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Piper agroforestry in the Indian Himalayas: indigenous peoples' practices, policies and incentives

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Abstract

Background Indigenous populations across the world play a significant role in sustainable land management and conservation of biodiversity. However, indigenous agricultural practices are rarely studied in depth and remain poorly documented in many regions of the world. Documenting such practices and identifying policies and incentives that affect them can unlock their potential for better land management and biodiversity conservation.

Methods We undertook household surveys and focus group discussions to document indigenous practices and the values of trees in Piper (*Piper betle*) agroforestry practiced by the ethnic Khasi (Pnar) community in the Indian Eastern Himalayas. We also undertook an in-depth vegetation sampling to quantify variations in phytosociology and tree diversity with stand age in Piper agroforestry and nearby native forests. In addition, we undertook strengths, weaknesses, opportunities and threats (SWOT) analysis and a desk review to identify policies, market support structures and incentives affecting cultivation of Piper, a cash crop of global importance.

Results Unlike in shifting cultivation, indigenous people do not fell trees in the Piper agroforestry; instead, they allow trees to regenerate naturally and also enrich by planting tree seedlings in the gaps. Depending on the stand age, 30–49 tree species were recorded in the Piper agroforestry compared to 39 in nearby natural forests. While tree density was higher in the natural forests, greater species richness, diversity and basal area was recorded in > 25 years old Piper agroforestry stands. However, landholders do not have legally transferable or heritable rights to the land or trees.

Conclusion It is concluded that the Piper agroforestry provides a pathway for averting land degradation due to shifting cultivation, biodiversity conservation and improving livelihoods of the indigenous community. Although existing policies are supportive, Piper agroforestry is not currently benefiting from incentives and market support structures. We recommend implementation of policies, market support structures, incentives and payment for ecosystem services so that indigenous communities can benefit from the global ecosystem services they provide.

Keywords Deforestation, Indigenous people, Nature-based solutions, Shifting cultivation, Sustainable development

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Background

Globally, a third of agricultural production occurs in sites of high conservation priority (Hoang et al. 2023). Hoang et al. (2023) showed how the production and consumption of 48 agricultural commodities conflict with conservation priorities for 7143 species. Agriculture is now a major driver of deforestation and habitat loss underpinning the global biodiversity crisis (Branthomme et al. 2023; Curtis et al. 2018; Hoang et al. 2023). According to Curtis et al (2018), close to 27% and 24% of global forest loss can be attributed to production of agricultural commodity and shifting agriculture, respectively. Indigenous populations across the world practice land management that can play a role in safeguarding the forest, the biodiversity therein and ecosystem services (Estrada et al. 2022; Fa et al. 2020; Fletcher et al. 2021; Garnett et al. 2018; O'Bryan et al. 2020). Some 370–476 million people fall under the category of indigenous populations (Estrada et al. 2022; World Bank 2022), representing a large proportion of the contemporary cultural diversity and over 3000 distinct languages and beliefs systems (Estrada et al. 2022). Until recently, indigenous natural resources management practices have remained underappreciated, rarely studied in depth and remain poorly documented. Indigenous populations are socially and culturally distinct, sharing ancestral ties with the natural resources in the areas they inhabit (World Bank 2022). Their identities, livelihoods, culture, and physical and spiritual well-being are intricately linked with the land and natural resources on which they depend (Estrada et al. 2022; Nath et al. 2022; Reang et al. 2022).

In India, the indigenous tribal populations account for over 84 million people, representing 8% of the total population (World Bank 2012). Most tribal people live in remote, forested and hilly areas and lack access to basic facilities (World Bank 2012; Giri et al. 2018). Tribal people in the Indian Eastern Himalayas exist in a harmonious relationship with the nature (Das 1996; Giri et al. 2018). Their vast indigenous knowledge plays an important role in natural resource management owing to their long-term experience (Giri et al. 2018; Nandy and Das 2013; Reang et al. 2022). More than 200 tribal communities inhabit the region (Giri et al. 2018). These tribal communities manage their natural resources in a diversifide and productive state using indigenous knowledge, cultural practices and religious beliefs (Giri et al. 2018; Reang et al. 2021a). The communities practice a variety of traditional agroforestry systems that vary depending on the region, but little is known about these varied practices (Giri et al. 2018; Raneri et al. 2021; Reang et al. 2021b, 2022).

These indigenous land managed systems have evolved as adaptive production strategies through years of farming experiences, and the knowledge and practices are orally passed down from generation to generation. In this study, we aim to gain a deeper understanding of Piper agroforestry, a popular indigenous practice by the *Pnar* communities. Originally, the tribe relied on shifting cultivation (also called slash-and-burn agriculture or swidden), which typically involves three phases: (1) slashing and burning forest patches, (2) cultivation for 1–3 years, and (3) land abandonment and fallow phases (3–20 years) (Laskar et al. 2021; Nath et al. 2022). Fire is the main tool in shifting cultivation, and it has immediate and direct impacts on soil properties (Laskar et al. 2021). This practice is ecologically viable if the fallow period is long enough (10–20 years) (Lal 2005), but full recovery of ecosystem properties may take up to 50 years. Shorter fallow periods invariably result in ecological imbalances (Laskar et al. 2021) including failure of forests to recover. The decrease in land availability and the deterioration of productivity have forced indigenous populations to convert land under shifting cultivation into a more productive and economically viable land use system. This has led to the evolution of various agroforestry systems, which involve a more sedentary agriculture than shifting cultivation (Reang et al. 2022). The practice under study involves an indigenous agroforestry system where *Piper betle* L. (Family: Piperaceae) is grown in association with live trees as support structures.

Piper betle is an economically and medicinally important cash crop widely distributed in East Africa and tropical countries of Asia (Nath and Inoue 2009; Nandy and Das 2013). It is cultivated in India, Sri Lanka, Bangladesh, Burma, Indonesia, Laos, Malaysia, Nepal, Pakistan, Vietnam, Taiwan, Thailand, Philippine Islands and other Southeast Asian countries (Biswas et al. 2022; Das et al. 2016; Haider et al. 2013). The leaves of *Piper betle* are widely used in Chinese and Indian folk medicine and also in religious ceremonies (Biswas et al. 2022). Various analyses have revealed that its leaves contain active ingredients with therapeutic value for treating various medical conditions in humans (Biswas et al. 2022; Das et al. 2016). Its leaves are primarily used as a mouth freshener, while leaf extracts are used in oral care, pharmaceutical products and cosmetics (Biswas et al. 2022). Its leaves are consumed annually by 15–20 million Indians and 2 billion people globally (Biswas et al. 2022; Das et al. 2016), particularly in the Gulf States, South and South-east Asia, and the Pacific islands (Nath and Inoue 2009; Nath et al. 2016). The plant is grown on over 55,000 ha lands (Das et al. 2016), with an annual production value of US$84–120 million (Berry 2021; Biswas et al. 2022). Over 20 million people in India earn a living from betel production (Guha 2006). According to the Agricultural and Processed food products Export Development Authority

(APEDA), 6,159.4 metric tons of betel leaves worth about US$3.6 million was exported from India in 2020/21.

The traditional Piper agroforestry (Piper agroforestry hereafter), locally known as *paan jhum*, is one of the indigenous practices developed by the ethnic *Pnar* community in North-Eastern India. Information is lacking on the indigenous practices and socio-economic constraints including tenure rights, markets and incentives for Piper agroforestry in the Indian Himalayan region. Understanding farmers' practices and constraints such as tenure, markets and incentives can help in developing evidence-based policies supportive of sustainable land management. The importance of tenure security for investing in agroforestry and other sustainable land management practices has been widely documented in India and elsewhere (Choudhury 2015; FAO and ICRAF 2019; Goswami 2015). According to Choudhury (2015), the wellbeing of communities dwelling in forest in the Eastern Himalayas depends not only on the security of their land rights, but also on their ability to use shared natural resources. Tree rights often differ from the land rights (Fortman 1985). When compared to people with temporary claims to the land, landowners usually have more favorable tree rights (Fortman 1985). Very little information exists on land and tree tenure in relation to agroforestry in the Indian Eastern Himalayas. Therefore, the objectives of this study were to: (1) quantify variations in phytosociology and tree diversity with stand age; (2) document the traditional management practices and the different uses and services of trees; and (3) identify policies and incentives affecting Piper agroforestry in the Indian Eastern Himalayas. The key hypotheses being tested here are: (1) Piper agroforestry managed by indigenous people guarantees conservation of native forests threatened by shifting cultivation; (2) indigenous management practices in Piper agroforestry encourage the maintenance of tree diversity; and (3) current policies, market structures and incentives do not adequately support Piper agroforestry.

