Variations in Vegetational Diversity and Carbon Stock in Large Cardamom Based Traditional Agroforestry System across Altitudinal Gradient in Darjeeling Himalayas

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Submitted to the
Uttar Banga Krishi Viswavidyalaya
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Doctor of Philosophy
in
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by

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CERTIFICATE- I

This is to certify that the thesis entitled, **"Variations in vegetational diversity and carbon stock in large cardamom based traditional agroforestry system across altitudinal gradient in Darjeeling Himalayas"** submitted by **Mrs. Vineeta (H-2018-020-D)** in partial fulfilment of the requirement for the degree of Doctor of Philosophy in Forestry of Uttar Banga Krishi Viswavidyalaya is a faithful and bonafide research work carried out under my personal supervision and guidance. The results of the study reported in the thesis have not so far been submitted for any other degree or diploma. The assistance and help received from various sources during the course of study have been duly acknowledged.

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ABSTRACT

Managing soil and biomass carbon in the traditional farming systems will be both an avoided emission and net addition of carbon and conserving these systems will not only improve livelihood but will also improve the carbon footprint of a region. The study was conducted in Darjeeling Himalayas from January 2019 to April 2021 which was classified into three altitudinal for analyzing the variation on phyto-sociology, diversity, soil parameters and ecosystem carbon stock of the systems adopting stratified random nested quadrate sampling method along with perception of the growers on ecosystem service and performance of the below canopy forest based traditional large cardamom based agroforestry farming systems. The growers were aware about the ecosystem services and declining productivity of their system along with the cause of decline and solutions for its revival. The systems were both vertically and horizontally heterogeneous in terms of its plant diversity and arrangement thus maintaining the original forest characteristics. The altitudinal location significantly influencing the diversity, soil parameters and available organic carbon (SOC) but influence of altitude on biomass and carbon stock was non-significant though it decreased gradually with increasing altitude. Generally, the diversity and soil parameters decreased with increasing altitude except available nitrogen and SOC. Overall 130 plant species were documented, of which 37 were trees, 25 shrubs, 46 herbs; eight ferns, 11 climbers and three orchids. The list included ICUN red listed species which signifies the conservation worth of the system. The system was also worth providing variety of ecosystem services from provisional to cultural. The floristic elements of the system were less similar with lower Sorenson's similarity index. The system was estimated with higher soil fertility with medium to high available primary nutrients and high available SOC. The tree biomass, tree biomass carbon, SOC and ecosystem carbon stock estimated was 447.67, 210.40, 84.62 & 295.02 Mg ha^{-1}, respectively. The contribution by the tree biomass carbon to the ecosystem carbon stock of the system at low-, mid- and high-altitude class was 81.57 %, 68.59 % and 59.39 %. Considering on a unit area basis this traditional agroforestry farming system was stocking higher carbon than homegardens, plantations and secondary forests while comparable to forests. The systems due to heterogeneous composition and structure with restrictions in biomass removal were permanent, stable and resilient tree based land use systems viable for offsetting regional carbon emission. The study recommends bailing out this dying tradition by supporting the growers in their effort to preserve their traditionality through institutional, extension and policy interventions which will not only improve the livelihood of the growers but will also fulfill the global 4 per mille initiative.

(Vineeta) **(Gopal Shukla)**

CERTIFICATE-II

This is to certify that the thesis entitled, "**Variations in Vegetational Diversity and Carbon Stock in Large Cardamom Based Traditional Agroforestry System across Altitudinal Gradient in Darjeeling Himalayas**" submitted by **Mrs. Vineeta** (H-2018-20-D) to Uttar Banga Krishi Viswavidyalaya, Pundibari in partial requirement for the degree of Doctor of Philosophy in Forestry has been approved by the Student's Advisory Committee on 01.11.2021 after online viva-voce on the same in collaboration with an external examiner and we recommend that the thesis be accepted for the award of the degree of Doctor of Philosophy in Forestry.

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(VINEETA)

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Chapter 1

INTRODUCTION

Traditional agroforestry farming are culturally developed sustainable land use systems which are diverse structurally and functionally (Murthy *et al*., 2013; Nandy and Das, 2013; Subba *et al.*, 2015, 2016, 2017_{a-d}, $2018_{a,\ b}$; Prasad *et al*., 2016; Nath *et al*., 2016; Pandey *et al*., 2017; Singh *et al*., 2018_{a}) that offer multipurpose benefits from ecological to livelihoods including restricting carbon emission and ensuring socio-economic security (Partap *et al*., 2014; Chavan *et al*., 2015; Prasad *et al*., 2016; Bijalwan *et al*., 2017; Pathania *et al*., 2020; Yadav *et al*., 2021). In mountains, the traditional agroforestry systems mimic or are very closer to the natural ecosystems or forests as they offer similar ecosystem services like forests (Sharma *et al*., 1994, 2007). These systems are significant in terms of their sustainable socio-environmental services towards water, carbon, nutrient cycling, cultural, socio-economic and livelihood contributions (Sharma and Sharma, 1997; Sharma *et al*., 2000; $2009_{a,\ b}$; 2016_{a-c}; Rathore *et al*., 2010; Singh *et al*., 2018_{a}; Keerthika *et al*., 2021) including food security, reducing poverty and improving ecosystem resiliency (Dhyani *et al*., 2005; 2009; Dhyani, 2012; Cilliers *et al.*, 2012; Nandy and Das, 2013; Prasad *et al*., 2016; Pandey *et al*., 2017; Selvan and Kumar, 2017). These traditional agroforestry farming systems now are recognized as a viable climate change mitigation strategy involving these producers (Watson *et al*., 2000_{a}; Kumar *et al*., 2012_{a}; Clarke *et al*., 2014; Deb *et al*., 2014; Nath *et al*., 2016; Pandey *et al*., 2017; Thakur *et al*., 2017; Subba *et al.*, 2017_{d}, 2018_{b}). Designing strategies for improving capacities of these traditional systems has become a new research paradigm for constructing sustainable food security systems, other goods and services for human life by understanding their spatio-temporal structure and function, associated traditional knowledge systems, economic worth and ecosystem services (Saha *et al*., 2009; Godfray *et al*., 2010; Kumar *et al*., 2012_{a}; Mbow *et al*., 2014; Subba *et al.*, 2015, 2016, 2017_{a-d}, $2018_{a,\ b}$; Sharma *et al.*, 2016_{a-d}; Pandey *et al*., 2017).

The eastern Himalayas region is also endowed with diverse traditional agroforestry systems with different species composition along the altitudinal gradient (Nandy and Das, 2013; Nath *et al*., 2016; Sharma *et al.*, 2016_{a-c}). These systems are the life line for people of mountainous regions crucial for survival while, also a sustainable land management system to improve and conserve the soil along with many livelihood benefits to the community (Partap *et al*., 2014; Banyal *et al*., 2015; Prasad *et al*., 2016;

Feliciano *et al*., 2018). Among the numerous traditional farming systems in Darjeeling and Sikkim Himalayas, large cardamom (*Amomum subulatum* Roxb.) based traditional agroforestry system or under-canopy large cardamom cultivation has gained research attention in the 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, 2007, 2008, 2009_b, 2016_{a-c}; Srinivasa, 2006; Avasthe *et al*., 2007, 2011; Sharma, 2013; Gudade *et al*., 2013; Partap *et al*., 2014; Mehta *et al*., 2015; Joshi and Joshi, 2016; Singh *et al*., 2018_a; Tarafder *et al*., 2018). This traditional large cardamom cultivation is done under-canopy of reserved forests of Sikkim and Darjeeling Himalayas leased out to the growers with no rights to cut the trees (Sharma *et al*., 1994, 2009_b). However, over the past decade its area and productivity has declined significantly as a consequence of climate change, insect pest, diseases and anthropogenic pressure (Sharma *et al*., 2002, 2009_b, 2016_c; Partap *et al*., 2014; Shukla *et al*., 2016; Negi *et al*., 2018).

Global climate is changing and eastern Himalayas are not an exception (Chettri *et al*., 2012; Shukla *et al*., 2016; Dey *et al*., $2017_{a,\ b}$). Farming and or traditional communities are more sensitive and vulnerable to changing climate due to their inherent livelihood dependency on farming and natural resources (Sharma *et al*., 2009_a; Manandhar *et al*., 2011; Shukla *et al*., 2016; Dey *et al*., $2017_{a,\ b}$; Meena *et al*., 2019). Drastic changes in patterns of climatic events are causing sharp decline in productivity of the farming systems with overall impact on livelihood wellness and security in the region (Dhaka *et al*., 2010; Choudhary *et al*., 2012; Chakravarty *et al*., 2015; Dey *et al*., 2017_a; Meena *et al*., 2019). Moreover, the impacts of climate change are comparatively intense in the mountainous regions than the plains (Surendra *et al*., 2010; Pepin *et al*., 2015; Palomo, 2017).

This complex traditional large cardamom based agroforestry systems of Darjeeling Himalayas are still not clearly understood in terms of their bio-physical and socio-cultural factors that determine its floristic composition, species diversity and distribution. This traditional farming system of the region has still been ignored by academic research studies in terms of distribution and relationship between on farm tree biomass, carbon and nutrient budgeting especially along the altitudinal gradient (Sharma *et al*., 2016_{a-d}; Subba *et al.*, 2017_d, 2018_b; Singh *et al*., 2018_a). Data on natural resources of Himalayan region is deficient and less studied due to poor accessibility, infrastructure and high spatio-temporal variability (Chawla *et al*., 2012; Shrestha *et al*., 2012; Nandy and Das, 2013; Pepin *et al*., 2015; Nath *et al*., 2016; Pandey *et al*., 2017). Therefore, the study entitled, **"Variations in Vegetational Diversity and Carbon Stock in Large Cardamom based Traditional Agroforestry System across Altitudinal Gradient in Darjeeling Himalayas"** was carried out to generate precise and systematic quantitative data on the potential of large cardamom based traditional agroforestry in the Darjeeling Himalayas along the altitudinal gradient for its ecosystem services with the following objectives:

1. To study socio-economic status along with grower's perception on ecosystem service and performance of the traditional large cardamom based agroforestry system.
2. To study the structure and composition of the traditional large cardamom based agroforestry system across the altitudinal gradient.
3. To analyze the soil nutrient status, biomass and total carbon storage across the altitudinal gradient of the traditional large cardamom based agroforestry system.

Chapter 2

REVIEW OF LITERATURE

Agroforestry the common feature of agriculture landscape (table 1) especially in the humid tropical region play very important role in managing ecological and environmental condition (Nair, 2011; Tamale *et al*., 1995; Vishvakarma *et al*., 1998; Viswanath *et al*., 2000; Sulaiman, 2001; Kaur *et al*., 2002; Angelsen and Kaimowitz, 2004; Garrity, 2004; Makundi and Sathaye, 2004; Puri and Nair, 2004; Thakur *et al*., 2004; 2005; Altieri and Toledo, 2005; Ibrahim and Sinclair, 2005; Kareemulla *et al*., 2005; Kumar, 2006$_{a}$; McNeely and Schroth, 2006; De, 2007; Pandey, 2007; Sharma *et al*., 2007, 2016$_{a-d}$; Akinnifesi *et al*., 2008; Zomer *et al*., 2009; 2014, 2016; Morgan *et al*., 2010; Thakur *et al*., 2011$_{a}$; Kumar *et al*., 2012$_{a}$; Sharma and Rai, 2012; Murthy *et al*., 2013; Mbow *et al*., 2014; Van Noordwijk *et al*., 2014; Subba *et al.,* 2015, 2016, 2017$_{a-d}$, 2018$_{a,\ b}$; Bhusara *et al*., 2016; Nath *et al*., 2016; Anon., 2017$_{a}$; Selvan and Kumar, 2017; Salve *et al*., 2018$_{a,\ b}$; Taran and Deb, 2019; Besar *et al*., 2020; Sanogo *et al*., 2020; Yadav *et al*., 2021) while, also ensuring the socio-economic stability of the farmers (Dash and Mishra, 2001; McNeely and Scherr, 2003; Schroth *et al*., 2004; Mosquera-Losada *et al*., 2011$_{a}$; Udawatta and Jose, 2011; Nandy and Das, 2013; Nath *et al*., 2016; Baah-Acheamfour *et al*., 2017; Tiwari *et al*., 2017; Tripathi *et al*., 2018; Taran and Deb, 2019).

Traditional agroforestry systems are unique and culturally sound land use systems which are still practiced globally by indigenous people since the time immemorial (Bareh, 1967; Albrecht and Kandji, 2003; Nair and Nair 2003; Altieri and Toledo, 2005; McNeely and Schroth, 2006; Perfecto and Vandermeer, 2008; Below *et al*., 2010; Altieri and Toledo, 2011; Nandy and Das, 2013; Casas *et al*., 2014; Fischer *et al*., 2014; Rendón-Sandoval *et al*., 2020) including the Himalayas (Sharma *et al*., 1994, 2000, 2002, 2007, 2008, 2009$_{b}$; 2016$_{a-b}$; Ramakrishnan, 2007; Murthy *et al*., 2013; Thakur *et al*., 2007, 2011$_{b}$, 2017; Bhusara *et al*., 2016). Eastern Himalayan region of India is a part of Indo Malayan Biodiversity Hotspot (Myers *et al*., 2000) and thus home of the different types of traditional agroforestry systems (Sharma *et al.*, 2016$_{a-c}$). Twenty per cent geographical areas of the India Himalaya are under different types of agroforestry systems (Salve *et al*., 2018$_{a,\ b}$).

Table 1. Agroforestry systems across the ecological zones of India

AEZ	Major benefits	Examples
Himalayan region		
AH	Fruits and food	Tuber, rhizome and cereals with orange, peach, guava, pecan nut, citrus and plum in Uttarakhand and north east region.
AS	Food, fodder and bund stabilization	Fodder trees in hills north west and north east region
MSS	Food, spices, fuel wood, timber	In Uttarakhand, north east region and West Bengal cultivation of coffee, large cardamom with alder, tea with legume trees and arecanut with black pepper and betel vine
SP	Fodder, fuel wood	Tree leaf forage in the Himalayas from *Celtis, Grewia, Quercus, Bauhinia* and other species
HP	Fruit, fodder, fuel wood	Peach and other fruit trees with grasses of rainy and winter season
Indo-Gangetic plains		
AS	Fuel, fodder, timber, shade	Poplar, *Tamarindus indica, Bombax ceiba, Eucalyptus, Dalbergia sissoo, Melia* spp
FBW	Fodder, soil conservation, fuel	Trees for fodder *Azadirachta indica, Albizia spp., Melia* spp., *Syzygium cumini*, Bamboo spp., *Casuarina, Dalbergia sissoo,* Eucalyptus
SP	Fuel, fodder, timber	*Bauhinia* spp., *Albizia* spp., *Dalbergia sissoo* and other important species
TSR	Reclamation	*Acacia nilotica, Prosopis* spp., *Parkinsonia* spp.
Arid and semi-arid region		
AS	Fodder, fuel wood, fruits	*Prosopis cineraria*, *Acacia senegal, A. nilotica*, *A. leucopholea*, *Ziziphus* spp., *Ailanthus excelsa*
FBW	Soil conservation, fodder, fuel	*Ziziphus nummularia*, *Prosopis* spp., *Acacia nilotica, Salvadora oleoides, S. persica*
WS	Sand dune stabilization	*Cassia* spp., *Acacia* spp., *Prosopis chinensis, Azadirachta indica, Tamarix* spp.
SP	Fodder, fuel shade, timber	*Ziziphus* spp., *Prosopis* spp., *Acacia senegal, Azadirachta indica, Acacia tortilis*
TSR	Reclamation of soil, fuel, fodder	*Casuarina* spp., *Albizia lebbeck, Azadirachta indica, Acacia tortilis* and other tree species
Humid and sub-humid region		
MS	Cash, multiple outputs	Coconut, Erythrina and Arecanut with fruit crops, coffee, cacao, black pepper, betel vine and large cardamom
Hg	Multiple outputs	Mixed plantation of trees, herbs and shrubs
MPT	Fodder, minor products	*Aegle marmelos, Acacia auriculiformis, Anogeissus latifolia, Albizia* spp., *Casuarina equisetifolia, Anthocephalus chinensis, Artocarpus* and *Diospyros melanoxylon*.

Source: Dhyani 2018; Parewa *et al.*, 2018; Yadav *et al.*, 2018

AEZ- Agro-ecological zone; AH- Agri-horticulture; AS- Agri-silviculture; MSS- Multi-storeyed and specialized system; SP- Silvi-pasture; HP- Horti-pastoral; FBW- Fodder banks and woodlots; TSR- Trees for soil reclamation; WS- Windbreaks and shelterbelts; MS- Multi-tier system or plantation crop combination; Hg- Homegardens; MPT- Multipurpose trees in agricultural fields

These indigenous agroforestry systems not only support the livelihood through production of food, fodder and fuel wood, but also are ecologically sustainable system and also mitigate the impact of climate change through carbon sequestration (Ramakrishnan, 2007; Sharma *et al*., 2007; 2016_{a-c}; Perfecto and Vandermeer, 2008; Singh *et al.*, 2008; Altieri, 2009; Bargali *et al.*, 2009; Altieri and Toledo, 2011; Arora *et al.* 2011; Mehta *et al*., 2015; Yadav *et al*., 2015; Thakur *et al*., 2017; Singh *et al*., 2018_{a}; Rendón-Sandoval *et al*., 2020; Keerthika *et al*., 2021).

One such system is large cardamom (*Amomum subulatum* Roxb.) based traditional agroforestry in the north eastern Indian states including the Darjeeling Himalayas (Srinivasa, 2006; Sharma *et al*., 2007; 2016_{a-d}; Mehta *et al*., 2015; Shrestha, 2018). Large cardamom, the oldest of spices is native to Sikkim and Darjeeling Himalaya including eastern hills of Nepal (Sharma *et al*., 2016_{a-c}; Shrestha, 2018; Shrestha *et al*., 2018). The distribution of large cardamom is very limited and mainly found in Eastern Himalayan region of India, Nepal and Bhutan (Mehta *et al*., 2015). Large cardamom is a shade loving perennial cash crop traditionally inter-mixed as understorey of natural forest tree on marginal lands and slopes with high moisture in areas of high rainfall between 1500-3500 mm at an altitude of 600 and 2000 m above mean sea level (Sharma *et al*., 1994, 2000, 2007, 2009_{b}; Sharma and Sharma, 1997; Das *et al*., 2012, 2017; Gudade *et al*., 2013; Yadav *et al*., 2015). Of the many shade trees associated with the large cardamom, Nepalese or Himalayan Alder (*Alnus nepalensis*) is prominent because of its nitrogen fixing capacity (Sharma and Ambasht, 1984; Gokhle *et al*., 1985; Sharma *et al*., 1994, 2007; Sharma and Sharma, 1997; Das *et al*., 2012; Chaudhary *et al*., 2015; Anitha and Hore, 2018; Negi *et al*., 2018). The area of cultivation in Sikkim and Darjeeling Himalayas in 2011-12 was 23154 ha 3305 ha, respectively with production of 3237 tonnes and 626 tonnes, respectively (Gudade *et al*., 2013). In Darjeeling Himalayas during 2015-16 area of cultivation, production and productivity of large cardamom was 2829 ha, 848.84 tonnes and 300.5 kg ha^{-1}; of which cultivation is prominently done the district of Kalimpong (80 % of the total cardamom area) and less in Darjeeling (Tarafder *et al*., 2018).

Studies on large cardamom based traditional agroforestry system in respect to vegetation analysis, biomass production, soil nutrient and carbon storage capacity were very few mainly reported from Sikkim Himalayas (Sharma *et al*., 2007; 2016_{a-c}) but none compared the large cardamom based traditional agroforestry system on aspect of altitudinal gradient. Perusal of literature revealed that there is no detailed study of large cardamom based traditional agroforestry system across an altitudinal gradient to understand the floristic diversity, structure and composition and their ecosystem services. The available literature on these aspects of traditional large cardamom based agroforestry systems was reviewed under the following category:

- Diversity and species composition
- Biomass and carbon stock
- Soil physico-chemical properties
- Ecosystem services and function

2.1. Diversity and Species Composition

Land-use and land cover pattern of Himalayan region of India are mostly dominated with tree based farming system such as forestry, agriculture, horticulture, agroforestry and animal husbandry (Sundiriyal *et al.*, 1994). A number of workers studied the farming systems of Himalayan including agroforestry systems (Toky *et al.*, $1989_{a,\ b}$; Gilmour and Nurse, 1991; Ralhan *et al.*, 1991; Zomer and Menke, 1993; Sundriyal *et al.* 1994; Thapa *et al.*, 1995; Sharma *et al.*, 1995; Semwal and Maikhuri, 1996; Singh *et al.*, 1997; Thakur *et al.*, 2004, 2005; Sood, 2006; Sharma *et al.*, 2007; 2016; Kumar *et al*., 2012_{a}; Pandey *et al*., 2017), but the quantitative information on vegetation analysis, plant biomass and other aspect of traditional agroforestry systems are very limited and scanty (Maikhuri *et al.*, 2000; Kumar *et al.*, 2012_{a}). Himalayan region of India is categorized by highly complex socio-ecological systems due to dominance of ethnic communities with rich cultural diversity directly associated with rich species diversity (Ramakrishnan, 2007; Kumar *et al.*, 2012_{a}) which are seen as the foundation for safeguarding human security in these socio-ecologically fragile mountain systems.

Indian Himalayas are spread over 59 million ha of which 22 million ha is degraded (Rao and Saxena, 1994). Plantation of indigenous multipurpose trees in degraded areas can bring significant direct (improved food production, fuel wood, fodder, timber and other useful products) and indirect (carbon sequestration, hydrological balance, soil fertility, recovery and slope stability) benefits, which can support the welfares of both local and global community (Houghton, 1996; Maikhuri *et* *al*., 1997_a; Montagnini and Porras, 1998; Anon., 2013; Dhyani *et al*., 2013). The structural features of plant community can be articulated both in qualitative and quantitative characters (Dansereaun, 1968). The qualitative characters are physiognomy, phenology, stratification, abundance, dispersion, sociability, vitality and life-form, whereas, quantitative characters include density, frequency, dominance and basal area (Odum, 1983). 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. Phyto-sociological characters vary among aspects and location even in the similar type of vegetation (Kusumlata and Bisht, 1991). Effect of slope on structure and diversity of vegetation was also studied by various workers (Joshi and Tiwari, 1990; Singh *et al*., 1991; Swamy, 1998; Jha, 2001). A variety of factors contribute to the diversity of plants in a region. Plant species diversity is affected by several topographic gradients and climatic variations. It is generally observed that areas with high species diversity are found in the middle latitudes, particularly in the tropics, because of the congenial climatic, edaphic and other factors prevailing therein (De, 2007). The structural and functional attributes of constituent species in agroforestry systems are greatly affected due to complex interactions. Performance of agroforestry systems is therefore determined by the associated components i.e. their density and frequency. Hence the study of community is a basic prerequisite to understand the structural and functional attributes, which are specific to locate better landscape management (Joshi and Tiwari, 1990).

