Ethnic homestead forests of North-East India revealed as diverse land-use systems

Demsai Reang · Uttam Kumar Sahoo · Krishna Giri · Animekh Hazarika · Arun Jyoti Nath

Abstract Ethnic homestead forests or the traditional agroforestry systems (TAFS) can achieve sustainable production, *in-situ* biodiversity conservation, and climate change mitigation while maintaining cultural values. The presence of trees under the TAFS increases the ecological and aesthetic value of the landscape and possesses important economic value for the farmer. This study aimed to determine the contribution of ethnic homestead forests to tree biodiversity, biomass storage and evaluated farmers' use criteria under the piper and pineapple systems of Assam and home gardens of Mizoram, North-East India. The results showed that tree species richness, basal area, and diversity were highest in the home gardens followed by piper and pineapple-based systems. On the other hand, stand density under these systems followed a reverse order. Altogether, 112, 91, and 15 tree species were documented from home gardens, piper, and pineapple-based systems with stand density of 399, 990, and 1225 (stems ha^{-1}) under the same systems respectively. Two economically viable tree species, i.e. *Aquilaria malaccensis* and *Parkia timoriana* that are no longer found in wild are widely domesticated in the pineapple-based system. In Assam, the biomass storage in piper-based systems (129.39 Mg ha^{-1}) was 19 % more than the nearby native forest (NF). In contrast, the biomass storage in the home gardens of Mizoram (117.32 Mg ha^{-1}) was 57 % lower than the NF. The farmer's use classes revealed that greater numbers of tree species under these TAFS provided fuelwood, timber, and economic needs. According to the farmer's report, the environmental services provisioned by most tree species include - shade for other crop species and in soil erosion control. This study demonstrates the potentiality of TAFS in the conservation of biodiversity, and biomass storage while additionally ensuring livelihood resilience and a wide array of environmental services.

Keywords Assam · Biodiversity conservation · Ecosystem services · Mizoram · Sustainable production · Traditional agroforestry systems

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Introduction

Homestead forests (HF), also widely referred to as home gardens (HG) or traditional agroforestry systems (Roy et al. 2013), are multifunctional managed ecosystems that play an important role in providing various tangible and intangible benefits (Alam 2012). Many studies on the tropics reveal that tree domestication and species choice in the TAFS have evolved along with civilization (Kumar and Nair 2006; Simons and Leakey 2004). Structurally and functionally these forests are the closest mimics of natural forests (Jose 2009) and are viable sites for plant conservation, especially the rare, threatened and data deficient species (Choudhury and Khan 2010; Roy et al. 2013; Yashmita-Ulman et al. 2021). For instance, a single HF recorded 602 species in West Java, Indonesia (Abdoellah et al. 2002). They hold great potential for climate change mitigation from the agriculture sector (Duguma et al. 2017; Nath et al. 2021) and increase farmers' adaptive capacity (Kuyah et al. 2019; Nath et al. 2021; Reang et al. 2021). Studies reveal that these forests provide nutritional security (Sahoo 2009; Sahoo and Rocky 2019) and enhance income generation (Barbhuiya et al. 2016). They form as the primary source for providing food and other household needs to the marginalized societies (Das and Das 2005; Roy et al. 2013). In Bangladesh, it is estimated that about 70 % of timber, 48 % of sawn and veneer logs, and 90 % of firewood, and bamboo requirements are met from HF (Uddin et al. 2001). Hence, tree diversity studies are of immense importance to understand the pattern of tree domestication and their distribution under such traditionally managed systems.

The North-East India (NEI) region is represented by diverse agro-climatic and biogeographic zones and is a global biodiversity hotspot. The region is culturally very diverse, inhabited by over 200 tribes (Giri et al. 2018). The multi-ethnicity has given special recognition to this region in terms of cultural, socio-economic wealth, and diverse land use (LU) practices for subsistence and economic well-being (Smith 1999). The majority of the ethnic tribes are forest dwellers and largely depend on forest resources for their livelihood. The major LU systems that sustained the livelihood of these ethnic folks are *jhum* (local name for shifting cultivation), wet terrace paddy cultivation, tea gardens, integrated farming, and agroforestry practices.

The TAFS under ethnic communities exhibit a considerable variation in crop diversity influenced by crop composition and rotation. Diverse tribe and location-specific agroforestry systems (AFS) hold promising potential to address livelihood issues, socio-economic and environmental sustainability (Selvan and Kumar 2017). In the current scenario of accelerated land degradation owing to *jhum* cultivation and LU conversions (Laskar et al. 2021), the promotion of permanent agroforestry practices could evolve as a problem-solving science to address these issues from a larger perspective (Nath et al. 2020). Studies on TAFS in the NEI region have been undertaken to explore the major genetic resources, plant and crop diversity, and their socio-economic and environmental benefits (Ramakrishnan et al. 1996; Shrivastava and Heinen 2005; Das and Das 2005; Sahoo 2009; Tangjang and Arunachalam 2009; Saikia and Khan 2014). Several studies have revealed that the TAFS in NEI are more diverse and species-rich than natural forests (Nandy and Das 2013; Das et al. 2020), highlighting their importance in biodiversity conservation. In light of the above, we aimed to study the tree species composition and diversity under different TAFS practiced by the ethnic communities of southern Assam and Mizoram, NEI. We also assessed the aboveground biomass (AGB) and compared it with the nearby existing NF. Additionally, the different uses and services provisioned through these TAFS were analyzed and reported.

