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Floristic diversity, and conservation status of large cardamom based traditional agroforestry system along an altitudinal gradient in the Darjeeling Himalaya, India

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Abstract This research aims to study the variation in phytosociology and plant diversity of large cardamom-based traditional agroforestry systems along an altitudinal gradient (700–2000 m) in the Darjeeling Himalayas. We analyzed the changes in phytosociology and plant diversity by adopting stratified random nested quadrate sampling method. The agroforestry managers were interviewed for their perception of ecosystem service following Millennium Ecosystem Assessment guidelines. The present study showed altitudinal location significantly influences plant diversity. Overall, 130 plant species were documented, of which 37 were trees, 25 shrubs, 46 herbs, 8 ferns, 11 climbers and 3 orchids. The low-, mid- and high-altitude classes were documented with 76, 60 and 52 plant species, respectively. Overall, the study system was highly heterogeneous and diverse with a higher Shannon and Wiener diversity index of 4.09 which decreased progressively with increasing altitude as evidenced from significant negative relationship of altitude with diversity (r=− 0.582**), species richness (r=− 0.648**) and plant population (r=− 0.587**). Of the total listed plant species, about 68% were data deficit, 29% were least concerned; two species (*Cryptomeria japonica* and *Cupressus cashmeriana*) were near threatened, and one species (*Brugmansia suaveolens*) was extinct in the wild. This indicates that the study system plays a vital role in harbouring and conserving regional plant diversity. The plant species documented were also classified based on their ecosystem services with 120, 47, 34 and 33 species providing provisional, cultural, regulatory and supporting services, respectively.

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Keyword Traditional agroforestry system · *Amomum subulatum* · Vegetational diversity · Ecosystem service · Altitude · Darjeeling Himalaya

Introduction

Traditional agroforestry farming forms a chief component in the livelihoods and economy of the rural poor population (Reang et al. 2022; Roy et al. 2022a), evolved in response to various factors such as social, economic, cultural, and environmental. In the mountains, the traditional agroforestry systems mimic the natural forests and offer similar ecosystem services to those under the forests (Sharma et al. 2007; Vineeta et al. 2021). One such traditional system is large cardamom (*Amomum subulatum* Roxb.) based agroforestry in the north eastern Indian states, including the Darjeeling Himalayas (Sharma et al. 2016). Large cardamom, the oldest of spices, is native to Sikkim and Darjeeling Himalaya, including the eastern hills of Nepal (Shrestha et al. 2018) and distributed in minimal areas and mainly found in the Eastern Himalayan region of India, Nepal and Bhutan (Mehta et al. 2015). The crop is sciophyte and traditionally inter-mixed as an understorey of natural forest trees on marginal lands and slopes with high moisture in areas of high rainfall between 1500 and 3500 mm at an altitude of 600 and 2000 m above mean sea level (Vineeta et al. 2021). Of the many shade trees associated with the large cardamom, Himalayan Alder (*Alnus nepalensis*) is prominent because of its nitrogen-fixing capacity (Negi et al. 2018).

In the tropical regions, some traditional agroforestry systems show high floristic diversities compared with other agroecosystems (Reang et al. 2021). However, plant density, species diversity and composition vary from place to place due to ecological and socio-economic factors (Roy et al. 2022b). Locality and topographic factors alter the microclimate and edaphic settings of a site and are accountable for shaping the position of vegetation in a particular habitat. Phytosociological characters vary among aspects and location, even in a similar type of vegetation (Roy et al. 2022b).

The ecosystem services provisioned in the form of food, timber, fiber, medicine, drinking and irrigation water from the Himalayan ecosystems are the source of livelihood to the people residing there (Sharma et al. 2015). In addition, some studies have reported that the mountains' forests and agroforestry systems help stabilize headwaters, prevent flooding, landslide and maintain steady year-round water flows vital for the densely populated downstream areas (Molden et al. 2014). However, the quality and quantity of ecosystem services have decreased due to anthropogenic activities and natural phenomena in the recent years (Sharma and Chettri 2021).

Among the numerous traditional farming systems in Darjeeling and Sikkim Himalayas, the large cardamom-based traditional agroforestry system has gained research attention in recent years due to its associated ecosystem services, which has sustained livelihood and supported economic growth of the farming households in the region (Sharma et al. 2000, 2016; Avasthe et al. 2011; Singh et al. 2018; Tarafder et al. 2018). However, few studies on large cardamom-based agroforestry systems covering phytosociological analysis and biomass production were reported mainly from Sikkim Himalayas (Sharma et al. 2007; 2016). As a result, little has been studied to understand the floristic diversity, structure and composition, and ecosystem services along an altitudinal gradient. Moreover, to date, there is no data available from Darjeeling Himalaya. Therefore, the study was carried out to generate precise and systematic quantitative data on the potential of large cardamom-based agroforestry systems in the Darjeeling Himalayas along the altitudinal gradient for their role in biodiversity conservation and ecosystem services. The specific objectives of this study are (i) to document plant diversity along an altitudinal gradient under the large cardamom-based agroforestry system, (ii) to classify the plant species based on IUCN status along the altitudinal gradient, and (iii) to explore the plant species for their known ecosystem services along the altitudinal gradient based on Millennium Ecosystem Assessment guidelines.