The ecological and environmental services that agroforestry systems can offered and particularly their potential role to biodiversity conservation, have recently attracted larger attention among the agroforestry and conservation scientist, policy maker and botanist (Saxena, 2000; Rai *et al*., 2001; Sharma *et al*., 2000; 2007; 2016_{a-d}; Puri and Nair, 2004; McNeely and Schroth, 2006; Pandey, 2007; Nair *et al*. 2008, 2009_a; Rigueiro-Rodríguez *et al*., 2011; Murthy *et al*., 2013; Casas *et al*., 2014; Tiwari *et al*., 2017; Tripathi *et al*., 2018; Rendón-Sandoval *et al*., 2020) due to its inherent desirable characteristic (Harvey *et al*., 2006; Jose, 2009) enumerated below in table 2. This new opinion is consistent with ecosystem approach to natural resource management supported by the Convention on Biological Diversity. At present the focus of scientific communities are shifted from on farm trail to larger landscape scale in agroforestry science which have direct link between agroforestry and conservation of biological diversity (McNeely and Schroth, 2006; Bhagwat *et al*., 2008; Moreno-Calles *et al*., 2010; Casas *et al*., 2014; Vallejo *et al*., 2016; Rendón-Sandoval *et al*., 2020).

Table 2. Desirable characteristics of agroforestry systems for biodiversity conservation

Activity	Variable	Desirable characteristics
Design	Species composition	Diverse species composition, mixture of early, mid and late succession species, preferably native species
	Tree/shrub density	Higher tree/shrub density (and greater areas) leads to greater biodiversity
	Type of agroforestry	Any system as long as it is floristically and structurally diverse
	Duration of agroforestry	Long rotation is desirable to provide stability
Management	Management regime	Minimal management is preferable
		Management strategies should maximize habitat heterogeneity and availability of diverse resources for wildlife
	Soil management	Minimal
	Harvesting of products	Minimal harvesting or harvesting that emulates natural disturbance regimes
	Fire management	Fire regimes should follow natural fire regimes to the extent possible
	Management of snags and coarse woody debris	Maintain snags and coarse woody debris as habitat for certain species
Spatial configuration	Location within broader landscape	Position the agroforestry practices strategically to enhance landscape connectivity, by functionally linking habitat fragments
		Position adjacent to protected areas, riparian corridors and remnant native habitat, to buffer these areas from agricultural impacts
	Types of land	Degraded sites, where revegetation through agroforestry will have a beneficial impact on biodiversity

Source: Harvey *et al*., 2006; Jose, 2009

Schroth *et al*. (2004) discussed three roles of agroforestry in biodiversity conservation on landscape scale: the provision of supplementary, secondary habitat for species that tolerate a certain level of disturbance; the reduction of rates of conversion of natural habitat in certain cases and the creation of a more benign and permeable matrix between habitat remnants compared with less tree-dominated land uses, which may support the integrity of these remnants and the conservation of their populations. Gupta *et al*. (2016) studied the existing agroforestry systems of India and recorded 1.81 to 204 tree/ha in farmers field on district basis with an average of 19.44 tree/ha. *Acacia nilotica* based traditional agroforestry of central India had an average 20 tree/ha with an age of <1 to 12 year and highest tree density was recorded in smaller farm as compared to > 8 ha farm (Viswanath *et al*., 2000).

In our country the traditional agroforestry systems have been influenced by many factors such as religious, social and economic since long time (Chinnamani, 1993; Sharma *et al*., 2000; 2007; 2016_{a-c}; Nandy and Das, 2013; Nath *et al*., 2016; Pandey *et al*., 2017) as well as these systems are also part of our tradition and culture (Kumar *et al*., 2012_{a}). Locality factors and people's choice are also important factors responsible for developing the numerous indigenous agroforestry systems over the years (Chandra *et al*., 2011; Kumar *et al*., 2012_{a}; Nath *et al*., 2016). It is well establish facts that these traditional agroforestry can resolve the major land-use problems in the rain fed farming systems and also helpful for improving the indigenous systems, food security, soil health and ecosystem services (Magcale-Macandog *et al*., 2010; Saha *et al*., 2010; Nath *et al*., 2015; Singh *et al*., 2015; Singh and Dwivedi, 2017; Jemal *et al*., 2018) and also enhance the stable carbon (passive carbon pool) in soil (De Stefano and Jacobson, 2018; Nath *et al*., 2018). Tree density of agroforestry systems in the Solan region of Himachal Pradesh was in the range of 182-419 trees/ha and species richness of 8-90 species (Toky *et al*., 1989_{a}). Similar trends were also reported for the hill agroforestry systems by many workers (Sundriyal *et al*., 1994; Thapa *et al*., 1995; Semwal and Maikhuri, 1996). It was also estimated by Bijalwan, (2012) that in the indigenous agroforestry systems the diversity index (1.058) and species richness (3.065) was highest in the southern aspect whereas Simpson Index (0.186), evenness index (0.418) and beta diversity (2.833) was recorded in northern aspect. Though substantial information is available on structural, ecological and economic attributes of agroforestry systems from different parts of India (Dadhwal *et al*., 1989; Toky *et al*., $1989_{a, b}$; Ralhan *et al*., 1991; Thapa *et al*., 1995; Maikhuri *et al*. 2000), studies on impacts of trees on crop yields are limited and confined largely to exotic timber and horticulture species (Khybri *et al*. 1992; Singh *et al*. 1997).

India is endowed with diverse agroclimatic zone; hence there are wide variations in agroforestry system in respect to structural complexity and species richness, their productive and protective attributes along with socio-economic dimensions (Pandey, 2007; Murthy *et al*., 2013; Prasad *et al*., 2016). They ranges from simple forms of shifting cultivation to complex homegardens along with some specific systems like sparse trees on farm land in arid region, high density multi-storey cropping in Kerala, intercropping with plantation crops (Dhyani *et al*., 2005; 2009; Ahmed and Hazarika, 2007; Deb *et al*., 2007; Harsh *et al*., 2007; Jamini and Tikka, 2007; Kumar, 2007; Kumar and Takeuchi, 2009; Pandey *et al*., 2007; Paramatma *et al*., 2007; Sahoo, 2007; Satish and Kushalappa, 2007; Sood *et al*., 2007; Sreemannarayana *et al*., 2007; Tomar *et al*., 2007; Murthy *et al*., 2013; Prasad *et al*., 2016). Dominance and association of the plant species in the agroforestry systems depends upon various factors like edapho-climatic condition, need and choice of the farmers, industrial and other facilities. Bhusara *et al*. (2016) studied the prominent traditional agroforestry systems in Valsad district, Gujarat, India and observed three agroforestry systems such as agri-horticulture (AH), agri-silviculture (AS) and horti-pasture practiced by the farmers of the region, which was dominated by *Mangifera indica*, *Tectona grandis* and fruits species was *Terminalia tomentosa*, *Acacia catechu* and *Mytragyna parviflora*. Six types of agroforestry systems were found in Uttara Kannada district of Karnataka, among them bund planting was most prominent agroforestry system, followed by horti-silviculture and least practiced was block plantation, whereas *Mangifera indica* was dominated fruit species (Varadarabganatha and Madiwalar, 2010).

Ralhan *et al*. (1991) studied the structure and function of the hill agroforestry system in Central Himalaya at 1000-2000 m elevation and found that the systems of the agroforestry were differing in the irrigated and rain fed areas in respect to crop composition and cropped area. In the Himalaya region the land use-land cover changes occurred due to the interaction of ecological, policy and social and cultural factors. It was evident that the present policy of treating forests and agriculture as closed and independent ecological or production system needs to be replaced by an integrated land use policy (Nautiyal *et al*., 1998). A study conducted by Nautiyal *et al*. (1998) in the rural landscape of Garhwal Himalaya to analyzed the status of different land use-land cover types. Authors found that four types of systems like simultaneous agroforestry, sequential agroforestry, homegarden and community forests accounted for 27.47 %, 27.47 %, 1.1 % and 43.96 %, respectively of the total geographical area of the village.

Indigenous agroforestry systems display a great complexity with regards to their component tree, shrub, climber and herb species (Thakur *et al*., 2005, 2017). Indigenous agroforestry systems in north-western Himalaya were preferred with common trees/shrubs in the ridge of the terrace farm without any extra inputs (Vishvakarma *et al*., 1998, Thakur *et al*., 2004 and 2005). Kumar *et al*. (2012_a) studied the traditional agroforestry system of Garhwal Himalaya and recorded the tree density was 940 tree/ha, 950 tree/ha, 1000 tree/ha, 1230 tree/ha 1310 tree/ha and 1560 tree/ha in six village of the region whereas, total basal area cover was 82.45-236.43 m^2/ha. Authors also reported that tree species such as *Grewia oppositifolia* and *Toona ciliata* were dominant in the study areas. Kumar *et al*., (2006) found that the *Grewia oppositifolia* is one of the preferred plant species in the tropical and sub-tropical region due to good quality fodder. Various workers studied the traditional agroforestry systems of Garhwal Himalaya and concluded that the systems were dominated by the some of the common trees species like *Grewia oppositifolia*, *Celtis australis*, *Bauhinia retusa*, *Morus alba*, *Ougeinia oojeinensis*, *Ficus* spp., *Quercus leucotrichophora*, *Melia azedarach*, *Pinus roxburghii*, *Toona serrata* and *Toona ciliate* (Sharma *et al*., 2009_b; Kala, 2010). The species composition pattern in traditional agroforestry systems in Himalaya is mainly comprised of indigenous multipurpose trees, varieties of agricultural crops and horticultural crops including vegetable and fruit plants, which vary based on the requirement of farmers, size of land along with climatic condition of the areas (Toky *et al*, $1989_{a,\,b}$; Rafiq *et al*., 2000; Sood, 2006).

Numbers of traditional agroforestry systems are found in the North-Western Himalayan region of Himachal Pradesh, among them agrihortisilvicultural, agrisilvicultural and agrihorticultural systems were prominent (Mazumdar, 1991; Rafiq *et al*., 2000; Thakur *et al*., 2004; 2005; 2017). Agroforestry land use systems viz. agrisilviculture (AS), pastoral-silviculture (PS) and pastoral-silvi-horticulture (PSH) of Solan (HP) were documented with 23 plant species, of which 11 were trees, four shrubs and eight herbs species (Thakur *et al*., 2005). Among the trees, *Grewia optiva* was found dominant in AS with density of 9.3 individuals per quadrate, basal area of 18.103 x 10^3 cm^2/ha and IVI values of 101.55, whereas *Acacia catechu* was dominant tree species (IVI of 131.66 & 125.13; basal area of 18.74 x 10^3 cm^2/ha & 16.88 x 10^3 cm^2/ha and density of 10.67 & 8.33 individuals/quadrate) in PS and PSH, respectively. Among the shrubs, *Murraya koenigii* (IVI-148.47, 125.54 and 174.33, respectively) was found dominant in these three agroforestry systems while, *Chrysopogon montanus* was found dominant among the herbs in PS and PSH (100.67 and 46.33 individuals/quadrate, respectively) and *Panicum maximum* was dominant in AS (29.67 individuals/quadrate). Similar species dominance in traditional agroforestry systems was also reported by Toky *et al*. (1989_a); Thakur and Tomar (1997); Gupta (2001) and Thakur *et al*. (2007).

Traditional agroforestry system of Darjeeling and Sikkim Himalayas was biodiversity rich due to association of shade trees like *Schima wallichii*, *Engelhardtia acerifolia*, *Eurya acuminata*, *Leucosceptrum canum*, *Maesa chisia*, *Symplocos theifolia*, *Ficus nemoralis*, *Ficus hookeri*, *Nyssa sessiliflora*, *Osbeckia paniculata*, *Viburnum cordifolium*, *Litsaea polyantha*, *Macaranga pustulata*, and *Alnus nepalensis* (Sharma *et al*., 1994). Large cardamom based indigenous agroforestry system supported highest tree diversity and diversity index as compared to other agroforestry systems of the region (Sharma and Sharma, 1997) and crop was grown under the canopy of alder tree with 400 tree density (Das *et al*., 2012). Further, high tree richness also supports birds and other wildlife which effect the ecological structure and functioning of the agroforestry system. Traditional agroforestry systems particularly the large cardamom based in the hills are very close to natural ecosystems as they offer wide range of ecosystem services similar to forests such as biodiversity, provision of NTFPs, water resources and its purification and conservation, biomass production, carbon sequestration, nutrient cycling and socio-cultural service for the well-being of the society (Zomer and Menke, 1993; Nandy and Das, 2013; Iqbal *et al.*, 2014_a; Nath *et al*., 2016; Pandey *et al*., 2017; Singh *et al.*, 2018_a). Multipurpose trees are an essential component of traditional agroforestry with role in rehabilitation, improvement of degraded wastelands and soil erosion (Dhadwal *et al*., 1986) as well as for green fodder during the lean periods (Pandey and Singh, 1984).

Shrub dominated ecosystems extend from arctic to tropical region and occur over the entire moisture gradient from desert to wetland (Specth, 1979; Di Castri, 1981; West, 1983). Shrubs are the common component in the indigenous agroforestry systems such as agri-silviculture, silvipasture, silvi-horticulture, agri-silvi-horticulture and agri-horticulture in India (Thakur *et al*., 2017; table 3). A total of 56 species of edible NTFPs were collected from forest based agroforestry, while 27 species from forest cardamom based, 16 species from farm based and 9 species from mandarin based agroforestry system (Sharma *et al.,* 2008, 2016$_{a-d}$). Shannon and Weaver index value of 4.1 estimated for the trees in the system clearly indicates the importance of tree diversity of these traditional large cardamom based agroforestry systems (Sharma *et al.,* 2008). Several studies have reported that planting Alnus trees in agricultural settings and other type of farming system have positive effects on plant growth, crop production and soil health (Vanlalhluna and Sahoo, 2009; Das *et al*., 2010; Mortimera *et al.,* 2015).

Table 3. Shrub species richness in traditional agroforestry systems

AFS	Species	Reference
Tehri Garhwal		
AS, AH	*Berberis asiatica, Rhus parviflora, Rubus, ellipticus, Ficus palmata, Carissa opeca, Vitex negundo* and *Euphorbia royleana*	Kala, 2010
AH	*Artemisia vulgaris, Eupatorium adenophorum, Berberis asiatica, Rubus ellipticus, Rosa brunonii, Zanthoxylum alatum, Rumex hastatus*	Bijalwan, 2012
North-western Himalayas		
AS	*Berberis lyceum, Murraya koenigii, Premna latifolia, Rubus ellipticus, Vitex negundo, Justicia adhatoda, Mimosa himalayana*	Thakur *et al*., 2004, 2005
SP	*Justicia adhatoda, Leptodermis lanceolata, Mimosa himalayana, Premna latifolia, Woodfordia fruticosa*	Thakur *et al*., 2004, 2005
SHP	*Carissa carandas, Justicia adhatoda, Mimosa himalayana, Leptodermis lanceolata*	Thakur *et al*., 2004, 2005
North-western inner Himalayan region (Kullu and Lahaul)		
AS, AH	*Berberis chitria, B. jaeschkeana, Cotoneaster bacillaris, Hippophae rhamnoides, Indigofera heterantha, Juniperus communis*	Rawat and Vishvakarma, 2010
North-western inner Himalayan region (Rajouri, J & K)		
AS, AH	*Barleria cristata, Inula cuspidata, Berberis lyceum, Euphorbia royleana, Desmodium elegans, Indigofera heterantha, Reinwardtia indica*	Jawaid *et al*., 2009
Western Ghat (Uttara Kannada)		
AH	*Theobromea cocoa, Hibiscus tiliaceus,* Karnataka *Murraya koenigii, Coffea arabica, Vitex negundo, Punica granatum* and *Jatropha curcas*	Varadarabganatha and Madiwalar, 2010
Eastern Himalayas (Upper Assam)		
Hg	*Camellia sinenses, Capsicum annum, C. annum* var longum, *Chromolaena odorata, Clerodendrum viscosum, Hibiscus rosa chinenesis, Ixora javania*	Saikia *et al*., 2012

Eastern Himalayas (Barak Valley, Assam)		
Hg	*Hibiscus rosa sinensis*, *Nyctanthes arboritristis*, *Adhatoda vasica*, *Bougainvillea spectabilis*, *Caesalpinia pulcherrima*, *Calamus tenuis*	Das and Das, 2005_b
Eastern Himalayas (Meghalaya)		
Hg	*Allamanda cathartica*, *Capsicum frutescens*, *Citrus assamensis*, *Clerodendron colebrookianum*, *Hibiscus rosa-sinensis, Manihot esculenta*	Tynsong and Tiwari, 2010
South Andaman Islands		
Hg	*Carica papaya*, *Cinnamomum tamala*, *C. zylanicum*, *Citrus limon*, *Gliricidia sepium*, *Manihot esculenta*	Pandey *et al*., 2006

AFS- Agroforestry System; AS- Agri-silviculture; AH- Agri-horticulture; SP- Silvi-pasture; SHP- Silvi-hortipasture; Hg- Homegarden

Soil organic carbon (SOC), total nitrogen and total phosphorus were found highest in the Alnus cardamom system (Sharma *et al*., $2016_{c,\ d}$). Traditional agroforestry systems of North East India were recorded with 44 tree species with stem density of 1255 stems/ha while, Shannon-Weaver diversity index, Simpson diversity index, Margalef species richness and Pielou's species evenness was 3.75, 0.03, 7.34 and 0.91, respectively (Das *et al*., 2020). Similar types of species richness were reported from North East India by Nath *et al*. (2016) and from other parts of the country by Pandey (2007), Umrao *et al*. (2017) and Salve *et al*. (2018_b) whereas, lesser species richness in traditional agroforestry systems than these studies were also reported by Abebe *et al*. (2010) and Udawatta *et al.* (2019). Further, diversity indices reported by Das *et al*., (2020) was higher than those reported in other studies (Saikia and Khan, 2016; Umrao *et al*., 2017; Salve *et al*., 2018_b; Wari *et al*., 2019). A total of 48 tree species was recorded in *paan jhum* in comparison to 42 species in natural forest of Barak valley, Northeast, India with higher diversity index of 3.36 as compared to natural forest with 3.27 (Nandy and Das, 2013). The study also reported higher genera, families and number of individuals/ha in paan jhum than the natural forest but estimated similar basal area for both the systems (40.50-68.75 m^2 ha^{-1} and 41.60-74.05 m^2 ha^{-1}, respectively).

Traditional agroforestry systems (TAFS) and conservation of native plant diversity of seasonally dry tropical forest (TDF) of Tehuacán-Cuicatlán Valley, Mexico was studied by Rendón-Sandoval *et al*. (2020). The study documented 132 perennial plant species represented by 101 genera and 39 families with highest number of 101 species in TAFS and 98 species in TDF. TAFS harboured most of the documented species (68 % of perennial species represented by 71 % of the families and 66 % of the genera), of which 95 % were native species. Family Fabaceae (14 genera and 19 species) dominated the list followed by Cactaceae (12 genera and 18 species) and Euphorbiaceae (16 genera and 9 species), of which Bursera was the dominated genus in the TAFS represented by seven species. All the documented species of TAFS were used by the growers for shade, firewood, edible fruits and medicine along with other household purposes. Higher relative density was recorded in TDF for *Croton alamosanus* (238 individuals/ha), *Aeschynomene compacta* (193), *Mammillaria carnea* (182), *Echinopterys eglandulosa* (169) and *Bursera aptera* (167) as compared to TAFS. Similar type of family and genera richness were also observed by other studies in the same region (Casas *et al*., 1997; Gillespie *et al*, 2000; Trejo and Dirzo, 2002; Valiente-Banuet *et al*., 2000; Moreno-Calles *et al*., 2010; Rzedowski and Calderón, 2013; Campos-Salas *et al*., 2016; Casas *et al*., 2017; Gallardo-Cruz *et al*., 2017).

Farmers of the north east region of India integrate several tree species in land uses but types of species vary from state to state and even from location to location within a state based on diversity of ethnic communities and food habits of the communities (Selvan and Kumar, 2017). About 40 plant species were cultivated in indigenous agroforestry systems of tropical and sub-tropical areas and 30 in temperate areas along with 28 bamboo species. Tree density varies with agroforestry systems, slope and land quality. Tree density reported in agri-horticulture system was 400 trees ha^{-1} and 200 tree ha^{-1} in agrisilviculture (Shankar, 2005). A total of 44 woody species was found in traditional agroforestry systems of Tripura (Deb *et al*., 2014). Among the various types of traditional agroforestry systems practiced by the Indigenous communities of Tripura, wetland agroforestry was reported prominent (Taran and Deb, 2019). Wetland agroforestry system of Tripura was found useful to balance the atmospheric carbon and also supported livelihood by providing fish and other agricultural products (Arunachalam *et al*., 2013). Wetland agroforestry system of Tripura was documented with 39 plant species represented by 24 families, of which *Mangifera indica* (IVI- 47.24), *Artocarpus hetrophyllus* (IVI- 37.86) and *Anacardium occidentale* (IVI- 20.43) were the dominated tree species (Taran and Deb, 2019). Mimosaceae was dominant family represented by four species followed by Anacardiaceae, Combretaceae Meliaceae, Myrtaceae and Rutaceae each represented by three species and Rahmnaceae represented by two species. Plant density, Shannon-Weaver index and Simpson index estimated was 65 individuals/ha, 3.56 and 0.62, respectively. Similar values of diversity index were estimated for traditional agroforestry system in another region of North-east, India (Tangjang *et al*., 2004) and for traditional homegardens in Bangladesh (Bardhan *et al*., 2012).

2.2. Biomass and Carbon Stock

Volume assessment of standing tree is essential as it provides a primary data on growing stock and help in taking management decisions (Fazakas and Nilsson, 1996). Quantification of total biomass rather than volume is essential as different parts play a vital role in structural and functional process of ecosystem (Chaturvedi and Singh, 1987; Tiwari, 1994). The biomass of the trees is generally estimated by use of species specific allometric equations and part wise (viz., stem, branch, foliage and root) biomass is assessed for both tree and shrub layers (Odum, 1983; Brown and Lugo, 1984; Tiwari and Singh, 1984; Swamy, 1998; Haripriya, 2000; Bijalwan, 2002). Tree based traditional farming systems were recommended for carbon emission offset by Kyoto Protocol under article 3.3 (Watson and Eyzaguirre, 2002; Albrecht and Kandji, 2003; Makundi and Sathaye, 2004; Smith *et al*., 2007; Takimoto *et al*., 2008; Bhusara *et al*., 2016) due to its financial possibility while, reducing pressure from the forests and enhancing soil productivity through long time accumulation of atmospheric carbon in its biomass in an agricultural landscape along with sustaining the farmers (Kursten, 2000; Nair, 2001$_{a,\ b}$; Kumar, 2003, 2005, 2006$_{a\text{-}c}$, 2007, 2008$_{a\text{-}d}$, 2011; Raizada *et al*., 2003; Ruark *et al*., 2003; Zhang and Zhang, 2003; Montagnini and Nair, 2004; Pregitzer and Euskirchen, 2004; Kaonga, 2005; King *et al*., 2005; Verchot *et al*., 2005; 2007; Sileshi *et al*., 2007; Gupta and Sharma, 2008, Kaonga and Coleman, 2008; Schoeneberger, 2008; Derwisch *et al*., 2009; Nair *et al*., 2009$_{a,\ b}$, 2010; Panwar and Chakravarty, 2010; Pinho *et al*., 2012; Saha and Pramod, 2012; Murthy *et al*., 2013; Shukla *et al*., 2014; Verma *et al*., 2014; Bhusara *et al*., 2016; Coelho, 2017; Kumar and Tripathi, 2017; Kumar *et al*., 2018; Mengistu and Asfaw, 2019; Dar *et al*., 2019; Das *et al*., 2020; Chakravarty *et al*., 2017$_{a,\ b}$, 2018$_{a,\ b}$, 2019, 2020).

