



# Conservation of Plant Diversity in Agroforestry Systems in a Biodiversity Hotspot Region of Northeast India

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**Abstract** In Assam, a north-eastern state of India, most of the traditional agroforestry systems are still practised. The plant species composition of three agroforestry systems namely homegardens tea gardens and agrisilvicultural systems, were assessed using quadrat method. A total of 516 plant species belonging to 241 genera under 91 families were recorded, which consisted of 134 trees, 143 shrubs (67 shrub species and 76 species of saplings) and 239 herbs (93 herb species, 33 climber species and 113 species of seedlings). Homegardens had the highest species richness (475 plant species) belonging to 234 genera under 90 families. This was followed by agrisilvicultural systems (101 spp., 43 genera, 29 families), and the least was in tea gardens (79 spp., 41 genera, 25 families). The highest average number of plant species per system was recorded in homegarden ( $108.96 \pm 5.96$ , range 23–207 spp.). A negative correlation was found between the agroforestry system plot size and plant species richness. Sorenson's similarity index showed a very low degree of similarity in the plant species recorded among the three selected systems. Out of 516 plant species recorded across the different agroforestry systems, 1.0% species ( $n = 3$ ) were vulnerable (*Aquilaria malaccensis*, *Saraca asoca* and *Santalum album*), 8.9% species ( $n = 46$ ) were least concerned, 1.6% species ( $n = 8$ ) were data deficient and 88.6% species ( $n = 457$ ) were not assessed. Only homegarden recorded all the three plant species under the vulnerable category of IUCN Red List. It can be concluded that the agroforestry systems, specially the homegardens harbour rich plant diversity and act as miniature versions of natural forests by conserving rare, threatened and data-deficient plant species. The results suggest that the agroforestry systems with some management interventions need to be promoted as conservation models in areas with high pressure on tropical forests.

**Keywords** Assam · Agroforestry system · Homegardens · Tea gardens · Plant species richness

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## Introduction

Traditionally, the farmers have been known to retain tree cover in agricultural landscapes, around home spaces and in cash crop plantations as shade trees. Apart from these traditional practices, the increasing rate of tropical deforestation has led to an increase in number of forest or secondary forest growth fragments intermingled with human-managed landscapes consisting of agriculture and plantations. These current forms of land-uses usually known as agroforests have now become the prominent landscapes which have a potential of conserving the natural and native vegetation [25]. These agroforestry systems not only provide food, fruits, vegetables, medicines and fuel but also

ecosystem services like shelterbelts, windbreaks, shade, live fences, nutrient recycling, etc.

The traditional homegardens are structurally very complex in structure and function. These systems have 3–4 vertical canopy layers and so have close resemblance with the natural forests. The tropical homegardens conserve very high species diversity [11, 42, 61]. Species diversity in homegardens can range from as low as less than five [1, 4, 71], between 5 and 100 species [15, 19, 21, 27, 37, 56, 65, 69, 76] to as high as more than 100 species [26, 41, 68]. The species diversity found in homegardens varies according to the region, culture, land holding size, ecology and socio-economic factors. Many studies have reported homegardens as a rich repository of medicinal plants [3, 54] and of rare, Red-listed and conservation importance species [30]. Studies in cocoa agroforests [18] show that the herb species richness increases with a decrease in distance from natural forest and are nearly similar to species present in forest. Studies in cocoa agroforests [33, 38, 47, 52, 62], coffee agroforests [2, 12, 20, 46, 64] and tea agroforests [51] reveal that these systems maintain trees which are not only of timber and fodder value but also of conservation value. Therefore, these agroforestry systems have a potential to conserve plant species diversity in the current situation wherein tropical forest destruction looks almost unstoppable.

Assam, a part of the East Himalayan biodiversity hotspot in India, harbours nearly 3017 species of flowering plants, 293 species of orchids, 38 species of bamboo, 14 species of cane and 952 species of medicinal plants [6]. Of the recorded plant species, about 165 plant species are endemic to Assam. Plant diversity of Assam is highly threatened due to various anthropogenic threats, and as a result 284, 149, 58 and 13 species of plants are classified under critically endangered, endangered, vulnerable and near-threatened categories of IUCN, respectively [6]. The protected area network of Assam includes 5 national parks and 18 wildlife sanctuaries covering an area of 0.40 million ha constituting 4.98% of the geographical area [7]. The state once covered with thick forest has only 35.22% of geographical area under forest cover at present [24]. In Assam, agrisilvicultural systems, homegardens and tea gardens are the most dominant forms of agroforestry systems in practice [73]. As the green lush natural forests of the state is dwindling, these agroforestry systems with secondary growth forest patches, high tree cover, complex vertical and horizontal vegetation structure may contribute in conservation of plant biodiversity as evident through studies [13, 16, 30, 59] in other parts of the world. With the plant biodiversity depleting at an alarming rate, agroforestry systems as a conservation model must be studied further [5, 14, 28, 29]. Most of the studies done in other parts of India show that the plants present in homegardens

depend on the traditional culture of the owner rather than research [45]. It is high time that the policymakers and the conservationists must focus on agroforestry system for conservation of flora as well as fauna as these systems closely follow the natural forests. Some changes in management practices or harvesting regimes may be made to serve the purpose of conservation if need be. But the management approach needed in such agroforestry systems can be known only when the policy researchers lay emphasis on research in the agroforestry systems for their conservation values.