Materials and methods

Study area

The study was conducted in three different TAFS i.e. the piper-based AFS (PbAFS) and pineapple-based AFS (PAFS) in Southern Assam and HG in the Lushai Hills of Mizoram, NEI. The two study regions fall under the same agro-ecological regions (humid and per-humid ecosystem).

The southern Assam, also popularly known as Barak valley, experiences a warm and humid climate with a mean temperature ranging from 13 to 37 °C and a mean annual rainfall of 2508 mm. The study was conducted in and around five ethnic villages, viz.

(i) Roskandy (24°42'13.17"N, 92°41'24.82"E), (ii) Meshipur (24°40'18.55"N, 92°41'00.15"E), (iii) Baghbahar (24°35'38.45"N, 92°41'11.83"E), (iv) Saiselpunjee (24°49'12.84"N, 93°03'16.87"E) and (v) Hmarkhawlien (24°47'37.20"N, 93°02'04.35"E). The first three villages are inhabited by the Khasi tribes that practice the PbAFS, while the other two villages are by the Hmar tribes that practice the PAFS. Both these TAFS are very distinct in terms of their management practices, and with the initiatives of the ethnic groups, these systems are traditionally managed for more than five decades at an elevation ranging from 21 to 116 m asl.

In the Lushai Hills of Mizoram, four villages viz. (i) Durtlang (23°47'45.69"N, 92°43'50.05"E), (ii) Sairang (23°48'37.00"N, 92°39'11.27"E), (iii) Selishi (23°47'59.82"N, 92°43'55.73"E) and (iv) Tanhril (23°44'15.22"N, 92°40'20.97"E) abundantly practices the HG that are included in this study. Lushai Hills (Fig. 1) is known to have the most variegated hilly terrains in entire Eastern India and experiences a pleasant climate characterized by cool summer (20 to 32 °C) and moderately cool winter (11 to 21 °C) with a mean annual rainfall of 2500 mm.

Sampling and data collection

Before site selection, information on the different ethnic tribes and their farming practices, associated knowledge on tree uses, etc. was gathered. We selected three ethnic groups practicing the TAFS, i.e. the Khasi (Pnar) and Hmar tribes of southern Assam and Mizo tribes of the Lushai Hills, Mizoram. Geo-coordinate readings of the TAFS sites and the landscape altitude were recorded using hand-held Garmin GPS. Additionally, the farm owners were interviewed for information about the farming practices' age, uses, and services of the different tree components, and their associated management strategies by targeting primarily the older-aged family members. The trees were classified into different 'use categories' and 'ecosystem services' classes based on the farmers' context in which they are being used. The trees were further grouped into native and exotic origin categories based on local and scientific knowledge. The representative landscape images of the different TAFS examined in the study regions are shown in Fig. 2.

The study was carried out from September 2020 to March 2021. A total of 32 TAFS plots and their ten nearby NF (control) plots were randomly selected for the study. The vegetation compositions within the sites were subjected to quantitative analysis by laying a uniform sampling quadrat size of 31.62 m x 31.62 m (∼0.1 ha). A minimum of 10 % of the area was sampled in each AFS by laying quadrats in the field randomly covering a dense to sparse part of the vegetation. All the tree species were identified in the field with local vital informants' help. Species not identified in the field were identified with the help of the Botanical Survey of India/flora of NEI. Plant individuals within the studied quadrats with ≥10 cm CBH (the circumference at breast height) were measured at 1.37 m from the ground for analysis. The CBH was measured using a diameter tape. In multi-stemmed trees, the tree's equivalent diameter was calculated as the square root sum of each stem measured at 1.37 m (Snowdon et al. 2002).

Data analysis

The collected field data were subjected to quantitative analyses for their phytosociological characters, floral diversity indices, and AGB stock estimation. Tree vegetation data was analyzed for basal area, density, frequency, abundance, relative density, relative frequency, relative abundance, and importance value index (Curtis and McIntosh 1950; Phillips 1959). The biodiversity indices were calculated using the following equations (Table 1).