Materials and methods

Study area

The study was carried out in Machipur, an ethnic Khasi (*Pnar*) village in the Cachar district of Assam in North-eastern India (24°40′25.13′′ N, 92°40′57.89′′ E) (Fig. 1). The district occupies an area of 3786 square kilo meters. The elevation ranges from 22 m asl in the east to 1657 m asl in the north (Reang et al. 2022). The study area is part of the Indo-Burma Center, a hotspot of biodiversity located in the foothills of the Himalayas. The region is characterized by undulating terrain, hillocks, broad plains, and low-lying waterlogged areas (Nandy and Das 2013). The Barak is the principal river draining in the area (Reang et al. 2018). The average annual rainfall is about 2290 mm, and the average temperatures range between 13.5 and 34.5 °C, with mean annual relative humidity of about 76% (Reang et al. 2022). The two most common soil types are sandy clay loam and sandy loam, both of which belong to the Barak series and are classified as Inceptisols according to the United States Department of Agriculture (USDA) classification. The soils correlate with Cambisols in the World Reference Base for Soil Resources (WRB) classification and correlation system (IUSS 2014). The vegetation is classified as Cachar tropical evergreen forest and semi-evergreen forest, which is dominated by a variety of floral entities.

To gain an in-depth understanding of the indigenous knowledge on Piper agroforestry and its traditional management, we undertook a detailed study in the Machipur village inhabited by the Khasi (*Pnar*) tribes. We deliberately chose the village because of certain important aspects; (a) it is easily accessible; (b) it is one of the oldest villages with agroforestry management in the area; (c) every household practices the Piper agroforestry; (d) the village lacks basic facilities; and (e) farmers mainly depended on the Piper agroforestry for livelihoods. The total area under the settlement is approximately 1.2 square kilo meters. and the total village population is estimated at 228 people belonging to 48 households.

Our study focused on the indigenous '*Pnar*' community commonly known as "Khasia" or "Khasi" in the study region. Khasi is a term that means, "born of the mother" (Bareh 1967). The *Pnar* are also known as "Synteng or Jaintias", chiefly distributed in the "Jaintia Hills" of Meghalaya, North-Eastern India, which is locally known as "Ka Ri Ki Khadar Doloi", literally meaning the land of 12 kingdoms (Jaiswal 2010). The *Pnar* have their own dialect known as "Mon-Khmer" group of Austric languages, which differs from those spoken by the other Khasis (Tyagi 2000). They constitute one of the rare communities in the world where matrilineal system still thrives (Bhutia and Liarakou 2018).

The *Pnar* tribes bear a history of migration dating back to 1905 to the southern part of Assam and became prominent inhabitants of the region (Sajem and Gosai 2006). However, information on the *Pnar* community is scanty. The actual population is unknown due to lack of census data. According to the Khasi-Jaintia Development Council Demand Committee, the population of Khasi-Jaintia is more than 1.70 million in over 375 villages in Barak valley of southern Assam (MeghalayaNews24 2020). They are primarily settled in the forest and rely on forest resources for their survival. Shifting cultivation (locally called *jhum*) is the most common type of agriculture in the North-Eastern India region for decades. It was once practiced by the *Pnar* population (Bareh 1967). Over time, many tribal groups like the *Pnars* have transformed

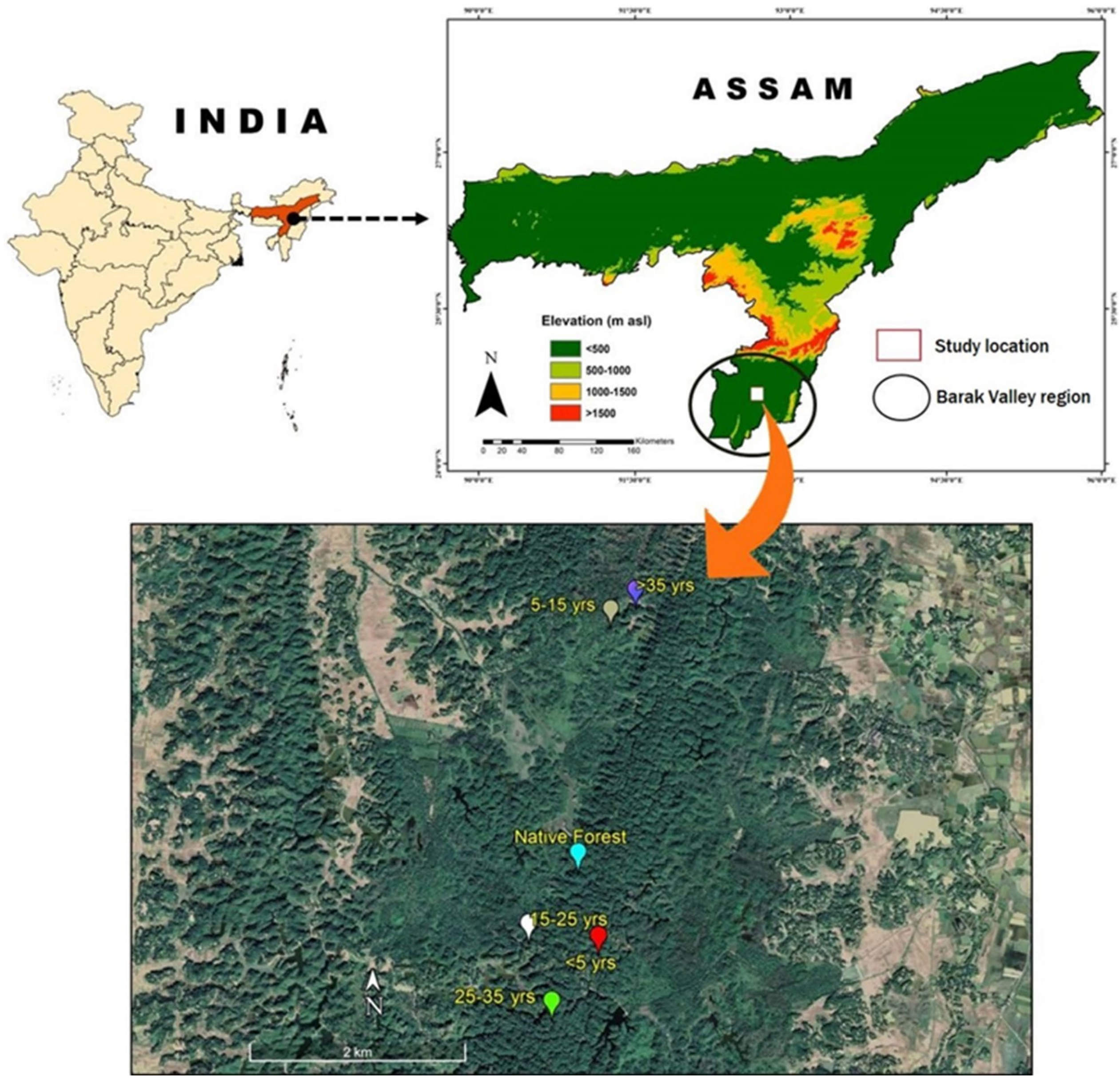

Fig. 1 Map showing location of the study area and sampled sites

shifting agriculture land to high-value cropping systems like agroforestry and other market-oriented sustainable tree-crop systems (Saxena et al. 2005; Reang et al. 2022).

Household surveys and focus group discussions

Initially, a pilot survey was conducted in the study village with prior permission of the tribe's Headman. Using the preliminary data, a close-ended questionnaire was developed, pretested, and adjusted before the final questionnaire was produced (Dutta and Hazarika 2020). The questionnaire covered social status, means of subsistence, and the existing farming systems. Then, the questionnaire was administered during face-to-face interviews with 40% of the household in the village. The face-to-face interviews eliminated the issues with incomplete questionnaires and/or respondents misinterpreting the questions (Neuman 2006). Both male and female respondents were considered in the process. However, we primarily intended to interview the oldest member of the household owing to their long farming experiences. However, in households where the oldest family member was not present, responses were obtained from the available eldest adult member of the household.