Material and methods

The study was carried out in the Darjeeling Himalayan region of West Bengal, India (Fig. 1) from January 2019 to April 2021 in an altitudinal range of 132–3660 m. The region is humid and sub-tropical to sub-alpine, with an average annual rainfall of 2700–3100 mm (Moktan and Das 2013). A reconnaissance survey was conducted to explore the large cardamom based traditional agroforestry systems. A total of 25 traditional holdings of 1–3 ha size were found during the survey. In this traditional farming, large cardamom is cultivated under the canopy of reserved or protected forest leased out to the growers by the State Forest Department with no rights to cut the trees (Sharma et al. 1994, 2009). Following the altitudinal chronosequence (Moktan and Das 2013; Cajee 2018), three altitudinal classes were considered: low (700–1200 m asl), mid (1200–1700 m asl)

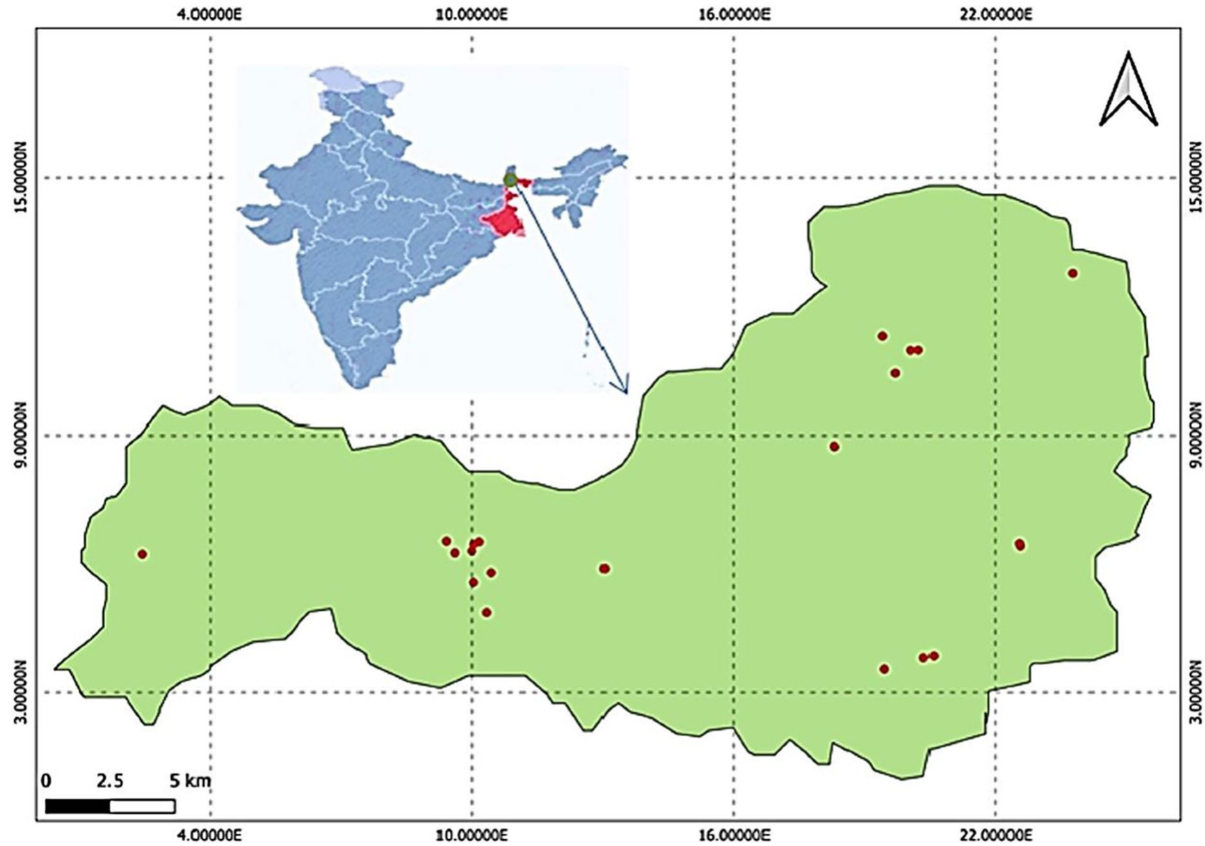


Fig. 1 Map of the study area showing different sampling points

and high (> 1700 m asl) with distribution of eleven, nine and five large cardamom agroforestry holdings, respectively. In these large cardamom holdings, 1–4 quadrates were laid for vegetation sampling depending on its size.