In agroforestry systems, carbon is situated in five main pools i.e. aboveground biomass, belowground biomass, litter, micro-organism and soil (Mosquera-Losada *et al*., 2011$_{a}$). These pools relate with each other via different ways of transformation and translocation. The fundamental of carbon sequestration prospect of agroforestry is through the biological processes of photosynthesis, respiration, and decomposition (Chavan and Rasal, 2010, 2012; Shi *et al*., 2013; Suryawanshi *et al*., 2014; Liu *et al*., 2015; Shukla *et al*., 2017$_{a}$; Vishnu and Patil, 2017; Kongmessup and Boonyanuphap, 2019). Net primary production of the agroforestry systems/tree based farming are more as bulk of the plant materials produced either are stored in the biomass or are revert back to the soil in form of organic carbon (Dawson and Smith, 2007; Poeplau *et al*., 2011; Uthappa *et al*., 2015; Chauhan *et al*., 2019). The relationship between biomass carbon stocks of agroforestry to its SOC stocks across a landscape was described to support in managing the carbon pools efficiently (Mathew *et al*., 2016; Prasad *et al*., 2016). Ever increasing carbon concentration and biodiversity reduction are the foremost threats for sustainable progress today (Albrecht and Kandji, 2003; Kale *et al*., 2004; Han *et al*., 2007; Van Noordwijk *et al*., 2011; Mishra *et al*., 2013; Bhusara *et al*., 2016; Chakravarty *et al*., 2017$_{a, b}$, 2018$_{a, b}$, 2019, 2020; Salunkhe *et al.*, 2018; Srinivas and Sundarapandian, 2018; Dar *et al*., 2019; Pitol *et al*., 2019; Rawat *et al*., 2019; Shankar *et al*., 2020; Sheikh *et al*., 2020).

Carbon sequestration in biomass and soils has enormous potential to mitigate GHG emission (Chakravarty *et al*., 2015, 2017$_{a, b}$; 2018$_{a, b}$; 2020). In addition, agroforestry systems can aid carbon sequestration of natural forests by offsetting potential deforestation e.g. one hectare of sustainable agroforestry can offset 5-20 hectares of deforestation (Nair and Nair, 2003; Kumar, 2006$_{a, b}$) and can increase soil carbon storage (Kumar and Nair, 2004; Palm *et al*., 2000, 2004; Montagnini, 2006; Nair *et al*., 2010; Jose and Bardhan, 2012; Bhusara *et al*., 2016; Zomer *et al*., 2016). The role of agroforestry in carbon sequestration has been recognised but understanding of carbon storage and sequestration potential is crucial in climate change adaptation and mitigation with adequate policy support for its adoption (Watson *et al*., 2000$_{a}$; Montagnini, 2006; Montagnini and Nair, 2004; Palm *et al*., 2004; Kumar, 2006$_{b}$; Sharma *et al*., 2007; Haile *et al*., 2008; Williams-Guillen *et al*., 2008; Nair *et al*., 2009$_{b}$; Van Noordwijk *et al*., 2011; Prasad *et al*., 2012; 2014; Schoeneberger *et al*., 2012; Murthy *et al*., 2013; Cubbage *et al*., 2013; Garrity, 2014; Lorenz and Lal, 2014; Bhusara *et al*., 2016; Possu *et al*., 2018; Thangavel *et al*., 2018)

Agroforestry systems have larger carbon sink than annual crops or pastures (Albrecht and Kandji, 2003; Lee and Jose, 2003; Nair and Nair, 2003; Nair *et al*., 2009_b; Nair, 2011; Morgan *et al*., 2010; Demessie *et al*., 2013; Murthy *et al*., 2013; Prasad *et al*., 2016; Shi *et al*., 2018). Developing countries around the world now have recognized the prospect of agroforestry systems towards mitigation of climate change and thus are promoting and accepting the agroforestry based REDD+ strategic options (Watson *et al*., 2000_a; Chauhan *et al*., 2009; Nair *et al*., 2010; Mbow *et al*., 2014; Minang *et al*., 2014; Zomer *et al*., 2016; Franks *et al*., 2017; Shi *et al*., 2018). Continued accumulation of woody biomass throughout the rotation length along with biomass conversion to durable items escalate the ability of the system to capture more carbon (Pandey, 2002; Dossa *et al*., 2008; Jose, 2009; Prasad *et al*., 2016) while, increasing sequestration also enhance soil carbon storage (Smith *et al*., 2007).

Agroforestry systems such as agro-silvopastoral, shifting cultivation, pasture maintenance by burning, paddy cultivation and animal production discharges greenhouse gases (GHG) in the atmosphere (Watson *et al*., 2000_a; Le Mer and Roger, 2001; Chakravarty and Mallick, 2003; Montagnini and Nair, 2004; Kandji *et al*., 2006; Chauhan *et al*., 2009; Chakravarty *et al*., 2015; Prasad *et al*., 2016; Salve *et al*., 2018_a). However, agroforestry are tree based land use systems with higher carbon contents than any other land uses in an agricultural landscape and hence has higher net gains in carbon stocks (Watson *et al*., 2000_b; Roshetko *et al*., $2002_{a,\ b}$; 2007; Smith and Scherr, 2002; Tomich *et al*., 2002; Albrecht and Kandji, 2003; Alavalapati *et al*., 2004; Montagnini and Nair, 2004; Palm *et al*., 2004; Das and Chaturvedi, $2005_{a,\ b}$; Fang *et al*., 2007; Rao *et al*., 2007; Sharma *et al*., 2007; Haile *et al*., 2008; Chauhan *et al*., 2009, 2015, 2019; Calfapietra *et al*., 2010; Kumar and Nair, 2011; Rizvi *et al*., 2011; Hergoualc'h *et al*., 2012; Haris *et al*., 2013; Kanime *et al*., 2013; Arora *et al*., 2014; Nielsen *et al*., 2014; Kane, 2015; Kutsokon *et al*., 2015; Bhusara *et al*., 2016; Newaz *et al*., 2016; Panwar *et al*., 2017; Jha, 2018; Singh and Sahoo, 2018; Dar *et al*., 2019; Das *et al*., 2020). Assessment of carbon sequestration potential of prevailing agroforestry systems for simulation period of 30 years in twenty-six districts from ten selected states of India was carried out by Gupta *et al*. (2016). The study found that biomass varied from 0.58 to 48.50 Mg ha^{-1} in trees and the total biomass (tree + crops) ranged from 4.96 to 58.96 Mg ha^{-1} whereas, SOC was in the range of 4.28-24.13 Mg ha^{-1}. The average annual carbon sequestration potential of the agroforestry systems estimated was 0.21 Mg ha^{-1} expressing varied edapho-climatic conditions at micro-landscape and country level. Nationally these agroforestry systems were able to mitigate 109.34 million-ton carbon dioxide annually offsetting 33 % of the total greenhouse gas emissions from agricultural activities.

Traditional agroforestry systems sequester carbon more efficiently than the simpler systems or monoculture farming (Thakur *et al*., 2004; 2005; 2007; 2011_a; Bhusara *et al*., 2016). The efficiency of systems to become carbon sink depend on size, natural site qualities, choice of species and management practices along with structure, function and composition modified by environmental and socio-economic factors (Capersen and Pacala, 2001; Newaj *et al*., 2001; Albrecht and Kandji, 2003; Kaushal and Verma, 2003; Montagnini and Nair, 2004; Oelbermann *et al*., 2004; Thakur *et al*., 2004; 2005; 2007; 2011_a; Murali *et al*., 2005; Swamy and Puri, 2005; Kumar, 2006_b; Peichl and Arain, 2006; Firn *et al*., 2007; Mani and Parthasarathy, 2007; Muñoz *et al*., 2007; Taylor *et al*., 2007; Vila *et al*., 2007; Haile *et al*., 2008; Newaj and Dhyani, 2008; Henry *et al*., 2009; Saha *et al*., 2009, 2010; Jacob *et al*., 2010; Kumar and Nair, 2011; Wang *et al*., 2011; Wardah *et al*., 2011; Borah *et al*., 2013; Bhusara *et al*., 2016; Prasad *et al*., 2016; Wang *et al*., 2016; Kuyah *et al*., 2017; Singh and Sahoo, 2018; Besar *et al*., 2020). Different tree species have different amount of carbon stock, while soil carbon also varies under different tree species in terms of its litter input and chemistry (Mulder *et al*., 2001; Eviner and Chapin, 2003; Vesterdal *et al*., 2008; Bhusara *et al*., 2016; Brahma *et al*., 2018; De Stefano and Jacobson, 2018; Guo *et al*., 2020; Hariah *et al*., 2020). Tree species vary in their influence to root: shoot ratio, litter quality and SOC (Turner and Lambert, 2000; Steinaker and Wilson, 2005; Guo *et al*., 2008). Other factors reported to influence tree biomass and its carbon were diameter of the tree, stand age, stand structure and diversity of the system (Chave *et al*., 2004; Bajigo *et al*., 2015). The tree components of agroforestry systems are capable enough to capture atmosphere CO_2 and responsible for returning the carbon to the soil through their litter than herbaceous crops (Gordon *et al*., 2006). Nutrient use efficiency in agroforestry systems is better due to high species richness which enhances carbon sequestration as compared to tree-less agronomic systems (Howlett *et al*., 2011; Rigueiro-Rodríguez *et al*., 2011; Hoosbeek *et al*., 2018). The growing rate of tree species is a major factor in stimulating carbon sequestration, i.e. faster the growth rate of a tree species, higher and quicker is the carbon sequestration by the species (Sharma, 2016_d).

Globally, agroforestry was reported to occupy about 1,023 million ha land area (Nair *et al*., $2009_{a,\ b}$; Kumar *et al*., 2014) and in India about 25.32 million ha (Dhyani, 2018) which is gradually increasing (Kumar *et al*., 2014). Carbon sequestration prospect of agroforestry systems reported was 0.72-7.81 Mg ha^{-1} yr^{-1} across ecological zones (Watson *et al*., 2000_a; Jarecki and Lal, 2003; Kanime *et al*., 2013; Rajput *et al*., 2015; Bhusara *et al*., 2016). About 1.2 billion rural people practice different agroforestry systems (Dhyani, 2018) Furthermore, with a moderate density, each hectare land area of agroforestry plantation sequesters at least 5-6 mega gram of carbon annually (Singh *et al*., 2016). The average carbon storage in agroforestry system was 9, 21, 50, and 63 Mg C ha^{-1} in semiarid, sub-humid, humid and temperate region (Prasad *et al*., 2016). The sequestration potential of smallholder agroforestry system in tropics was ranges from 1.5 to 3.5 Mg C ha^{-1} (Montagnini and Nair, 2004). Annual carbon potential of Indian agroforestry varied from 19.56 Mg ha^{-1} in Uttar Pradesh to a carbon pool of 23.46-47.36 Mg C ha^{-1} in tree based agroecosystems of arid region of Rajasthan (Prasad *et al*., 2016). Agroforestry systems have a high potential for carbon sequestration and thus could constitute a carbon sink, helping to reduce adverse global climate change. It is reported that, agroforestry in India could annually sequester 0.25 (Kaur *et al*., 2002) to 19.14 Mg C $ha^{–1}$ $yr^{–1}$ (Nath and Das, 2012).

Monoculture of trees and food crops were reported to sequester 40 and 84 %, respectively less carbon than when inter-cropped together in agri-silviculture system (Dhyani *et al*., 2009). The impact of (*Tectona grandis*), sissoo (*Dalbergia sissoo*), eucalyptus (*Eucalyptus globulus*) and neem (*Azadirachta indica*) agroforestry blocks (age 28 years) in association with pineapple (*Ananas comosus*) on SOC stocks and its fraction pools was analysed at Lembucherra, Tripura, India (Yadav *et al*., 2021). The study quantified highest SOC stocks in 0-15 cm soil depth (22.1 ± 1.4 Mg/ha) and 30-60 cm soil depth (18.0 ± 4.3 Mg/ha) in combination of sissoo + pineapple agroforestry block. Overall significantly higher SOC stock of 65.3-71.60 Mg ha^{-1} was estimated for the agroforestry blocks up to 100 cm soil depth than non-agroforestry cultivated lands (52.8 ± 2.6 Mg ha^{-1}). Among the agroforestry blocks, sissoo + pineapple system accumulated the highest SOC of 71.6 ± 5.8 Mg ha^{-1} up to 0-100 cm soil depth. The portion of passive carbon (less labile + non-labile) pools to SOC stocks in the agroforestry blocks was in the order of sissoo + pineapple > teak + pineapple > neem + pineapple > eucalyptus + pineapple. The passive carbon or recalcitrant pool of SOC stocks at 0-100 cm soil depth was 54.2-60.6 % in different agroforestry blocks. Establishment of pineapple based agroforestry systems on degraded lands enhanced the quantity of carbon and also significantly influenced soil quality as compared to monoculture or cropland. Numerous other studies also reported higher SOC in agroforestry systems due to addition of litter, pruning residue and root inputs (Zingore *et al*., 2003; Sierra and Nygren, 2005; Sileshi and Mafongoya, 2007; Nyamadzawo *et al*., 2012; Negash and Starr, 2013, 2015; Shi *et al*., 2013; Ramesh *et al*., 2015; Germon *et al*., 2016; Weerasekara *et al*., 2016). Incorporation of leguminous trees in agroforestry systems was reported to influence both passive and active carbon pools in the soil (Nath *et al*., 2018; Thangvel *et al*., 2018).

Singh *et al*. (2018_a) assessed the effect of multipurpose tree on production of large cardamom and soil fertility in agroforestry systems in Sikkim Himalayas. In this study highest soil microbial biomass carbon was quantified in mixed agroforestry system (847 mg kg^{-1}) and lowest in control (398 mg kg^{-1}) at upper layer of soil. Soil microbial biomass carbon was highest in all the studied agroforestry systems in both (0-20 and 21-40 cm) the soil layers. Similar type of results was also reported by He *et al*. (2013) with 1.45 times more microbial biomass carbon in *Alnus nepalensis* due good growth of microorganism under the canopy of *Alnus* due to influence on functional properties of soil microbial communities (Sroka *et al*., 2018). Himalayan alder and large cardamom intercrop of eastern Nepal was studied at sixty sites to quantify the biomass production (Zomer and Menke, 1993). The study estimated annual biomass production of 14 Mg ha^{-1} in typical plantation with average annual increment of 11 Mg ha^{-1} in standing biomass after thinning and average standing biomass of 273 t ha^{-1} in plantation of 25 years. Total standing biomass in alder plantations of poorest to best sites quantified in the study was in the range of 169-400 Mg ha^{-1}. Large cardamom based traditional agroforestry systems in Sikkim Himalayas were reported rich in SOC but lesser than natural forest cardamom agroforestry (Sharma *et al*., 2007, 2008, 2016_{a-c}). Total biomass and carbon in trees in a 20-year-old traditional cardamom agroforestry system of Sikkim Himalayas estimated was 81.91 Mg ha^{-1} and 38.47 Mg ha^{-1}, respectively which contributed 27% to the total ecosystem carbon (Lepcha and Devi, 2020_a). Herbs and detritus carbon estimated in the system was 2.34 Mg ha^{-1} and 3.64 Mg C ha^{-1} respectively. The cumulative SOC estimated for 0-45 cm soil depth was 89.90-to 117.91 Mg ha^{-1}.

The traditional agroforestry systems around Srinagar, Garhwal Himalayas were dominated by tree species *Grewia oppositifolia* followed by *Toona ciliata* and carbon stock estimated in these was 19.85-57.45 Mg ha^{-1} with an average of 32.56 Mg ha^{-1} (Kumar *et al*., 2012_a). The SOC estimated in these traditional agroforestry systems of Srinagar was 12.78-146.88 Mg ha^{-1} with an average of 56.74 Mg ha^{-1}. Bamboo based agroforestry were also reported as significant carbon sink due to their fast growth and productivity (Krishnankutty, 2005; Das and Chaturvedi, 2006; Kiyono *et al*., 2007; Nath and Das, 2007, 2008, 2011; Nath *et al*., 2008, 2009). Annual carbon sequestration potential of planted tree species on abandoned agricultural land (3.9 Mg ha^{-1}) was higher than degraded forestry (1.79 Mg ha^{-1}) and *Alnus nepalensis* sequestered more carbon annually (0.256 Mg ha^{-1}) than *Dalbergia sissoo* (0.141 Mg ha^{-1}) when intercropped with wheat and paddy (Maikhuri *et al*., 2000). Teak based agroforestry (teak + rice) accumulated the highest woody above ground biomass (40.15 Mg ha^{-1}), below ground biomass (10.44 Mg ha^{-1}) and total biomass (50.59 Mg ha^{-1}) while, mango based agroforestry system (mango + banana) accumulated lowest above ground (25.41 Mg ha^{-1}), belowground (6.6 Mg ha^{-1}) and total (32.01 Mg ha^{-1}) woody biomass among the prominent traditional agroforestry systems in Valsad District of Gujarat (Bhusara *et al*., 2016).

Traditional parkland agroforestry systems of Sahel were estimated with larger carbon stock than the improved agroforestry systems while; improved agroforestry system was potentially higher in sequestering atmospheric carbon (Takimoto *et al*., 2008). The soil carbon content in traditional parkland agroforestry, improved agroforestry and abandoned land of West African Sahel estimated was in the range of 1.33-4.69, 1.11-4.42 and 3.69-5.30 g kg^{-1} in parkland agroforestry, improved agroforestry and abandoned land, respectively (Takimoto *et al*., 2009). On-farm stem density, basal area, above ground tree biomass and SOC increased with altitude on the slopes of Mount Kilimanjaro while, SOC stock was weakly correlated with above ground carbon due to masking effect of other factors like soil type, precipitation and land management (Mathew *et al*., 2016). The annual carbon storage of agroforestry systems (parklands, live fences and homegardens) in West African Sahel, East Africa and Southern Africa was estimated in the range of 0.2-0.8 Mg C ha^{-1} (Luedeling *et al*., 2011).

The carbon storage of 145 Mg ha^{-1} estimated for Panamanian traditional agroforestry systems was lesser than the managed forests (335 Mg ha^{-1}) but higher than the pastures (46 Mg ha^{-1}; Kirby and Potvin, 2007). The total carbon stored in simple agroforestry systems at adjacent buffer zone of Lore Lindu National Park, Central Sulawesi estimated was 125.97 Mg ha^{-1}, while in complex agroforestry systems it was 209.39 Mg ha^{-1} (Wardah *et al*., 2011). The ecosystem carbon stock (biomass and soil) in two agroforestry systems of Mana district, southwestern Ethiopia was 157.77 and 194.96 Mg ha^{-1} (Betemariyam *et al*., 2020). SOC contributed 82 % and 68 % of the ecosystem carbon stock in these two agroforestry systems of Mana district, southwestern Ethiopia, respectively. Altitudinal gradient was reported to significantly affect the carbon stock potential of farmland scattered trees in Tigray, Northern Ethiopia with highest aboveground, belowground, soil organic and total carbon stock of 17.97, 6.53, 23.09 and 47.59 Mg ha^{-1}, respectively at the highest studied altitude of 2500-3000 m above sea level (Gebrewahid *et al*., 2018).

In Sabah, Malaysia, total ecosystem carbon stock in agroforestry systems, monoculture and natural forests estimated was 80.87, 68.37 and 287.29 Mg ha^{-1}, respectively (Besar *et al*., 2020). Silvopastoral agroforestry systems in North America sequester more carbon than the forests or pasture alone (Clason and Sharrow, 2000; Nair *et al*., 2008; Udawatta and Jose, 2011) while, in Europe agroforestry systems sequester more carbon than the systems without trees (Mosquera-Losada *et al*., 2011_a). The annual carbon sequestration of silvopasture systems was 0.52 and 0.74 Mg ha^{-1} higher than pasture and sole plantation, respectively (Sharrow and Ismail, 2004). In temperate America, annual carbon sequestration potential of riparian buffers, alley cropping, silvopasture, windbreaks and agroforestry systems quantified was 4.7, 60.9, 474, 8.79 and 548.4 tera gram (Tg), respectively (Udawatta and Jose, 2011). Silviarable and silvipasture are the most common agroforestry systems in Europe (Dupraz *et al*., 2005; Eichhorn *et al*., 2006; Mosquera-Losada *et al*., 2006, 2009, $2011_{a,\ b}$; Grünewald *et al*. 2007; Quinkenstein *et al*. 2009). Silvopastoral systems with fast growing tree species like poplar were reported to reduce carbon emissions in Canada as the net carbon sequestration of the system was almost three times more than by a monoculture pasture system (Gordon *et al*., 2006).

Most of the previous researches on agroforestry systems were concentrated on the effect on soil organic matter and fertility (Young, 1989; Chander *et al*., 1998) but now the emphasis is on soil health and quality. Globally, numerous studies are available on the plant biomass carbon sequestration potential of agroforestry systems (Mangalassery *et al*., 2014; Sharma *et al*., 2016_d; Rizvi *et al*., 2019; Dhyani *et al*., 2020; Yadav *et al*., 2021) and very few studies on SOC, hence very limited information on SOC and sequestration capacity of agroforestry soil is available (Lenka *et al*., 2012; Cardinael *et al*., 2015; Ramesh *et al*., 2015; Sarkar *et al*., 2015). The soil is one of the most significant pools of carbon storage in terrestrial ecosystems, accounting for about 75 % of total stored carbon (Lal, 2005; Dresner *et al*., 2007). SOC in addition to vegetation particularly woody species composition, litter quality and age also varies with locality factors, geographic position, land use and management systems but only a few studies have evaluated this relationship at different spatial and temporal scales (Kaushal and Verma, 2003; Nieder *et al*., 2003; Bunker *et al*., 2005; Henry *et al*., 2009; Li *et al*., 2010; Shi and Chi, 2010; Chauhan *et al*., 2011; 2012; Muñoz-Rojas *et al*., 2012; Brar *et al*., 2013; Negash, 2013; Lorenz and Lal, 2014; Mangalassery *et al*., 2014; Cooper *et al*., 2011; Kim *et al*., 2016; Newaj *et al*. 2016; Sharma *et al*., 2016_d; Cardinael *et al*., $2018_{a,\ b}$; 2020; Feliciano *et al*., 2018; Shi *et al*., 2018; Corbeels *et al*., 2019; Yadav *et al*., 2021). Soil properties such as clay content determine the extent of carbon enrichment in humus. Organic matter inputs generally build a carbon gradient from the surface to sub-surface layers of the soil worldwide (Howlett *et al*., 2011). Main drivers of soil organic matter production, incorporation, and mineralisation is temperature and humidity (Theng *et al*., 1989).