Focus group discussions were conducted in the surveyed village with open-ended questionnaire for about three hours (Cavestro 2003) to document farmers' management practices. Ten residents were selected to participate in the focus group discussions in consultation with the Headmen, based on their ability to provide reliable and relevant information. The respondents included the Headmen (village Chief), other village members and representatives of women from the village. The discussions were related to land preparation and planting activities, harvesting and processing of leaves, Piper diseases and their management, and the local uses and services of the agroforestry trees.

Vegetation sampling

We carried out vegetation sampling in Piper agroforestry and nearby native vegetation during the dry months of October 2021–February 2022. Twenty-four plots, each measuring 0.1 ha (31.62 m × 31.62 m) were sampled, covering different aged stands of Piper agroforestry and a nearby natural forest. Four plots were laid under each of the different Piper agroforestry stands (< 5 years, 5–15 years, 15–25 years, 25–35 years and > 35 years) and natural forest. The locations of the different sampled stands are presented in Fig. 1. The owners of the farms and the elderly villagers provided age estimates for the stands. However, we anticipate considerable overlap in the stand ages, particularly for older stands whose owners are unable to pinpoint the exact year of planting. Therefore, we defined the age of a particular stand as time period between the initiation of betel cultivation and the survey date. For instance, a stand of 5 years old indicates that the farm has only recently begun planting vines at the time of the survey in October 2021.

Then, vegetation sampling was conducted in the chosen stands where all live trees with a circumference at breast height (CBH) of more than 10 cm were measured at a height of 1.37 m from the ground. For trees with several stems, the equivalent diameter of the tree was determined by adding the 1.37 m square roots of each stem (Snowdon et al. 2002). Finally, local flora guides and online data sources were used to identify plant species. The conservation status of the tree species was assessed with reference to the International Union for Conservation of Nature (IUCN) red list.

Data analysis

The socioeconomic survey data were summarized into binary responses (coded as 0 and 1) and entered in Microsoft Excel worksheets. The vegetation data collected were analyzed for quantitative characteristics, including basal area, stem density, frequency, abundance, relative density, relative frequency, and relative abundance. Additionally, several species diversity indices and the importance value index (IVI) of tree species were calculated. The procedure outlined by Mishra et al. (2013) was used to determine the IVI of the tree species. The IVI of a species indicates how dominant it is in a community (Parthasarathy and Karthikeyan 1997). The species diversity is one of the most important metrics to determine the health and sustainability of the forest community (Sarkar and Devi 2014). The species diversity of the various stands was quantified using the following indices:

Shannon–Wiener's diversity index (H) = $-\sum_{i=1}^{n}(p_i \ln p_i)$ (Michael 1984).

Margalef's species richness index (R) = $\frac{(S-1)}{\ln(N)}$ (Margalef 1958).

Species evenness index (E) = $\frac{H}{\ln(S)}$ (Pielou 1966).

where N stands for the overall total of all the species, pi for the number of individuals of ith species/total number of individuals in the samples, and S for the total number of species.

Strengths, weaknesses, opportunities and threats (SWOT) analysis

We carried out SWOT analysis of the Piper agroforestry to identify internal enhancers of competence, valuable resources, or desirable traits under "Strengths," and the internal inhibitors of the success-critical competence, resources, or attributes under "Weakness." We listed external performance enhancers under "Opportunity" that can be explored or taken advantage of. We also identified external performance barriers under "Threats" that may lower success (Leigh 2009). Based on the farmer's responses and the author's field observations, we compiled the SWOT factors.

Finally, we reviewed policy documents relating to agriculture, forestry and agroforestry focusing on land and tree tenure. The term "tree tenure" refers to a set of rights that apply to trees, including the rights to grow trees, own or inherit trees, utilize trees and their products, dispose off trees, and exclude others from using trees (Fortman 1985). Land tenure refers to the relationship that people and groups have with regard to land and resources found on it, such as trees, minerals and water.

Results

Characteristics of the land manager, farm size and land tenure

Men made up 59.2% of the population with primary literacy skills, 4.1% with high school credentials, and 2% with bachelor's degrees. On the other hand, 54.4% of

Table 1 Vegetation attributes and diversity indices under traditional Piper agroforestry systems and nearby natural forest stand in Cachar district, Assam, North-Eastern India

Parameters	Piper agroforestry stand age (years)					Natural forest
	< 5	5–15	15–25	25–35	> 35	
Plantation cycle	1	1	2	3	4	–
Piper production status	No	Yes	Yes	Yes	Yes	–
Stand density (stems ha^{-1})	860	930	1010	1130	1020	1170
No. of species	30	34	35	39	49	39
Total basal area (m^2 ha^{-1})	13.1	22.6	28.7	30.4	42.8	29.0
Shannon–Wiener diversity index (H)	3.02	3.03	3.04	3.35	3.65	3.14
Margalef richness index (R)	6.51	7.28	7.37	8.04	10.38	7.98
Species evenness index (E)	0.89	0.86	0.85	0.92	0.94	0.86

females were literate at the elementary level, 8.7% at the high school level, and 2.2% at the higher secondary level. People with no literacy made up 34.7% of the male population and 34.8% of the female population.

The *Pnar* families lease lands from the revenue or the forest department to use for farming. The area of privately owned land was on average 0.40 (± 0.63) ha. In contrast, the area that the forest and revenue department leased to the farmers ranged from 0.26 to 5.35 ha. Private home gardens were maintained by all households on an average area of 0.29 (± 0.46) ha.

Management of land for home gardens was widespread among the households. One of the most crucial components in home gardens is areca nut (*Areca catechu*), which is valued primarily for sale and domestic consumption. Areca nut sales ranged from 1.32 to 2.62 US dollars per kilogram. The Piper agroforestry system provided farmers with average monthly revenue of 132 US dollars. In addition, raising cattle and selling agricultural goods from a home garden added the family's profits. The *Pnar* raised animals such as chickens (37.50%), pigs (31.26%) and cows (28.13%) more than goats (3.13%) ($\chi 2 = 8.875$, df = 3, $p > 0.01$).

Land acquisition for farming is often granted through customary rights. The *Pnar* community prefers forest land for the betel cultivation, and families lease land from the revenue department or the forest department. Land acquired from the revenue department is processed through an annual patta (land deed) system where landholders do not have legally transferable or heritable rights but only possessory rights. Under the Assam Forest Policy, a permit is issued by the forest department per household for a specific area and time. In addition, there is a restriction on harvesting of timber from forested land. The major disadvantage is the clarification of boundaries that can initiate land disputes. Additionally, when larger plots are split, it can lead to land fragmentation, rendering them too small to support agroforestry. There is no operating statutory tree tenure. However, the *Pnar* community is strongly influenced by the customary rules over their livelihood. Traditionally, the rights to a tree belongs to the person who planted it. In some cases, certain trees may be designated by customary laws for use by everyone in the community, while other trees may be privately owned. Apart from timber, farmers can harvest firewood, fruits and fodder from their Piper agroforestry practice inside the forest.

Species richness, diversity, evenness and conservation status

From the studied plots, including the Piper agroforestry system and the natural forest stands, a total of 104 tree species in 38 different families were identified (Additional file 1: Table S1). Piper agroforestry > 35 years old stand had the highest tree species (49), which was higher than nearby native forests stand (39). About the same numbers of tree species were present in both the natural forest and the 25–35 years old Piper agroforestry stand (Table 1). The Shannon–Wiener Index, Margalef richness, and evenness in the agroforestry stands ranged from 3.02–3.65, 6.51–10.38, to 0.89–0.94, respectively. Notably, as the agroforestry stands matured, their biodiversity increased, with the oldest stands having the highest biodiversity index values. Furthermore, those over 25 years had diversity comparable or even superior to native forest stands (Table 1). Across all the Piper agroforestry stands, 102 tree species in 38 families of flowering plants were identified (Additional file 1: Table S1). Members of the family Fabaceae (10.5% of all families) dominated the tree species in the Piper agroforestry, followed by Moraceae (6.7%), Myrtaceae (6.7%), Meliaceae (5.7%), Malvaceae (4.8%), and Lauraceae (4.8%). In terms of conservation status under the IUCN categories, 46.8% of the tree species are classified as least concern, 3.8% do not have sufficient data, while 43.8% have not been assessed. Three species, namely, *Aquilaria malaccensis*, *Dipterocarpus turbinatus* and *Dimocarpus longan* were listed as Critically Endangered, Vulnerable and Near Threatened, respectively. It is worth noting that *A. malaccensis* and *D. turbinatus* were exclusively found in the older (mostly in > 35 years old) stands. Conversely, *D. longan* was present in stands aged 5–15 and 15–25 years, and also in the > 35 years stand (Additional file 1: Table S1).