The species diversity index (S_{Di}) value initiates from 0 and reaches a maximum of 1 with an increase in the species number (Odum 1971). Shannon–Wiener diversity index (H) value is highest when the individual number of all species is equal; the value 0 indicates the presence of only one species (Michael 1984). Margalef's index (R) is greater in populations that include a greater number of species (Margalef 1958). Simpson's diversity index (D) value of 1 indicates no diversity and 0 represents infinite diversity. This index is thought of as neither intuitive nor logical, so to overcome this problem, the value of D is generally subtracted from 1 to derive the dominance of Simpson's index (D'). The D' with greater value represents greater sample diversity where the maximum index value is 1 (Magurran 1988). Species Evenness index (E) assumes a value ranging between 0 and 1 where the
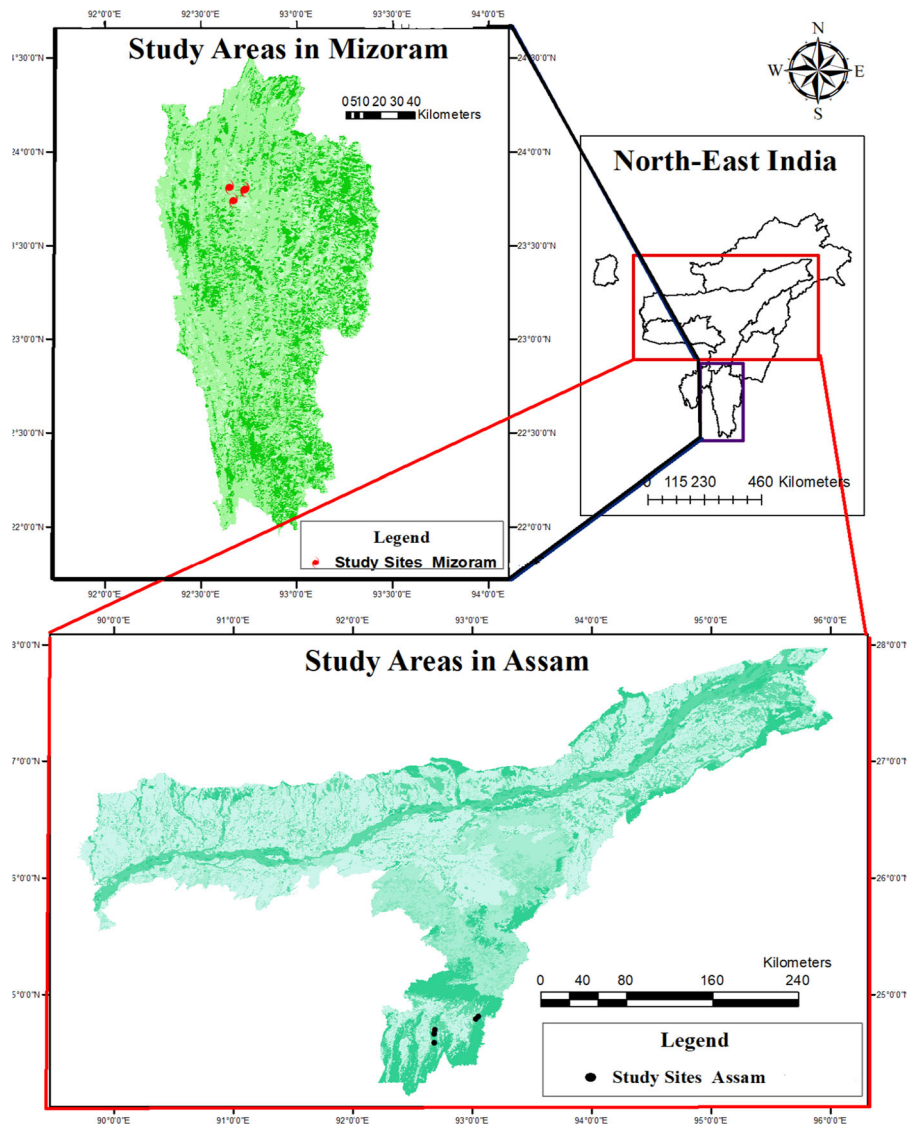
Fig. 1 Map of the study area showing the sites selected from the NEI states of Assam and Mizoram

value of 1 being complete evenness (Pielou 1966) and is also referred to as Shannon's equitable index.

In NEI, widely used generalized models for estimating biomass have rarely been validated by ground-truthing. Further, different species-specific models have restricted their application for biomass estimation in the NEI's multispecies forest ecosystems. Thus, the AGB was calculated using the NEI's biomass equation, which was developed using the measured baseline data from the region (Nath et al. 2019).

$$AGB_{est} = 0.18DBH^{2.16} \times 1.32 \qquad (1)$$

where, AGB_{est} = above ground biomass (kg tree^{-1}).

DBH= diameter at breast height.

1.32= correction factor.

Areca palm biomass was estimated using the model developed from NEI by Das et al. (2021).

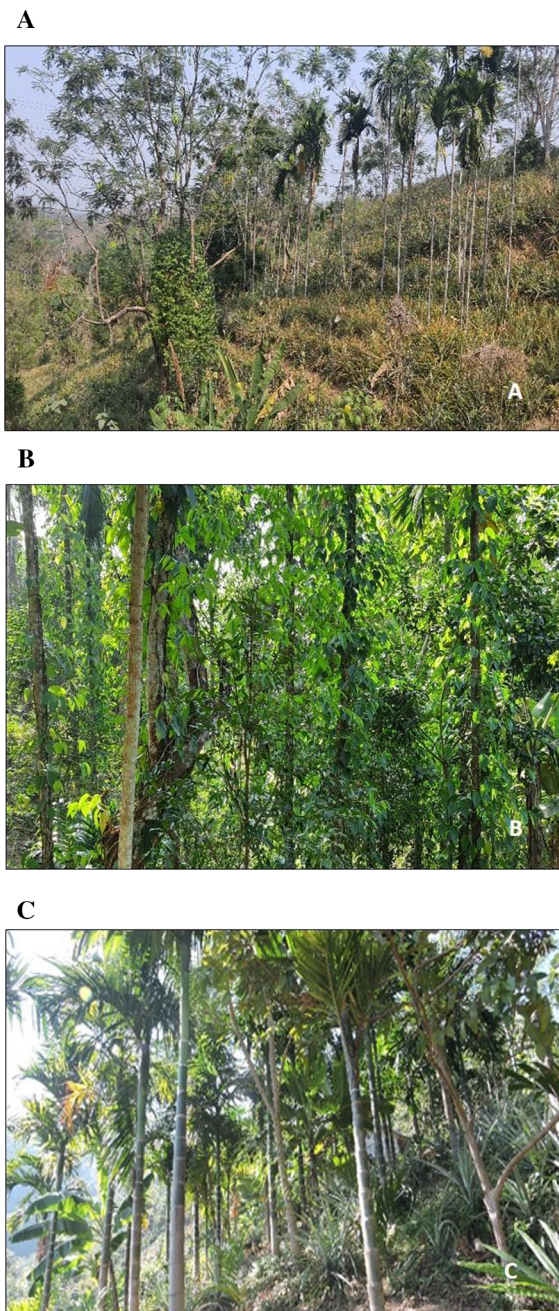$$AGB = \exp(-1.853 + 0.728 * \ln DBH^2 h) * 1.074 \qquad (2)$$

Fig. 2 Traditional agroforestry systems in southern Assam **a** Pineapple agroforestry system and **b** Piper agroforestry system and Mizoram **c** Home gardens

where, AGB is the biomass stock (kg plant^{-1}), Ln is Natural log, DBH is diameter at breast height, h is the plant height, and 1.074 is the correction factor.