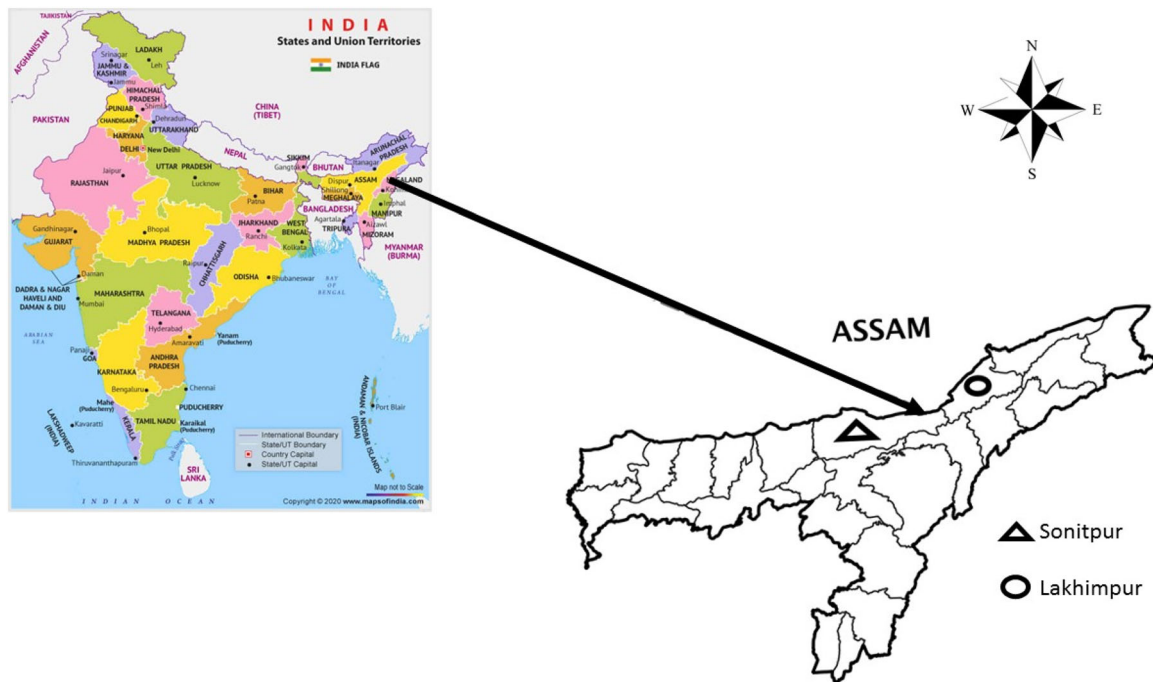
Though the agroforestry system is a major land-use system in Assam [75], a research analysing how far these systems have been able to conserve plant biodiversity is still lagging. Most of the studies done in Cachar district [21, 22] and in Jorhat and Golaghat districts [53, 54] of Assam concentrate on structure, diversity and utilization of plants present in homegardens. Except these three districts, there are no reports from other districts of the state. There is no information on the floristic diversity present in other types of agroforestry systems except homegardens. So, this study was designed keeping in mind these knowledge gaps, and therefore, the three most dominant agroforestry systems were compared for their plant species richness. From the findings of the studies done earlier by [18, 36, 55] in other parts of the world, it was expected that the plant species diversity, density and composition in agroforestry systems would vary according to the systems, their sizes and their distance from natural forest. The main objective of the present study was to understand the species diversity, composition and community characteristics of plants present in the different agroforestry systems like agrisilvicultural systems, homegardens and tea gardens and their contribution towards conservation of plant biodiversity.

## Materials and Methods

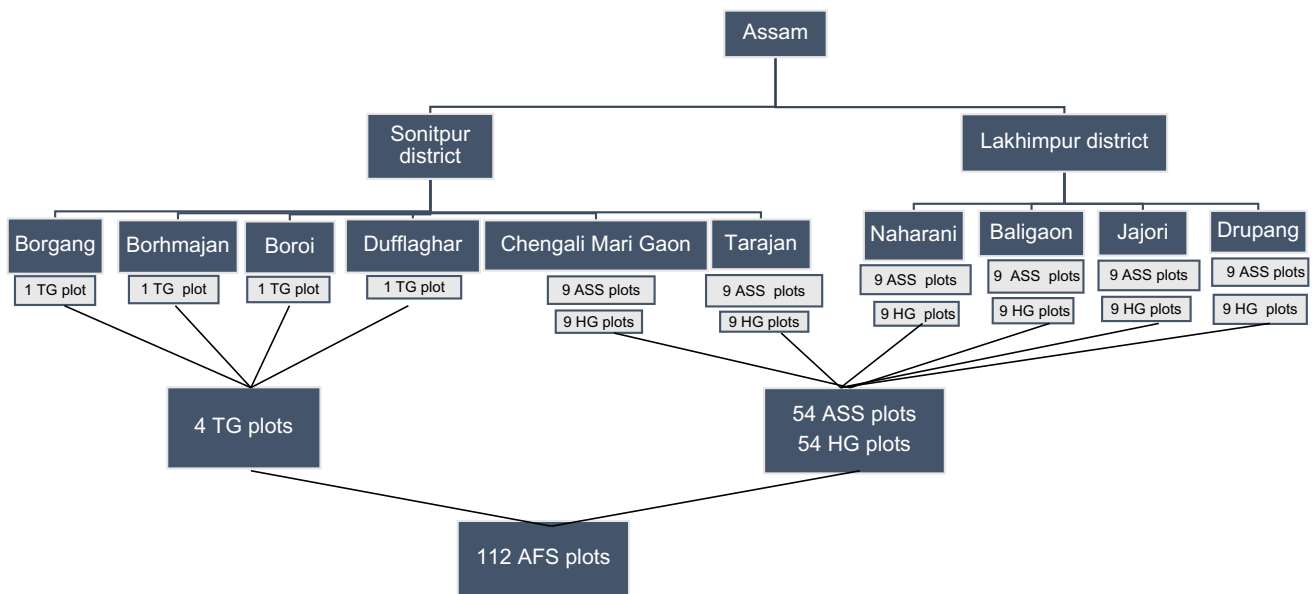
### Study Site

The study was carried out in two districts of Assam, namely Lakhimpur and Sonitpur. For assessing the plant (trees, shrubs and herbs) diversity in the different agroforestry systems in these two districts, six villages (four villages from Lakhimpur district and two villages from Sonitpur district) were chosen for homegarden and agrisilvicultural systems and a total of four villages were selected for tea gardens from Sonitpur district (Figs. 1, 2).