Indigenous management practices in Piper agroforestry

The different management practices compiled from farmers' responses and personal field observations are briefly summarized below. The *Pnar* typically chose sites with light crown forests to facilitate proper amount of shade during betel cultivation. Farmers clear densely forested patches, leaving only the trees and a few tall shrubs to provide shade and support for the betel vines. To improve the soil nutrient content, the trimmed twigs, leaves and branches are left to dry in agroforestry stands. Contrary to traditional shifting cultivation, fire is not used during any part of the field preparation. For planting more betel vines, farmers encourage tree saplings to grow and reach desirable heights (often 4–5 m). In the process of preparing the land, they pollarded trees and then plant betel vine cuttings at the base of the pollarded trees. Pollarding makes it possible for enough sunlight to penetrate the forest canopy, which is critical for the growth of new vines (Fig. 2A).

The *Pnar* use fresh stem cuttings from healthy vines as planting material. They typically choose soft and green vines older than three years for cuttings. They discard pale, yellow and hard cuttings because they believe that shoots take longer to emerge. Two, four, or six branched cuttings with lengths of about 30 cm, 50 cm, and 80 cm are employplanted, depending on the girth size of the support tree. Cuttings are prepared by making a slanted incision above the node using a sharp knife, and cuttings are planted on the same day they are prepared. In some situations, they preserve cuttings in a cool, wet environment with one node submerged in moist, well-drained soil. According to the farmers, the ideal time for planting betel vines is the monsoon season (May to August). Farmers typically prepare 20 cm × 20 cm × 30 cm planting pits at a distance of about 12 cm from the support tree. The planting methods ensured that at least two cutting nodes will remain underground, and one node will remain above ground. Cuttings do not require nurturing until new shoots emerge after 20–30 days. Planting grounds are kept clear of weeds during this phase. In some cases, betel vines tend to creep on the ground at initial growing stage. Therefore, farmers frequently use bamboo prepared ropes to attach these vines to the supporting trees. There is no use of manure or other fertilizers. Weeding is carried out on average twice annually and the weeded vegetation is used for mulching to retain soil moisture and enrich soil nutrients. Due to sufficient rainfall in the region, farmers do not commonly water the vines. However, in adverse conditions, watering is manually done.

There is restriction on felling of trees inside the Piper agroforestry. Fast-growing trees such as *Lagerstroemia speciosa, Aglaia spectabilis, Bombax ceiba, Spondias pinnata, Toona ciliata, Neolamarckia cadamba, Duabanga grandiflora* are planted if production is high in the specific site. Planting additional tree species in the farms results in higher number of tree individual growth (Fig. 2B). However, tree species that shed their bark were typically cut down and not favored for use as support trees. With proper management, farmers reported the productive life span of betel vines to be about 10–15 years. Both male and female members of the tribe are involved in various operations and tasks. Male members were primarily engaged in preparing the planting pit, preparing cuttings, planting, weeding and plucking betel leaves. While females were mainly engaged in mulching, binding, sorting and packing betel leaf.

The harvest operation starts after 2–3 years of planting, as the vine attains a height of at least 2 m. Betel leaves are harvested during the months of June–August, as high precipitation accelerates production of betel leaves. To gather betel leaves from tall trees, farmers construct a special type of ladder from a single mature bamboo stalk (Fig. 2C). Male family members generally engaged in the plucking of betel leaves, but sometimes when required, the farmers hired additional labour for plucking. With the onset of first monsoon (April–May), fresh leaves emerge from the vines which are generally small and soft. Farmers typically gathered relatively matured hard leaves during this time. From June to August, betel leaf yield reaches its peak. During this time, farmers only keep two to three leaves, removing all the leaves from the vines. Farmers pick leaves solely from the lowest part of the vines between September and November. Mid-November marks the beginning of the collection of betel leaves from the tops of vines, which lasts until December. From January to March, farmers remove every leaf remaining on the vines and remove less productive vines.

Freshly collected leaves are brought home and placed in simple bamboo baskets. To maintain freshness during storage, the fresh betel leaves are placed over banana leaves and sprinkled with water. After that, the leaves are sorted and bundled for sale (Fig. 2D). To tie bundles of the sorted leaves, farmers use a shrub called *Molineria*

Fig. 2 **A** pollarding of support trees during farm preparation; **B** 5–15 years Piper agroforestry stand; **C** harvesting of betel leaves using bamboo ladder; **D** Sorting and packing of betel leaves for sale

capitulata, which grows on their farms. Betel leaves are available for sale in the market as *mora* consisting of 336 leaves, or as *kuri* 6720 betel leaves. An average of 250,000 betel leaves are produced annually per hectare.

The most serious diseases of betel are leaf rot and root rot. Leaf rot disease appears with spots on the leaves in the early stage. The spread of the disease turns the vines brown, causing it to rot and slowly die. Leaf rot disease can occur throughout the year; however, severe spread of the disease is common during high rainfall and humid condition. As an immediate preventive measure, farmers uproot all infected vines and bury them far away from the farm. Root rot disease appears on the stem and destroys the vines within a week. Farmers observed that the diseases could be spread through other creepers, insects, birds, monkeys, and other animals or even through human intervention. Farmers uproot the infected vines and bury them far away from the farmland and keep the land fallow for 3–5 years. After cleaning the infected farmlands, farmers usually wash their tools and take

Table 2 Importance value index (IVI) of dominant and co dominant species in traditional Piper agroforestry and a nearby natural forest stand

Stand age (years)	Dominant species	IVI	Co-dominant species	IVI
< 5	*Ficus racemosa*	33.6	*Litsea accedens*	26.6
			Pterospermum acerifolium	24.3
5–15	*Artocarpus chama*	37.4	*Ficus racemosa*	26.6
			Litsea salicifolia	24.5
15–25	*Ficus racemosa*	36.5	*Syzygium cumini*	26.6
			Schleichera oleosa	20.7
25–35	*Syzygium cumini*	25.6	*Syzygium cumini*	26.6
			Artocarpus chama	16.7
			Syzygium nervosum	14.9
> 35	*Pterygota alata*	17.7	*Syzygium cumini*	13.8
			Aglaia spectabilis	13.8
Natural forest	*Litsea accedens*	38.5	*Syzygium nervosium*	24.8
			Syzygium fruticosium	18.0

a bath with warm water. According to the farmers, frequent disease infestation means severe economic loss to the family. In addition, farmers believe ant eggs laid at the base of newly emerging vines, nodes and roots result in rotting roots. Therefore, farmers immediately clean the ant eggs or discard the vines as a remedy.

Stand density, basal area and importance value index

In comparison to the Piper agroforestry stands, the natural forest showed a higher stand density. The lowest tree density was recorded in five years old stands (860 stems ha^{-1}), and the highest in stands that were 25–35 years old (1130 stems ha^{-1}). Compared to the natural forest, stands older than 35 years had a greater basal area (42.83 m^2 ha^{-1} over 28.99 m^2 ha^{-1}). Basal area increased with stand age in the Piper agroforestry system (Table 1).

Analysis of the importance value index revealed differences among stand ages of the Piper agroforestry (Table 2). *Ficus racemosa* was the dominant species in < 5 years old and 15–25 years old stand. *Syzygium cumini* and *Pterygota alata* were the dominant species in the 25–35 years old and > 35 years old stands, respectively. The nearby natural forest was dominated by *Litsea accedens* and co-dominated by *Syzygium nervosium* and *Syzygium fruticosium*. Figure 3 shows the top five dominant tree species for the various land use types.

Tree species richness and density (Fig. 4a) across the different girth classes showed identical trends to a certain degree in all the study plots. Lower girth classes (under 30–40 cm) had a rising trend. As girth classes increased, richness and density share gradually decreased. In comparison to the natural forest, there were more individuals in the > 120 cm girth class in the Piper agroforestry stands. In < 5 years old stands, the majority of individuals (35%) were in the 30–40 cm girth range, whereas in the subsequent stands, the majority were in the 20–30 cm girth range (Fig. 4). The highest basal area was recorded in the girth class > 120 cm, with the exception of the < 5 years old stands that had the highest basal area in the 30–40 cm girth class (Fig. 4b).