Phytosociological analysis

In each large cardamom holding, 10 m × 10 m sized quadrats were laid for trees within which two 5 m × 5 m sub-quadrats were laid at diagonal corners for shrubs and five 1 m × 1 m sub-quadrats at four corners and centre of the main quadrat for herbs. Individual plant species were counted species-wise in each quadrant and sub-quadrant while, the plant species richness in each quadrant was also recorded. In addition, the name of the species, family and genera were documented following the Plant List of World Flora Online at www.worldfloraonline.org and www.tropicos.org of Missouri Botanical Garden.

Diversity indices

The number of plant species documented is the species richness (S). Species diversity or Menhinick's index ($D' = S/\sqrt{N}$) is based on species richness (S) in proportion to the total number of individuals of all species (N) (Menhinick 1964). Shannon–Wiener diversity index ($H' = \sum n_i/N \ln n_i/N$); where '$n_i$' is the number of individuals of a species, 'N' is the number of individuals of all species and 'ln' is the natural logarithm (Shannon and Weaver 1949; Shannon and Weiner 1963). Concentration of dominance or Simpson's index ($C = \sum (n_i/N)^2$ where 'n_i' is the number of individuals of a species and 'N' is the number of individuals of all species documented from the sampled area, and its value is 0–1 (Simpson, 1949). Species evenness index ($EI = H'/\ln N$) indicates the degree of species distribution (Pielou 1975) where 'H′' is the Shannon–Wiener diversity index, and 'ln N' is the natural logarithm of a number of individuals of all species.

Sorenson's similarity index

This index (SI) estimates the degree of similarity in species among the habitats or plant assemblages, and the equation used following Sorenson (1948) was:

$$S = \frac{2D}{A + B + C}$$

where, A is the number of species unique in area A, B is the number of species unique in area B, C is the number of species unique in area C, and D is the number of species common in all the areas A, B and C.

Conservation status

The conservation status of the documented species was based on the IUCN Red List category. Among the mentioned nine IUCN categories, the documented plant species represented only four categories which are data deficit (DD), least concern (LC), near threatened (NT) and extinct in the wild (EW) (Anonymous 2021).

Ecosystem services

Ecosystem services provided by different species in the traditional large cardamom-based agroforestry system were collected through personal interviews with the agroforestry managers (Lepcha et al. 2018, 2019), and species were then classified following Millennium Ecosystem Assessment guidelines (MEA 2005; Supplementary Table 1). The information was gathered through personal interviews with the holding owners by an enumerator (a local resident) in the presence of any of the authors of this study. The interview focused on the utilization of the documented plant species by the respondents. Based on the utilization of plant species by the respondents, we broadly classified the species as provisionary, regulatory, supporting and cultural ecosystem services.

Data analysis

We analyzed the research data using the range, mean, Karl Pearson's coefficient of correlation and multiple regressions with analysis of variance (Goldstein and Dillon 1985) using IBM SPSS version 2020 using R 3.6.3 (R Core Team 2020) statistical software.

Result and discussion

Floristic composition and diversity

Species richness

Overall, the plant species enlisted for the large cardamom based traditional agroforestry systems in the Darjeeling Himalayas were 130 species represented by 63 families and 107 genera. Altogether, there were 37 tree species represented by 23 families and 30 genera; 25 shrubs species represented by 15 families and 21 genera; 46 herbs species represented by 23 families and 38 genera; 8 ferns species represented by 8 families and eight genera; 11 climbers species represented by 8 families and 9 genera and 3 orchids species represented by 2 families and 3 genera (Supplementary Table 2). The low-altitude class was documented with 76 plant species represented by 63 genera and 43 families. In comparison, the mid-altitude class was represented by 60 species belonging to 57 genera and 40 families and in the high-altitude, class 52 species represented by 45 genera and 35 families were listed. The plant species richness ranges from 8 to 50 species at low altitudes, 8–30 at mid-altitudes and 9–21 at high altitudes (Table 1). The species richness, genus and family of the life forms in the altitudinal classes are given in Table 1. The major plant form found in all the altitude classes was herb, followed by tree, shrub, climber, fern and orchid.