Lakhimpur district is situated approximately between 93°42' to 94°20'E longitude and 26°48' to 27°53'N latitude. On the west, it is bordered by Gohpur sub-division of Sonitpur district, on the south by Majuli Sub Division of Jorhat district, on the east by Subansiri river and Dhemaji



**Fig. 1** Map showing districts surveyed for plant diversity assessment in agroforestry systems practised in Assam



**Fig. 2** Schematic representation of selected study sites and plots for plant diversity assessment in Assam (AFS agroforestry systems, ASS agrisilvicultural system, HG homegarden, TG tea garden)

district of Assam and on the north by Papumpare and Siang district of Arunachal Pradesh [74]. It has 1185 villages [8]. Sonitpur district lies between 26°30' to 27°1'N latitude and 92°16' to 93°43'E longitude. It covers an area of around 5324 km<sup>2</sup>. It shares its borders with Darrang district of Assam on its west, Brahmaputra river on its south, North Lakhimpur district of Assam on its east and Arunachal

Pradesh on its north [74]. This district comprises of 1615 villages [9].

Description of the agroforestry systems studied is as follows:

1. Agrisilvicultural systems: These systems are a combination of crops and trees to produce agricultural crops as well as forest crops from the same unit of land. In

India, agrisilvicultural system is used for intercropping of a forest crop with agricultural crops in the initial years, until the canopy of the forest tree closes. The traditional practice of the farmers of northeast India is to plant tree species like *Mangifera indica*, *Dillenia indica*, *Bombax ceiba* and bamboo species like *Bambusa balcooa*, *Bambusa tulda*, etc. either on the boundaries of their farms or along with the agricultural crops depending on the choice of the farmer and the silvicultural requirements of the plant species [74]. The average size of agrisilvicultural system was estimated as 1.30 ha ranging from 0.50 to 3.00 ha (Table 1).

- Homegardens: These systems are usually a combination of trees, shrubs and herbs along with cultivated annual and perennial agricultural crops and livestock forming a complex vegetation structure and composition, all confined within the same unit of area [23]. It consisted of three or four canopy layers. *Areca catechu* and bamboo species like *Bambusa balcooa* (Bhaluka bamboo), *Bambusa tulda* (Jati bamboo), *Melocanna baccifera* (Muli bamboo), *Dendrocalamus hamiltonii* (Koko bamboo) and *Dendrocalamus giganteus* (Mokalm bamboo) are found in almost every household [72]. Other tree species like *Mangifera indica*, *Artocarpus heterophyllus*, *Musa* spp., *Citrus* spp., *Aegle marmelos*, etc., are also common. These systems also have pond, bamboo groves and dense forest tree plantation usually in the backyard of the house or sometimes in the front of the house or both. The average size of homegarden was 0.42 ha varying from 0.01 to 2.17 ha (Table 1).
- Tea garden agroforestry system: Currently around 3,12,210 ha of total area of Assam is under tea gardens [10]. During the British colonial period, most of the tea gardens were established by clear-felling the natural forests of Assam which were under the British custody and the rest of the private land was acquired from the villagers to cultivate tea [66]. Therefore, most of the tea gardens created ecotone zones with the adjoining reserve forests or protected areas. The tea gardens had two canopy layers. The shade tree species like *Albizia odoratissima*, *Albizia chinensis*, *Albizia lucidior* etc. formed the canopy layer and *Camellia sinensis* formed

the shrub layer. Some remnant forest patches along with streams and ponds were also observed in the tea gardens. The average size of tea garden was 706.11 ha, having a range of 527.11 to 898.64 ha (Table 1).

## Data Collection

### Plant Diversity Assessment

The 112 plots (agroforestry system sites) (Fig. 2) were considered for assessment of plant diversity by using quadrat method from September 2016 to February 2017. A total of 670 random quadrats (121 in agrisilvicultural systems, 405 in homegardens and 144 in tea gardens) of 10 m × 10 m were laid for studying tree species diversity. Within one 10 m × 10 m quadrat, one 5 m × 5 m and two 1 m × 1 m quadrats were laid for studying shrubs and herbs, respectively [44]. A total of 6.70 ha of land comprising 1.21 ha of agrisilvicultural systems, 4.05 ha of homegardens and 1.44 ha of tea gardens were studied for plant diversity. Trees (> 15 cm girth at breast height of 1.37 m, > 3 m height), shrubs (< 15 cm girth at breast height of 1.37 m, < 3 m height), saplings (5–10 cm collar diameter at base, < 1 m height) and seedlings (< 5 cm collar diameter at base, < 20 cm height) were considered for sampling [34, 43, 44]. The herbaceous succulents, seedlings and climbers were considered as herbs. For analysis, Bamboo species and *Musa* spp. were considered as trees. Shrubs and saplings together were classified as shrubs for the purpose of analysis. The woody climbers, lianas and orchids had been identified but not included in the analysis. Girth at breast height (1.3 m aboveground) was measured with the help of a measuring tape. Height of the individual tree was measured using the range finder [57]. Unidentified plant species collected were identified by consulting different volumes of flora of Assam [32] and herbarium of the Botanical Survey of India, Eastern Circle, Shillong and Botanical Survey of India, Itanagar.

### Effect of Distance from Natural Forest on Plant Diversity

To estimate the distance of the selected plots of agroforestry systems from the natural forest, the extraction tool

**Table 1** Average size and range of agroforestry system plots in the study sites

Types of AFS	Average size of plot (ha) (Mean ± SE)	Range of plot size (ha)	Number of plots
ASS	1.30 ± 0.09	0.50–3.00	54
HG	0.42 ± 0.06	0.01–2.17	54
TG	706.11 ± 88.14	527.11–898.64	4

AFS agroforestry systems, ASS agrisilvicultural system, HG homegarden, TG tea garden

of Google Earth was used [74]. The mean distance of the selected agroforestry system plots from natural forest is given in Table 2.

### Data Analyses

The following community parameters were calculated using the below given formulae:

1. Importance Value Index (IVI) for trees = Relative Frequency + Relative Density + Relative Dominance
2. Importance Value Index (IVI) for shrubs and herbs = Relative Frequency + Relative Density
3. Shannon Weiner index [58]

$$H' = \sum_{i=1}^s p_i \ln p_i$$

where  $p_i$  is often the proportion of individuals belonging to the ' $i$ 'th species in the dataset and ' $s$ ' is the species richness. This index varies between 1 to 4, where 1 represents less diversity and 4 represents high diversity.

4. Simpson's index [60]

This was calculated according to Simpson [60] to measure the concentration of dominance (CD) of plant species.

$$CD = \sum_{i=1}^s (p_i)^2$$

where  $p_i$  is the proportion of the IVI of the ' $i$ 'th species and IVI of all the species ( $ni/N$ ). The values of Simpson's index are limited to 1 where 1 shows dominance by a single species.

