actions and plans. Lowest average schooling and the absence of more robust management interventions could be some reasons for which households in Haluaghat obtained a lower return from ecosystem services, regardless of their investment, which was the highest among the studied areas. Contrarily, households in Gouripur and Ishwarganj managed to craft robust management interventions through better knowledge, education, and skill, which boosted their percentage return from ecosystem services every ten years. Thirdly, in terms of tree species diversity, the diversity indices are increasing across all the study areas (Table 5); however, the dominance index accounted for the difference. Households in Gouripur surpassed other study areas in terms of tree species dominance index, which indicates that households in Gouripur are more concerned about choosing and replacing introduced and native species.

Conclusions

This study demonstrates how household preferences and managed interventions can transform an untapped natural homestead agrobiodiversity into choice-based profitable biodiversity. Such a study based on preferences and controlled interventions has not been done before in Bangladesh. Our findings support that household preferences are a crucial determinant of homestead biodiversity richness, dominance, and evenness. Although the diversity increased, it is notably due to the introduction of non-native species. Management intervention only occurred when households realized homestead biodiversity could be a potential source of earning that could supplement their family income. As the investment for the homestead biodiversity increased, the intervention became more managed and better planned. Management intervention occurred in the following forms: willingness to spend labor-hour, willingness to pay for labor-hour, and willingness to invest in the homestead biodiversity, considering it a business enterprise. We observed that homestead biodiversity contributed significantly to family income, making it a profitable enterprise. Our findings also indicate that fruit production, bamboo production, and livestock rearing were the significant biodiversity earning sources of the respondents. Furthermore, investment in homestead biodiversity created employment opportunities for the households (i.e., in 2014, it created 157.8 person-days employment/household in Gouripur).

Regarding the diversity of tree species, the total number of fruit trees declined, whereas the timber tree population increased. Overall, tree species diversity, richness, and evenness increased across the study areas, and dominance decreased. We found mango among fruit trees, mahogany among timber, and bamboo among fuelwood most dominant. Furthermore, we found the stand structure of the tree species in 2014 profitable. As Bangladesh is losing its natural forest reserve rapidly, homestead agroforestry can be a new hope of increasing the tree population. This paper can contribute to policy

formation for homestead agroforestry. Animal species diversity and evenness decreased while dominance and richness increased. We found cattle and hens as the most dominating livestock and poultry species in the study areas. Fish and vegetable species richness also showed an increasing trend. Overall, this study supports that respondents preferred and invested in those species that had a considerable direct impact on their livelihood. Regarding the spatial differences and heterogeneities across the selected households, the households vary significantly in terms of socio-economic characteristics, expectations regarding income from ecosystem services (i.e., agroecosystem), management interventions, and profitability indicators. Heterogeneity across households deters households from getting the maximum benefit from ecosystem services, and it cannot be mitigated as there is no “one size fits all” solution. However, policies can be formed to boost the socio-economic status of the households dwelling in rural Bangladesh so that their interventions become better managed, that the interventions ensure the coexistence of mankind and environmental elements, and that the interventions generate the least possible negative externalities on the environment.

Due to the lack of baseline surveys on the tree, animal, vegetable, and fish species in the study area, we had to rely on the aided recall method to collect data for 1994 and 2004, which is a significant limitation of this study. However, the aided recall method is a widely used method for collecting data. Despite of having this limitation, we believe that the findings of our study are novel and can create an impact on our society by motivating households based on the foreseeable benefits of homestead agrobiodiversity management to use their homestead areas even if it is a very tiny space to grow more trees and raise more animals to restore the balance of our biodiversity.

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Declarations

Conflict of interest We declare no conflict of interest.

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