Overall, Asteraceae was the prominent family with 11 species while, the prominent genera were *Pilea* and *Ficus*, each with 4 species (Supplementary Table 2). Asteraceae, represented by 8 species was the principal family at low altitudes while, the most prominent genera were *Piper, Ficus* and *Oxalis*, each represented by 3 species. In the mid-altitude, Asteraceae, Acanthaceae and Rosaceae, each represented by 4 species, were the prominent families and *Ageratum* and *Rubus*, each represented by 2 species, were the major genera. The prominent families recorded in the high-altitude were Asteraceae and Urticaceae, each represented by 6 species and *Magnolia* with 3

Table 1 Plant richness of large cardamom based traditional agroforestry systems

Richness	Low	Mid	High	Overall
Plants				
Species richness (SR)	76	60	52	130
Individual richness (IR)	4308	2684	2562	9554
Range of SR	16–50	8–30	9–21	8–50
Family richness (FR)	43	40	35	63
Genera richness (GR)	63	57	45	107
Trees				
SR	21	18	14	37
IR	368	237	156	761
FR	14	15	11	23
GR	18	17	13	30
Shrubs				
SR	10	10	11	25
IR	351	228	222	801
FR	9	8	6	15
GR	10	9	9	21
Herbs				
SR	28	23	19	46
IR	2356	1352	1504	5212
FR	13	17	13	23
GR	24	22	16	38
Fern				
SR	7	6	3	8
IR	972	811	582	2365
FR	7	6	3	8
GR	7	6	3	8
Climber				
SR	8	3	3	11
IR	206	56	61	323
FR	6	3	3	8
GR	6	3	3	9
Orchid				
SR	2	0	2	3
IR	55	0	37	92
FR	1	0	2	2
GR	2	0	2	3

Low, 700–1200 m asl; Mid, 1200–1700 m asl; High, > 1700 m asl

species was the major genus documented in the high-altitude class.

The plant species richness and plant population decreased significantly with increasing altitude. Altitude was found significantly and negatively correlated with both species' richness ($r = -0.648^{**}$, Table 2) and plant population ($r = -0.587^{**}$, Table 2). However, a significant positive relationship between species richness and plant population was observed ($r = 0.890^{**}$, Table 2). The traditional large cardamom agroforestry systems are forest-based and very close to natural ecosystems, which are not intervened by human interference except the natural factors, including climate and soil (Sharma et al. 1994, 2007). In such a condition, species richness and population are prominently governed by the temperature and modified by the altitude of the geographical area (Odum 1971). Species richness and plant population of woody species in the large cardamom based traditional agroforestry system thus varied depending on geographical location (topography) and climatic conditions of the region (Kumar and Nair 2004). The inverse relationship of plant species richness with altitude has been reported by other researchers from different studies (Bachman et al. 2004; Trigas et al. 2013; Pandey et al. 2018). Distribution of vegetation exhibit decreasing trend with elevation due to decrease in temperature with the increase in altitude (Wangda and Ohsawa, 2006a, 2006b).

Diversity indices

The diversity indices like Menhinick's species diversity index, the concentration of dominance, the Shannon–Wiener index and evenness index estimated for the Darjeeling Himalayan traditional large cardamom-based agroforestry systems at different altitude classes are given in Table 3. The Menhinick's species diversity index of the studied systems at Darjeeling Himalayas was 1.36, while the index estimated for the different altitude classes was lesser than the overall index, i.e., 1.16, 1.16 and 1.03 for low-, mid- and high-altitude class, respectively (Table 3). The diversity index decreased with increasing altitude class ($r = -0.648^{**}$, Table 2) which can be attributed to significant inverse relationship of species richness ($r = -0.648^{**}$, Table 2) and plant population ($r = -0.587^{**}$, Table 2) with altitude. A higher index indicates that plant species in the low-altitude class were more diverse but less frequently present than those in the higher altitude class. This is because the index is a function of both the total number of species and a total number of individuals of all the species of the sampled sites and lower altitude classes were more species rich than the higher altitude classes

Table 2 Pearson correlation matrix of plant diversity of large cardamom based traditional agroforestry systems and altitude

	A	SR	PP	D	C	H′	HI
A	1						
SR	– 0.648**	1					
PP	– 0.587**	0.890**	1				
D	– 0.648**	1.0**	0.890**	1			
C	– 0.580**	0.893**	0.979**	0.893**	1		
H′	– 0.582**	0.879**	0.997**	0.879**	0.962**	1	
EI	– 0.582**	0.879**	0.997**	0.879**	0.962**	1.00	1

A, altitude; SR, species richness; PP, plant population; D, Species diversity or Menhinick's index; C, Concentration of dominance; H′, Shannon–Wiener diversity index; EI, Evenness index

**Significant at 0.01 level

*Significant at 0.05 level

Table 3 Diversity indices of plant assemblages in large cardamom based traditional agroforestry systems

Diversity indices	Low	Mid	High	Overall
Menhinick's species diversity index	1.16	1.16	1.03	1.36
Concentration of dominance	0.03	0.04	0.06	0.03
Shannon–Wiener index	3.79	3.64	3.24	4.09
Evenness index	0.45	0.46	0.41	0.45

Low, 700–1200 m asl; Mid, 1200–1700 m asl; High, > 1700 m asl

due to decreasing temperature with increasing altitude. The diversity index estimated at all the altitude classes was much lesser than the other agroforestry systems of Darjeeling Himalayas, particularly the home gardens (Sarkar 2020), because the species present in the large cardamom based traditional agroforestry systems were more frequent than the species at home gardens of Darjeeling Himalayas.