Organic matter in soil was reported to increase with increasing altitude due to cumulative annual addition of leaf litter with slower decomposition rates (Dimri *et al*., 1997). Soil productivity and its organic carbon pool was reported to be determined by quality and quantity of organic matter in the soil (Bhattacharyya *et al*., 2001; Kimble *et al*., 2007; John, 2010; Gama-Rodrigues *et al*., 2011; Koul *et al*., 2011; Gairola *et al*., $2012_{a,\ b}$; Shukla and Chakravarty, $2012_{a,\ b}$; Kanime *et al*., 2013; Murthy *et al*., 2013;

Pandya *et al*., 2013; Aggarwal, 2014; Arora and Chaudhary, 2014; Goswami *et al*., 2014; Gupta and Sharma, 2014; Suryawanshi *et al*., 2014; Scotti *et al*., 2015; Sharma *et al*., 2016_d) and in agroforestry trees are the main source of soil organic matter (Chivaura-Masusa *et al*., 2000; Bishaw *et al*., 2013). Organic inputs from trees lower soil pH which help in soil carbon accumulation and nutrient cycling through microbial inhibition (Beets *et al*., 2002; Zhang and Zhang, 2003; Mutuo *et al*., 2005; Makumba *et al*., 2007; Yadav *et al*., 2008; Vallejo *et al*., 2010; Schmidt *et al*., 2011; Hoosbeek *et al*., 2018; Parewa *et al*., 2018).

Higher root biomass and efficient distribution of organic matter across soil layers support more soil organic matter production in tree based farming (Fisher *et al*., 1994; Yadav *et al*., 2021). Higher species richness in traditional agroforestry support continuous carbon build-up in its soil even at deeper layers while reducing net emission (Johnson *et al*., 2006; Wutzler and Reichstein, 2007; Meinen *et al*., 2009; Schmidt *et al*., 2011; Stockmann *et al*., 2013; Mbow *et al*., 2014). Unfortunately, the influence of tree species to soil carbon along with its quantity, mechanism and duration of storage in the soil before the carbon is sequestered as an option for mitigation is not still clearly understood (Jandl *et al*., 2007; Krna and Rapson, 2013; Mackey *et al*., 2013) as quantitative estimates of tree species effect on soil carbon is very less (Sariyildiz *et al*., 2015).

2.3. Soil Physico-chemical Properties

There is close connection between the natural evolution of the vegetation and the improvement of the soil. It has been verified that the vegetation effects the physical and chemical composition of soil to a great extent (Young, 1989; Breman and Kessler, 1995; Rhoades, 1997; Guo *et al*., 2008, 2018, 2020; Misra, 2011). There is a complex interrelationship between the soil and vegetation. Soil properties influenced the vegetation and vice-versa. Selective absorption of nutrient elements by different tree species and its capacity to return nutrients to the soil bring about the changes in soil properties (Singh *et al.*, 1986_a; Misra, 2011; Sarvade *et al*., 2014; Parewa *et al*., 2018). Soil is one of the essential natural resources that provide base and support to stock water and nutrients prerequisite for development and growth of plants, hence ultimately influencing the production and productivity. Soil properties in relation to forest cover were studied in different regions of India (Banerjee *et al.*, 1981; Singh *et al.*, 1983).

The potential for soil health improvement by the trees is one of the central themes of agroforestry (table 4; Palm, 1995; Rhoades, 1997; Misra, 2011; Sarvade *et al*., 2014) and presence of scattered tree in crop land and pasture for improving the soil is very common in semi-arid and humid tropics (MacDicken and Vergara, 1990). Agroforestry systems established on traditional knowledge with water management as an integral component are more operational for rehabilitation of degraded community lands than afforestation with plantation crops (Maikhuri *et al.*, 1997_b; Pandey, 2007; Parewa *et al*., 2018). A few studies were also carried out for the soil nutrients of temperate agroforestry systems (Toky *et al.* 1989_b). In central and south America, nitrogen fixing plants like *Alnus*, *Inga* and *Erythrina* were planted within the pasture and crop land for enhancing soil fertility and forage quality (Galloway, 1986; Budowski, 1993). Long term tree plantation enhances the soil physical, chemical and biological properties (Ponge *et al*., 2013; Prasad *et al*., 2016; Cardinael *et al*., 2019; Guillot *et al*., 2019; Battie-Laclau *et al*., 2020; Marsden *et al*., 2020). Under the continuous tree cover, the bulk density of soil decline and there is an attended increase in soil porosity, water holding capacity, field capacity, permeability and infiltration rate (Turner and Ward, 2002; Mishra *et al*., 2004; Jose, 2009; Misra, 2011; Chakraborty *et al*., 2015; Paul *et al*., 2017; Lana *et al*., 2018).

Table 4. Soil health and fertility under agroforestry systems

Zone/Area	**Utilization**	**Changes**	**Reference**
Central India	Production of biomass in soils with nitrogen and phosphorus stress	In depleted soils trees such as *Azadirachta indica* was suitable for biomass production	Puri and Swamy, 2001
Central India	Soil health and fertility	Proportion of sand particles declined with increased nitrogen, phosphorus, organic carbon and mineral nitrogen	Pandey *et al.*, 2000
Sikkim	Soil health and fertility	Nitrogen-fixing tree species regulated soil organic with higher rates of nitrogen mineralization due to increased litter production.	Sharma *et al.*, 1996
Kurukshetra	Improvement of sodic soils	Increased soil organic matter, available nitrogen and carbon accumulation with increased biological productivity.	Kaur *et al.*, 2002
Himalayan region	Restoration of neglected crop	Soil physico-chemical properties and carbon sequestration	Sathaye and Ravindranath,

	lands	improved. Agroforestry biomass (3.9 Mg ha^{-1}) was more than degraded forests (1.1 Mg ha^{-1})	1998
North-western Himalayas	Soil and water conservation on sheer slopes	Hedgerows (contour tree-rows) reduced runoff (40 %) and soil (48 %) loss	Narain *et al.*, 1997
Uttarakhand Himalaya	Production from rainfed marginal lands by agri-horti system	Improved fertility and organic carbon through litter of *Carya illinoenensis* trees	Yadav and Bisht, 2014
Western India	Soil fertility improvement of moderate alkaline soils	Low MBC (~ 96 g g^{-1} soil) in rice-berseem cropping system but increased (~ 109 g g^{-1} soil) under tree plantation with 11-52 % increment in soil carbon	Kaur *et al.*, 2000
Rajasthan	Crops and trees compatibility	Ideal tree density with pulse intercropping was 417 trees ha^{-1}	Gupta *et al.*, 1998

Silvopastoral systems have higher nitrogen, phosphorus and organic carbon as compared to open system (Hazara, 1990). Vegetation increases the nutrients availability of the agroforestry systems due to their capability to build-up a total nutrient in the soil (Yadav and Bisht, 2014). Moreover, incorporation of leguminous tree in agroforestry system makes it nitrogen self-sufficient (Prasad *et al*., 2016) with addition of annual dry biomass and improvement of soil nutrients (Young, 1989, 1997; Palm, 1995; Sharma and Kapoor, 2005; Rao and Saha, 2014). Agroforestry systems with nitrogen fixing tree species enrich the biological nitrogen fixation in soil by addition of organic matter and efficient recycling of nutrients (Sharma *et al*., 1994; Patiram *et al*., 2003; Das and Chaturvedi, 2008; Yadav *et al*., 2008; Misra, 2011; Sarvade *et al*., 2014; Parewa *et al*., 2018).

Rao and Saha (2014) observed that tree species such as *Alnus nepalensis, Parkia roxburghii, Michelia oblonga, Pinus kesiya* and *Gmelina arborea* with higher surface cover, constant addition and decomposition of litter fall and extensive root systems enhanced SOC by 96.2 %, improved aggregate stability (24 %), improved soil moisture (33.2 %) and reduced soil erosion (39.5 %). Annual nitrogen fixation ability of the trees varies from species to species like 60-110 kg N ha^{-1} in *Casuarina equiestifolia,* 200 kg N ha^{-1} in *Acacia mearnsii*, 15-35 kg ha^{-1} in *Faidherbia albida*, 13-108 kg ha^{-1} in *Gliricidia sepium*, 100-350 kg ha^{-1} in *Leucaena leucocephala*, 29-117 kg N ha^{-1} *Alnus nepalensis* & *Alnus glutinosa*, 12-32 kg ha^{-1} in *Acacia dealbata*, 40-100 kg ha^{-1} in

Acacia nilotica , 30-80 kg ha^{-1} in *Prosopis juliflora* and 94 kg ha^{-1} in *Albizia lebbeck* (Silva and Uchida, 2000; Sharma and Kapoor, 2005; Shetta *et al*., 2011; Mishra and Rai, 2013). Some of the nitrogen fixing tree species like *Leucaena* spp., *Acacia* spp. and *Alnus* spp. has the ability to fix the atmospheric nitrogen up to 400-500 kg, 270 kg and 100-300 kg ha^{-1}, respectively (Misra, 2011). Alder plantation with annual crops was the most remunerative traditional agroforestry system found in the eastern Himalayas and also ecologically and environmentally sounds system that reduced erosion and increased soil fertility (Rathore *et al*., 2010; Selvan and Kumar, 2017).

Assessment of soil chemical properties of traditional agroforestry systems of north-eastern region showed a remarkable increase in soil pH, organic carbon, exchangeable calcium, magnesium, potassium and available phosphorus within 10-15 years time periods (Prasad *et al*., 2016). Dry matter production and nutrient cycling was compared between agroforestry systems of cardamom grown under nitrogen fixing *Alnus* and mixed tree species (non-nitrogen fixing) in the Sikkim Himalayas (Sharma *et al*., 1994; Singh *et al*., 2018$_a$; Lepcha and Devi, 2020$_a$). The study found stand total biomass, tiller number, basal area and biomass of cardamom crop was much higher under the influence of *Alnus*. Addition of litter amount and nitrogen fixation in alder was influenced by tree density which was in the range of 48.3-184.8 kg ha^{-1} with a tree population of 60-625 trees ha^{-1} while, phosphorus, potassium and calcium status also improved under the *Alnus* plantation. Soil properties under multipurpose tree species plantation were examined by Singh *et al*. (2018$_a$) at Sikkim. The study quantified highest amount of nitrogen (395.2 kg ha^{-1}), phosphorus (23.6 kg ha^{-1}), potassium (430.8 kg ha^{-1}), zinc (2.54 mg kg^{-1}), manganese (37.65 mg kg^{-1}) and boron (6.68 mg kg^{-1}) under *Alnus nepalensis* plantation while, iron (37.41 mg kg^{-1}) under *Schima wallichii*, copper (2.84 mg kg^{-1}) under *Terminalia myriocarpa* and organic carbon (1.53 %) and acidity (pH- 5.53) under mixed forest as compared to rest of the tree species. Soil pH under alder and large cardamom plantation up to 0-20 cm and > 20 cm was acidic in nature and rest of the soil parameters were highly variable in nature (Zomer and Menke, 1993). Soil under alder-based agriculture system of Khonoma Village, Nagaland was highly rich in nutrients (3.11 % SOC, 5.36 % organic matter, 670 ± 2.31 kg ha^{-1} available nitrogen, 83.44 ± 1.03 kg ha^{-1} available phosphorus and 326 ± 3.21 kg ha^{-1}

exchangeable potassium) and high microbial population of 109 × 106 colony forming units of bacteria per gram soil recorded (Giri *et al*., 2018).

Zabo indigenous farming system is very popular farming system of Phek district of Nagaland and total area under the system is 958 ha. Generally, this system is the combination of forest, agriculture, livestock and fisheries with proper soil and water conservation base, which is helpful for water resource development, water management and protection of environment (Das *et al*., 2009; Sharma *et al*., 1994). Zabo system is developed by indigenous communities through their creativity, talent and understanding of the local condition over long time. In this system, forest land at top of the hill is not disturbed while; water harvesting structure, livestock and paddy field are managed in the middle and lower part of the hill. The soils in the Zabo farming are very rich in organic carbon (1.79-2.87 %), nitrogen (209-370 kg ha^{-1}), phosphorus (6.7-18.8 kg ha^{-1}) and potassium (60-160 kg ha^{-1}; Sharma *et al*., 1994). The farmers applied Leaves of *Alnus nepalensis* are incorporated into the soil for maintaining its health and fertility (Selvan and Kumar, 2017).

The rice and fish culture based traditional agroforestry systems is practiced by Apatani tribes in Subansiri district of Arunachal Pradesh at an altitude of about 1524 m and elevation up to 2438 m above mean sea level. This traditional system is highly efficient farming system in reducing soil erosion, conserving water for irrigation and culturing fish with paddy (Sharma and Sharma, 1997). Besides restricting soil erosion, this system also reduces the pressure from forest as farmers grow some important tree species like *Terminalia myrinalia*, *Ailanthus excelsa*, *Michelia* sp., *Magnolia* sp., and bamboos which also regulate ecological balance and continuous flow of watercourses. Consequent of this farming practice, siltation of rivers and other water bodies, dying of water sources, degradation of soil health, loss of flora, fauna and forest resources are negligible in this area (Das *et al*., 2012).

Singh and Dhyani (1995) studied the jackfruit and arecanut/Khasi mandarin based agroforestry systems. The study estimated the organic carbon content of the jackfruit + Khasi mandarin system was 2.0-2.5 %, available phosphorus was 10.4-13.2 ppm and exchangeable cations content was 5.9-8.4 cmol (p+) kg^{-1} in the surface soil. Similarly, for jackfruit + arecanut system the values estimated were 1.5-1.8 %, 3.8-6.7 ppm and 3.9-5.9 cmol (p+) kg^{-1} in surface soil, respectively. Long term effect of agri-horticulture (Khasi mandarin + agricultural crops and Assam lemon + agricultural crops), agrisilviculture (multipurpose tree species + agricultural crops), silvi-horti-pastoral (alder + pine apple + fodder grasses) and multi-storeyed agroforestry system (alder + tea + black pepper + agricultural crops between the tree rows) on soil physico-chemical properties was assessed in Meghalaya with natural forest as control (Majumdar *et al*., 2004). Organic carbon was reported to increase between 1.17-165 folds as compared to initial status, 43.2 % higher exchangeable aluminium compared to control and pH decreased by 0.50 units. The exchangeable calcium, magnesium, sodium, potassium, and aluminium and available nitrogen, phosphorus, and potassium content were higher in all the systems compared to control (forest) at surface layer and decreasing trends of nutrient content was observed with increasing soil depth. Similar type of effects on soil properties were also observed in silvopastoral, silvi-horticulture and agri-horti-silvipastoral of agroforestry systems of Meghalaya also by Majumdar *et al*. (2002). Maximum reduction in soil bulk density was observed due to shifting cultivation in forest of Meghalaya (17.6 %) followed by agri-horti-silvipastoral (14.3 %), livestock based (13.4 %), natural fallow land and the least reduction of 12.6 % in agriculture (Saha and Mishra, 2007). However, macro-aggregates (54.5 %), organic carbon (2.95 %) and biotic activity were higher in forest land use as compared to rest of the systems. The forest, multi-storied agroforestry and silvi-horti-pastoral systems with continuous vegetation cover throughout the year had healthier soil aggregation due to higher organic matter build up, higher clay content and higher amount of Al and Fe oxides in soil (Saha and Mishra 2007). Continuous addition of leaf litter and extensive root system of the trees increased the SOC (96.2 %), porosity (10.9 %), aggregate stability (24.0 %) and soil moisture (33.2 %) concurrently reducing bulk density and erosion ratio by 15.9 and 39.5 %, respectively.

A study was carried out in Kinnaur district of Himachal Pradesh in temperate high hills (C_1) and high hills temperate dry and cold (C_2) climatic conditions with three different agroforestry systems such as agri-horticulture system (AH), agri-silviculture system (AS) and agri-horti-silviculture system (AHS) to assess the effect of these systems on some soil physico-chemical parameters (Salve *et al*., 2018_a). Bulk density (1.34g cm^3) and pore space (46.99 %) was higher in AS system. Particle density (2.49 g cm^3) was higher in AH system. Organic carbon was significantly higher in AHS system

(1.26 %) under C_2 climatic condition whereas, exchangeable calcium (5.52 mg/100g) was higher in AHS system under C_1 climatic condition. Surface soil layer (15-30 cm) was estimated with significantly higher acidity, nitrogen (0.25 %), phosphorus (0.97 mg/100g) and potassium (1.69 mg/100g) than the deeper layers. Organic carbon significantly increased with increasing altitude which was attributed to accumulation and slower rate of litter decomposition. Similar soil physico-chemical properties under agroforestry systems were also reported in numerous earlier studies also (Toky *et al*., $1989_{a,\ b}$; Banerjee *et al*., 1998; Tornquist *et al*., 1999; Jacot *et al*., 2000; Majumdar *et al*., 2004; Notaro *et al*., 2013; Kashyap *et al*., 2014; Mario *et al*., 2014; Gardini *et al*., 2015).

2.4. Ecosystem Services and Function

The agricultural land-use activity includes agroforestry, horticulture and animal husbandry, besides growing crops in the fields (Sundiriyal *et al.*, 1994; Maikhuri *et al*., 2000; Parewa *et al*., 2018). High and imbalanced use of resources in modern agriculture leads to degradation of ecosystem services provided by agriculture (Fagerholm *et al*., 2016). However, several alternate land-use systems such as agroforestry can safeguard and enhance the various ecosystem services (O'Farrell and Anderson, 2010; Dhyani, 2018). Agroforestry has long been seen as a better option for adaptation and mitigation of challenges arises due to global climate change (Nair and Garrity, 2012; Dhyani, 2018). Different studies have shown the importance of agroforestry in conserving the biodiversity, sustainable use of natural resources and providing various ecosystem services (Albrecht and Kandji, 2003; Montagnini and Nair, 2004; Alam *et al*., 2014; Cardinael *et al*., $2018_{a,\ b}$; Guo *et al*., 2020).

Trees are an integral and indispensable part of the farming systems; they are deliberately retained on farmlands to support agriculture and are either planted or preserved to provide various amenities of life. Trees reduce erosion by binding the soil through roots and also act as great air purifier by removing carbon dioxide and other pollutants from atmosphere as well as offer shade and wind breaks to keep us cooler in summer and warmer in winter. Trees are maintained in the farms mainly for fodder and rarely for fuel purposes (Palm, 1995; Dhyani, 2012; Dhyani and Handa, 2014; Pathania *et al*., 2020). The most suitable land has already been used for farming and even the area of this land is being reduced by urban demands for more houses and roads, more industrial development and more amenity areas. So, the next available alternative of raising productivity of land already farmed has gained momentum through adoption of agroforestry practices (Garforth *et al*., 1999; Malla, 2000; Neupane *et al*., 2002; Tiwari, 2003; Sood, 2003; 2006; Kalaba *et al*., 2010; Dhyani and Handa, 2014; Pathania *et al*., 2020). In a changing scenario of decreasing availability of good arable land for agriculture, degradation of soil and water resources, increasing environmental pollution, the new approaches in farming systems have made rapid strides in the last two decades (Mishra *et al*., 2011; Dhyani, 2012; Dhyani and Handa, 2014; Ram *et al*., 2016). Making the country self-sufficient in food, fodder, fibre, firewood and timber production, deliberate inclusion of trees in the existing farming/cropping systems and adoption of agroforestry approaches on all kinds of land is one of the viable options to achieve sustainability while, optimizing productivity (Sood, 2003; 2006; Jose, 2009; Prasad *et al*., 2016; Pathania *et al*., 2020). The most important factor responsible for such an achievement is the widespread adoption of agroforestry technology (Sharma *et al*., 2005; Bucagu *et al*., 2013; Pathania *et al*., 2020).

Contribution of direct and indirect ecosystem services in societal security and ecosystem functioning by the natural ecosystems was acknowledged since the publication of Millennium Ecosystem Assessment Report (Sharma and Chettri, 2005; Sharma and Liang, 2006; Jose, 2009; O'Farrell and Anderson, 2010; Vihervaara *et al*., 2010; Cardinale *et al*., 2012; Mace *et al*., 2012; Nair and Garrity, 2012; Reich *et al*., 2012; Lele and Srinivasan, 2013; Loreau and de Mazancourt, 2013; Alam *et al*., 2014; Dhyani and Handa, 2014; Laxmi *et al*., 2015; Fagerholma *et al*., 2016; Kamiyama *et al*., 2016; Ouyang *et al*., 2016; Prasad *et al*., 2016; Sharma *et al*., $2016_{a\text{-}d}$; Singh *et al*., 2016; Dev *et al*., 2018; Rana *et al*, 2018; Chaudhary *et al*., 2019_{a}; Pramesh *et al*., 2019; Sanogo *et al*., 2020). Ecosystem services (table 5) include provisioning, regulating, cultural and supporting or protective services, providing both tangible and intangible benefits to human society like security of life, materials production for good life, health as well as social relations (Anon., 2005; Jose, 2009; Akinnifesi *et al*., 2010; Garrity *et al*., 2010; Mbow *et al*., 2014; Kamiyama *et al*., 2016; Liu *et al*., 2016; Moreno *et al*., 2018; Sida *et al*., 2018; Thierfelder *et al*., 2018; Haile *et al*., 2019; Kay *et al*., $2019_{a,\,b}$; Sanogo *et al*., 2020).

Table 5. Typology of ecosystem services

Type	Items under each service
Provisioning	Goods, such as food or freshwater, that ecosystems provide and humans consume or use, fuel-wood, fodder, timber and poles, fiber, useful molecules, genetic resources.
Regulatory	Services such as flood reduction and water purification, other hydrological benefits, micro-climatic modifications provided by agroforestry systems or climate regulation, disturbance regulation, hydrological flow regulation, water purification, air purification, disease regulation, erosion control, biological control, pollination, carbon sinks
Supportive	Soil formation and retention, nutrient cycle, trace element cycle, carbon cycle, primary production, oxygen production, necromass recycling, natural habitats
Cultural	Intangible benefits, such as inspiration, aesthetics, education, recreation, sense of belonging, cultural, scientific and educational heritage, spiritual benefits

Source: Anon., 2005

In an agricultural landscape production can be persistent by the resiliency and flexibility of these ecosystems through genetic variation within agricultural crops to help ecosystem functions (Balana *et al*., 2010; Sunderland, 2011; Gebrewahid and Meressa, 2020). Ecosystem services and benefits provided by the agroforestry systems are not confined *in situ*, but occur over a wide range of spatial and temporal scale (Jose, 2009). Ethnic societies have a antiquity and indigenous knowledge of growing and preserving diverse food and medicinal plants to support their livelihoods both in rural and urban regions (Henry *et al*., 2009; Panwar and Chakravarty, 2010; Pei *et al*., 2010; Srithi *et al*., 2012; Bajpai *et al*., 2013; Clarke *et al*., 2014; Gerard Grubben *et al*., 2014; Salako *et al*., 2014; Perrin *et al*., 2015; Furlan *et al*., 2016; Ragassa *et al*., 2016). Traditional farming systems includes local crops, indigenous trees species, coarse millet and local fruit trees are now recognized as best option to maintaining the ecosystem functions of the landscape while improving rural livelihoods, food security and wellbeing, so now promoted by the scientists and policy makers for sustaining and conserving the natural resources (Bhagwat *et al*., 2008; Henry *et al*., 2009; Polegri and

Negri, 2010; Santhoshkumar and Ichikawa, 2010; Jose, 2012; Schupp and Sharp, 2012; Galhena *et al*., 2013; Mohri *et al*., 2013; Smith *et al*., 2013; Bustamante *et al*., 2014; Salako *et al*., 2014; Gbedomon *et al*., 2015; Subba *et al.,* 2015, 2016, 2017_{a-d}, $2018_{a,\ b}$; Lepcha *et al*., 2019; Santika *et al*., 2019; Sanogo *et al*., 2020; Sarkar, 2020).