5. Pielou's evenness index [50] =  $H'/\log_{10}N(S)$   
where  $H'$  is the Shannon Weiner Index of diversity and  $S$  is the total number of species.
6. Sorenson's similarity coefficient [63]

$$\text{Sorenson similarity coefficient} = \frac{2C}{A+B}$$

where  $C$  is the number of species common to both sites,  $A$  is the total number of species in site  $A$ , and  $B$  is the total number of species in site  $B$ . Sorenson's coefficient gives a

value between 0 and 1; the closer the value is to 1, the more the communities have in common.

### Statistical Analyses

The parametric Welch ANOVA test and one-way ANOVA test were used to analyse data with normal distribution, and the nonparametric Kruskal–Wallis test was used to analyse data with non-normal distribution [77].  $p < 0.05$  was considered statistically significant for all the above-mentioned analyses. In order to understand the correlation between plant species richness, diversity, density and agroforestry system plot size and distance from natural forest, nonparametric rank correlation analysis (Spearman rank correlation matrix) and parametric correlation analysis (Pearson's correlation) were used [77]. All analyses were run on SPSS (version 16.0 for Windows). For correlation analysis purpose,  $p < 0.01$  was considered statistically significant. Means, standard errors of mean ( $\pm$ ) and range are given in text and tables.

## Results

### Plant Diversity

A total of 516 plant species belonging to 241 genera under 91 families were recorded in the three different types of agroforestry systems studied which consisted of 134 trees, 143 shrubs (67 shrub species and 76 species of saplings) and 239 herbs (93 herb species, 33 climber species and 113 species of seedlings) (Supplementary Tables 1, 2; Supplementary Figs. 1, 2, 3, 4, 5). Apart from trees, shrubs and herbs, species of lianas (6) and orchid *Rhynchosyilis retusa* (1) were also recorded from the studied agroforestry systems (Table 3; Supplementary Fig. 5). Homegardens supported all these lianas and orchid (*Rhynchosyilis retusa*) (Table 3). But these have not been included for further analysis.

Among the three different types of agroforestry systems studied, homegardens had the highest species richness, i.e. 475 plant species (126 trees, 132 shrubs (66 shrub species and saplings each) and 217 herbs (91 herb species, 33 climber species and 93 species of seedlings)) belonging to

**Table 2** Mean distance and range of agroforestry system plots from natural forest in the study sites

Types of AFS	Mean distance of plot (km) (Mean $\pm$ SE)	Range of distance (km)
ASS	3.65 $\pm$ 0.65	1.35–5.97
HG	3.93 $\pm$ 0.82	1.32–6.82
TG	2.52 $\pm$ 1.22	0.57–5.99

AFS agroforestry systems, ASS agrisilvicultural system, HG homegarden, TG tea garden

**Table 3** Lianas and orchid found in the selected plots of agroforestry systems

S/ N	Order	Family name	Scientific name	Local name	Habit	*Occurrence of species in AFS			**IUCN status
						ASS	HG	TG	
1.	Magnoliales	Annonaceae	<i>Artabotrys caudatus</i> Hook.f. and Thomson	Dhuplata	Liana	–	+	–	NA
2.	Fabales	Fabaceae	<i>Caesalpinia bonduc</i> (L.) Roxb.	Latanggutti Gaach	Liana	+	+	–	NA
3.	Fabales	Fabaceae	<i>Mezoneuron cucullatum</i> (Roxb.) Wight. and Arn.	Tejmuri	Liana	–	+	–	NA
4.	Celastrales	Celastraceae	<i>Celastrus paniculatus</i> Willd.	Kijri	Liana	–	+	–	NA
5.	Myrtales	Combretaceae	<i>Combretum acuminatum</i> (Roxb.)	Maloti	Liana	+	+	–	NA
6.	Lamiales	Oleaceae	<i>Jasminum rotterianum</i> Wall. ex DC	Kharikalata	Liana	+	+	–	NA
7.	Asperagales	Orchidaceae	<i>Rhynchosstylis retusa</i> (L.) Blume	Kopouphul	Orchid	+	+	+	NA
Total						4	7	1	

\*Occurrence of species in AFS agroforestry systems: HG homegarden, TG tea garden, ASS agrisilvicultural system, + present, – absent, \*\*IUCN status: NA not assessed

234 genera under 90 families (Appendices 1, 2). This was followed by agrisilvicultural systems, i.e. 101 plant species (43 genera and 29 families). The least species richness was recorded from the tea gardens (79 plant species) belonging to 41 genera under 25 families (Supplementary Table 1). Species richness in different agroforestry systems is presented in Fig. 3.

The highest average number of plant species per system was recorded in homegarden ( $108.96 \pm 5.96$ , range 23–207 spp.), followed by tea garden ( $59.75 \pm 4.55$ , range 48–70 spp.), and the least in agrisilvicultural systems ( $20.65 \pm 0.46$ , range 12–27 spp.). Homegarden was found to have the highest average number of tree species per plot ( $18.93 \pm 1.29$ , range 1–45 spp.), shrub species per plot ( $24.54 \pm 1.76$ , range 4–60 spp.) and herb species per plot ( $65.50 \pm 3.83$ , range 13–144 spp.) (Figure 4).