The overall concentration of dominance was estimated at 0.03, and it increased with the increase in altitude (Table 3). The highest index value at the high-altitude class indicates that the chances of a species encountered during sampling in this altitude class were highest than in the lower altitude classes. However, the chances of species encountered during sampling in the present study area decreased significantly with increasing altitude ($r = -0.580^{**}$, Table 2) as both species' richness and plant population significantly decreased with altitude ($r = -0.648^{**}$, -0.587^{**}, respectively; Table 2). Shannon Wiener's index of the traditional large cardamom-based agroforestry farming of Darjeeling Himalayas was estimated at 4.09 (Table 3), which was less than the traditional home gardens from a similar geographical region (4.75) (Sarkar 2020). The plant diversity decreased with altitude in a progressive manner from 3.79 in low-altitude class to 3.64 in mid-altitude class and 3.24 in high-altitude class, respectively. Altitude inversely influenced diversity, as evidenced by their significant negative relationship (-0.582^{**}, Table 2).

The evenness index of the traditional large cardamom-based agroforestry systems (0.45) was slightly less than traditional home gardens (0.51) (Sarkar 2020). The diversity indices of trees, shrubs, herbs, climbers, orchids and ferns estimated at different altitude class are given in Table 4. Herbs were more diverse than any other life form and estimated with the highest Shannon–Wiener diversity index compared to other plant forms. The traditional large cardamom agroforestry systems are forest-based with minimal anthropogenic interference, which supports the growth and development of under storey vegetation (Sharma et al. 1994, 2009). Therefore, forest sites with less disturbances have higher herb and under-storey life form diversity (Han et al. 2011). Following herbs, trees were estimated with an overall Shannon–Wiener diversity index of 3.24, and at low-, mid-and high-altitude class, the values were 2.91, 2.69 and 2.35, respectively. The diversity of herbs, trees, climbers and orchids decreased gradually with increasing altitude, but the diversity of shrubs and ferns increased.

Orchids were the least diverse among the plant forms with an overall Shannon–Wiener diversity

Table 4 Diversity indices of various plant forms in large cardamom based traditional agroforestry systems

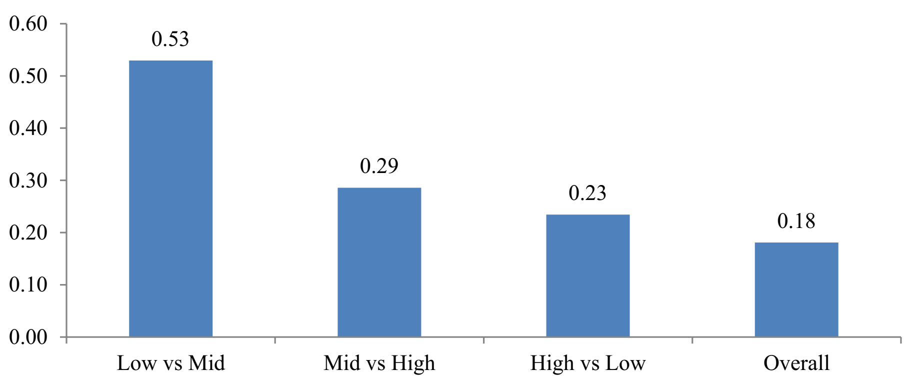
LF	A	D	C	H′	HI
Trees	Low	1.10	0.06	2.91	0.49
	Mid	1.17	0.08	2.69	0.49
	High	1.12	0.11	2.35	0.46
	Overall	1.36	0.05	3.24	0.49
Shrub	Low	0.53	0.18	1.93	0.33
	Mid	0.66	0.16	1.99	0.37
	High	0.74	0.11	2.27	0.42
	Overall	0.96	0.07	2.94	0.45
Herb	Low	0.58	0.06	3.03	0.39
	Mid	0.63	0.06	2.97	0.41
	High	0.49	0.09	2.59	0.35
	Overall	0.64	0.04	3.43	0.40
Climber	Low	0.56	0.17	1.91	0.36
	Mid	0.40	0.43	0.94	0.23
	High	0.51	0.33	1.20	0.29
	Overall	0.70	0.13	2.20	0.39
Orchid	Low	0.27	0.51	0.68	0.17
	Mid	0.00	0.00	0.00	0.00
	High	0.33	0.56	0.63	0.17
	Overall	0.29	0.36	1.06	0.23
Fern	Low	0.23	0.27	1.53	0.22
	Mid	0.21	0.20	1.68	0.25
	High	0.08	0.50	0.69	0.11
	Overall	0.15	0.27	1.54	0.20