Agroforestry has traditionally been practiced in India as a way of life and livelihood since ancient time (Dev *et al*., 2018). Increased food production can be achieved in different ways by an increase in the area of land, devoted to farming, particularly agroforestry or by increasing the productivity of land already farmed (Gupta *et al*., 2016; Dhyani, 2018). Agroforestry systems offer several ecosystem services such as provisioning (food, fuelwood, fodder, timber, poles etc.), regulatory (ex. hydrological benefits and modifications of micro-climatic), supportive (ex. nutrient cycling and agro-biodiversity conservation) and cultural service like recreation and aesthetics (Subba *et al.,* 2015, 2016, 2017_{a-d}, $2018_{a,\ b}$; Sarkar, 2020). Agroforestry in developing nations acted as to address many problems and supplying a range of economic, environmental and socio-economic benefits particularly after the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). Agroforestry also played an active role in reducing the vulnerability, enhancing resilience of agriculture and buffering households against climate extremes (Dhyani and Handa, 2014).

Several studies have reported the ecosystem services provided by large cardamom based agroforestry system in the Eastern Himalayas (Sharma and Sharma, 1997; Sharma *et al*., 2002; 2009_{b}; 2015; 2016_{a-d}; Avasthe *et al*., 2007; Rathore *et al*,.,2010; Joshi and Joshi, 2016; Anitha and Hore, 2018; Negi *et al*., 2018; Singh *et al*., 2018_{a}) especially from Sikkim but no such studies were reported from Darjeeling Himalayas to understand the floristic diversity, carbon and nutrient storage and ecosystem services of the large cardamom based agroforestry system in Darjeeling Himalayas. Reports from Sikkim Himalayas indicate that large cardamom growers relate decline in their crop yield to changing weather conditions over the year and post-harvest storage quality (Sharma *et al*., 2002; 2016_{c}; Negi *et al*., 2018; Singh *et al*., 2018_{a}). Understanding about what owner understands, their attitudes and preferences in the management decisions will be helpful for adoption of sustainable management of these traditional systems through increased acceptability of the newer farming technologies while, realising its ecosystem services (Macura *et al*., 2011; Dagar, 2012;

Palett *et al*., 2013). The socio-ecological and economic resiliency of this traditional agroforestry system thus depends on the designing and implementation of integrated farming schemes involving all the concerned stakeholders (Sharma *et al*., $2016_{a\text{-}d}$).

Agroforestry systems were better land use options to generate income by the farmers producing carbon-credits (Sharma *et al*., 2016_d; Pala *et al*., 2020; Sanogo *et al*., 2020). Introducing or increasing species in the systems have some ecological and environmental benefits particularly with higher potential to provide ecosystem service like carbon sequestration (Kumar, 2011). There is rising interest in the study of ecosystem services delivered by agroecosystems or traditional farming systems, owing to the environmental, social and economic benefits that they provide (Calvet-Mir *et al*., $2012_{a,\ b}$; Caballero-Serrano *et al*., 2016; Cardinael *et al*., 2020). Ecosystem services provided by the traditional agroforestry systems need to be understood and enumerated for landscape planning, management and decision making (de Groot *et al*., 2010; Seppelt *et al*., 2011; de Souza Queiroz *et al*., 2017; Sarkar, 2020). Alnus-cardamom based traditional agroforestry system of Sikkim Himalayas (Sharma *et al*., 2007) and traditional homegardens of Darjeeling Himalayas (Sarkar, 2020) offered provisional, supporting, regulating and cultural services in the form of food, fodder, fuel wood, nitrogen fixing, reducing soil erosion as well as improving the aesthetic beauty of the areas. Mamlay watershed of south Sikkim was reported to support about 80 % of it's the population for their livelihood especially from its traditional farming systems (Sundriyal *et al*., 1994).

The indigenous communities of Darjeeling and Sikkim Himalayas are culturally rich as they consider all plants, animals, agroforestry systems, soil and water are sacred and culturally important (Ramakrishnan 2001). Among them large cardamom based indigenous agroforestry plays an important role in socio-economic, cultural and spiritual traditions in the region (Sharma and Sharma, 1997). This system shows that how an ecological and economical traditional farming practice has evolved indigenously as the main agroforestry practice in the region (Sharma and Sharma, 1997, Singh *et al*., 2018_a; Lepcha and Devi, 2020_a). Its cultivation is a unique model of how a local mountain niche can be utilized in a sustainable minor. *Alnus nepalensis* is most prominent shade trees because large cardamom profusely grows under the canopy of alder tree and has proved to be ecologically and economically viable. This system is shadow to natural ecosystems as they offer similar types of ecosystem services to the forests such as the biodiversity conservation, provision of food and fibre, water resources management and its purification, climate regulation and carbon sequestration, nutrient cycling, quality oxygen, soil formation and recreation and the cultural services for the well-being of the local society (Sharma *et al*., 2007). Most of the plantations are found in the steeper marginal and fragile lands so as to minimize the runoff, soil erosion and landslides (Sharma and Sharma, 1997) beside tress easily grows naturally on land slide affected locations and fix atmospheric nitrogen (Sharma and Ambasht, 1984). These indigenous agroforestry systems thus are highly helpful for helpful soil and water conservation as evidenced from the data available from other farming systems in the region (Sharma *et al*., 1994, 2001). A wide range of roles and services from maintaining soil fertility to soil and water conservation, enhancing the production potential of soil and reducing the erosion of soil in this agroforestry proves the system to be ecologically and economically sustainable (table 6; Sharma *et al*., 2001). Large cardamom based agroforestry also acts as a habitation for pollinators and biological agents of pests and disease organisms.

Use of ecosystem service was vary with geographical location and social structure based on income, gender, class and education (Izac, 2003; Jose, 2009; Garrity *et al*., 2010; Avohou *et al*., 2012; Weinzettel *et al*., 2013; Kumar and Yashiro, 2014; Mbow *et al*., 2014; Lakerceld *et al*., 2015; Prasad *et al*., 2016; Miao, 2017; Murali *et al*., 2017; Chaudhary *et al*., 2018; Dev *et al*., 2018; Kibria *et al*., 2018; Sanogo *et al*., 2020). Rural households with low income depend on natural resources due to easy availability, lack of markets and limited alternative (Kumar and Yashiro, 2014; Ward and Shackleton, 2016; Derkzen *et al*., 2017; Sanogo *et al*., 2020). Household with higher income with better access to natural resources and mark*et* also utilize more and variety of ecosystem services (Kamanga *et al*., 2009; Daw *et al*., 2016). Strategies on conservation of ecosystem service and biodiversity were thus recommended to be formulated based on societal needs (Garrett and Mcgraw, 2000; Garrity, 2004; McNeely, 2004; Schroth *et al*., 2004; Dhyani *et al*., 2005; Harvey *et al*., 2006; Pandey, 2007; Jose, 2009; Nair *et al*., $2009_{a, b}$; Daw *et al*., 2011).

Table 6. Ecosystem services provided by agroforestry systems related to soil health

Process	Triggers and management options	Ecosystem services	References
Water infiltration, run-off	Roots, soil fauna soil cover, tillage, deep-rooted plants	Flood regulation, water purification	Bayala and Prieto, 2020 Huo *et al*., 2020 Ling *et al*., 2020
Hydraulic lift	Roots deep-rooted trees	Nutrient cycling, provisioning	Bayala and Prieto, 2020 Huo *et al*., 2020
Competition, facilitation, niche complementarity	Roots, mycorrhiza, tree density Trees and crops, root pruning, tillage, fertilization, amendments	Nutrient cycling, provisioning	Battie-Laclau *et al*., 2020 Bayala and Prieto, 2020 Borden *et al*., 2020 Isaac and Borden, 2020 Sida *et al*., 2020
Litter decomposition	Micro- and macro-organisms Litter quality, fertilization, tillage	Improved fertility and carbon	Marsden *et al*., 2020
SOC sequestration	Roots, mycorrhiza, soil fauna Soil cover, tillage, deep-rooted plants	Climate regulation	Terefe and Kim, 2020
Nitrogen fixation	Bacteria N_2-fixing plants, inoculation, fertilization	Nutrient cycling	Isaac and Borden, 2020
Mineral weathering	Roots, mycorrhiza Deep-rooted plants	Soil formation	Isaac and Borden, 2020
Nutrient leaching	Roots Deep-rooted plants, manuring	Nutrient cycling, water purification	Bayala and Prieto, 2020
Aggregate stabilization	Roots, mycorrhiza, soil fauna Soil cover, tillage, plant density, manuring	Climate regulation, water purification	Marsden *et al*., 2020 Wartenberg *et al*., 2020
Soil porosity	Roots, soil fauna Tillage, deep-rooted plants	Flood and climate regulation, water purification	Marsden *et al*., 2020 Ling *et al*., 2020

Agroforestry systems are socially and culturally associated with mountain communities as most of the systems supported the soil and water conservation, improving soil fertility as well as offer varieties of food, fodder and NTFPs to the local communities (Sharma and Chettri, 2005; Sharma and Liang, 2006; Sharma *et al*., 2007, $2016_{a,\ b}$; Sharma and Rai, 2012; Abdulai *et al*., 2018; Sarkar, 2020). In mountain villages of India, along an elevation gradient (500-3500 m asl), as many as 42 multipurpose tree and shrub species are cultivated in and around agricultural fields in different agroforestry systems for fodder, fuel, timber and various other miscellaneous uses (Bhatt and Verma, 2002). Most of the farming systems through the use of trees were found to be at their subsistence level (Fonzen and Obertholzer, 1984; Ralhan *et al.*, 1991; Shah, 1982; Sharma, 1991; Singh *et al.*, 1984; Toky and Ramakrishnan, 1981; Nautiyal *et al.*, 1998; Prasad *et al*., 2016; Sharma *et al*., $2016_{a\text{-}d}$; Sanogo *et al*., 2020). The decisive aim of agroforestry is to increase and sustain the livelihood of marginal and small farmers in time of climate change (Dhayni *et al*., 2013; Prasad *et al*., 2016). Mixing of trees with agricultural crops has the prospect to expand local economy through constant income, crop diversification and rural skills, improved food, fuel and fodder security besides improving the environment (Dhyani, 2012; Prasad *et al*., 2016). Agroforestry systems have the potential for lifting the socioeconomic status of farmers and for contributing to the overall development of the region. This can be seen in terms of increased income and in the creating employment opportunities (Prasad *et al*., 2016; Dhyani *et al*., 2013). Only in Himalayan region agroforestry has the potential to generate employment up to 5.76 million-person days per year (Dhyani *et al*., 2005). Furthermore, agroforestry systems are more labour demanding as compared to monoculture, hence different component of agroforestry systems diversifies the skills base of the labour force (Campos-Salas *et al*., 2016).

In order to improve the efficiency of indigenous agroforestry systems, we need to have a systematic procedure to evaluate such systems. Since productivity, sustainability and social acceptability are the key attributes of all agroforestry systems, evaluation procedures should encompass all these criteria. But the precise criteria for such evaluations have still not been fully developed (Nair and Dagar, 1991). Considering the country's unique land-use, demographic, political, and socio-cultural characteristics as well as its strong record in agricultural and forestry researches, India's experience in agroforestry research is important to agroforestry development, especially for developing nations (Puri and Nair, 2004). To promote well-being of the society, management of multifunctional agroforestry needs to be strengthened by innovations in domestication of useful species and crafting market regimes for the products, derived from agroforestry and ethnoforestry systems (Pandey, 2007). Studies have assessed the social, cultural and economic benefits of various tangible and intangible benefits of agroforestry but ignored the socio-economic processes involved in the success and failure of the systems (Solanki and Bisaria, 1999; Puri and Nair, 2004).

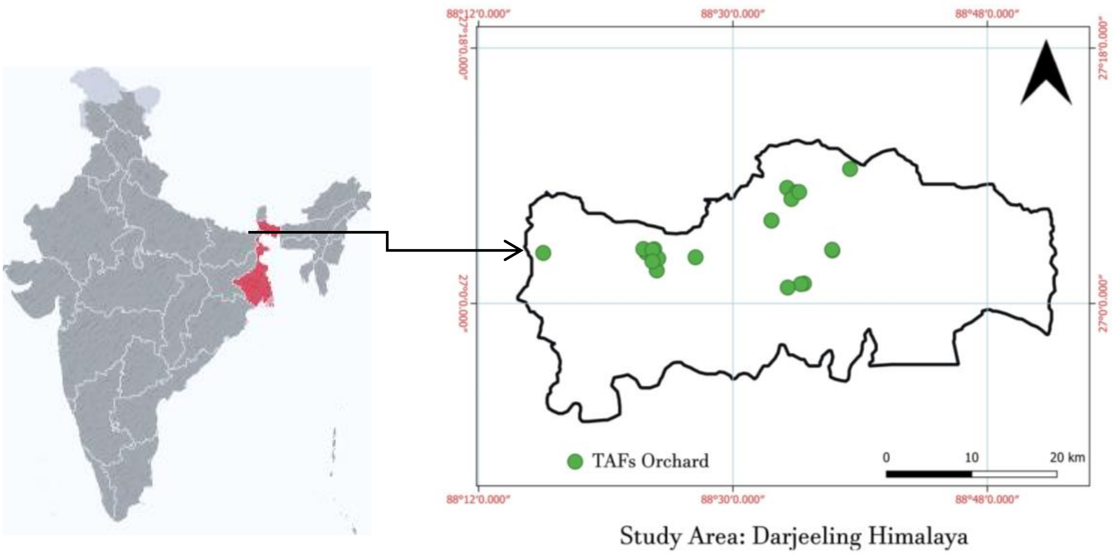
MATERIAL AND METHODS

The present study entitled, **"Variations in Vegetational Diversity and Carbon Stock in Large Cardamom based Traditional Agroforestry System across Altitudinal Gradient in Darjeeling Himalayas"** was carried out in Darjeeling Himalayan region of West Bengal, India from January, 2019 to April, 2021. The details of study area, materials used, methodology adopted in conducting the study are detailed below.

3.1. Site Description

Kalimpong and Darjeeling the two administrative districts (including eight community development blocks, 112 Gram Panchayats and four municipalities) in the study site i.e. Darjeeling Himalayas in the state of West Bengal, India is in Singalila range of the Eastern Himalayas exclusive the plain or Terai region of Darjeeling district i.e. Siliguri sub-division (fig. 1).

Fig. 1. Outline map of study area



Indian state of Sikkim and China on north, Nepal on west, Bhutan on east and Bangladesh on south surrounds the region. The study site covering 3149 km^2 extends between 26° 27' 05"-27° 13' 10" N latitude and 87° 59' 30"-88° 53' E longitude with altitude of 132-3660 m. Narrow valleys with precipices and ridges stretching from north to south and from south west to north east are prominent features of the study site (De and Bera, 1990; Saxena, 2005). Rivers Teesta and Mahananda with its tributary Balasan in west and by Lish and Gish (tributary of Teesta) in east dissect the landforms of the region more than by the valleys flow southwards following the main ridge. Convex slopes of 1-2 km length inclined at 20-48° steepness dissect edges of the hills which have concave base elevated from a few hundred to 1500 m heights (Basu, 2000_a; Starkel, $2000_{a, b}$; Starkel and Gill, 2000). The slopes are both covered with forests and tea gardens. Sandakphu (3,639 m), Phalut (3,597 m), Tiger Hill (2,560 m), Sukhia Pokri (2,170 m) and Mirik at 1,697 m are the major elevations of Darjeeling Himalayas (De and Bera, 1990; Starkel, 2000_a).

Five seasons experienced in the study area are spring (March-April), summer (May-June), monsoon (June-August), autumn (September-November) and winter (December-February) with spring and summer not much differentiated. The region is humid and sub-tropical to sub-alpine with dry winter where normal temperature of coldest month is -3-18°C and warmest month is above 22°C (Saxena, 2005). South-west monsoon is responsible for rainfall in the region and the average annual rainfall is 270-310 cm from, majority of which (80 %) occurs during June-August (Moktan and Das, 2013). A typical climatic condition of Darjeeling Himalayas is occurrence of fog for at least 100 days annually from June to August (Rao, 1981). Soils of the region categorized as mountain and glacial soil, brown hill soil, forest soil, brown forest soil, tea soil, cinchona soil and terai soil types (Kawosa, 1988; Talwar, 1988; De and Bera, 1990) are acidic, yellow to red-brown in colour, silty loam to sandy loam textured and poor in calcium, magnesium, nitrogen, potassium, phosphate and organic matter (Talwar, 1988; De and Bera, 1990; Froehlich and Sarkar, 2000).

Forests (33957 ha) and agriculture including tea gardens (131063 ha) are the prominent land uses of Darjeeling Himalayas. Tropical (below 800 m), subtropical (800-1600 m), temperate (1600-2400 m), cold-temperate (2400-3200 m) and sub-alpine (3200-4000 m) types of vegetation are found in the Darjeeling Himalayas (Das and Chanda, 1987; Bhujel, 1996; Moktan and Das, 2013; Cajee, 2018). The forests in the region are mostly reserved and protected which were classified into five altitudinal zones by Basu (2000_b) as tropical moist deciduous (300-1000 m), tropical evergreen lower montane (1000-2000 m), tropical evergreen upper montane (2000-3000 m), temperate coniferous (3000-3500 m) and sub-alpine forest (> 3500 m). Low and mid altitudes (up to 2000 m) is dominated by trees of 20-30 m height like *Shorea robusta*, *Quercus* and *Castanopsis* having with under-storey of tree ferns and ferns. *Castanopsis* occurring above *Shorea robusta* indicates a montane forest. Water courses and plantation areas are prevalent with *Alnus nepalensis* (Nepal Alder) and *Cryptomeria* *japonica*, respectively. In lower altitudes, tea and cinchona plantations are the major land uses while, steep ridges at altitudes of 2,500-2,800 m are dominated with bamboo and Rhododendrons. Secondary vegetation dominates the abandoned sites with species like *Alnus nepalensis, Schima wallichii, Maesa chisia* and *Rhus semialata*. *Quercus* and *Lauraceae* are dominant in tropical evergreen upper montane forests which are dense with mixed species composition of taller trees (30 m) and bamboo, ferns, nettles and raspberries as under-storey.

The population of Darjeeling according to 2011 census was 1,842,034 (934,796 males and 907,238 females) with sex ratio 971 females per 1000 males, density of 585 people km^{-2} and average literacy rate of 79.92 %. The population is diverse with marginally agrarian communities like Nepalis, Limbus, Lepchas, Tamang, Bhuita, and tea plantation labourers cultivating paddy, maize, millet, chilies, ginger, orange, large cardamom, flowers, orchids and other vegetables. All these communities have their own distinct culture and beliefs. The economy of Darjeeling Himalayas however, is tourism and tea based with its tea recognized as geographical indicator (www.darjeeling.gov.in). National Highway 55 connects the region with rest of the country along with State Highways and Jeep able roads at higher altitudes.

Reconnaissance survey was conducted in the study area to explore the large cardamom based traditional agroforestry systems. The traditional large cardamom based agroforestry farming in Darjeeling and Sikkim Himalayas were reported as the systems where large cardamom are 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_b; photo 1a, b).

Not many traditional large cardamom based agroforestry systems/holdings were found in the study area. The size of the large cardamom holdings found were about 1-3 ha similar to the size reported from Sikkim (Sharma and Sharma, 1997; Sharma *et al*., 2000, 2009_b). There was large cardamom under canopy cultivation in agricultural landscapes also which were not considered for the present study because these cultivations were adopted not more than a decade ago that too under the canopy of planted trees.

Photo 1a. Large cardamom based agroforestry system of Darjeeling Himalaya

Photo 1b. Large cardamom based agroforestry system of Darjeeling Himalaya

3.2. Sampling Design

A total of 25 traditional large cardamom based agroforestry holdings found during the reconnaissance survey of the study area were distributed in the elevations between 700-2000 m, of which 17 were in Kalimpong district and only eight were in Darjeeling district (photo 1a, b). The geographical locations of the holdings were recorded with Garmin 72 (fig. 1). Following the altitudinal chronosequence for distribution of vegetation in Darjeeling Himalayas by Das and Chanda (1987), Bhujel (1996), Moktan and Das (2013), Cajee (2018) and Sarkar (2020) the available traditional large cardamom holdings in the study area was also classified into three altitude class as low (700-1200 m asl), mid (1200-1700 m asl) and high (> 1700 m asl) with eleven, nine and five holdings, respectively. All the large cardamom holdings were analyzed for their phyto-sociological, diversity, physical (biomass) and edaphic attributes adopting stratified random nested quadrate sampling method (Shukla and Chakravarty, 2018; Subba *et al*., $2018_{a,\ b}$; Shukla *et al*., 2019; Sarkar *et al*., 2020; Rai *et al*., 2021; Tamang *et al*., 2021). In these large cardamom holdings 1-4 quadrates were laid for vegetation and soil analysis depending on its size. Holdings with size less than one hectare were laid with only quadrate in its centre and so on. Similarly, all the growers or owners of the holdings were interviewed for their perception on ecosystem service and performance of their traditional large cardamom based agroforestry farming system.

3.3. Grower's Perception

Two main sources of information were used for the collection of data; first one was growers through interview (photo 2 a, b) and second one was through focused group discussions related to sustainable management of the traditional large cardamom based agroforestry system, their benefits and ecosystem services; problems faced while practicing this system and remedial measures.


Photo 2 a, b. Interviewing large cardamom grower

The first source used for data collection was through questionnaire based personal in-depth interviews (Frechtling *et al*., 1997; Dey *et al*., $2017_{a,\ b}$; Lepcha *et al*., 2018, 2020; annexure- I). The schedule was administered in local dialect/language with the help of an enumerator to the head of the household (i.e. father) as the society was patriarchal, however in absence of the household head any senior member of the household either mother or else was interviewed. On the basis of the objectives of study, pre-tested semi-structured personal interview schedule was designed and developed. After construction of schedule, the same was discussed with the expert in the field of forestry, agricultural extension, agricultural statistics and scientists who have very good knowledge about the theme of the study.