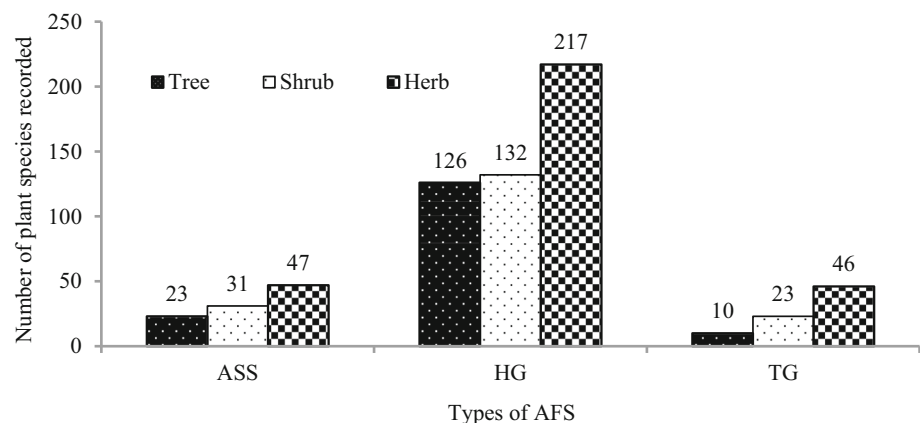
Overall, the data showed that Fabaceae contributed the highest number of genera and species (22 genera and 31

species) followed by Cucurbitaceae, Malvaceae, Labiate, Poaceae, Amaranthaceae, Moraceae and Solanaceae (Supplementary Table 1). Fabaceae were found to be the most dominant family in all the three habitats, namely trees (12 genera and 16 species), shrubs (14 genera and 21 species) and herbs (17 genera and 26 species) (Supplementary Table 1).

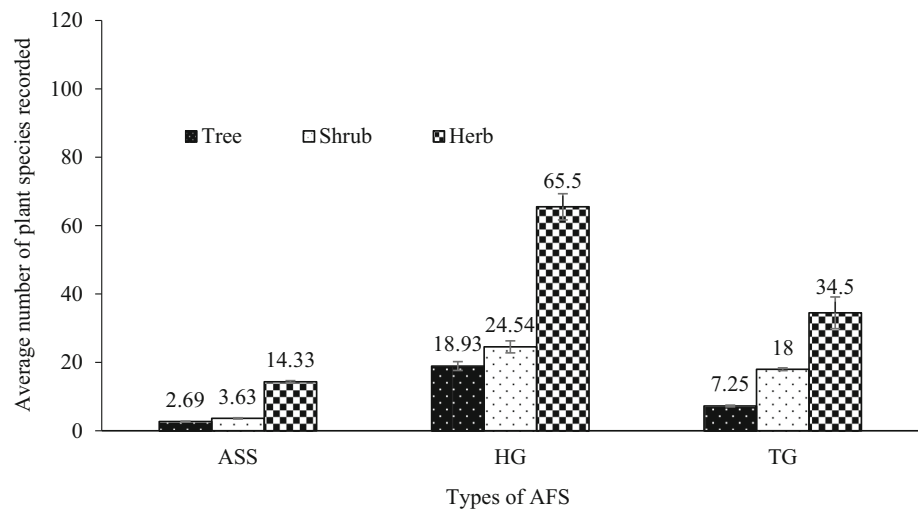
### Plant Species Richness

Homegardens had the highest plant species richness ( $349.17 \pm 8.85$ , range 316–374 spp.) (Table 4). The plant species richness varied significantly among the three agroforestry systems (Welch ANOVA,  $F_{(2,6,009)} = 440.328$ ,  $p = 0.000$ ) (Table 4). The highest tree species richness ( $66.33 \pm 3.31$ , range 57–78 spp.), shrub species richness ( $89.33 \pm 5.10$ , range 71–102 spp.) and herb species richness ( $193.50 \pm 4.68$ , range 180–208 spp.)

**Fig. 3** Plant species richness recorded in selected plots of agroforestry systems



**Fig. 4** Average number of plant species per plot recorded in selected agroforestry systems (Mean  $\pm$  SE) (AFS agroforestry systems, ASS agrisilvicultural system, HG homegarden, TG tea garden)



were recorded in homegarden (Table 4). The three agroforestry systems revealed statistically significant difference in species richness among them (Table 4). The Shannon Weiner Index for tree, shrub and herb also followed the same trend as species richness (Table 4).

#### Effect of Plot Size and Distance from Forest on Species Richness and Diversity

Plant species richness ( $r_s(16) = -0.843$ ,  $p = 0.000$ ), tree species richness ( $r_s(16) = -0.849$ ,  $p = 0.000$ ), shrub species richness ( $r_s(16) = -0.657$ ,  $p = 0.000$ ) and herb species richness ( $r_s(16) = -0.738$ ,  $p = 0.001$ ) increased with the decrease in agroforestry system plot size. Shannon Weiner Index of Tree ( $r_s(16) = -0.840$ ,  $p = 0.000$ ) and shrub ( $r_s(16) = -0.896$ ,  $p = 0.000$ ) increased with a decrease in plot size, whereas correlation between agroforestry system plot size and herb Shannon Weiner Index ( $r_s(16) = -0.521$ ,  $p = 0.039$ ) was insignificant. No relationship existed between the distance of natural forest from the plots of agroforestry systems and the plant species richness ( $r_s(16) = 0.125$ ,  $p = 0.644$ ). Similar was the result with other variables of species richness and Shannon Weiner Index.

#### Plant Density, Dominance and Evenness

The highest tree density was recorded in homegardens ( $649.67 \pm 17.40$ , range 597–697 individuals  $\text{ha}^{-1}$ ), followed by tea garden ( $196.50 \pm 5.50$ , range 191–213 individuals  $\text{ha}^{-1}$ ) and agrisilvicultural system ( $171.67 \pm 7.96$ , range 155–209 individuals  $\text{ha}^{-1}$ ). The three agroforestry systems revealed statistically significant difference in tree density among them (Kruskal–Wallis,  $X^2(2) = 12.149$ ,  $p = 0.002$ ) (Table 4). Agroforestry system plot size had no

significant effect on tree density ( $r_s(16) = -0.575$ ,  $p = 0.020$ ).

The species which had contributed the highest towards the stand density and dominance in homegarden, agrisilvicultural systems and tea gardens were *Areca catechu* (207.01 individuals  $\text{ha}^{-1}$  and 64.88 IVI), *Dillenia indica* (31.40 individuals  $\text{ha}^{-1}$  and 51.24 IVI) and *Albizia odoratissima* (53.47 individuals  $\text{ha}^{-1}$  and 101.6 IVI), respectively (Supplementary Table 3). Among the Bamboo species, *Bambusa tulda* (34.14 individuals  $\text{ha}^{-1}$ ) contributed the highest to stand density as compared to the other three bamboo species found in the study area. None of the species among the highest density contributors were common to all the three agroforestry systems (Supplementary Table 3, Fig. 5). Details about density and importance value index (IVI) are presented in Supplementary Table 3. The shrub density recorded among the three agroforestry systems varied significantly (One-way ANOVA,  $F_{(2,13)} = 1174.000$ ,  $p = 0.000$ ) (Table 4). Agrisilvicultural systems ( $790,666.50 \pm 17,176.00$ , range 733,611–849,722 spp.) had the highest herb density (Table 4). The tree, shrub and herb Simpson's index and Pielou's evenness index are presented in Table 4.