Biomass storage in the *Musa* sp. was estimated using the model developed from North-East India by Laskar et al. (2020)

$$AGB = \exp(-4.54 + 0.874(\ln DBH^2 hp) * 1.06 \quad (3)$$

where, AGB is the biomass stock (kg plant^{-1}), Ln is Natural log, DBH is diameter at breast height, hp is pseudo-stem height, and 1.06 is the correction factor.

The plant height of *Areca* and *Musa* was measured in the field using a Hypsometer.

Results

Tree density, basal area, and importance value index

The lists of sampled species for different agroforestry systems and natural forests are given in (Supplementary Table 1a-e). In the present study, the stand density (stems ha^{-1}) in the TAFS was recorded highest in the PAFS (1225), followed by PbAFS (990) and least in the HG (399), while the stand density in the NF of Southern Assam and Mizoram were 1290 and 905 stems ha^{-1}, respectively (Table 2). Among the TAFS, the total basal area was in the order of HG (33.79 m^2 ha^{-1}) > PbAFS (24.87 m^2 ha^{-1}) > PAFS (16.85 m^2 ha^{-1}). The estimated basal area was 49.91 m^2 ha^{-1} and 21.95 m^2 ha^{-1} for NF of Mizoram and Southern Assam, respectively.

Based on the values of IVI, the most dominant tree species in the HG is identified as *Areca catechu* (8.94), co-dominated by *Citrus macroptera* (7.01) and *Psidium guajava* (6.51). In the PbAFS, the most dominant species is *Artocarpus chama* (15.66), co-dominated by *Ficus racemosa* (14.15) and *Litsea accedens* (11.5), and the PAFS was dominated by *A. catechu* (87.22), *Albizia procera* (41.41) and *Parkia timoriana* (37.57). In the NF of Southern Assam, the most dominant species is *Palaquium polyanthum* (62.76), co-dominated by *Polyalthia simiarum* (19.35) and *Ziziphus rugosa* (17.95). In the NF in Mizoram *Oroxylum indicum* having IVI 34.66 dominated the stand, co-dominated by *Quercus oblongata* (26.81) and *Helicia excelsia* (16.93). Other conspicuously dominant species in both TAFS and NF of southern Assam and Mizoram are presented in Fig. 3.

Table 1 The list of equations used to estimate biodiversity indices of the sampled vegetation

Equation no.	Biodiversity indices	Formula	References
1	Species diversity index	$S_{Di} = \frac{S}{N}$	Odum (1971)
2	Shannon-Wiener's diversity index	$H = \sum_{i=1}^{n}(p_i ln p_i)$	Michael (1984)
3	Shannon's maximum diversity index	$H_{max} = ln(S)$	Kent (2011)
4	Margalef's species richness index	$R = \frac{(S-1)}{ln(N)}$	Margalef (1958)
5	Simpson's diversity index	$D = \sum_{i=1}^{n} pi pi$	Magurran (1988)
6	Dominance of Simpson's index	$D' = 1 - D$	Magurran (1988)
7	Pielou's species evenness index	$E = \frac{H}{ln(S)}$	Pielou (1966)

Where, H: Shannon–Wiener's diversity index

N: total number of individuals of all the species

pi: number of individuals of ith species/total number of individuals in the samples

n: is the number of individuals of each species

S: total number of species

Table 2 Comparative account of the phytosociological attributes and biodiversity indices in TAFS and NF of Mizoram and Southern Assam, North-East India

Vegetation attributes	Mizoram		Assam		
	HG	NF	PbAFS	PAFS	NF
Stand density (stems ha^{-1})	399	905	990	1225	1290
Number of species	112	51	91	15	26
Total basal area (m^2 ha^{-1})	33.79	49.91	24.87	16.85	21.95
Highest IVI species	*Areca catechu* (8.94)	*Oroxylum indicum* (34.66)	*Artocarpus chama* (15.66)	*Areca catechu* (87.22)	*Palaquium polyanthum* (62.76)
S_{Di} index	0.03	0.14	0.09	0.06	0.2
H index	4.38	3.16	3.89	1.79	2.71
H_{max} index	4.72	3.93	4.51	2.70	3.21
R index	13.55	8.48	13.04	2.54	5.14
D index	0.02	0.07	0.03	0.22	0.11
D′ index	0.98	0.92	0.96	0.77	0.88
E index	0.99	0.80	0.86	0.66	0.83

Species richness and Biodiversity indices

A total of 112, 91, and 15 tree species were found in HG, PbAFS, and PAFS respectively. Compared to the total number of species observed in the NF in the two regions, the HG (51 against 112 species) in Mizoram and PbAFS (26 against 91 species) in Southern Assam represented a higher number of tree species (Table 2).