index of 1.06, and at low- and high-altitude classes, the values were 0.68 and 0.63, respectively. We did not find orchid in the mid-altitude. However, trees were less frequently present with higher estimated Menhinick's species diversity index (overall value of 1.36 and at low-, medium- and high-altitude class with values of 1.10, 1.17 and 1.12, respectively) than the shrubs, climbers, herbs, orchids and ferns. Trees were most evenly distributed with the highest evenness index (with an overall value of 0.49 and at low-, mid-and high-altitude class with values of 0.49, 0.49 and 0.46, respectively) followed by shrubs, herbs, climbers, orchids and ferns. The diversity and dominance of species in the large cardamom based traditional agroforestry systems were lesser than the home gardens at all altitude classes (Sarkar 2020). Similar diversity indices of plant species, particularly the trees, were also reported from large cardamom based traditional agroforestry system of Sikkim Himalayas (Sharma et al. 2008) and other traditional agroforestry systems in India (Salve et al. 2018; Taran and Deb 2019) and elsewhere (Udawatta et al. 2019; Wari et al. 2019).

Sorenson's similarity index suggests a lesser similarity (0.18) for species encountered in large cardamom based traditional agroforestry systems (Fig. 2). In addition, only 17 species were common throughout the altitudinal gradient (Supplementary Fig. 1). Seven species of herbs (*Amomum subulatam*, *Ageratina adenophora*, *Ageratum conyzoides*, *Ageratum houstonianum*, *Brachiaria reptans*, *Dichroa febrifuga* and *Drymaria cordata*); 4 species of trees (*Alnus nepalensis*, *Cryptomeria japonica*, *Cupressus cashmeriana* and *Terminalia myriocarpa*), 3 species of shrubs (*Boehmeria platyphylla*, *Girardinia palmata* and *Phlogacanthus thyrsiformis*); two species of ferns (*Diplazium esculentum* and *Selaginella denticulate*) and 1 species of climber (*Piper boehmeriaefolium*) were found in all the three altitudes.

The similarity of the species decreased gradually with increasing altitude as 36 species were common between low- and mid-altitude class with a similarity

Fig. 2 Similarity index of plant species in the large cardamom based traditional agroforestry systems



index of 0.53, while only 16 species were common between mid- and high-altitude class with a similarity index of 0.29, and 15 species were common between low- and high-altitude class with a similarity index of 0.23 (Fig. 2 and Supplementary Fig. 1). In total, 91 unique or specialist species were listed, of which 39, 21 and 31 species were unique to low, mid and high altitudes (Supplementary Fig. 1). Most of the species documented (70%) in Darjeeling Himalayas' traditional large cardamom-based agroforestry systems were specialists or unique to the altitude class (i.e., low, mid and high). This indicates vast differences or variations among the floristic elements of these traditional systems. This is because topographic factors affect the microclimate and edaphic condition across the altitudinal gradient, thus influencing the vegetation composition (Jha 2001; De 2007).

Similarly, numerous studies also had documented plant species diversity of traditional agroforestry systems across the globe (Nath et al. 2016; Salve et al. 2018; Taran and Deb 2019; Udawatta et al. 2019). The traditional agroforestry system of Darjeeling and Sikkim Himalayas was biodiversity-rich due to the association of shade trees (Sharma et al.1994). Large cardamom based indigenous agroforestry system supports higher tree diversity than other agroforestry systems in the Sikkim Himalayas (Sharma and Sharma 1997; Das et al. 2012). Moreover, traditional agroforestry systems, particularly large cardamom-based agroforestry, are culturally associated with the hill farming community.

Conservation status

The ICUN conservation status of plant species (130 species) from the large cardamom-based agroforestry systems, 89 species were data deficit (68.46%), 38 species were least concerned (29.23%); 2 species (*Cryptomeria japonica* and *Cupressus cashmeriana*) were near threatened, and 1 species (*Brugmansia suaveolens*) was extinct in the wild (Supplementary Table 2, Supplementary Fig. 2). These near threatened and extinct from the wild species are exotics, introduced to India and their IUCN profile indicates their global status, particularly in their native habitat. For instance, *Brugmansia suaveolens* is extinct from the wild in Brazil (Hay 2014) but occur in Darjeeling and neighbouring foothill regions of West Bengal, India (Mallick 2020).

The highest number of data deficit (47 species) and least concerned (26 species) was recorded from the low-altitude, followed by mid-altitude (41 and 17 species, respectively) and high-altitude (35 and 15 species, respectively; Fig. 3). The two documented near-threatened species were found throughout the altitudinal classes, while *Brugmansia suaveolens* was found only at the low-altitude class. The inventory of diverse native plant species along with ICUN red-listed ones indicate that these forest-based traditional large cardamom-based agroforestry systems play an important role in harbouring and conserving both native and exotic plant genetic resources (Campos-Salas et al. 2016; Rendón-Sandoval et al. 2020).