From the growers, the information of socio-economic profile of the household, species utilization pattern and plant part used was recorded along with their perceptions of traditional large cardamom agroforestry and ecosystem services of the system. The questionnaire included three sections with 28 opinion statements on socio-economic profile of the grower (eight statements), present status of the traditional agroforestry farming (eight statements), problems faced during farming (six statements) and mitigation of the problems (six statements) those emerged out of group discussions. Relevancy test following (Dey *et al*., $2017_{a,\ b}$) of each statement in terms of linguistic and educational perspectives of the respondents was done after expert (social scientists, rural and agricultural development experts and experts from forestry) opinion. Total weightage score method was adopted by assigning different weights to the questions. Each respondent was asked to specify the level of agreement or disagreement against each question along a five point Likert scale (strongly agree or 'SA' with score of five, agree or 'A' with score of four, undecided or don't know or 'U' with score of three, disagree or 'D' with score of two and strongly disagree or 'SD' with score of one (Shukla *et al*., 2016; Dey *et al*., 2017_a; Chaudhary *et al*., 2019_b; Pathania *et al*., 2020). Weight based on their rank was assigned and multiplied values were added to obtain the total score. The statement with highest score was given first rank and the one with the lowest score was given the lowest.

Ecosystem services (table 7) provided by every species documented from the traditional large cardamom based agroforestry system was collected following Millennium Ecosystem Assessment guidelines (Anon., 2005). The second data source was from ten focused group discussion involving 10-15 participants including growers of the locality; village elders, senior person of the village institution or village head man; local entrepreneur (if available), extension person and official from government departments (like agriculture, horticulture, forestry and any other relevant department), block level local administrator, bank and market official (if available), subject experts, researcher and scientist from the Regional Research Station (Hill zone) of the Uttar Banga Krishi Viswavidyalaya located at Kalimpong.

Table 7. Ecosystem services

Provisioning services	Food, fiber, fuel, genetic resources, natural medicines, ornamental resources and fresh water.
Regulatory services	Air quality regulation, climate regulation, water regulation, erosion regulation, water purification, disease regulation, pest regulation, pollination and natural hazard regulation.
Cultural services	The non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences – thereby taking account of landscape values.
Supporting services	Soil formation, photosynthesis, primary production, nutrient cycling and water cycling.

The information came out of these focused group discussions along with information analyzed from the personal interview with the respondents was used to formulate the criteria and indicators of sustainable management and conservation of traditional large cardamom based agroforestry systems of Darjeeling Himalayas.

Before starting the present work, few days were devoted in the study area for first hand information and to establish rapport with the local community especially the traditional cultivators to record their socio-economic profile and perception. Age, community, occupation, education, annual income, family size, size of large cardamom holding and land holdings were treated as socio-economic variable in the present study (Supe, 2007; Kumar *et al*., 2021). The number of years rounded to the nearest whole number the responded lived since birth at the time of interview was considered the age of respondent. Gender is the biological differentiation of human being with the help of their socially ascribed roles. Education defines the amount of formal education, completed successfully or literacy level acquired by the respondent at the time of interview. Based on this the respondents were classified as with no formal education or illiterate, up to 5, 5-10, up to 12, degree (up to 14). Occupation defines the way of livelihood through which the family earns income for livelihood and classified as agriculture and non-agriculture. Income is the economic measurement of respondent's status defined as gross income earned from all the viable sources in a month and expressed in Indian National Rupee (INR- ₹). The gross income is the total income generated from agriculture, dairy, poultry, fishery, business, services and any other. Land holding was recorded by considering the total land owned by the respondents during the study in hectares.

3.4. Identification of Species

Identification of the specimens was done at the field as far as possible with their available local names (photo 3 a, b).

Photo 3 a, b. Species collection for identification and herbarium preparation

All the specimens were collected properly than dried with blotting paper, poisoned with two per cent mercuric chloride in rectified sprit. The dried and poisoned specimens were mounted on slandered herbarium sheets and labeled with relevant information (photo 4 a-c). The unidentified vouchers specimens were identified in the North Bengal University, Siliguri and Department of Forestry, Uttar Banga Krishi Viswavidyalaya, Pundibari, assigned with a voucher number and deposited in its herbarium. 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.

Photo 4 a, b, c. Herbarium of collected plant species

3.5. Vegetation Study/Phyto-sociological Analysis

In each large cardamom holding, 10 m × 10 m quadrates were laid down for trees within which two 5 m × 5 m sub-quadrates were laid at diagonal corners and five 1 m × 1 m sub-quadrates at four corners and centre of the main quadrate. In each large cardamom holding the plant community was studied for their qualitative and quantitative character or phytosociology (photo 5 a-c). The trees, shrubs, herbs, climbers or any other vegetation was noted to keep an account of the floral composition of the plot. The species were also listed as native or exotic along with their IUCN conservation status.

Photo 5 a, b, c. Data collection in large cardamom based agroforestry system

3.5.1. Life form

Vegetation were stratified in to different layers according to its life forms like trees, shrubs, herbs, climbers, orchids and ferns (Johnson, 1983) and every documented species were individually assigned a symbol like T, S, H, C, O and F, respectively.

3.5.2. Frequency or occurrence/presence

The degree of dispersion of an individual species in a community, i.e. chance of occurrence of species in a given habitat is frequency (F) and expressed in per cent.

$$F = \frac{\text{No. of quadrates in which a species occurs}}{\text{Total no. of quadrates}} \times 100$$

Species documented from the large cardamom holdings were categorized as very less/rare (r), seldom present/less frequent (s), often present/frequent (o) and mostly or generally present/abundant (f) based on ≤10, 10-25, 25-75 and ≥ 75 % occurrence/presence, respectively of the total sampled homegardens.

3.5.3. Relative frequency

The frequency of a species relative to frequency of all other species in a community is relative frequency (RF) and can be determined by using the following formula:

$$RF = \frac{\text{No. of occurrence of a species}}{\text{No. of occurrence of all species}} \times 100$$

3.5.4. Raunkiaer's law of frequency

The frequency values are grouped in frequency classes to study the homogenous/heterogeneous nature of vegetation (Raunkiaer, 1934). The law of frequency states that the numbers of species of a community in the five twenty per cent classes are A, B, C, D and E distributed as 0-20, 20-40, 40-60, 60-80 and 80-100 %, respectively.

3.5.5. Density

Abundance of a species in a unit area is expressed as density (D) which indicates the numerical strength of a species in its community. Dominance and rarity of a species in a community is also indicated with density. It also reflects the standing biomass or productivity of an ecosystem.

$$D = \frac{\text{Total no. of individuals of a species}}{\text{Total no. of quadrates}}$$

3.5.6. Relative density

Relative density (RD) is per cent representation of a species in term of number of individuals relative to all other species in a community.

$$RD = \frac{\text{No. of individuals of the species}}{\text{No. of individuals of all species}} \times 100$$

3.5.7. Abundance

Individuals of a species present in sampled area are expressed as abundance (A) of a species that also reflect commonality of the species in a studied habitat.

$$A = \frac{\text{No. of individuals of the species in sampled quadrates}}{\text{No. of quadrates in which a species occurred}}$$

Species abundance distribution (SAD) indicates most abundant and rare species in an ecosystem and was described through a number of models. Likelihood and Akaike Information Criterion (AIC) was used to fit the best SAD model out of the five models used i.e. Log-normal, Mandelbrot, Zipf, Null and Preemption models using abundance data of plant species documented from the 150 homegardens across an altitudinal gradient (Baldridge *et al*., 2016).

Log-normal model, a log-normal distribution is defined as a distribution whose variate conforms to the normal laws of probability. For SADs, the log-normal distribution characterizes a sample with relatively low abundance or very rare species (Matthews and Whittaker, 2014). Preston (1948) introduced the log-normal SAD by demonstrating a good fit to a large number of data sets covering a number of different communities.

$$\text{Log-normal } (\hat{a}r) = \exp\,[\log(u) + \log(\sigma)\,\Phi]$$

Zipf and Zipf-Mandelbrot model was originally developed for information systems, assessing the cost of information (Frontier, 1985). In plant communities, the presence of a species can be seen as dependent on previous physical conditions and previous species presences.

$$\text{Zipf } (\hat{a}r) = N\hat{p}1r\gamma$$

$$\text{Zipf-Mandelbrot } \hat{a}r = (r + \beta)$$

Neutral-theory model was proposed by Hubbell (2001) and noted that the relative abundance of species within and the species diversity of a community can be explained through neutral drift of individual species abundances.

Neutral-theory $\phi n = \theta + \frac{J!}{n!(J-n)!}\frac{\Gamma(y)}{\Gamma(J+y)!}\int_0^{y} \frac{\Gamma(n+y)}{\Gamma(1+y)}\frac{\Gamma(J-n+y-y)x^2}{\Gamma(y-y)}\exp\left(\frac{y\theta}{dy}\right)$

Niche-preemption model was proposed by (Motomura, 1932) and assumes that the percentage of the total niche occupied by the first species is α, the second species occupied a percentage α of the reminder, $(1 - a)$, and so on.

Niche-preemption $(\hat{ar}) = (1 - a) - 1$

Note: $\hat{ar}$ is the expected abundance of species at rank r, S is the number of species, N is the number of individuals, Φ is a standard normal function, $\hat{p}1$ is the estimated proportion of the most abundant species, and α, σ, γ, β and c are the estimated parameters in each model. In neutral-theory model, where Γ(z) = ∫ $t\infty\ z-1\ 0\ e-t$dt which is equal to (z-1)!, for integer z and γ = $m(J-1)\ 1-m$, θ is fundamental diversity number, m is migration rate.

3.5.8. Relative abundance

Abundance of a particular species relative to total number of individuals of all species in the sampled area is relative abundance (RA).

$$RA = \frac{\text{Abundance of a species}}{\text{Sum of the abundance of all species}} \times 100$$

3.5.9. Basal area

Total ground area occupied by a tree is its basal area (BA) which is estimated by measuring its diameter at breast height (1.37 m). BA of a tree species gives an idea on the proportion of its dominance in the community along with its relative size, volume and biomass. Basal area is calculated by the following formula (Chauhan *et al.*, 2009).

$$BA = 0.7854 \times (DBH)^2$$

3.5.10. Importance value index

Importance value index (IVI) reflects the sociological structure of a species in a community as it indicates its importance in the community. The summation of RF, RD and RA of a species is its IVI (Curtis, 1959; Kershaw, 1973; Cintron and Novelli, 1984).

3.5.11. Height

The height of all the trees in a homegarden was measured with help of a Ravi's Multimeter and expressed in meter.

3.5.12. Distribution pattern

The abundance to per cent frequency ratio (A/F) provides information about the distribution pattern (DP) of species (Cottam and Curtis, 1956). If the value is < 0.025, 0.025-0.05 and > 0.05 the distribution of species can be expressed as regular (R), random (R′), and contagious (C_o), respectively.

3.6. Diversity Indices

Out of numerous diversity indices reported following were used to analyze diversity of the traditional large cardamom based agroforestry farming systems.

3.6.1. Species richness

The total number of plant species documented from the large cardamom holdings is its species richness (S).

3.6.2. Species diversity or Menhinick's index

This index ($D' = S/\sqrt{N}$) is based on species richness (S) in proportion to total number of individuals of all species (N) in the traditional large cardamom based agroforestry systems (Menhinick, 1964). Unlike Shannon-Wieners index or Simpson's index this index indicates rarity of a species.

3.6.3. Shannon-Wiener diversity index

The index ($H' = \sum n_i/N \ln n_i/N$; where '$n_i$' is number of individuals of a species, 'N' is number of individuals of all species and 'ln' is natural logarithm) estimate diversity of plant assemblages in a habitat and also indicates community structure in terms of complexity of the habitat i.e. higher the index more diverse the community is (Shannon and Weaver, 1949; Shannon and Wiener, 1963).

3.6.4. Concentration of dominance or Simpson's index

This index (C) evaluates the level of dominance of a species within a community (Simpson, 1949) and was estimated with the following equation:

$C = \sum (n_i/N)^2$ where 'n_i' is number of individuals of a species and 'N' is number of individuals of all species documented from the sampled area and its value is 0-1. The index indicates the number of chances of a particular species that could be encountered during sampling which is inversely proportional to Shannon and Wiener index i.e. a higher the index less diverse the community is.

3.6.5. Species evenness index

This index (EI) indicates the degree of distribution of species in a community or habitat Pielou (1975) and was estimated using the following equation:

EI = H′/ ln N; where ‘H′’ is Shannon-Wiener diversity index and ‘ln N’ is natural logarithm of number of individuals of all species documented from the sampled area.

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

3.7. Soil Physico-chemical Parameters

Composite soil samples from every quadrate were collected at 0-20, 20-40 and 40-60 cm soil depths separately (photo 6 a-c). Samples were air dried in shade, ground with wooden pestle, passed through 2 mm sieve and stored in cloth bags for analysis (photo 7 a-d).

Photo 6a, b, c. Soil sample collection

Photo 7 a, b, c, d. Soil analysis

The following physico-chemical attributes of soils were determined (table 8).

Table 8. Physico-chemical characteristics of the soil

Sn	Parameter	Method
1	Bulk density	Core sampler method (Piper, 1950)
2	Moisture	Volumetric method (Piper, 1966)
3	Electrical conductivity (EC)	Soil water suspension (Jackson, 1967)
4	pH (1:2 soil: water suspension)	Beckman's pH meter (Jackson,1967)
5	Organic carbon	Walkley and Black's rapid titration method (Walkley and Black, 1934; Jackson,1967) and elemental analyzer
6	Available nitrogen (kg ha^{-1})	Modified Kjeldahl method (Jackson, 1967)
7	Available phosphorous (kg ha^{-1})	Bray's method (Bray and Kurtz, 1945; Jackson, 1967)
8	Available potassium (kg ha^{-1})	Flame Photometer method (Jackson, 1967)

3.8. Soil Fertility Indices

Soil fertility was quantified by estimating soil fertility index, SFI (Moran *et al*., 2000) and soil evaluation factor, SEF (Lu *et al*., 2002).

SFI = pH + organic matter content (%) + available P + exchangeable K (ceq kg^{-1}, dry soil) + exch. Ca (ceq kg^{-1}, dry soil) + exch. Mg (ceq kg^{-1}, dry soil) - exch. Al (ceq kg^{-1}, dry soil)

SEF = [exch. K + exch. Ca + exch. Mg – log (1 + exch. Al)] x organic matter content + 5

Exchangeable cations i.e. calcium (Ca), potassium (K), and magnesium (Mg) were extracted with 1 M ammonium acetate ($NH_4CH_2CO_2$ at pH 7.0). Potassium content was determined by flame photometry while, Ca and Mg were determined by ethylenediaminetetraacetic acid (EDTA) titration. Exchangeable Al was extracted with 1 N potassium chloride (KCl) solution and titrated with 0.1 N sodium hydroxide (NaOH) solutions.

3.9. Soil Organic Carbon Stock

Soil organic carbon (SOC) stocks of a given soil depth expressed as mega grams (Mg) ha^{-1} was quantified following Joao Carlos *et al*. (2001) as

SOC stock = SOC (of particular depth) X soil depth X bulk density of that depth

3.10. Tree Biomass and Biomass Carbon

Indirect or non-destructive method was adopted for estimating the above ground biomass (AGB) of trees following an allometric model suggested by Nath *et al*. (2019) and below ground biomass (BGB) was quantified as 15 % of the AGB (Subba *et al*., 2017_d; 2018_a; Shukla and Chakravarty, 2018; Shukla *et al*., 2018**;** Pala *et al*., 2020). Tree biomass carbon was considered as half of the tree biomass (Woomer, 1999; Subba *et al*., 2017_d, 2018_a; Shukla and Chakravarty, 2018**;** Shukla *et al*., 2018; Pala *et al*., 2020).

AGB = $0.18D^{2.16}$ x 1.32; where D is diameter at breast height

BGB = 25 % of AGB (Anon, 2006)

Tree biomass (TB) = AGB + BGB

Tree biomass carbon (TBC) = 0.47 X TB (Anon, 2006)

In this study only, tree biomass was considered for plant biomass as shrub and herb biomass is very negligible (Subba *et al*., 2017_d, 2018_a; Shukla and Chakravarty, 2018**;** Shukla *et al*., 2018; Pala *et al*., 2020) while, carbon in these vegetation forms is not permanent or for longer duration.

3.11. Statistical Tools

The important statistical measures that are used to analyze the survey or research data are frequency, per cent, range, mean, standard deviation, coefficient of variation, Karl Pearson's coefficient of correlation and multiple regressions with analysis of variance (Gomez and Gomez, 1984; Goldstein and Dillon, 1985) using IBM SPSS version 2020 and species abundance modeling was carried out using R 3.6.3 (R Core Team, 2020) statistical software.

RESULTS AND DISCUSSIONS

The result of the present study entitled, **"Variations in Vegetational Diversity and Carbon Stock in Large Cardamom based Traditional Agroforestry System across Altitudinal Gradient in Darjeeling Himalayas"** is presented below:

4.1. Socio-economic Profile of the Large Cardamom Growers

Socio-economic profile of the traditional large cardamom based agroforestry growers is given in table 9.

Table 9. Socio-economic profile of the growers

Indicators	%	Mean	σ
Age (years)			
20-40	35	30.04	3.02
40-60	47	48.19	4.19
>60	18	62.89	4.72
Community			
ST	39	-	-
SC	6	-	-
OBC	43	-	-
GEN	12	-	-
Occupation			
Farmer	58	-	-
Self employed	14	-	-
Govt. Service	16	-	-
Private	12	-	-
Education (years)			
Illiterate (0)	8	0	0
up to 5	58	4.0	1.24
5-10	17	9.0	2.10
Up to 12	8	12.0	4.09
Degree (up to 14)	9	14.0	4.18
Household income (in lakh INR₹)			
<0.5	29	28.0	4.87
0.5-1.0	64	61.0	7.25
>1.0	7	150.0	8.21
Land Holding (decimal)			
< 100	43	57.00	5.74
100-300	34	140.0	6.81
300-500	13	350.0	7.24
> 500	10	740.0	7.57

n- Frequency; σ- Standard deviation

Most of the growers (47 %) were in the age group of 40-60 years. Most of them represented other backward community (43 %). The growers mostly attended up to five years of formal education (58 %) and were mostly dependent on farming activities (58 %). Majority of the respondents (43 %) were found with land holding of less than 100 decimals. This land holding was not related to land used for large cardamom based traditional agroforestry farming. The traditional large cardamom cultivation in Darjeeling Himalayas was also 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 similar to those reported from Sikkm Himalayas (Sharma *et al*., 1994, 2009_b). Total monthly household income of 64 % growers was INR ₹ 0.5-1.0 lakhs, 29 % with <INR ₹ 0.5 lakhs and only seven per cent growers with total monthly household income of >INR ₹ 1.0 lakhs, of which contribution by the large cardamom was 39.78 %, 46.20 % and 47.70 %, respectively.

4.2. Grower's View on Traditional Large Cardamom Farming

Large cardamom based agroforestry is a traditional farming by the indigenous communities of the Darjeeling Himalayas and still being continued by the households due to certain socio-cultural instigators (table 10).

Table 10. Grower's view of traditional large cardamom farming

S no. Opinion statements	SA	A	U	D	SD	TWS	R
S1. You inherited the TAF as heirloom?	78%	22%	0%	0%	0%	478	II
S2. TAF is culturally, traditionally and sociallylinked with your household.	32%	35%	0%	33%	0%	366	V
S3. Certain varieties are superior than your traditional cardamom variety?	86 %	14 %	0 %	0 %	0%	486	I
S4. TAF is economic worth to you.	9 %	23 %	0 %	58 %	10%	263	VII
S5. TAFs supplies fuelwood and fodder.	51%	39%	0 %	10 %	0%	431	III
S6. You still get high returns from TAF.	3 %	15 %	0 %	19 %	63 %	176	VIII
S7. You preferred this crop for its high economic value.	27 %	43 %	0 %	30 %	0%	367	IV
S8. You preferred this crop because it is easy to grow with minimum inputs	21 %	49 %	0 %	30 %	0%	361	VI

S no.- statement number; SA- strongly agree; A- agree; U- undecided or don't know; D- disagree; SD- strongly disagree; TWS- total weighted score; R- rank

The growers held their large cardamom farming system as traditional and cultural pride that was heir loomed over from generation to generation. The growers also linked the farming system culturally, traditionally and socially with their household and livelihood. The Darjeeling growers also acknowledged the declining productivity and failure of their large cardamom farming system to sustain household livelihood as was also reported from Sikkim (Avasthe *et al*., 2011; Kumar *et al*., $2012_{b,c}$; Partap *et al*., 2014; Shukla *et al*., 2016) Inspite of this, majority of growers disagreed on its economic worth to the household and its high return but were still continuing their traditional practice of growing large cardamom. The growers instead giving priority to economic worth of the large cardamom farming system (indicated from the least total weighted score of the statements S4 and S6, table 10) were valuing cultural and traditional worth of associated with the system (indicated from total weighted score of statement S1 and S2, table 10) as their cultural pride and identity which they proudly inherited as an heirloom from their parents and their parents from their ancestors.

Moreover, majority of the growers (90 %) justified their continued loyalty towards their traditional large cardamom farming because of the provisionary services like fuel wood and fodder they receive from the system. The growers valued these aspects worthy for their livelihood (indicated from total weighted score of statement S5, table 10) than it's economic worth *per se* (indicated from total weighted score of statement S4 and S6, table 10). Majority of the growers justified their continued cultivation of large cardamom due to its ease of cultivation with minimum inputs and efforts (statement S8, table 10) and high economic value (statement S7, table 10). All the traditional large carmamom growers also believed improvement or rejuvenation of their diminishing traditional farming system through improved or superior varieties than their present cultivated variety which inferior in quality to resist/tolerate climate change and climate change mediated insurgence of pest and diseases. The growers expected institutional support and availability of quality planting material to bail out their ailing traditional large cardamom farming system. The farmers in neighbouring state of Sikkim were also of the similar opinions and expectations on their large cardamom crop like the Darjeeling farmers (Negi *et al*., 2018). Similarly, studies documented views of farmers on the status of their agroforestry systems in Kashmir (Banyal *et al*., 2015) and Himachal Pradesh (Pathania *et al*., 2020) which matched the views of our respondents.

4. 3. Grower's Perception on Constraints of Large Cardamom Farming

The statement of problems perceived by the traditional large cardamom growers which they faced cultivating the crop and were believed responsible for decreased productivity of the traditional large cardamom based traditional agroforestry system with their total weighted score is given in table 11.