In the TAFS, the H index was highest in the HG (4.38), followed by PbAFS (3.89) and least in PAFS (1.79), while H indexes of 3.16 and 2.71 were recorded for Mizoram and southern Assam NF, respectively.
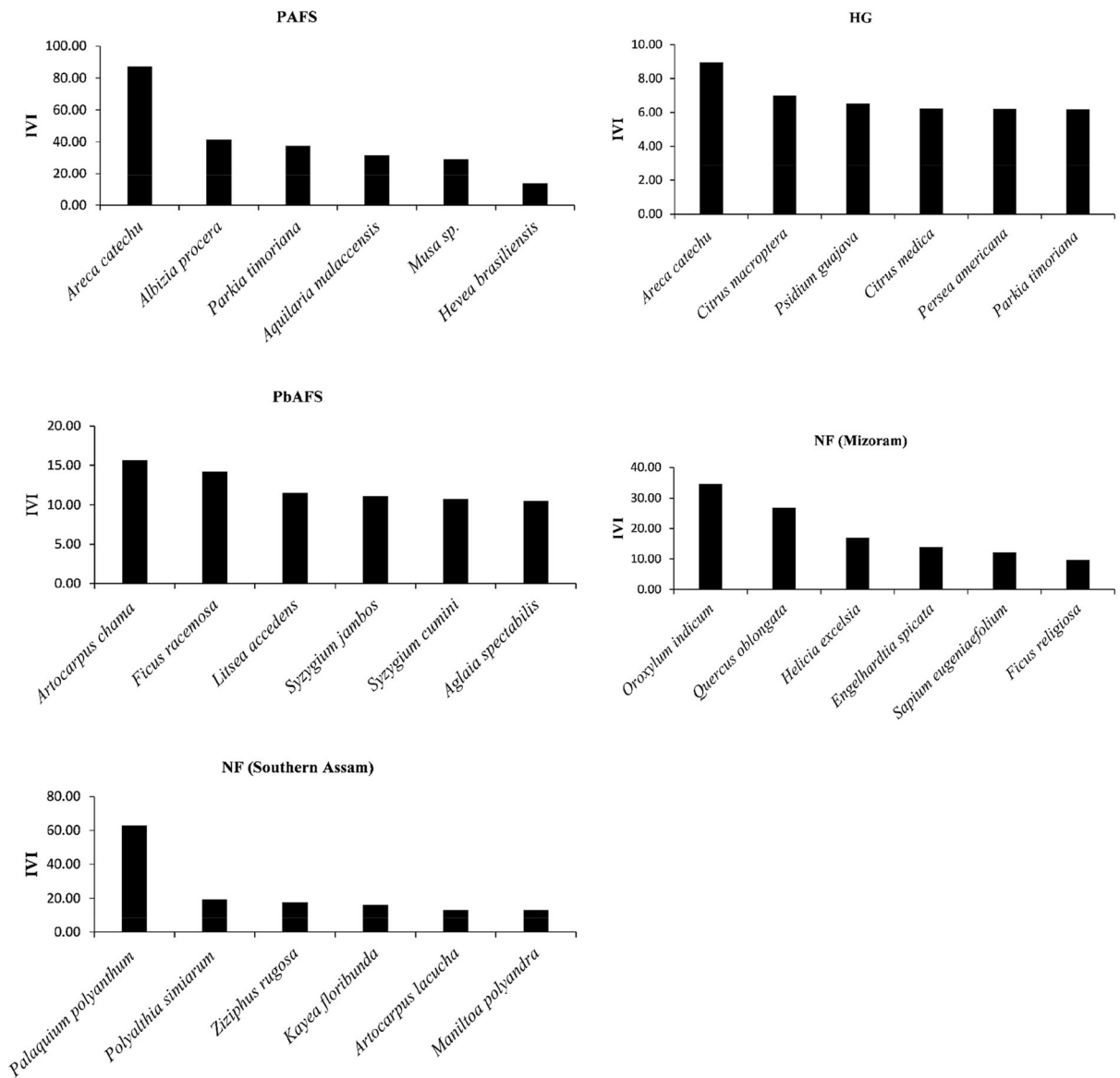
Fig. 3 Dominant species in TAFS and NF of Southern Assam and Mizoram, North-East India

Likewise, the R index was highest in the HG (13.55) and PbAFS (13.04), and relatively low (2.54) for PAFS. The E index of 0.99 estimated in HG was close to complete species evenness, while in the other two TAFS, the evenness index (E) value was comparatively lower i.e. 0.86 and 0.66 (PbAFS and PAFS, respectively). On the other hand, the E index value for NF was 0.80 and 0.83 in Mizoram and southern Assam, respectively. Similarly, the other biodiversity

indices recorded in different systems are presented in Table 2.