#### Tree Basal Area

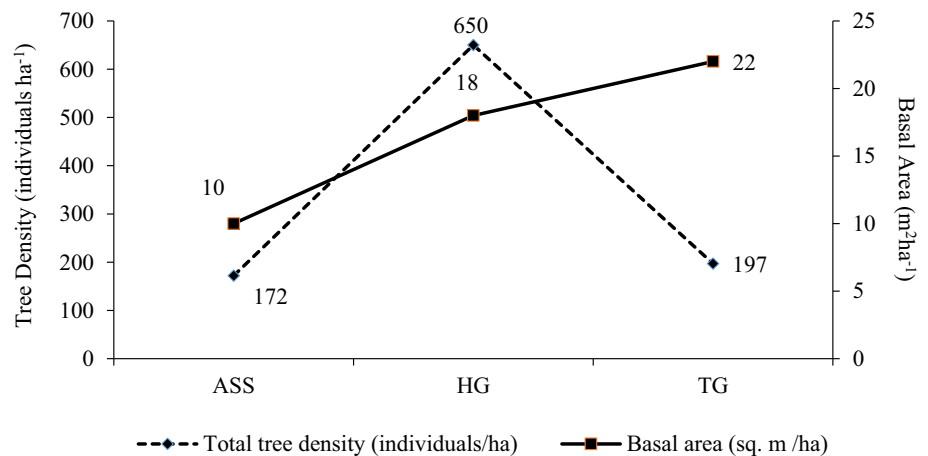
Based on the basal area values, the tea garden had the highest basal area values ( $22.01 \pm 0.96$ , range 20.78–24.89  $\text{m}^2 \text{ha}^{-1}$ ). The three agroforestry systems revealed statistically significant difference in tree basal area among them (Kruskal–Wallis,  $X^2(2) = 12.077$ ,  $p = 0.002$ ) (Table 4). The species contributing the highest to basal area were *Mangifera indica* (1.53  $\text{m}^2 \text{ha}^{-1}$ ), *Areca catechu* (2.81  $\text{m}^2 \text{ha}^{-1}$ ) and *Albizia odoratissima* (10.61  $\text{m}^2 \text{ha}^{-1}$ ) in agrisilvicultural systems, homegardens and tea gardens, respectively (Supplementary Table 3).

**Table 4** Community characteristics of plant species in the selected agroforestry systems

Habit Parameters	Types of AFS			W or F or KW, p value
	ASS Mean ± SE (Range)	HG Mean ± SE (Range)	TG Mean ± SE (Range)	
Plant Species richness	69.33 ± 1.80 (63–75)	349.17 ± 8.85 (316–374)	59.75 ± 4.55 (48–70)	W = 440.328, p = 0.000
Tree Species richness	14.50 ± 0.99 (10–17)	66.33 ± 3.31 (57–78)	7.25 ± 0.25 (7–8)	KW = 13.333, p = 0.001
Total density (individuals ha <sup>-1</sup> )	171.67 ± 7.96 (155–209)	649.67 ± 17.41 (597–697)	196.50 ± 5.50 (191–213)	KW = 12.149, p = 0.002
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	9.50 ± 0.22 (9.01–10.25)	18.25 ± 1.80 (12.56–24.67)	22.01 ± 0.96 (20.78–24.89)	KW = 12.077, p = 0.002
Shannon Weiner Index	2.34 ± 0.07 (1.96–2.48)	3.50 ± 0.11 (3.13–3.98)	1.75 ± 0.04 (1.70–1.87)	KW = 13.255, p = 0.001
Simpson's Dominance Index	0.11 ± 0.01 (0.09–0.18)	0.06 ± 0.01 (0.02–0.10)	0.21 ± 0.01 (0.17–0.23)	F = 32.861, p = 0.000
Evenness index	0.89 ± 0.01 (0.85–0.94)	0.83 ± 0.02 (0.75–0.92)	0.88 ± 0.006 (0.87–0.90)	F = 4.320, p = 0.036
Shrub Species richness	17.00 ± 0.85 (15–21)	89.33 ± 5.10 (71–102)	18.00 ± 0.40 (17–19)	W = 90.483, p = 0.000
Total density (individuals ha <sup>-1</sup> )	892.33 ± 55.50 (666–1022)	4905.33 ± 150.77 (4494–5501)	8863.25 ± 83.80 (8622–8977)	F = 1174.000, p = 0.000
Shannon Weiner Index	2.54 ± 0.06 (2.34–2.81)	3.91 ± 0.07 (3.59–4.09)	1.56 ± 0.01 (1.54–1.61)	KW = 13.255, p = 0.001
Simpson's Dominance Index	0.10 ± 0.01 (0.07–0.14)	0.03 ± 0.004 (0.02–0.05)	0.41 ± 0.008 (0.39–0.43)	F = 473.723, p = 0.000
Evenness index	0.90 ± 0.01 (0.84–0.93)	0.87 ± 0.007 (0.84–0.89)	0.53 ± 0.004 (0.53–0.55)	F = 309.094, p = 0.000
Herb Species richness	37.83 ± 1.19 (33–41)	193.50 ± 4.68 (180–208)	34.50 ± 4.64 (22–44)	F = 625.166, p = 0.000
Total density (individuals ha <sup>-1</sup> )	790,666.50 ± 17,176.00 (733,611–849,722)	331,359.16 ± 10,960.00 (290,517–357,957)	52,000.00 ± 6529.38 (36,250–66,388)	F = 706.933, p = 0.000
Shannon Weiner Index	2.13 ± 0.02 (2.02–2.20)	3.93 ± 0.007 (3.91–3.96)	2.96 ± 0.13 (2.58–3.18)	W = 1941.000, p = 0.000
Simpson's Dominance Index	0.32 ± 0.005 (0.31–0.35)	0.01 ± 0.002 (0.01–0.02)	0.07 ± 0.008 (0.06–0.10)	KW = 13.657, p = 0.001
Evenness index	0.58 ± 0.005 (0.56–0.60)	0.74 ± 0.003 (0.73–0.75)	0.84 ± 0.006 (0.83–0.86)	F = 674.751, p = 0.000