Table 11. Grower's perception on constraints of large cardamom farming

S no. Opinionstatements	SA	A	U	D	SD	TWS	R
S1. Poor marketing channel	72%	20%	8%	0%	0%	464	II
S2. Lack of quality planting materials	25%	27%	6%	42%	0%	335	VI
S3. Infestation of disease, pests and poor pollination	91%	3%	0%	6%	0%	479	I
S4. Area under large cardamom TAF decreased	70 %	12 %	6 %	12 %	0 %	440	III
S5. Improper management of the TAF system.	67 %	15%	0 %	18 %	0 %	431	IV
S6. No extension and supporting services	50%	28%	0 %	14 %	8 %	398	V

S no.- statement number; SA- strongly agree; A- agree; U- undecided or don't know; D- disagree; SD- strongly disagree; TWS- total weighted score; R- rank; TAF- traditional agroforestry system

According to the total weighted scores estimated for the statements of problems faced by the large cardamom growers, the prominent was increased infestation of disease and pests including decreased pollinator population followed by unavailability of market, shrinking cropping area, improper system management, absence of extension and supporting services and least prominent was unavailability of quality planting material. These problems were agreed by 52-94 % of the growers. The growers believed that the problems of pest and disease infestation along with decreased population of bumble bee, the pollinator of their large cardamom crop was due to increasing temperature over the years in their area which they didn't faced a few decades earlier. The farmers beliefswere also validated by many scientific studies conducted in the region (Sharma and Partap, 2011; Partap *et al*., 2014; Sharma *et al*., 2016$_{a\text{-}c}$; Shukla *et al*., 2016; Negi *et al*., 2018). The growers perceived these problems as the major cause of decline in their large cardamom productivity. The problems perceived by the

Darjeeling traditional large cardamom growers were already reported perceived by the traditional large cardamom growers of Sikkim which were also validated by scientific studies conducted in the region (Sharma *et al*., 2000, 2016_{a-c}; Sharma, 2013; Partap *et al*., 2014; Kumar *et al*., 2015; Tarafder *et al*., 2018)

4.4. Grower's Perception on Solution for Problems of Large Cardamom Farming

Grower's perception on solution of problems faced by them cultivating large cardamom in traditional agroforestry farming system with total weighted score of each solution statement is given in table 12.

Table 12. Grower's perception towards solution of traditional large cardamom farming

S no. Opinion statements	SA	A	U	D	SD	TWS	R
S1. Availability of quality planting material	28 %	34 %	38 %	0 %	0 %	390	V
S2. Proper and timely crop management including field sanitation	22 %	25%	46 %	7 %	0 %	362	VI
S3. Shade tree management and rejuvenation of the old fields	46 %	28 %	13 %	13 %	0 %	420	II
S4. Morevalue added products of large cardamom should be explored	28 %	49 %	23 %	0 %	0 %	405	IV
S5. Direct market linkage should be developed.	57 %	16 %	11 %	16 %	0 %	414	III
S6. Proper extension and training for capacity building including institutional support	80 %	16 %	4 %	0 %	0 %	476	I

S no.- statement number; SA- strongly agree; A- agree; U- undecided or don't know; D- disagree; SD- strongly disagree; TWS- total weighted score; R- rank

Most prominent solution to the problems perceived by 96 % of the traditional large cardamom growers was the need for proper and timely extension services with adequate institutional support. The growers expected themselves to be capacity build so that they can efficiently and properly manage their large cardamom to realise the full potential of the system. The least prioritised solution i.e. perceived by 47 % of the growers was crop management, while 46 % of the respondents remained undecided on the solution. This was because the growers believed that they were managing their crop properly and timely based on what they know based on their experience and traditional knowledge. However, they agreed that these were inadequate in today's situation of climate change and they need to do more scientifically with latest technology. This attitude of the farmers clearly reflects their expectation of getting proper extension services and adequate institutional support to become capacity build. The other important solutions perceived by 62-77 % of the growers were value adding large cardamom for more consumer preference and more income, rejuvenation of their traditional agroforestry system, assured marketing of their product and assured supply of quality large cardamom planting material. Studies from Sikkim also documented similar perceptions by the large cardamom growers of Sikkim towards solution of the problems faced cultivating large cardamom traditionally (Kumar *et al.*, 2015). The solutions perceived by the growers were also validated by the studies conducted both at Sikkim and Darjeeling Himalayas (Sharma and Sharma, 1997; Sharma *et al.*, 2007, 2009_{b}, $2016_{a\text{-}c}$; Sharma, 2013; Kumar *et al.*, 2015; Sharma and Liang, 2006; Tarafder *et al.*, 2018).

The urge to continue with traditional large cardamom based agroforestry farming in spite of decreasing productivity and profit has instigated the growers to find out the solution faced by them. Awareness of the problems and their solution also indicates that the growers were well aware of the modern resources, methods and technologies to overcome the problems. Information, awareness, motivation to adopt and capacity building might have been the source of instigation to perceive the solution of the problems (Patt and Schröter, 2008; Wollenberg and Springate-Baginski, 2009; Sonwa *et al.*, 2012). This is because most of the respondents were formally educated for at least five years (table 9). Education level was always associated with awareness, urge for of gathering more information, ability to receive, decode and understand information for innovative decisions by a person (Wozniak, 1984; Adesina and Forson, 1995; Daberkow and McBride, 2003; Dey *et al.*, $2017_{a,\ b}$). However, marginality and poor financial status (table 9) might have been responsible for lack of expertise and inability to act on the solutions which they were aware. This is because the solution strategies perceived by the respondents needed both financial involvement and technical know-how on which they were neither trained nor had institutional access which was reflected from urge for capacity building by 96 % of the growers (table 12). Constraints in human and physical capital were linked with the inability of the stakeholders to take decisions on mitigating actions (Salau *et al*., 2012; Gukurume, 2013). Similarly, poor forest dependent communities in the eastern Himalayan foothills of West Bengal, India (Dey *et al*., 2017$_b$), traditional large cardamom farmers in Sikkim (Shukla *et al*., 2016), peasant farmers in Zimbabwe (Gukurume, 2013) and local communities in Nepal (Maharjan *et al*., 2011) couldn't adopt mitigation strategies of their problems due to their poor financial conditions.Similar improper human-environment relationship existed in Darjeeling Himalayas also where large cardamom farmers were dependent on natural resources, poor, deprived and neglected while, lacking development, technology, infrastructure, dignified livelihood, resources, technical know-how, information, institutional and policy support (Dow *et al*., 2006; Chapagain *et al*., 2009; Ericksen *et al*., 2011).

4.5. Floristic Composition and Diversity

4.5.1. Species richness

The plant species richness documented in the the large cardamom based traditional agroforestry (TAF) systems at different altitude class is given in table 13 and 14. Overall plant species enlisted for the large cardamom based traditional agroforestry systems in the Darjeeling Himalayas was 130 species represented by 63 families and 107 genera which included 37 tree species represented by 23 families & 30 genera; 25 shrubs species represented by 15 families & 21 genera; 46 herbs species represented by 23 families & 38 genera; eight ferns species represented by eight families &eight genera; 11 climbers species represented by eight families &nine genera and three orchids species represented by two families & three genera. Low- (700-1200 m asl), mid- (1200-1700 m asl) and high- (< 1700 m asl) altitude class was documented with 76 plant species represented by 63 genera & 43 families, 60 species represented by 57 genera & 40 families and 52 species represented by 45 genera & 35 families. The overall range of plant species richness range recorded was 8-50 species with 16-50 species at low altitude class, 8-30 species richnessat mid-altitude class and 9-21 species at high altitude class.

Table 13. 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

Table 14. Plant species directory of traditional large cardamom agroforestry system

Sn	Fa/SN	Fo	L	M	H_i	ES	IS
I	**Acanthaceae**						
1.	*Hypoestes phyllostachya* (Baker)	S	+	-	-	C	DD
2.	*Justicia prostrata* (Ness) T. Anderson	H	+	+	-	P	DD
3.	*Lepidagathis incurva* (Buch.-Ham) ex D. Don	H	+	+	-	P	DD
4.	*Phaulopsis dorsiflora* (Retz.) Santapau	H	+	-	-	P	DD
5.	*Phlogacanthus thyrsiformis* (Roxb.)	S	+	+	+	P, S	DD
6.	*Strobilanthes* exserta (C.B. Clarke)	H	+	+	-	P, C	DD
II	**Achariaceae**						
7.	*Gynocardia odorata* (R.Br.)	T	-	+	-	P, R, S	DD
III	**Amaryllidaceae**						
8.	*Zephyranthes carinata* Herb.	H	-	+	+	C, R	DD
IV	**Apiceae**						
9.	*Centella asiatica* (L.) Urb.	H	-	+	+	P	LC
10.	*Oenanthe thomsonii* (C. B. Clarke)	H	-	+	-	P, C	DD
V	**Araliaceae**						
11.	*Brassaiopsis mitis* C.B.Clarke	T	-	+	-	P	DD
12.	*Hydrocotyle javanica* (Thunb.)	H	-	-	+	P	LC
13.	*Hydrocotyle nepalensis* (Hook)	H	-	+	-	P	DD
VI	**Asperagaceae**						
14.	*Peliosanthes griffithii* (Baker)	O	-	-	+	P	DD
VII	**Onocleaceae**						
15.	*Matteuccia struthiopteris* (L.) Tod.	F	+	+	-	P, R	LC
VIII	**Asteraceae**						
16.	*Acmella uliginosa* (SW) Cass.	H	+	-	-	P	LC
17.	*Ageratina adenophora* (Spreng.) R. M. King & H. Rob.	H	+	+	+	P	DD

Sn- serial number; Fa- family; SN- scientific name; Fo- Form (C- Climber, F- Fern, H- Herb, S-Shrub, T- Tree; O-Orchid); L- low altitude class (700-1200 m asl); M- mid altitude class (1200-1700 m asl); H_i- high altitude class (>1700 m asl);-ve sign represent absent; +ve sign represent present; ES- Ecosystem service (P- Provisioning, R- Regulatory, C- Cultural, S-Supportive); IC- IUCN status (DD- Data Deficit, LC-Least Concern)

Table 14 contd.

Sn	Fa/SN	Fo	L	M	H_i	ES	IS
18.	*Ageratum conyzoides* (L.)	H	+	+	+	P, R	LC
19.	*Ageratum houstonianum* Mill.	H	+	+	+	C, R	DD
20.	*Anaphalis triplinervis* (Sims) C.B.Clarke	H	-	-	+	C, P, R	DD
21.	*Artemesia vulgaris* Linn.	H	+	+	-	P	DD
22.	*Bidenspilosa* (L.)	H	+	-	-	P	DD
23.	*Gynura cusimbua* (D. Don) S. Moore	H	-	-	+	P	DD
24.	*Mikania micrantha*Kunth.	C	+	-	-	P	DD
25.	*Senecio densiflorus* (Wall.)	S	-	-	+	P, C	DD
26.	*Synedrella nudiflora* (L.) Gaerth	H	+	-	-	P	DD
IX	**Athyriaceae**						
27.	*Diplazium esculentum* (Retz.) Sw.	F	+	+	+	P	LC
X	**Betulaceae**						
28.	*Alnus nepalensis* (D. Don)	T	+	+	+	C, R, S, P	LC
XI	**Bignoniaceae**						
29.	*Begonia palmata* (D. Don)	H	-	-	+	P	DD
30.	*Begonia tessaricarpa* C. B. Clarke	H	-	-	+	P	DD
31.	*Oroxylum indicum* (L.) Kurz.	T	+	-	-	C, P	DD
XII	**Bischofiaceae**						
32.	*Bischofia javanica* Blume	T	-	+	-	P, R, S	LC
XIII	**Cannabiaceae**						
33.	*Celtis tetrandra* (Roxb.)	T	+	-	-	P, R, S	LC
XIV	**Caryophyllaceae**						
34.	*Drymaria cordata* (L.) Willd. Ex Schult.	H	+	+	+	P	DD
XV.	**Celastraceae**						
35.	*Euonymus attenuatus* Wall. Ex M.A. Lawson	T	-	-	+	P	DD

Sn- serial number; Fa- family; SN- scientific name; Fo- Form (C- Climber, F- Fern, H- Herb, S-Shrub, T- Tree; O-Orchid); L- low altitude class (700-1200 m asl); M- mid altitude class (1200-1700 m asl); H_i- high altitude class (> 1700 m asl); -ve sign represent absent; +ve sign represent present; ES- Ecosystem service (P- provisioning, R- Regulatory, C- Cultural, S-Supportive); IC- IUCN status (DD- Data Deficit, LC-Least Concern)

Table 14 contd.

Sn	Fa/SN	Fo	L	M	H_i	ES	IS
XVI	**Combretaceae**						
36.	*Terminalia myriocarpa* Van Heurck & Mull. Arg.	T	+	+	+	P, R, S	DD
XVII	**Commelinaceae**						
37.	*Commelina suffruticosa* (Blume)	H	-	-	+	P	DD
38.	*Floscopa scandens* (Lour.)	H	+	-	-	P	LC
XVIII	**Cucurbitaceae**						
39.	*Solena amplexicaulis* (Lam.) Gandhi	C	+	-	-	P	DD
XIX	**Cyperaceae**						
40.	*Carex sylvatica* (Maxim.) Ex Boeckeler	H	-	-	+	R, S	DD
XX	**Cyatheaceae**						
41.	*Alsophila dregei* (Kunze) R.M. Tryon	F	+	-	-	P, C	DD
XXI	**Cupressaceae**						
42.	*Cupressus cashmeriana* (Royle) Ex Carriere	T	+	+	+	C, P	NT
43.	*Cryptomeria japonica* (Thunb. Ex L.f) D. Don	T	+	+	+	C, P, S	NT
44.	*Juniperus indica*Bertol.	T	+	-	-	P, R, C	LC
45.	*Thuja plicata* (Donn) Ex – D. Don	T	-	-	+	C, P, S,	LC
XXII	**Ericaceae**						
46.	*Rhododendron griffithianum* Wight	T	-	-	+	C, P, R	LC
XXIII	**Equisetaceae**						
47.	*Equisetum arvense* (L.)	H	+	-	-	P	LC
48.	*Equisetum debile* Roxb. Ex Vaucher	H	+	+	-	P, R	LC
XXIV	**Euphorbiaceae**						
49.	*Acalypha accedens* Müll.Arg.	H	-	+	-	P	DD
50.	*Croton caudatus* (Geiseler)	S	+	-	-	P, S	DD

Sn- serial number; Fa- family; SN- scientific name; Fo- Form (C- Climber, F- Fern, H- Herb, S-Shrub, T- Tree; O-Orchid); L- low altitude class (700-1200 m asl); M- mid altitude class (1200-1700 m asl); H_i- high altitude class (> 1700 m asl); -ve sign represent absent; +ve sign represent present; ES- Ecosystem service (P- provisioning, R- Regulatory, C- Cultural, S-Supportive); IC- IUCN status (DD- Data Deficit, LC-Least Concern)

Table 14 contd.

Sn	Fa/SN	Fo	L	M	Hi	ES	IS
51.	*Macaranga denticulata* (Blume) Müll.Arg.	T	+	+	-	P, R	DD
52.	*Mallotus tetracoccus* (Roxb.) Kurz	T	-	+	-	P, C, R, S	DD
53.	*Ostodes paniculata* (Blume)	T	+	-	-	P, C	LC
XXV	**Fabaceae**						
54.	*Albizia odoratissima* (L.f.) Benth.	T	+	-	-	P, R, S	LC
55.	*Albizia procera* (Roxb.) Benth.	T	+	-	-	P, R, S	LC
56.	*Erythrina variegate* L.	T	+	+	-	P, R	DD
XXVI	**Fagaceae**						
57.	*Castanopsis indica* (Roxb. ex Lindl.) A.DC.	T	+	-	-	P, R, S	LC
XXVII	**Hamamelidaceae**						
58.	*Exbucklandia populnea* (R.Br. Ex Griff.) R.W.Br	T	-	+	-	P	LC
XXVIII	**Hydrangeaceae**						
59.	*Dichroa febrifuga* (Lour.)	H	+	+	+	P, R	LC
XXIX	**Lamiaceae**						
60.	*Colebrookea oppositifolia* Sm.	S	-	+	-	P, R	DD
61.	*Leucosceptrum canum* Sm.	T	-	+	-	P, C, R	DD
62.	*Pogostemon andersonii* (Prain) Panigrahi	H	-	+	-	P	DD
63.	*Scutellarialateriflora* (L.)	H	-	-	+	P, S	LC
64.	*Vitexnegundo* (L.)	S	+	-	-	P	LC
XXX	**Lauraceae**						
65.	*Litsea glutinosa* (Lour.) C.B.Rob.	T	-	-	+	C, P, S	LC
66.	*Litsea monopetala* (Roxb.) Pers.	T	+	-	-	P	LC
67.	*Machilus edulis* King ex Hook. f	T	-	-	+	P	LC

Sn- serial number; Fa- family; SN- scientific name; Fo- Form (C- Climber, F- Fern, H- Herb, S-Shrub, T- Tree; O-Orchid); L- low altitude class (700-1200 m asl); M- mid altitude class (1200-1700 m asl); H_i- high altitude class (> 1700 m asl); -ve sign represent absent; +ve sign represent present; ES- Ecosystem service (P- provisioning, R- Regulatory, C- Cultural, S-Supportive); IC- IUCN status (DD- Data Deficit, LC-Least Concern)

Table 14 contd.

Sn	Fa/SN	Fo	L	M	H_i	ES	IS
XXXI	**Lycopdiaceae**						
68.	*Lycopodium japonicum*Thunb	F	+	+	-	P, C, S	LC
XXXII	**Melastomataceae**						
69.	*Melastoma malabathricum* (L.)	S	-	-	+	P, S	DD
XXXIII	**Manispermaceae**						
70.	*Stephania japonica* (Thunb) Miers	C	+	-	-	C, P	DD
XXXIV	**Meliaceae**						
71.	*Toona ciliate* M.Roem.	T	+	+	-	P, S	LC
XXXV	**Magnoliaceae**						
72.	*Magnolia doltsopa* (Buch.-Ham. Ex DC.) Figlar	T	-	-	+	P	DD
73.	*Magnolia grandiflora* (L.)	T	-	-	+	P, C	LC
74.	*Magnolia lanuginose* (Wall) Figlar and Noot.	T	-	-	+	R, S, P	DD
XXXVI	**Moraceae**						
75.	*Ficus auriculata* Lour.	T	+	-	-	P, C	LC
76.	*Ficus lacor* Buch.-Ham.	T	+	-	-	P	DD
77.	*Ficus semicordata* Buch.-Ham.ex Sm.	T	+	+	-	P, R,S	LC
78.	*Ficus* spp.	T	-	+	-	C, P, R	
XXXVII	**Nephrolepidaceae**						
79.	*Nephrolepis cordifolia* (L.) C. Persl	F	+	+	-	P, C	DD
XXXVIII	**Orobanchaceae**						
80.	*Lindenbergia grandiflora* (Buch.-Ham. ex D. Don) Benth.	H	+	+	-	P	DD
XXXIX	**Orchidaceae**						
81.	*Goodyera oblongifolia* (Raf.)	O	+	-	-	P, C	DD
82.	*Spathoglottis plicata* (Blume)	O	+	-	+	P, C	DD

Sn- serial number; Fa- family; SN- scientific name; Fo- Form (C- Climber, F- Fern, H- Herb, S-Shrub, T- Tree; O-Orchid); L- low altitude class (700-1200 m asl); M- mid altitude class (1200-1700 m asl); H_i- high altitude class (> 1700 m asl); -ve sign represent absent; +ve sign represent present; ES- Ecosystem service (P- provisioning, R- Regulatory, C- Cultural, S-Supportive); IC- IUCN status (DD- Data Deficit, LC-Least Concern)

Table 14 contd.

Sn	Fa/SN	Fo	L	M	H_i	ES	IS
XL	**Oxalidaceae**						
83.	*Oxalis corniculata* L.	H	+	-	-	P	DD
84.	*Oxalis latifolia* (Kunth)	H	+	-	-	P	DD
85.	*Oxalis martiana*Zucc.	H	+	-	-	P	DD
XLI	**Pinaceae**						
86.	*Pinuswallichiana*A.B.Jacks.	T	-	-	+	R, C, P	DD
XLII	**Piperaceae**						
87.	*Piper attenuatum* (L.) Buch.-Ham ex – Miq	C	+	-	-	P	DD
88.	*Piper boehmeriaefolium* (Miq.) Wall ex C. DC.	C	+	+	+	P	DD
89.	*Piper peepuloides* (Roxb.)	C	+	-	-	P	DD
XLIII	**Plantaginaceae**						
90.	*Plantago asiatic*a L.	H	-	-	+	P	DD
91.	*Plantago major* (L.)	H	-	-	+	P, S	DD
XLIV	**Plumbaginaceae**						
92.	*Plumbagoauriculata* (Lam.)	H	-	+	-	C, P	DD
XLV	**Poaceae**						
93.	*Brachiaria reptans* Gard & Hubb.	H	+	-	-	R	DD
94.	*Thysanolaena latifolia* (Roxb. Ex Hornem.)	H	+	+	+	P	LC
XLVI	**Polygonaceae**						
95.	*Persicaria capitata* (Buch.-Ham. Ex D.Don)	H	+	-	-	R, S	DD
96.	*Persicaria chinesis* (L.) H. Gross	C	+	+	-	P	DD
97.	*Polygonum rude* (Meisn.)	S	-	+	-	P, C	DD
XLVII	**Primulaceae**						
98.	*Ardisiamacrocarpa* (Wall.)	S	-	-	+	P, S	DD

Sn- serial number; Fa- family; SN- scientific name; Fo- Form (C- Climber, F- Fern, H- Herb, S-Shrub, T- Tree; O-Orchid); L- low altitude class (700-1200 m asl); M- mid altitude class (1200-1700 m asl); H_i- high altitude class (> 1700 m asl); -ve sign represent absent; +ve sign represent present; ES- Ecosystem service (P- provisioning, R- Regulatory, C- Cultural, S-Supportive); IC- IUCN status (DD- Data Deficit, LC-Least Concern)

Table 14 contd.

Sn	Fa/SN	Fo	L	M	H_i	ES	IS
XLVIII	**Myrsinaceae**						
99.	*Myrsine semiserrata* (Wall.)	S	-	+	-	P, C	LC
XLIX	**Pteridaceae**						
100.	*Adiantum capillus* Sw.	F	+	+	-	P	LC
L	**Putranjivaceae**						
101.	*Drypete slancifolia* (Hook. F.) Pax & K. Hoffm.	S	+	-	-	P, S	DD
LI	**Rosaceae**						
102.	*Fragaria nubicola* (Lindl. Ex Hook.f.) Lacaita	H	+	+	-	P	DD
103.	*Prunus cerasoides* Buch.-Ham. Ex D.Don	T	-	+	-	P, C	LC
104.	*Rubus diffuses* Sanadze	S	-	+	-	P	DD
105.	*Rubus holosericeus* (L.)	S	-	-	+	P	DD
106.	*Rubus species*	S	-	+	-	P	
LII	**Rubiaceae**						
107.	*Rubia cordifolia* (L.)	C	-	+	-	P, S	DD
LIII	**Rutaceae**						
108.	*Citrus spp.*	T	+	-	-	P	DD
109.	*Zanthoxylum piperitum* Benn.	S	-	+	-	P, S	DD
LIV	**Schizaeaceae**						
110.	*Lygodium flexuosum* (L.) Sw.	F	-	-	+	P, R	DD
LV	**Selaginellaceae**						
111.	*Selaginella denticulata* (L.) Spring	F	+	+	+	P	LC
LVI	**Smilacaceae**						
112.	*Smilax ovalifolia* (Robx.) Ex – D.Don	C	-	-	+	P, C, S	DD

Sn- serial number; Fa- family; SN- scientific name; Fo- Form (C- Climber, F- Fern, H- Herb, S- Shrub, T- Tree; O-Orchid); L- low altitude class (700-1200 m asl); M- mid altitude class (1200-1700 m asl); H_i- high altitude class (> 1700 m asl); -ve sign represent absent; +ve sign represent present; ES- Ecosystem service (P- provisioning, R- Regulatory, C- Cultural, S-Supportive); IC- IUCN status (DD- Data Deficit, LC-Least Concern)

Table 14 contd.