Uses and services of trees in Piper agroforestry

Tree species in Piper agroforestry have multiple roles and substantial economic value to farmers. Here, the ecosystem services provided by Piper agroforestry are classified as shade, support (companion) tree, soil fertility, live fencing, fuelwood, fodder, timber, food, cash crop, medicinal and others (religious and biodegradable leaf plate) (Fig. 5). Among the tree species reported by farmers, 99% of the species were used as shade trees for growing betel crop, and 87.3% of the species were managed as companion or supporting structures for betel vines. Tree species belonging to the family Fabaceae accounted 3.9%, and these species were reported to have soil fertility improvement benefits. About 83.3% of the species were reported to be used for fuelwood. Timber tree species accounted for 60.8%, while 11.8% of the tree species produced fodder for livestock. Wild fruits consumed as food were gathered from about 24.5% of the tree species in the Piper agroforestry. Fruit trees provide supplementary nutrition to households and played an important role as secondary sources of income. Fruits and other parts (e.g., leaf, bark, roots) of some tree species also served as the source of traditional medicine. For example, extracts from fruits of *Terminalia chebula* and *Syzygium cumini* are used to cure jaundice and dysentery. A list of the uses

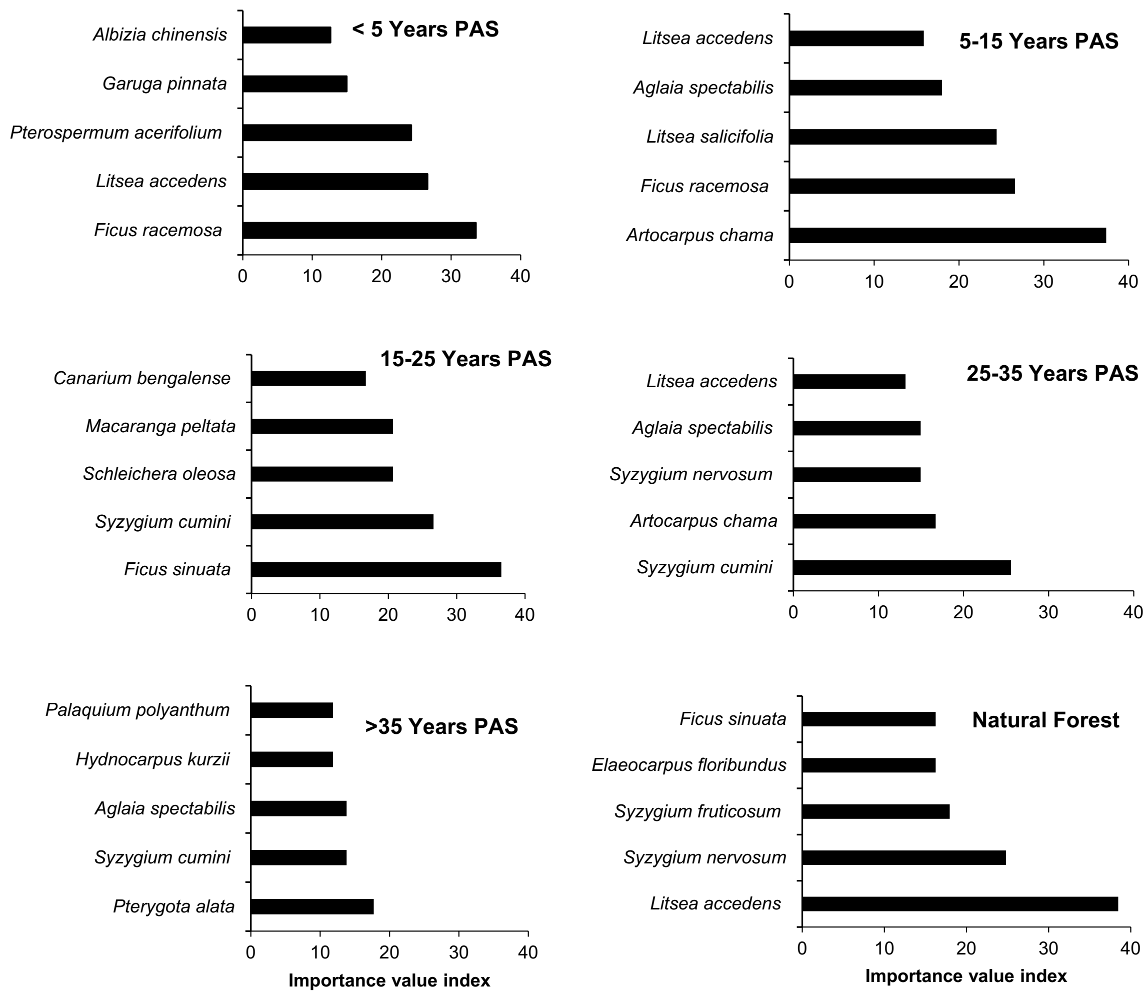

Fig. 3 Variations in tree species dominance based on the importance value index (IVI) in the different Piper agroforestry stands and a nearby natural forest

and services provide under the Piper agroforestry system is presented in Additional file 1: Table S2.

Strengths, weaknesses, opportunities and threats

The SWOT analysis results are presented in Table 3. The strengths and opportunities represent the enhancers of the system and/or the positive performance of the Piper agroforestry system. In contrast, the weaknesses and threats represented the negative components of the system adoption in the area, thereby needing policy improvement and decision-making by local governments/organizations. The key strengths of Piper agroforestry were that it is deeply rooted in indigenous knowledge, it is low-input, and that it provides multiple environmental benefits and is a strong reliable source of income for the local farmers. However, the farmers lack of technical knowledge, and the absence of other alternatives and marketing system were among the major weakness of the system in the region. Other inhibitors (threats) of the system performance include the incidence of diseases, no external support during crop failures, and the sudden change in local climate.

Policies, market support and incentives

Review of the existing policy documents identified the following policies relevant to the study: (1) National Forest Policy of 1988, (2) the Forest Act of 1980, (3) the Forest Rights Act of 2006, (4) the Assam State Forest Policy 2004 and (5) the National Agroforestry Policy of 2014. The National Forest Policy 1988 is supportive of restoration of forested landscapes to a state where it can provide benefits such as biodiversity conservation, disaster risk mitigation and livelihood enhancement. The Forest policy also regulates the diversion of forestland for non-forestry purposes and provides for compensatory afforestation. The Scheduled Tribes and other Traditional Forest