AFS agroforestry systems: ASS agrisilvicultural system, HG homegarden, TG tea garden. The level of significance is ( $p < 0.05$ ). W is for Welch ANOVA, F value is for one-way ANOVA, and KW is for Kruskal–Wallis



**Fig. 5** Stand density and basal area of tree species in selected agroforestry systems**Table 5** Girth and number of culms per clump of bamboo species in selected homegardens and agrisilvicultural systems

S/N	Species name	Culm GBH (m) Range (Mean ± SE)	No. of culms/clump Range (Mean ± SE)	
			ASS	HG
1.	<i>Bambusa balcooa</i> Roxb.	0.06–0.17 (0.11 ± 0.0006)	5–33 (16.22 ± 2.85)	16–87 (48.27 ± 2.11)
2.	<i>Bambusa nutans</i> Wall. ex Munro	0.04–0.10 (0.06 ± 0.0005)	15–48 (31.50 ± 16.50)	12–82 (52.21 ± 3.35)
3.	<i>Bambusa pallida</i> Munro	0.05–0.10 (0.07 ± 0.0005)	14–27 (20.50 ± 6.50)	18–82 (53.37 ± 4.19)
4.	<i>Bambusa tulda</i> Roxb.	0.05–0.12 (0.08 ± 0.0003)	6–72 (19.50 ± 6.15)	8–79 (48.87 ± 1.59)

GBH girth at breast height, ASS agrisilvicultural system, HG homegarden

Among the four bamboo species found in homegardens, *Bambusa tulda* and *Bambusa balcooa* had significant share in the high basal area with values of 1.02 and 0.94 m<sup>2</sup> ha<sup>-1</sup>, respectively (Supplementary Table 3). The range (Mean ± SD) of number of culms/clump and range (Mean ± SD) of culm GBH for each bamboo species recorded in the study area are given in Table 5. Again, there were no species that were common to all the three agroforestry systems that had highly contributed to the basal area value. Details about basal area are presented in Supplementary Table 3.

### Plant Sorenson's Similarity Indices

This gave an inference that there was a very low degree of similarity in plant species between the different agroforestry systems studied (Table 6).

**Table 6** Sorenson's similarity index among different selected agroforestry systems

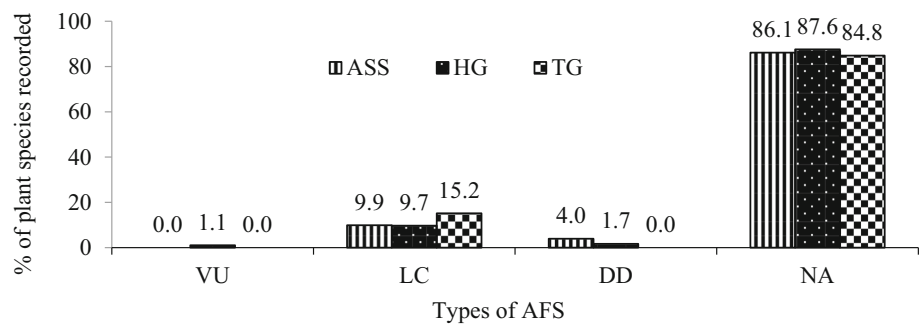
	ASS	HG	TG
ASS	1.00		
HG	0.31	1.00	
TG	0.26	0.20	1.00

ASS agrisilvicultural system, HG homegarden, TG tea garden

### Conservation Status of Plant Species

Out of 516 plant species recorded across the different agroforestry systems, 1.0% species ( $n = 3$ ) were vulnerable (*Aquilaria malaccensis*, *Saraca asoca* and *Santalum album*), 8.9% species ( $n = 46$ ) were least concerned, 1.6% species ( $n = 8$ ) were data deficient and 88.6% species ( $n = 457$ ) were not assessed. Among the three agroforestry systems under study, homegarden recorded the highest number of species of conservation concern. Out of 475 species in homegarden, 1.1% species ( $n = 5$ ) were vulnerable, 9.7% species ( $n = 46$ ) were least concerned, 1.7% species ( $n = 8$ ) were data deficient and rest 87.6% species ( $n = 416$ ) were not assessed according to the IUCN Red List (Fig. 6).

**Fig. 6** Conservation categories of plant species recorded in selected agroforestry systems as per IUCN Red List criteria (AFS agroforestry systems, ASS agrisilvicultural system, HG homegarden, TG tea garden, VU vulnerable, LC least concern, DD data deficient, NA not assessed)



## Discussion

Homegarden has been reported to have the highest plant species richness in the current study (475 plant species consisting of 126 trees, 66 shrubs, 66 saplings, 91 herb species, 33 climber species and 93 species of seedlings). This was much higher than the studies done in Assam and Arunachal Pradesh [78] and south Meghalaya [67]. This study is based on the hypothesis that the homegardens would have the highest species diversity as compared to the other agroforestry systems. The Shannon Weiner Index of trees ( $3.50 \pm 0.11$ ), shrubs ( $3.91 \pm 0.07$ ) and herbs ( $3.93 \pm 0.07$ ) in homegarden confirms this hypothesis (Table 4). This tree diversity is similar to those recorded in tropical rain forests [17, 35].

In the present study, the average number of tree species was recorded as  $18.93 \pm 1.29$ , range 1–45 spp. per homegarden plot (Fig. 4) which agrees with the results of Das and Das [21] who reported an average of 20 tree species per homegarden. In general, smaller agroforestry system plot size had higher tree and shrub species diversity. This finding also conforms to the hypothesis set at the beginning of conducting this study that small-sized plots would have more plant diversity as compared to the large-sized agroforestry plots. The small landholders must have ensured optimum land use by utilizing the horizontal and vertical space in their farms through cultivating a whole range of diverse plant species giving them multiple products. This result is similar to the findings of Kumar et al. [36], Sahoo et al. [55] but dissimilar to that of Kabir and Webb [31].