Uses and ecosystem services under TAFS

Farmers reported uses and services provisioned from managing tree species under TAFS are analyzed and described. Out of the total tree species in a system, we

Fig. 4 Number of tree species (in percent) under farmer's different uses categories in the TAFS
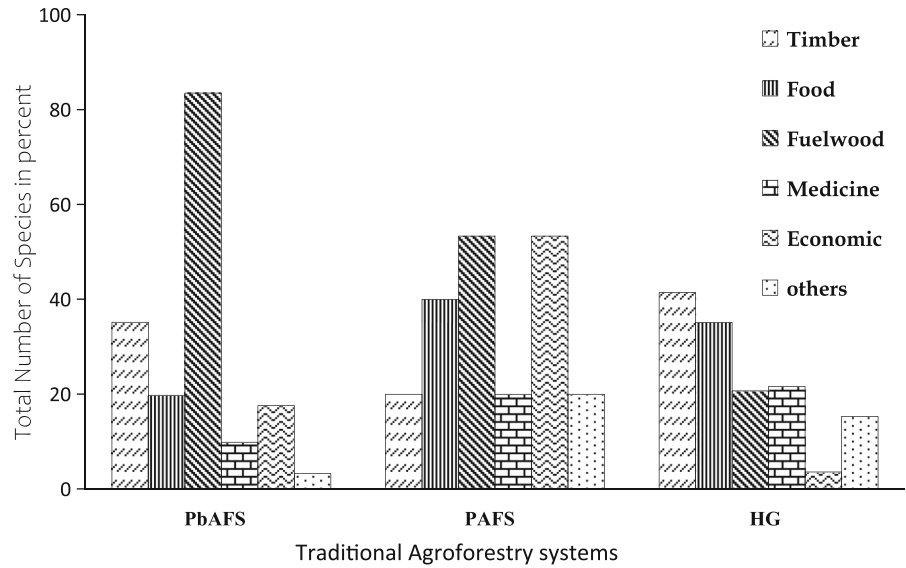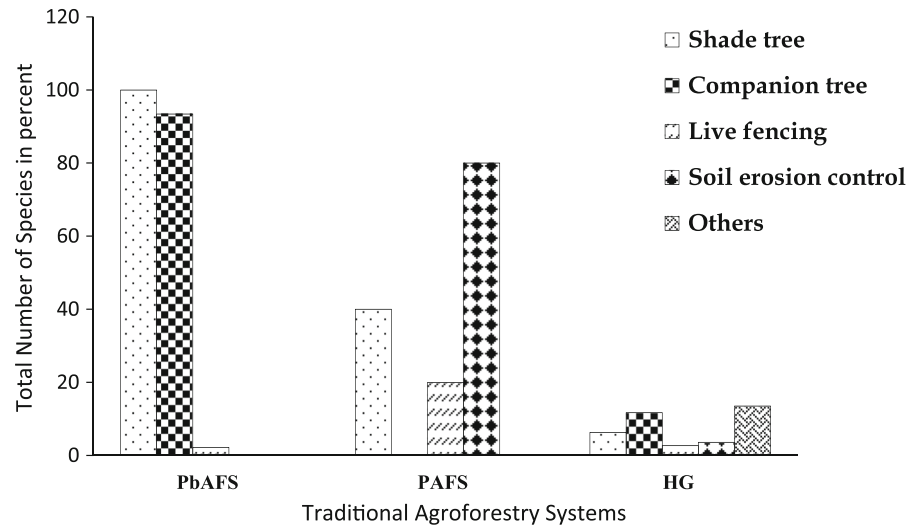

Fig. 5 Number of tree species (in percent) under different environmental services in the TAFS

present the proportion of these species being reported for different uses and services in percent. As such, some tree species provide multiple uses and/or services, while others are of less importance to the farmers.

In the present study, the various uses documented are classed as - food, timber, medicine, fuelwood, economy, and others (ornamental, fodder, fiber, charcoal preparation, etc.). Among the various use classes, fuelwood was the essential product contributed by most tree species (84 %), followed by timber (35 %) from PbAFS. In the PAFS, the majority of the tree species provided economic benefits (53 %) and

Table 3 Biomass storage in the ethnic agroforestry systems in North-East India

Location	Land uses	Biomass stock (Mg ha^{-1})
Assam	PAFS	43.25
	PbAFS	129.35
	NF	108.97
Mizoram	HG	117.32
	NF	270.72

fuelwood (53 %), followed by food (40 %) needs. While in the HG, 41 % of the tree species were reported to provide timber and 35 % for food requirements (Fig. 4).

The different environmental services documented include; shade trees for other understory crops, companion trees, live fences, soil erosion control, and others (windbreaks). With respect to environmental services provisioning, all tree species within PbAFS were reported to be used as shade trees (100 %), and 93 % of these species were managed as companion tree species. A companion tree is a host tree that is managed by farmers to grow other crops, e.g. trees used as supporting structures for growing the betel vines. In the PAFS, most tree species (80 %) were reported to aid in soil erosion control, followed by tree species for providing shade (40 %). In the HG, the majority of trees fall under the 'others' (14 %) and 'shade' (12 %) categories. In PbAFS, all tree species were of specific environmental service use and therefore there was no 'others' category reported. Similarly, no 'companion tree' category was reported in PAFS (Fig. 5).

Above ground biomass storage

In Southern Assam, the highest biomass storage was observed under PbAFS (129.35 Mg ha^{-1}) (Table 3). The PAFS stored 60 % less biomass stock in comparison to NF of Assam. In contrast, the PbAFS stored 19 % more biomass than that under the NF of Assam. The biomass storage in HG in Mizoram was estimated at 117.32 Mg ha^{-1} that is 57 % lower than the biomass storage value of NF of Mizoram.

Discussion

Agroforestry systems have the potential to fulfill economic, social, and environmental goals through optimized land productivity (Ahmad et al. 2018). Carbon sequestration, soil enrichment, biodiversity conservation, and improvement in air and soil quality are four major ecosystem services delivered by AFS (Jose 2009). These systems optimally ensure the *in-situ* conservation of native tree species (de Souza et al. 2012). Therefore, information on the

phytosociological attributes is vital for effective management in terms of economic value, regeneration potential, and conservation of biodiversity (Wyatt-Smith 1987; Verma et al. 1999).