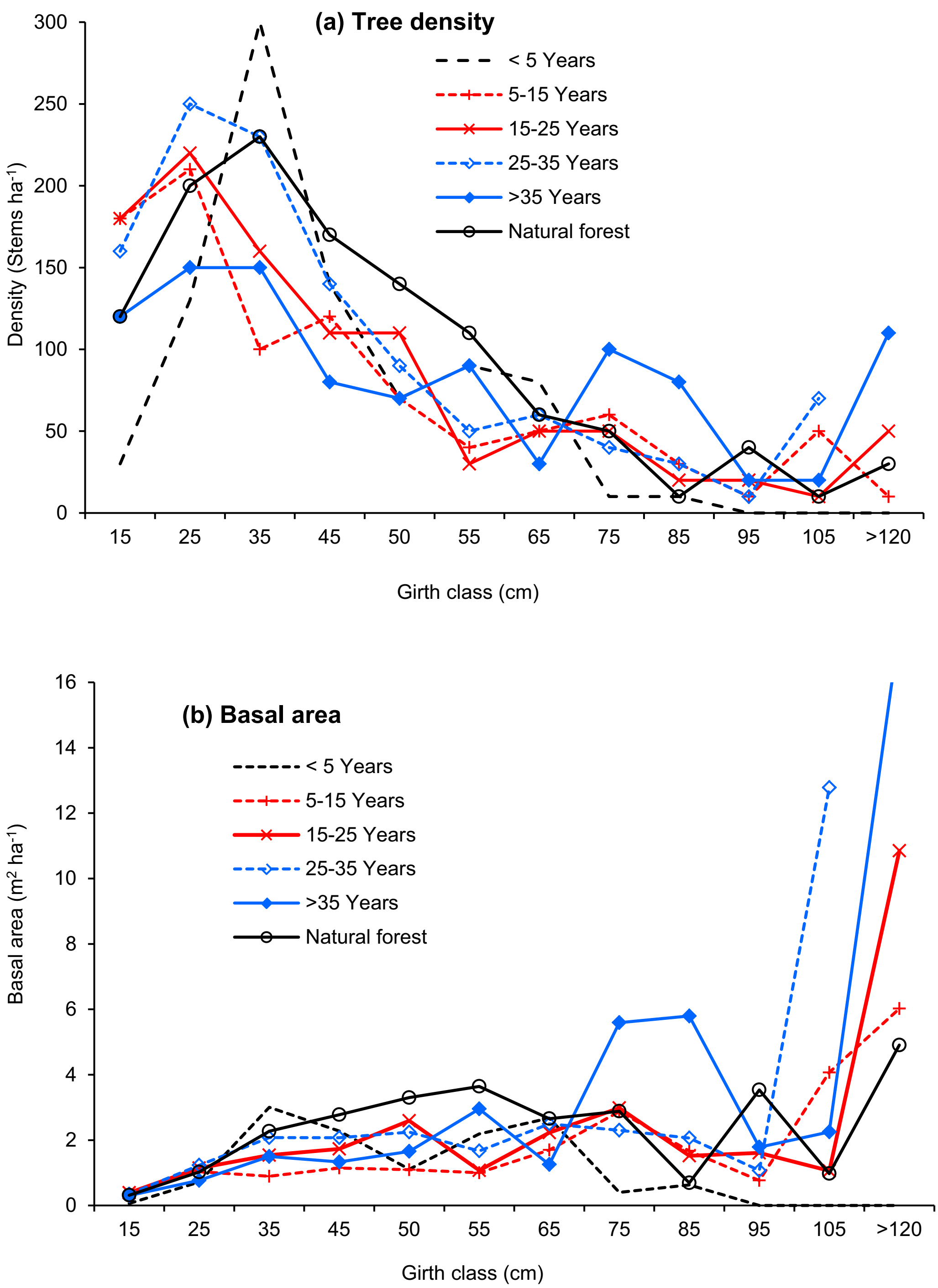

Fig. 4 Tree density (**a**) and basal area (**b**) distribution across different girth class in Piper agroforestry stands and natural forest

Dwellers under the Forest Rights Act of 2006 acknowledges secure land tenure as a crucial component of the success of an incentive-based policy aimed at preserving forests. For the residents of India's forest villages, this Act guarantees both individual and collective property rights, ensuring the security of land tenure. The act also gives forest communities a means of securing their livelihoods. The National Policy for Farmers (2007) is supportive of agroforestry. It acknowledges the limitations placed by the state governments on the collection and transportation of agroforestry products, particularly those that are found growing in the surrounding forests.

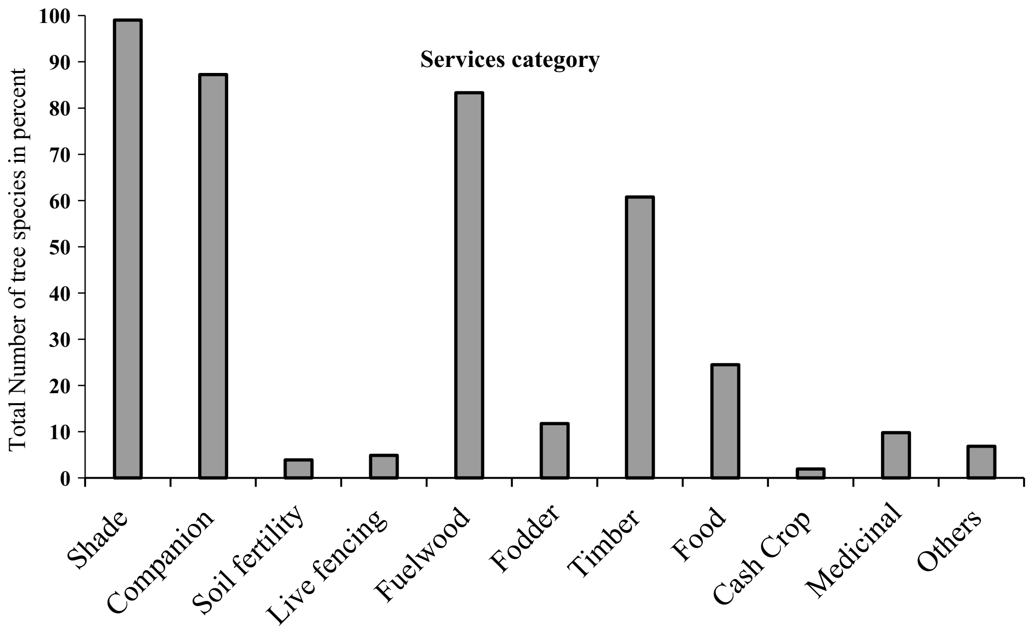

Fig. 5 Number of tree species (in % of total) in Piper agroforestry providing different functions and services

Table 3 SWOT analysis under the traditional Piper agroforestry adoption and management

	Strengths	Weaknesses
Internal	Based on indigenous knowledge	Lack of modern practices/techniques knowledge
	Low-input farming system	Farmers livelihood solely depends on Piper agroforestry
	Improved soil quality	No basic facilities for system improvement
	Farmers are hard workers and receptive	Lack of marketing system
	Conserves the local tradition and culture	Poor connectivity infrastructure
	Conserves local biodiversity and landscapes	
	Opportunities	**Threats**
External	Can be practised in fallow land or degraded forest lands	Local climate change and variability
	Provision for livelihood improvement	Disease and pest attacks
	Rural employment opportunities	Frequent natural hazards
	Scope for Research and development	Lack of external support during crop failure
	Supportive national agroforestry policy	Lack of incentives systems
	Good markets for betle	Insecurity of land and tree tenure
	ENHANCERS	INHIBITORS

It also acknowledges the burdensome and expensive process of acquiring permits for harvesting and transportation discouraging farmers from planting trees on farmlands. The Assam Forest policy encourages innovative community-based reforestation in forested areas as a means of rehabilitating land under shifting cultivation. It stipulates that forestry programmes will pay special attention to avoid the exploitation of tribal people, and proposes proper market development and establishment of a minimum price for important forest products. In addition, it proposes that this be done while safeguarding the customary rights and interests of tribal and scheduled castes who live in or near forests. The policy also suggests passing laws governing land use and tenure as well as an enabling environment. Nonetheless, such legislation has not yet been established by the time of writing this manuscript.

The marketing of betel leaf involves a complex chain of intermediaries. Farmers sell their product directly in the local markets or to an intermediary trader. In some cases, betel leaves are directly sold by producers to the retailer or in nearby weekly market. Local wholesalers buy betel leaves from farmers, who then sell the goods to retailers. The local wholesalers transport their products to district centres and sell them to agents from where betel leaves are distributed through district-level wholesalers and retailers. Occasionally, betel leaves are transported for sale to neighbouring districts and metropolitan cities like Guwahati, which is the business hub of northeast India. The betel leaf market is more profitable for intermediaries because of highly segregated markets and unequal bargaining power between buyers and sellers. The method of sale is traditional, non-transparent and coercive; intermediaries neither maintain documents nor issue receipts. Leaf productivity and prices vary between seasons. During January–March (winter season), the production of betel leaves is relatively low and prices are very high. From May to August (in-season), the price is low because of more production. The price of leaves per *kuri* ranges from 19.24 US$ to 89.80 US$. During the dry season (February and March), betel leaf prices are higher than they are in the other months. According to the farmers' report, per *kuri* price sometimes hits 192.43 US$ during the less productive periods.

The National Agroforestry Policy proposes creating incentives and support structures, such as input subsidies and an interest moratorium during the gestation period to promote agroforestry. Yet, the Piper agroforestry systems in the Indian Himalayan region lacks an incentive-based mechanism. In India, the minimum support price (MSP) for significant crops provides a floor for market prices. It assures that farmers get a certain "minimum" remuneration so that their costs of cultivation can be recovered during falls in market price. Therefore, MSPs creates the benchmark for farm prices in the case of market failure. However, such provisions are currently not available for indigenous agroforestry products. Piper agroforestry has also not benefited from mechanisms such as Reducing Emissions from Deforestation and Degradation (REDD+) and other payment for ecosystem services schemes.