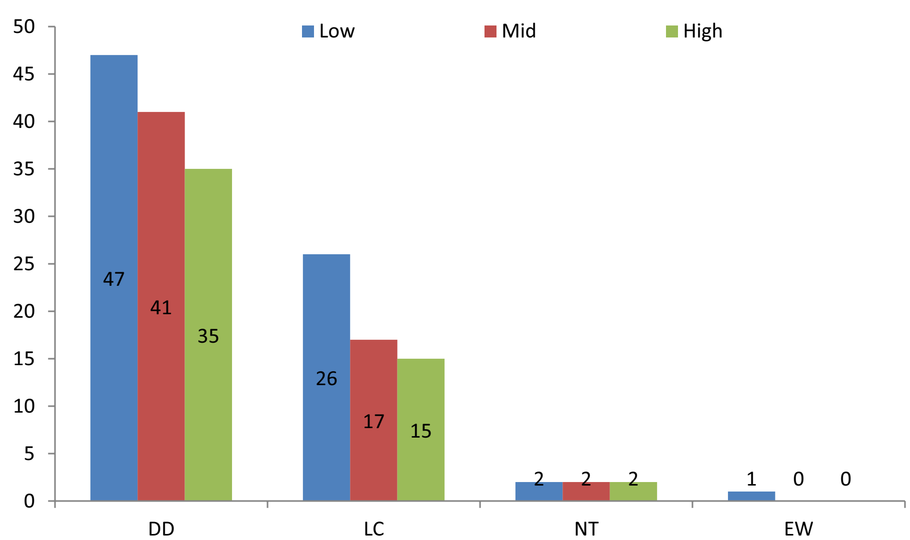


Fig. 3 ICUN status of the documented plant species at altitude classes

Ecosystem services

The documented plant species were also classified based on their ecosystem services, i.e., provisional, regulatory, supportive, and cultural service (Figs. 4, 5). Overall, in the large cardamom based traditional agroforestry systems 120, 47, 34 and 33 species were classified to provide provisional, cultural, regulatory and supporting ecosystem services, respectively. The agroforestry managers opined that the shade trees ameliorate the microclimate of the area, while agroforestry patches along the mountain slopes prevent soil erosion. The agroforestry managers generally collect dead wood and fallen branches for firewood and non-timber forest products (NTFPs), particularly for food, folk medicine, and other daily provisionary and cultural use. Such agroforestry systems have also been reported to support a variety of regional avifauna and other small wildlife species and ensure green fodder during the lean periods as well (Pandey and Singh, 1984; Sharma and Sharma, 1997). The large cardamom traditional agroforestry systems being very close to natural ecosystems, has the potential to offer a variety of ecosystem services from provisional to cultural services like NTFPs, biodiversity conservation, water regulation and purification, biomass production, carbon sequestration, nutrient cycling and socio-cultural service for the wellbeing of the society (Singh et al. 2018; Vineeta et al., 2021). The present study documented only the preliminary information about the ecosystem services provided by the agroforestry managers and which may differ from farmer to farmer based on their actual utilization, experiences and perceptions. The study tried associating the system at a micro-landscape level with perceived ecosystem services (Kamiyama et al. 2016) rather than its multidimensional roles in enhancing human well-being (Mosina and Maroyi 2016). Inconsistencies lie in perceived information that must be validated comprehensively through interdisciplinary studies at inter- and intra-specific levels within diversified environmental and cultural contexts (Agbogidi and Adolor, 2013). This is because the intangibility of provisioning services may undermine the regulatory services because the perception of provisions (food or medicines) is considered more beneficial than other services (Caballero-Serrano et al., 2016).

Conclusions

The present study showed that the altitudinal gradient significantly influenced the species richness, population, and diversity indices. The diversity of herbs, trees, climbers and orchids decreased gradually with increasing altitude, but the diversity of