Phytosociological attributes and biomass stock under TAFS

The basal area of any ecosystem is influenced by the size of the tree components, species composition, and growth pattern (Condes and Del-Rio, 2015). In Southern Assam, the basal area in PbAFS is more than that of PAFS and NF. Nandy and Das (2013) reported similar findings in a comparative study between PbAFS and NF in the region. In the present study, the estimated basal area in NF was slightly lower than the reported values in the region by Borogayary et al. (2018). Higher basal area in the PbAFS is attributed to the traditional management regimes. PbAFS involves the cultivation of the betel vine in a near-natural environment where the crop is raised under the shade of forest trees without tree removal. This in turn not only provides enough shade requirement for crop growth but retention of the trees also results in providing other ecosystem services like higher biomass/carbon accumulation. The farmers plant trees in the forest gaps under this traditional system as a means of local flexibility and for optimum LU so that the system results in increased overall basal coverage. This is a good example of how the farmers in the region use local wisdom in utilizing their land resources most judiciously. On the contrary, the PAFS farmers prefer growing small to medium-sized trees like *Areca* palm (*Areca catechu*) and agarwood (*A. malaccensis*) to allow optimum light penetration for the understory crops. The nature of the tree and its growth characteristic determine the basal area and therefore PAFS has a lower basal cover than PbAFS. Saikai and Khan (2014) similarly reported a very low basal area (6.01 m^2 ha^{-1}) for tree species in agar-based AFS in Assam. In comparison to their estimates, the tree species under the PAFS had a higher basal area for Southern Assam. The basal area in the HG of Mizoram was much higher than the two TAFS (PbAFS and PAFS) of Southern Assam. Mizo HGs are characterized by high tree diversity often associated with drawing numerous ecosystem services from these systems. Mizoram is a frontier state in the landlocked NEI, as a result, the farmers introduce a variety of tree

species (both local and exotic) in their HG to ensure food and nutritional security (Sahoo 2009). Over the years, many of these tree species have attained large girth size and thereby exhibiting higher basal cover. Overall, the basal area under the different studied systems (TAFS and NF) in Southern Assam and Mizoram was within the reported range for the tropical dry evergreen forest of peninsular India, Tamilnadu (Mani and Parthasarathy 2006).

The stand density in the NF was higher than the TAFS in both study regions. Anthropogenic interventions and management practices are reported to hugely influence stand density in plantation and modified agroecosystems (Schall and Ammer 2013). Hence, the comparatively lower stand density in the TAFS is attributed to selective felling for making ways for other useful species unlike NF (Reang et al. 2021). Among the TAFS, stand density under the PAFS was more than that of PbAFS and HG. Debbarma et al. (2015) reported that the density and frequency of a species indicate farmers' desire and intensity for a preferred species. It was obvious that higher tree density in the PAFS was to supplement farmers' additional requirement for soil enrichment through fast leaf decomposing traits of many of the tree species that are grown under this system, and thus the choice for higher species domestication. The PAFS farmers primarily prefer the growing of *Areca*, bean tree, Agar, and rubber species to other trees. These tree species have a straight trunk and small to moderate girth size characteristics, thereby allowing farmers to grow more numbers of individuals within farmlands, resulting in high stand density. Another reason is the reduced spacing while planting the individuals. For example, *Areca* is planted at ~ 2 m spacing in comparison to other commercially grown tree species in southern Assam (Brahma et al. 2018).

The IVI value of tree species reflects a species' dominance in a community (Parthasarathy and Karthikeyan 1997). The IVI identified *P. polyanthum* as the most dominant species in the NF of Southern Assam. Borogayary et al. (2018) reported *P. polyanthum* as the most dominant species in this region. In contrast, the dominant species in PbAFS were represented by *A. chama*. Interestingly, the three most dominant tree species present in the NF and PbAFS differed even though the latter is a system commonly practiced in NF lands. In essence, *P. betel* is generally grown as a subordinate crop mixed with forest trees to

derive economic and other ecological benefits from the resultant interaction. On the contrary, the dominant species in PAFS were represented by *A. catechu, A. procera*, and *P. timoriana*. PAFS is a traditional farming system solely practiced for economic generation. Hence, the naturally growing forest trees are least preferred and are gradually replaced by economically important species (*A. catechu*), and hence represent as the dominant species. While, co-dominance of the naturally growing tree species, *A. procera* in the PAFS is due to the species being retained to provide shade for a certain period during the early phases of pineapple growth. On the other hand, edible fruit trees (*A. catechu*, *C. macroptera* and *P. guajava*) managed for sale and household consumption hugely represented the most dominant species in the Mizo HG. Comparing the IVI values of the TAFS and their nearby NF in both the study regions reveals noteworthy observations. The three most dominant species in the TAFS were not of similar species to their nearby NF. On the contrary, one dominant species (*A. catechu*) was found similar in the TAFS of these regions (HG and PAFS).

The present study revealed that HG accommodated 101 indigenous and 11 exotic species, PAFS housed 12 indigenous and 3 exotic species, while PbAFS did not have any exotic species (Supplementary Table 1). Among the studied TAFS, species richness was highest in the HG, followed by PbAFS, and the least was recorded for PAFS. Lesser tree species number recorded in the PAFS attributes to the management practices/choice of species for domestication as discussed earlier. On the other hand, management processes under the HG and PbAFS involve retaining forest tree species and additionally growing more trees in gaps, therefore higher species richness. However, the present study estimated a lower number of species in the HG than the previous report for HG in Mizoram (Barbhuiya et al. 2016) and Southern Assam (Das and Das 2005). While the estimated number of species under PbAFS was recorded higher than the previous report for PbAFS in Southern Assam (Nandy and Das 2013).