Discussion

Unlike the conventional shifting cultivation, Piper agroforestry does not involve fire or clearing of entire forestlands for cultivation, but it is a sedentary form of land use. Piper agroforestry encourages regeneration of more forest tree species. The system is also protected and preserved with religious beliefs and taboos of the indigenous tribes (Nandy and Das 2013). Similar to India's sacred groves, the indigenous agroforestry practiced by the *Pnars* contributes to the conservation of rich diversity, as the system is culturally ingrained within these communities. Consequently, this practice fosters enhanced growth and regeneration of tree species within the system. In this study, tree species numbers, density and diversity were found to be higher in the agroforestry stands than in the nearby forest, and this was consistent with other reports from this region (e.g., Nandy and Das 2013; Reang et al. 2021b). For example, Nandy and Das (2013) reported slightly higher tree species richness (37–48 species) in Piper agroforestry compared to natural forests (32–42 species) in this region. In Bangladesh, Quazi and Ticktin (2016) similarly reported higher tree species richness and diversity in Piper agroforestry (51 species) compared to natural forests of the same age (45 species). A comparative study of tree diversity between four distinct agroforest systems and natural forests in Bangladesh revealed that Piper agroforestry not only exhibited higher diversity than the other agroforestry systems (14–26 species) but also higher diversity than natural forest stands (37 species) (Mukul 2016). These observations underscore the crucial role that Piper agroforestry systems play in preserving the biodiversity akin to natural forests. Beside plant diversity, Piper agroforestry also harbors a rich avian diversity, with some reporting higher diversity than in natural forests (Mukul 2016; Quazi and Ticktin 2016). As such, these indigenous systems could play a vital role in curbing the global decline in species diversity due to anthropogenic activities.

Certain management practices of the indigenous people appear to favor the presence of high tree densities and species richness in Piper agroforestry. For example, farmer assisted naturally regeneration of trees and the intentional planting of more trees in the gaps are noteworthy. The *Pnar* farmers also do not allow felling of trees inside Piper agroforestry, thereby allowing for more tree growths. On the other hand, native forests in the study are mostly degraded owing to poor forests management (Reang et al. 2018). Unlike in other communities in the eastern Indian Himalayas where monoculture stands of economically important such as *Tectona grandis*, *Hevea brasiliensis* and *Aquilaria malaccensis* are planted after clearing forest land, the *Pnar* utilize degraded forests for regenerating the land and enhancing household incomes without compromising ecosystem integrity. This highlights the significance of indigenous practices such as the Piper agroforestry in land restoration and biodiversity conservation where government and policies often fail to safeguard the local natural forest and its biodiversity.

The total basal cover and diversity increased with increase of agroforestry stands, with old stands (>35 years) recorded higher than nearby native forests. This findings are in agreement with other studies (e.g., Nandy and Das 2013; Reang et al. 2021b) reporting higher basal area and species diversity in the piper agroforestry compared to the native forests in this region. Although the natural forest had slightly higher stand density, species richness in older Piper agroforestry stands exceeded that of the natural forest. As mentioned elsewhere, the natural forests in the region have a long disturbance history that likely impacted their basal area and species richness. The observation that older Piper agroforestry stands have comparable tree species density to that of the native forests is a testament to the conservation potential of these systems. While species density is a vital component of biodiversity, other factors such as species evenness, functional diversity, and genetic diversity also play crucial roles. Within the Piper agroforestry stands, there was increase in basal area with increase in the age of the stand. Piper agroforestry is typically established on degraded leased lands and/or secondary forests. Such stands often exhibit a limited number of mature trees, with a more prominent presence of young saplings and small-sized trees. Consequently, younger stands were identified with lower values in terms of tree stands, biomass, and other phytosociological attributes compared to the matured or older stands. Additionally, older stands are commonly situated farther from settlements, which reduced their accessibility, and benefit from reduced collection of the forest products compared to more accessible locations.

The observed increase in basal area and species richness with the age of agroforestry stands is probably an outcome of the cumulative effect of enhanced nutrient availability, improved structural complexity, and efficient management practices that safeguard regeneration while minimizing detrimental disturbances. The older stands, having traversed through varied successional stages, embody a synthesis of ecological processes and human interventions, fostering a milieu where both basal area and species richness can flourish. With proper management and time, Piper agroforestry systems can not only mimic but also enhance the biodiversity seen in natural forests. Nonetheless, the highest basal area value (42.83 $m^2\ ha^{-1}$) recorded in our study was lower than the basal area (74.05 $m^2\ ha^{-1}$) reported by Nandy and Das (2013) for Piper agroforestry in the study region. But the basal area recorded in this study is higher than the basal area of 31.15 $m^2\ ha^{-1}$ reported in Piper agroforestry in Bangladesh (Quazi and Ticktin 2016).

The species diversity index in > 25 years old Piper agroforestry stands were higher than in the natural forest. Similar findings were reported for the Piper agroforestry in other areas of Barak valley (Nandy and Das 2013). According to Nandy and Das 2013, species diversity index ranged between 3.12 and 3.36 under the Piper agroforestry areas in other areas of Barak valley. Our findings show relatively higher diversity (H = 3.35–3.65) than the range of values reported in Nandy and Das (2013). We surmise that with time, more tree species grow in the Piper agroforestry, hence ensuring more diversity. Our findings also suggest that as the number of stems increases, more species are encountered (Table 1). This demonstrates a multi-species recruitment of individuals and also a more equitable distribution of individuals among species, both of which enhance species diversity. The importance value index reveals that tree species such as *Ficus racemosa*, *Artocarpus chama*, *Syzygium cumini* and *Pterygota alata* mainly dominated the Piper agroforestry stands. These species, prevalent throughout the region, also exhibit their dominance in the studied sites. Their dominance also reflects farmer choice of tree species that contribute a potential higher ecosystem services provisioning.

Only two species, namely, *Neolamarckia cadamba* and *Artocarpus heterophyllus*, found in the natural forests were absent in the Piper agroforestry. *Artocarpus heterophyllus*, commonly known as the jackfruit tree, possesses traits that inhibit the growth of betel vines. Its smooth bark lacks the crevices and roughness essential for vine tendrils or rootlets to secure a grip. When the tree is wounded or cut, it exudes a sticky latex, which can act as a deterrent to vines and creepers by hindering their adherence or potentially being toxic to the vines. The lush canopy of mature jackfruit trees casts a shadow on the understory, creating a challenging environment for growth due to diminished sunlight. Additionally, the abundant production and its pattern during the fruiting season can negatively impact distribution of betel vines and their overall yield. Furthermore, farmers in this region intentionally thwart the growth of vines on jackfruit trees to facilitate easy fruit access and minimize the risk of competition or pest infestations. This elucidates why jackfruit trees are commonly found in the home gardens of the *Pnars* yet are noticeably absent in the Piper agroforestry. The absence of the *Neolamarckia cadamba* (Kadamba tree) may be attributed to characteristics similar to those of the jackfruit tree. For example, the Kadamba tree, particularly when young, has smooth bark. Additionally, mature Kadamba trees can develop a dense canopy, among other traits. Some common species found in majority of the Piper agroforestry stands included *Artocarpus chama*, *Cynometra ramiflora*, *Ficus racemosa*, *Litcea accedens*, and *Syzygium cumini*. These species were more preferred by the farm owners resulting in their commonness within the agroforestry stands. In Bangladesh, the Khasi tribes were reported to prefer *Artocarpus chama* and *Areca catechu* as support trees for growing betel leaf (Haider et al. 2013). However, the *Pnar* farmers in our study area did not incorporate

Areca catechu into their Piper agroforestry farmlands. Nonetheless, *Artocarpus chama* was reported favorable by the farmers, and *Areca catechu* was observed to be common only in home gardens.