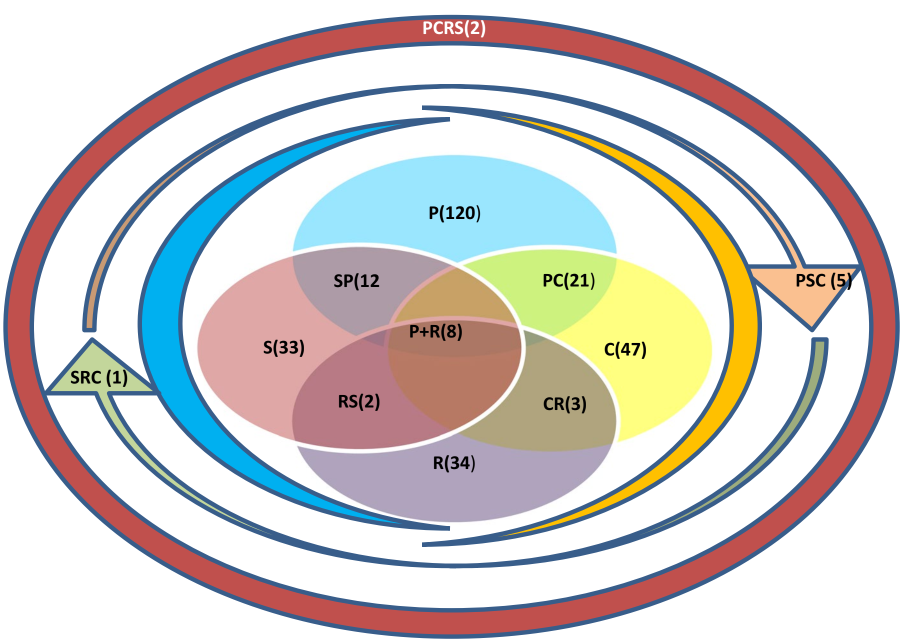


Fig. 4 Ecosystem services of overall documented plant species

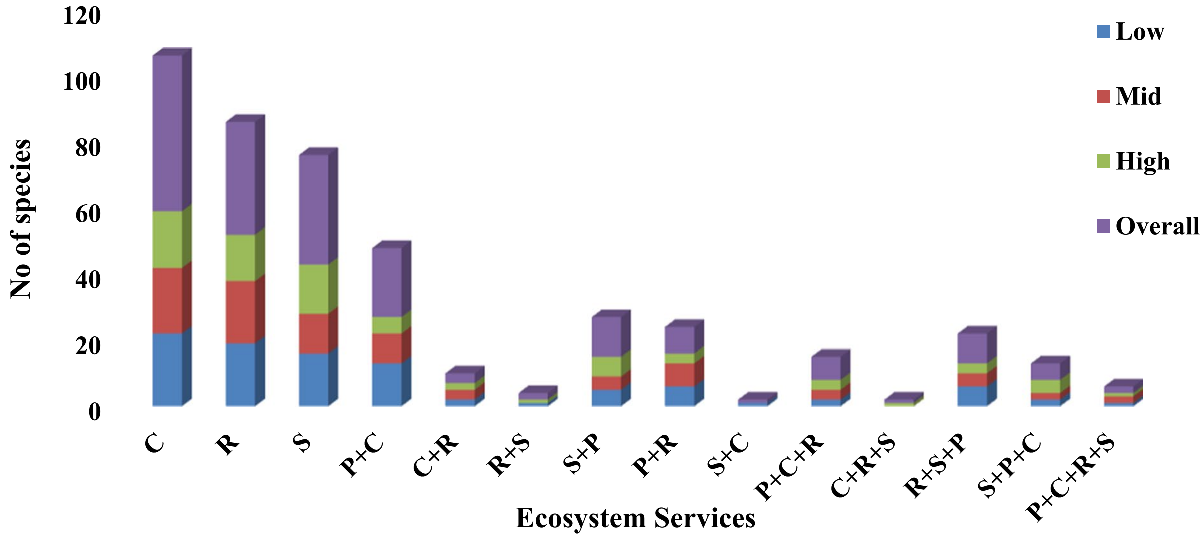


Fig. 5 Ecosystem services of the documented plant species at altitude classes. P = Provisional (70, 53 & 48 species respectively at low-, mid- and high altitude class); C = Cultural (22, 20 & 17 species respectively); R = Regulatory (19, 19 & 14 species respectively); S = Supportive (16, 12 & 15, species respectively); P + C = 13, 9 & 5, species respectively; C + R = 2, 3 & 2, species respectively; R + S = 1, 0 & 1 species respectively; S + P = 5, 4 & 6, species respectively; P + R = 6, 7 & 3, species respectively; S + C = 1, 0 & 0, species respectively; P + C + R = 2, 3 & 3, species respectively; C + R + S = 0, 0 & 1, species respectively; R + S + P = 6, 4 & 3, species respectively; S + P + C = 2, 2 & 4, species respectively; P + C + R + S = 1, 2 & 1, species respectively

shrubs and ferns increased with increasing altitude. However, trees were less frequently present with higher estimated Menhinick's species diversity index than the other plant life forms. Trees were most evenly distributed with the highest evenness index, followed by shrubs, herbs, climbers, orchids and ferns. The system's heterogeneity can be attributed to the richness of 130 plant species represented by 63 families and 107 genera. Documentation of ICUN red-listed species indicates that the large cardamom-based agroforestry system plays an essential role in harbouring and conserving regional plant diversity. Additionally, the system was found to offer a variety of ecosystem services.

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Declarations

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

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