The present study showed a higher H index in two TAFS (HG and PbAFS) than their nearby NF. In addition, the estimated H index of HG and PbAFS was higher than the values for tropical evergreen forests reported by previous workers in Southern Assam and Mizoram (Nandy and Das 2013; Borogayary et al.

2018; Wapongnungsang Ovung et al. 2021). The above findings highlight that traditionally managed systems potentially help in conserving the local biodiversity of these regions. Das et al. (2020) similarly reported that plant diversity indexes in the TAFS are more diverse than most tropical and subtropical ecosystems in the region.

Biomass storage in the TAFS falls within the range reported from India and elsewhere (Nath et al. 2021). However, the figures we provide are likely to underestimate TAFS actual biomass storage, as we have not included belowground biomass and the biomass storage of other associated herbs and shrub species. The lower biomass storage in the PAFS is due to the dominance of *Areca* and *Musa* sp. that stores low biomass stock due to their growth pattern. Overall, the TAFS holds excellent potential for creating carbon sinks and mitigating emissions from agriculture while also increasing adaptive capacity (Nath et al. 2021; Reang et al. 2021) and providing other potential non-climate benefits.

Uses and Ecosystem services

TAFS is an important component in the livelihoods and economy of the poor in rural areas (Roy et al. 2013). We encountered some introduced exotic species (Supplementary Table 1a and Ic) in HG and PAFS which are now naturalized, being acclimatized in the systems over several years. Among the introduced species *Borassus flabellifer, Callistemon lanceolatus, Delonix regia, Grevellia robusta* being ornamental are introduced in the agroforestry to provide better aesthetic and recreational look; *Litchi chinensis* to provide better fruit yield; *Cassia javanica* for diverse medicinal use; *Hevea brasiliensis* for higher economic return; *Eucalyptus globulus* for meeting fuelwood requirement. The presence of these trees on farms increases the ecological and aesthetic value of these landscapes and has important economic value for the farmer (Sheppard et al. 2020). They are reported to produce higher output more sustainably than forestry or agriculture in isolation (Lehmann et al. 2020) and provide important products like fuelwood, timber, fruit, etc. to meet the owners' household needs (Roy et al. 2013). The TAFS in the study regions has different uses starting from food security, medicines, and cash to construction materials. Amongst the various reported use classes, the majority of the tree

species under PbAFS met fuelwood and timber needs as the system is primarily composed of forest trees. In the HG, food and timber requirements were derived from the majority species. Therefore, a larger number of fruit-bearing trees are represented in the HG. Das and Das (2005) reported that HG is more of a food-producing farming system where fruits for food form the dominant use component. On the contrary, most tree species domesticated and managed under the PAFS met farmers' economic requirements. Hence, a larger proportion of the tree components under PAFS are represented by economically important species, such as *A. catechu, A. malaccensis, P. timoriana, H. brasiliensis*, etc. In Assam, the price of a single *A. malaccensis* tree was reported to vary from US$ 3.00 to US$ 800.00 or even US$ 2000.00 based on its resin quantity, highly valued for its medicinal, incense, and perfumery properties (Saikia and Khan 2014; Nath et al. 2020). Another example is the bean tree, *P. timoriana*, where a single plant is said to generate approximately US$ 100.00 to 200.00 per annum (Rocky et al. 2004). Besides improving the financial status, *P. timoriana* is also drawing enormous attention among the ethnic farming communities in NEI because of its high nutritional value, adaptability to grow in different agro-climatic regions, and uses for firewood and lumber (Singha et al. 2021).

Aside from delivering the day-to-day livelihood goods and services to the farmers, TAFS plays a vital role in provisioning environmental services resulting from farmers' interaction and management. In the PbAFS, all the tree individuals were reported to provide shade and some among these were managed to act as companions or hosts for growing the primary crop (*Piper betel*). Interaction with the farmers reveals that species with high bark fall characteristics were the ones discarded for use as companion species. While in the PAFS, the majority of the tree species are managed to reduce soil erosion through *Areca* and *Musa* plantations distributed within and on the farm boundaries. From the above findings, it is evident that tree domestication in the TAFS not only increases green cover but also provides a myriad of benefits.

Conclusions

The present study demonstrates the importance of traditional agroforestry systems in conserving

biodiversity and its role in biomass accretion. Tree species that are not found in the wild due to overexploitation are conserved largely under these traditional farmlands. Further, we found that traditional agroforestry suffices a wide array of day-to-day needs and additional multiple environmental services. The study focused only on tree species, however, there are myriads of crop species that are grown in the agroforestry systems which support the farmers' food and nutritional security that additionally, needs to be studied for their role in eradicating poverty and resolving multiple environmental crises. The species-specific biomass estimation models or the volume equation for estimation of biomass were not available for many of the native tree species grown in the biodiverse-rich ethnic agroforestry systems. We suggest future studies to estimate the carbon storage potential of these systems precisely using species-specific equations so that the role of ethnic agroforestry systems in mitigating the current climate change is better understood while acting as *in-situ* conservation sites for many native endangered species like *Aquilaria malaccensis* and *Borassus flabellifer* in the region.

Conflict of interest The authors declare that they have no conflict of interest.

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