We documented three species i.e., *Dimocarpus longan*, *Dipterocarpus turbinatus* and *Aquilaria malaccensis* under the Near Threatened, Vulnerable and Critically Endangered categories of the IUCN, respectively. All three species were present in the Piper agroforestry, while only *D. longan* was found in the natural forest stand. Other studies have also reported *A. malaccensis* to be found only in traditional agroforestry (Reang et al. 2021a, b; 2022). This species is highly exploited in the region owing to its high economic value, consequently wiping out population in the natural forest in the region. In Assam, a single *A. malaccensis* tree is worth US$ 2000 based on its resin quantity (Reang et al. 2021b). This critically endangered species is conserved in the traditional agroforestry lands but is no longer found in the wild. As such, Piper agroforestry acts as conservation sites, possible due to the protection provided by the local communities. Anthropogenic pressure on the rare and threatened species reduces within agroforestry because there are entry restrictions. This characteristic facilitates better conservation of species and the local natural resources (Nandy and Das 2013).

Traditional agroforestry systems are more than just conservation sites; they can also act as carbon sinks providing societal and environmental benefits (Reang et al. 2021b). Cardinael et al. (2021) asserts that agroforestry can be a good solution to climate change mitigation and adaptation. The system also has a huge potential to boost family income. It is reported to be an important source of income among the indigenous Khasi tribes in Bangladesh, providing a family income of about US$ 46.3 per month (Rahman et al. 2009). This emphasize that Piper agroforestry not only helps to restore landscape but also has high potential in augmenting family income.

In the study area, much of the household goods (e.g., fuelwood, construction materials, timber, medicine, etc.) were obtained from Piper agroforestry. Similar livelihood dependency on the Piper agroforestry was reported among the Khasi community of Sylhet district in Bangladesh (Rahman et al. 2009). According to Rahman et al. 2009, with a benefit cost ratio of 4.47, the Piper agroforestry is a highly profitable system. The SWOT analysis revealed that adoption of the traditional system provisions greater positive aspects than the negative aspects. In Piper agroforestry, much of the benefits are provisioned, highlighting its positive performance and greater potential in generating multiple essential ecosystem services. Therefore, the management of this system can be crucial in addressing concerns with livelihood and environmental sustainability (Nandy and Das 2013; Nath et al. 2016; Reang et al. 2021b).

The *Pnar* communities raise livestock as a part of enhancing the family income. However, based on the household survey results, there is not enough evidence to suggest a significant preference among the *Pnar* people for raising one type of animal over another. The frequency of mention of the types of animals raised (37.50% chickens, 31.26% pigs, 28.13% cows, and 3.13% goats) does not significantly deviate from what we might expect to see if there were no particular preference for a specific animal type. Even though the differences in the type of animals raised are not statistically significant at the 1% level, the observed percentages might still be of practical significance and could be explored further through intensive research on this aspect.

Our review identified a number of policies supportive of agroforestry, although some are not yet operational at the local level (Chavan et al. 2015). As in other parts of the world, land tenure is insecure for indigenous people because their rights are often overlooked during formulation of policies. Even in case when indigenous rights are acknowledged, they are not always formalized or registered. Tree tenure is also not functional in the Indian Eastern Himalayas. Secure tree tenure entails the ability to register, harvest, transport and market trees and tree products. The success of tree-based systems has been linked to farmers who have less security over their lands and tree tenure (Kang and Akinnifesi 2000). Consideration must be given to a variety of resource rights, including tenure rights to the land where agroforestry is located and to the agricultural products, in order to provide security to those who practice agroforestry (FAO and ICRAF 2019). Individual tree tenure grants households the sole right to use any trees they have planted, inherited, or managed. Farmers may become eager to invest in tree planting and management under private user rights since they retain exclusive rights to the benefits of such investments (German et al. 2009). Despite playing a critical role in sustaining rural livelihoods, women can particularly suffer from the lack of access to land and resources in general. But, in matrilineal traditions, men more than women may experience such tenure uncertainties, which discourages them from making long-term investments in the land (Hansen et al. 2005). Therefore, it is essential to promote agroforestry programs through a "gender lens," including policies and practices.

We believe that the Piper agroforestry is a promising nature-based solution for sustainable land management, biodiversity conservation and in the livelihoods of the indigenous community in the study area. This land management practices enhances tree diversity and serves as a reservoir of some rare and threatened species as well.

Additionally, Piper agroforestry has enormous potential for sequestering atmospheric carbon, which would significantly contribute to the mitigation of climate change (Reang et al. 2021b), an important global societal challenge also highlighted by IUCN. Therefore, incentives and market support structures such as minimum support price need to be formulated for agroforestry goods. Additionally, incentive mechanisms such as REDD + and payment for ecosystem services schemes need to be explored.

We acknowledge that our study has some limitations. The first main limitation is that the study was located only in a limited area focusing on a single indigenous group. Additional research in regions with the same agroforestry approach would probably allow better understand Piper agroforestry in the Eastern Himalayan region. The second limitation is that the household survey was based on respondents from one village due to the limited resources we had at our disposal. We expect the management practices to differ with locations and ethnic groups practicing Piper agroforestry in the Eastern Himalayan region. Thirdly, the ages of the stands are approximate as the farmers could not recall exact stand ages. Hence, the results may have been more accurate if better methods for estimating stand ages. Regardless of these limitations, we believe this study has provided valuable insights into practices of indigenous people and the challenges they face. We recommend future studies to cover wider geographic areas to better understand farmers' indigenous knowledge and management practices.

The SWOT analysis underscored strengths of Piper agroforestry, particularly its deep roots in indigenous knowledge, environmental benefits, and its role as a reliable income source. These strengths, when juxtaposed with results of our ecological studies, highlight the system's potential for biodiversity conservation, especially given its capacity to harbor rare and threatened species. From a management perspective, the indigenous practices of the *Pnar* community, such as selective clearing and the avoidance of fire, not only promote biodiversity but also ensure the system's resilience. The fairly high tree species diversity and density in older Piper agroforestry stands surpassing the native forests is a strength of this practices. Oher environmental benefits are also evident, for example, in the system's ability to act as a carbon sink, addressing global concerns of climate change mitigation. However, Piper agroforestry is not without challenges. The identified weaknesses, such as the farmers' lack of technical knowledge and the absence of a robust marketing system, can hinder the system's scalability and economic viability. The policy landscape also presents both opportunities and threats. While the existing policies provide a supportive framework, the lack of operationalization at the local level, especially concerning land and tree tenure, can impede the system's expansion. The marketing challenges, characterized by a complex chain of intermediaries and a lack of transparency, further emphasize the need for policy interventions. Instituting a minimum support price for agroforestry products, akin to other significant crops in India, could provide a safety net for farmers, ensuring economic sustainability. Taken together, these observations highlight that its success hinges on an integrated approach harmonizing traditional practices with modern technical knowledge and a more conducive policy framework that addresses both land tenure and market challenges.

Conclusion and recommendations

We conclude that Piper agroforestry is a promising nature-based solution for sustainable management of land degraded by shifting cultivation, biodiversity conservation and livelihoods of indigenous communities in the Eastern Himalayan region. We also conclude that tree species richness and basal area increase as stand age increases in Piper agroforestry and exceed those recorded in nearby native forest stands. We further conclude that existing policies are supportive of Piper agroforestry but this indigenous practice is not currently benefiting from land tenure and tree security as well as incentives and market support structures. We argue for a strong support for the farming communities by the state and regional governments. The government may implement a minimum support price by providing farmers with a base price for their agroforestry products. Additionally, incentive mechanisms such as REDD + and payment for ecosystem services schemes need to be explored so that indigenous communities can benefit from the global ecosystem goods and services they provide. We are keenly aware that our study has certain limitations including its focus on a single indigenous group in a limited area. However, we believe the results are probably relevant to other indigenous groups in the region and the insights gained can serve as an example to highlight challenges such as land and tree tenure and market constraints faced by indigenous populations practicing agroforestry.

Abbreviations

APEDA	Agricultural and Processed food products Export Development Authority
CBH	Circumference at breast height
IVI	Importance value index
IUCN	International Union for Conservation of Nature
MSP	Minimum support price
REDD +	Reducing emissions from deforestation and degradation

SWOT Strengths, weaknesses, opportunities and threats
USDA United States Department of Agriculture
WRB World Reference Base for Soil Resources

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s43170-024-00214-5.

Additional file 1. Table S1. Lists of tree species recorded under different age stands of Piper agroforestry system and natural forest in Cachar District of Assam, Northeast India. **Table S2.** IUCN conservation status, uses and services of different tree species under the Piper agroforestry system in Cachar district, Assam

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Declarations

Competing interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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