*Areca catechu* has been reported to be the dominant tree (64.89 IVI) with highest density (207.01 individuals  $\text{ha}^{-1}$ ) in the present study (Supplementary Table 3). It is found in 92.5% of the homegardens studied, but only 3.65% of homegardens have monocultural plantations of *Areca catechu* and rest are all mixed crops in combination with *Musa acuminata*, *M. balbisiana*, *M. calosperma*, *M. paradisiaca* or other timber and fruit-yielding species. Moreover, the Shannon Weiner Index ( $3.50 \pm 0.11$ ) and Simpson's Dominance Index ( $0.06 \pm 0.01$ ) (Table 4) suggest that

there is more tree diversity and less of dominant tree species in homegardens. All the above-mentioned facts prove that the homegardens in the study area still follow the traditional characteristics of diverse species composition and have not turned into cash crop production systems as of yet. This contradicts with the observations done in homegardens of Kerala [37, 49] and south Andaman [48].

The tea gardens are in a close proximity with the forests ( $2.52 \pm 1.22$  km) (Table 2), but this factor had no effect on the plant species richness or diversity in the selected agroforestry systems. One of the hypotheses of this study was the closer the agroforestry system plot to the forest, the higher its species diversity. But this correlation was not found in the study. Only 10 tree species were recorded in the tea gardens which were planted as shade trees for *Camellia sinensis*. The reported tree species richness was lower when compared to the studies done in coffee plantations [62, 206 spp. and 20, 40 spp.] and higher than cocoa plantations [33, 5 spp.]. As the tea gardens were used for commercial production, they must have been subjected to deliberate shade tree selection and management practices like regular weeding, removal of climbers and epiphytes, herbicide application, etc., resulting in lower species richness. So, this might be one of the reasons for failing to meet the expected hypothesis. This result is dissimilar to the study conducted in cocoa agroforests [18], wherein the species diversity was influenced by the distance from forest.

In the current study, 80% of the plant species planted as shade trees were native species. This result is similar to the studies done in cocoa agroforests of Cameroon [38] and coffee farms of Mexico [39] but dissimilar to that in cocoa agroforests of Nigeria [47] which depicts dominance of exotic species. Native species like *Albizia* spp. (142.4 individual  $\text{ha}^{-1}$ , 72.1%) (Supplementary Table 3) might have been planted as the tea garden owners must be aware of its nitrogen fixing properties. The higher percentage of native shade trees planted at high density in the present study suggested that these agroforestry systems despite being managed intensively have a high potential in preservation of regional plant diversity [12, 64].

The tea plant density was 7836 individuals ha<sup>-1</sup> in tea garden in the current study (Supplementary Table 3), which is much higher than that of 1071–1239 individuals ha<sup>-1</sup> in coffee agroforests of West Africa [20] and 4100 individuals ha<sup>-1</sup> in coffee farms in Ethiopia [2]. This higher density of tea plants in the current study may be because of the differences in species of tea and coffee. Both these species differ in the spacing requirement (1.56 × 1.56 m for coffee and 0.75 × 0.75 m for tea), structure and habit.

In the present study, the agrisilvicultural system is reported to have 101 plant species which is higher than that observed in swidden agroforestry system of Peru (25 spp.) [70]. The major difference in swidden agroforestry system from the agrisilvicultural system was the absence of tree component. Most of the species recorded in the aforementioned study were shrubs and herbs, i.e. cash crops and food crops, whereas in the current study they were diverse (food crops, timber crops and weeds). In the swidden agroforestry system, crop is cultivated twice in a year, whereas in the agrisilvicultural systems the food crops are cultivated only during the monsoon season. The species richness obtained in the agrisilvicultural systems was higher than the study conducted in Karnataka (15 spp.) [59]. This high diversity in agrisilvicultural systems of Assam may be accorded to the cultural farming practices of farmers who preferred having shade trees in fields which could also provide timber and fruits.

As far as the similarity index for the current study is considered, it showed very low resemblance between the three agroforestry systems, i.e. very few species were common between the different agroforestry systems (Table 6). This result is supported by the studies which found low similarity between different agroforestry systems [59, 70]. This low similarity is quite understood as all the three systems serve different purposes in the study area. The tea gardens and agrisilvicultural systems are more of a commercial farming system, whereas the homegardens are subsistence farming systems.

The present study reported three species under the vulnerable category as per IUCN Red List in homegardens, which was lower than the study of Kabir and Webb [30, 6 spp.]. The presence of Red-listed species in the homegardens might just have been a matter of chance as the frequency of its occurrence was as low as *Aquilaria malaccensis* (3.04%), *Santalum album* (0.91%) and *Saraca asoca* (0.30%). The reason of planting *Aquilaria malaccensis* and *Santalum album* is their trade value, whereas *Saraca asoca* is planted for its medicinal property. The trees species found in homegardens are usually according to the preferences and requirements of the owner. Therefore, it is quite possible that the homegarden owners are totally unaware of the IUCN Red List status of these trees and merely planted these species for their use. The current

study failed to report species of conservation importance in tea gardens. This finding is not supported by the studies which have encountered IUCN Red-listed species in their study areas [20, 38, 40, 51]. This study shows that IUCN Red-listed species are seldomly included into agroforestry systems which is a matter of concern and must be looked into seriously by the conservationists and policymakers.

## Conclusions

This study highlights the importance of agroforestry systems, especially homegardens in conservation of plant diversity. Homegarden is a home to many species listed under data deficient and not assessed categories of IUCN, making this system very important for further research. The presence of IUCN Red-Listed species is just by chance. This implies that the policymakers must take an account of this and implement policies in a manner that the species of conservation importance in the homegardens can be saved from possible extinction. Homegardens also ensure the survival of native species according to the owner's choice and utility. When compared with the natural forests, it has been seen that homegardens preserve many diverse varieties of plants and have a potential to act as replicas of protected areas in the current era of deforestation, fragmentation and encroachments. Therefore, awareness must be created about such agroforestry systems which help conserve diversity as well as native and endangered species. The tea gardens had low species diversity owing to their commercial nature because of which these systems promoted exotic species and weeding throughout the year, thus reducing the plant diversity. The use of indigenous and suitable shade trees must be promoted in this system to increase its value of plant diversity conservation.

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