Sn	Fa/SN	Fo	L	M	H_i	ES	IS
LVII	**Solanaceae**						
113.	*Brugmansia suaveolens* (Humb. & Bonpl. Ex Willd.)	S	+	-	-	C, S	EW
LVIII	**Sterculiaceae**						
114.	*Firmiana colorata* (Roxb.) R.Br	T	+	+	-	R, C	DD
LVIX	**Theaceae**						
115.	*Schima wallichii* Choisy	T	+	+	+	P	LC
LX	**Urticaceae**						
116.	*Boehmeria cylindrica* (L.) Sw.	H	+	-	-	P, C	LC
117.	*Boehmeria platyphylla* D. Don	S	+	+	+	P	DD
118.	*Girardinia diversifolia* (Link) Friis	S	-	-	+	P	DD
119.	*Girardinia palmata* (Forssk.) Gaudich.	S	+	+	+	P	DD
120.	*Laportea bulbifera* (Siebold & Zucc.) Wedd. .	S	-	-	+	P	DD
121.	*Pilea cordifolia* Hook.f.	H	+	-	-	P, C	DD
122.	*Pilea involucrate* (Sims) C.H.Wright& Dewar	S	-	-	+	R, S, C	DD
123.	*Pilea melastomoides* (Poir.) Wedd.	S	-	-	+	P, S	DD
124.	*Pilea nummulariifolia* (Sw.) Wedd.	H	-	+	-	C	DD
125.	*Pouzolzia zeylanica* (L.) Benn	H	+	-	-	P	DD
LXI	**Verbenaceae**						
126.	*Lantana camara* (L.)	S	+	+	-	P, C	DD
LXII	**Vitaceae**						
127.	*Cayratia geniculate* (Blume.) Gagnep	C	+	-	-	P, S	DD
128.	*Tetrastigma serrulatum* (Roxb.) Plunch	C	-	-	+	C, P	DD
129.	*Vitis pedata* (Lam.) Wallich ex Wight	H	+	-	-	P	DD
LXIII	***Zingiberaceae***						
130.	*Amomum subulatum* (Roxb.)	H	+	+	+	P, C, R	DD

Sn- serial number; Fa- family; SN- scientific name; Fo- Form (C- Climber, F- Fern, H- Herb, S-Shrub, T- Tree; O-Orchid); L- low altitude class (700-1200 m asl); M- mid altitude class (1200-1700 m asl); H_i- high altitude class (> 1700 m asl); -ve sign represent absent; +ve sign represent present; ES- Ecosystem service (P- provisioning, R- Regulatory, C- Cultural, S-Supportive); IC- IUCN status (DD- Data Deficit, LC-Least Concern)

The richness of trees documented at low-, mid- and high-altitude class was 21 (14 families & 18 genera), 18 (15 families & 17 genera) and 14 (11 families & 13 genera) species, respectively; shrub richness was 10 (nine families & 10 genera), 10 (eight families & nine genera) and 11 (six families & nine genera), respectively; herb richness was 28 (13 families & 24 genera), 23 (17 families & 22 genera) and 19 (13 families & 16 genera), respectively; fern richness was seven (seven families & seven genera), six (six families & six genera) and three (three families &three genera) species, respectively; climber richness was eight (six families & six genera), three (three families & three genera) and three (three families & three genera) species, respectively and orchid richness was two (one family & two genera), zero and two (two families & two genera) species, respectively. The dominant plant form found in all the altitude class was herbs followed by trees, shrubs, climbers, ferns and least was orchids.

The plant species richness and plant population decreased significantly gradually with increasing altitude as altitude was found significantly and negatively correlated with both species' richness (r = - 0.648**, fig. 2; table 15) and plant population (r = - 0.587**, fig. 3; table 15).

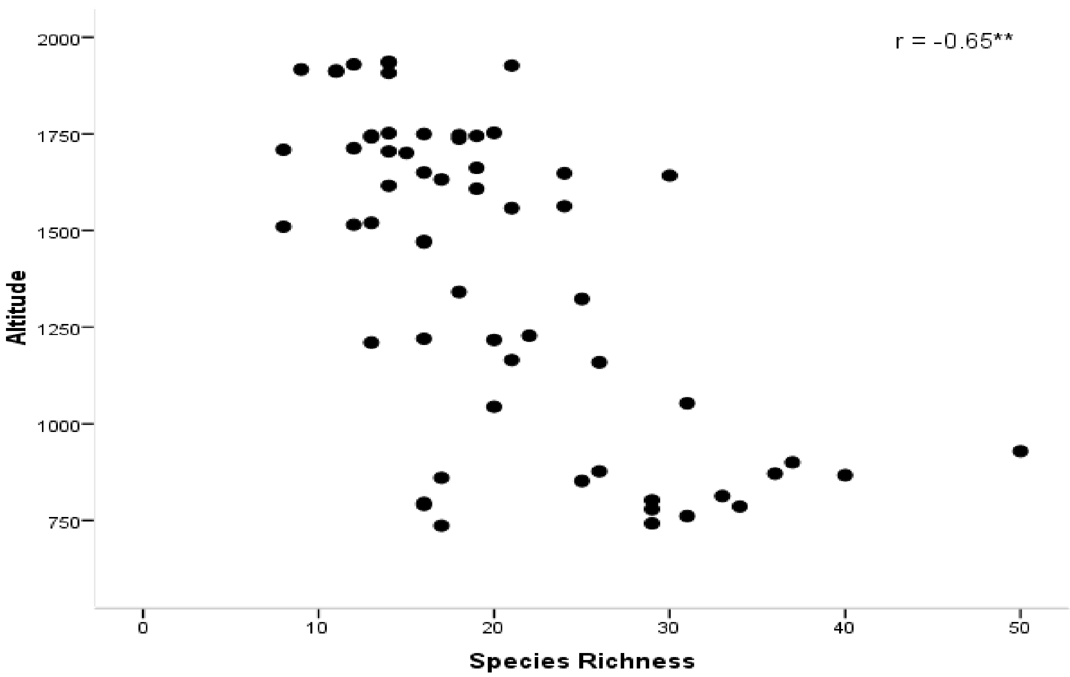


Fig. 2. Scatter plot between species richness and altitude

Table 15. Pearson correlation matrix of plant diversity of large cardamom based traditional agroforestry systems and altitude

	A	SR	PP	D	C	H′	EI
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

****Significant at 0.01 level; *Significant at 0.05 level; 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**

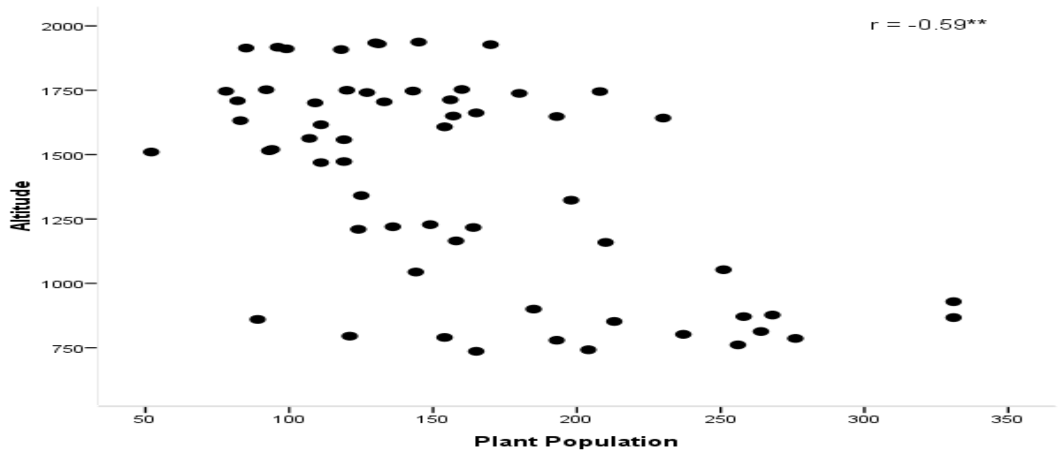


Fig. 3. Scatter plot between plant population and altitude

However, significant positive relationship between species richness and plant population was observed (r = 0.890**, fig. 4; table 15).

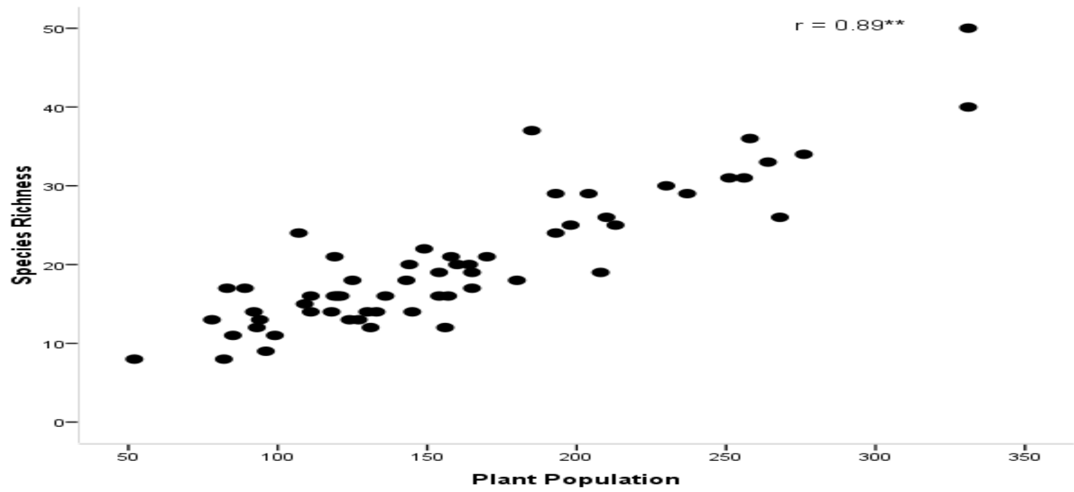


Fig. 4. Scatter plot between species richness and plant population

This is because the traditional below canopy large cardamom farming systems are forest based and very close to natural ecosystems which are not intervened upon by frequent human interference except the natural factors of climate and soil. In such a condition distribution of plants in terms of species richness and population is prominently governed by the temperature which in turn is modified by the altitude of a place (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).

Overall, family Asteraceae dominated with 11 species followed by Urticaeae with 10 species; Acanthaceae with six species; Euphorbiaceae, Lamiaceae & Rosaceae with five species each and Moraceae & Cyperaceae with four species each. Similarly, nine families were represented by three species each, eight families represented two species each and 38 families were each represented by single species. Most dominating genera documentd was *Pilea* and *Ficus* each with four species followed by *Rubus, Piper, Oxalis and Magnolia* each with three species. Similarly, nine genera were represented by two species each and rest of genera were represented by single species each. Dominant tree families were Moraceae and Cupressaceae represented by four species each followed by Magnoliaceae, Euphorbiaceae, Fabaceae and Lauraceae represented by three species each while 17 families each were represented by single species. The most dominated tree genera were Ficus represented by four species each followed by Magnolia represented by three species each, Albizia and Litsea represented by two species each and remaining genera each represented by single species. Urticaceae was the dominant shrub family represented by six species followed by Roasaceaerepresented by three species; Acanthceae, Asteraceae &Lamiaceae represented by two species each and ten families each represented by single species. Rubus was the most dominanted shrub genera with three species, followed by Girardinia&Pileawith two species each and rest of the genera i.e. Melastoma, Hypoestes, Senecio, Colebrookea and Drypetes were each represent by single species. Climbers weredominated by family Piperaceae with three species; Vitaceae with two species and families Schizaeaceae, Asteraceae, Polygonaceae, Rubiaceae, Smilaceae, Cucurbitaceae and Manispermaceae each were represented by single species. Entire documented orchids were represented by two families and three genera i.e. Orchidaceae (two species) and Asperagaceae (one species). Ferns were represented by seven families and seven genera each with single species.

The dominant family of low altitude class found was Asteraceae with eight species followed by Acanthaceae with six species; Urticaceae with five species; Cupressaceae, Euphorbiaceae, Fabaceae, Moraceae, Oxalidaceae and Piperaceae each with three species; Equisetaceae, Orchidaceae, Poaceae, Polygonaceae and Vitaceae each with two species and remaining 28 families each with single species. The most dominant genera found in the low altitude was Piper, Ficus and Oxalis with three species each followed by Ageratum, Albizia, Boehmeria, Equisetumand Persicaria each with two species and remaining 50 genera each with single species. Herbs were dominantly represented by family Asteraceae with seven species while, dominant genera were Ageratum, Equisetum and Oxalis each with two species. Cupressaceae, Fabaceae and Moraceae each with three species were the dominant trees families while dominant tree genera were Ficus and Albizia each with two species. Shrubs were dominated by family Acanthaceae with two species, climbers were dominated by family Piperaceae and genera Piper with three species each, orchids were dominated by family Orchidaceae with two species and ferns were represented by seven families each with single genera and single species.

In the mid altitude dominant families were Asteraceae, Acanthaceae, Rosaceae each represented by four species followed by families Euphorbiaceae, Urticaceae and Lamiaceae each represented by three species. Families Apiaceae, Araliaceae, Cupressaceae, Moraceae and Polygonaceae were represented by two species each while, 29 families were found represented by single species each. Ageratumand Rubuseach with two species was the dominating genera in the mid-altitude class and remaining 55 genera were represented by single species each. Asteraceae with four species was the dominant herb family found in the mid-altitude class followed by Acanthaceae with three species, Apiaceae with two species and remaining 14 families each were represented by single species. *Ageratum* with two species was dominating herb genera found in the mid-altitude class. Tree were dominated by Cupressaceae, Euphorbiaceae and Moraceae families represented each two species while, remaining 12 families each were represented by sinlge species. Ficus was the dominant genera with two species and remaining 16 genera were each represented by single species. Shrubs were dominated by families Rosaceae and Urticaceae each with two species each while, dominant genera were Rubus with two species. Remaining six families and eight genera of shrubs were represented by single species each. Ferns were represented by six families and six genera each with single species. Similarly, climbers were also represented by three families and three genera each represented by single species. Orchids were not found in the mid-altitude class.

In the high-altitude class, among the documented families Asteraceae and Urticaceae were dominant each represented by six species followed by Bignoniaceae, Cupressaceae, Cyperaceae, Lauraceae, Magnoliaceae, Plantaginaceae each with two species and remaining 27 families each were represented by single species each. The dominant genus found in the high-altitude class was Magnolia with three species followed by Ageratum, Begonia, Girardinia, Pilea and Plantago with two species each and 39 genera each represented by single species. Family Asteraceae with five species and genera Ageratum, Begonia and Plantago each with two species dominated the herbs. Magnoliaceae with three species was dominant tree family followed by Cupressaceae and Lauraceae with two species each and remaining seven families with single species each. Genera Magnolia with three species was the dominant tree genus followed Schima with two species and remaining 10 genera were represented by single species each. Family Urticaceae with six species and genera Girardinia and Pilea each with two species dominated the shrubs. No famiy and genera was found dominating the ferns, climbers and orchids as each were represented by single species.

Among the documented species from the large cardamom based traditional agroforestry systems at Darjeeling Himalayas (130 species) following the ICUN conservation status of plant species (Anon., 2021), 89 species were data deficit (68.46 %), 38 species were least concerned (29.23 %); two species (*Cryptomeria japonica* and *Cupressuscashmeriana*) were near threatened and one species (*Brugmansiasuaveolens*) was extinct in the wild (table 14, fig. 5). These near threatened and extinct from the wild 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).

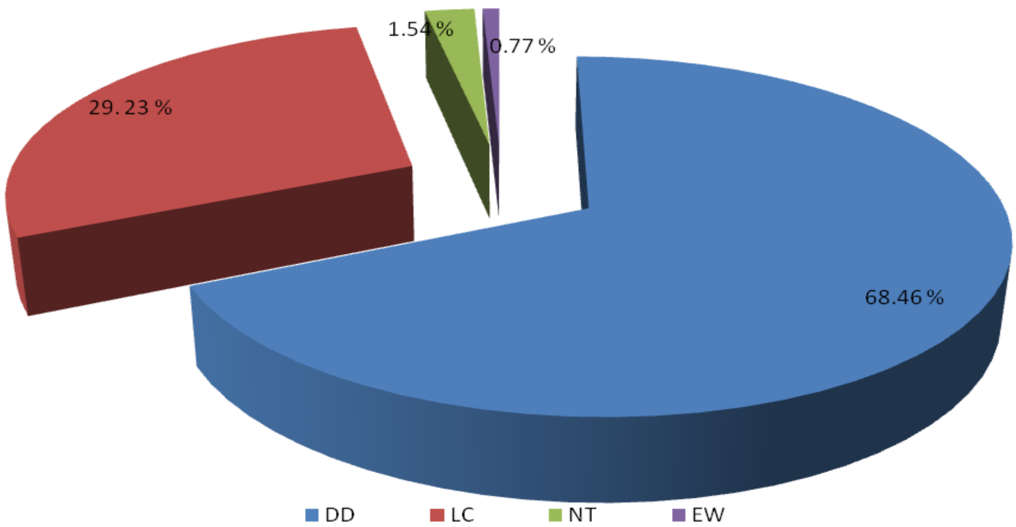


Fig. 5. ICUN status of the overall documented plant species

Highest number (47 and 26 species, respectively) of data deficit and least concerned 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. 6).

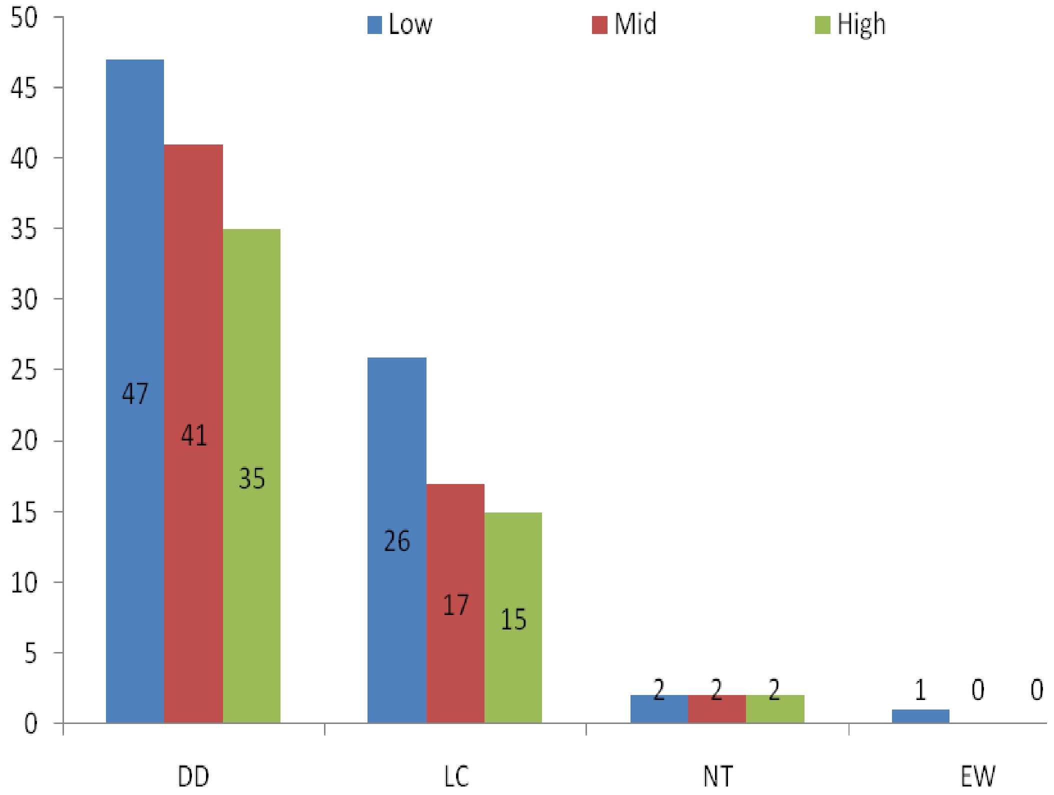
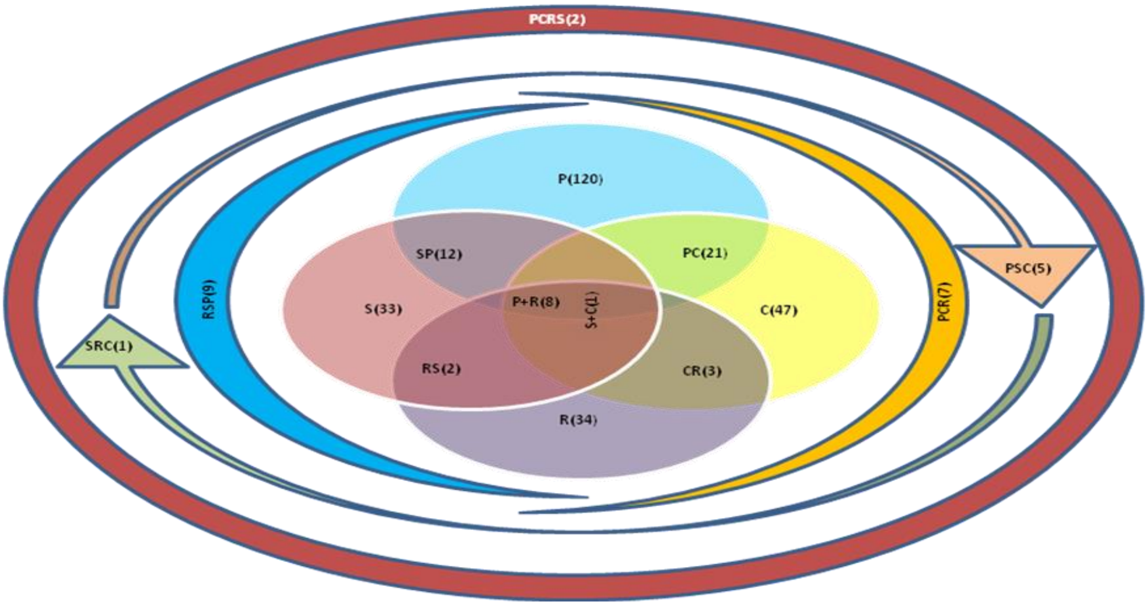


Fig. 6. ICUN status of the documented plant species at altitude classes

The two documented IUCN near to threatened species was found throughout the aititudinal classes while, IUCN extinct in wild species was found only at the low-altitude class (fig. 6). Documentation of diverse native plant species along with ICUN red listed ones indicate that these forest based traditional large cardamom based agroforestry farming systems are playing an important role of harbouring and conserving the both native and exotic plant genetic resources (Casas *et al*., 1997, 2017;Gillespie *et al*, 2000; Valiente-Banuet *et al*., 2000; Trejo and Dirzo, 2002; Moreno-Calles *et al*., 2010; Rzedowski and Calderón, 2013; Campos-Salas *et al*., 2016; Gallardo-Cruz *et al*., 2017; Rendón-Sandoval *et al*., 2020).

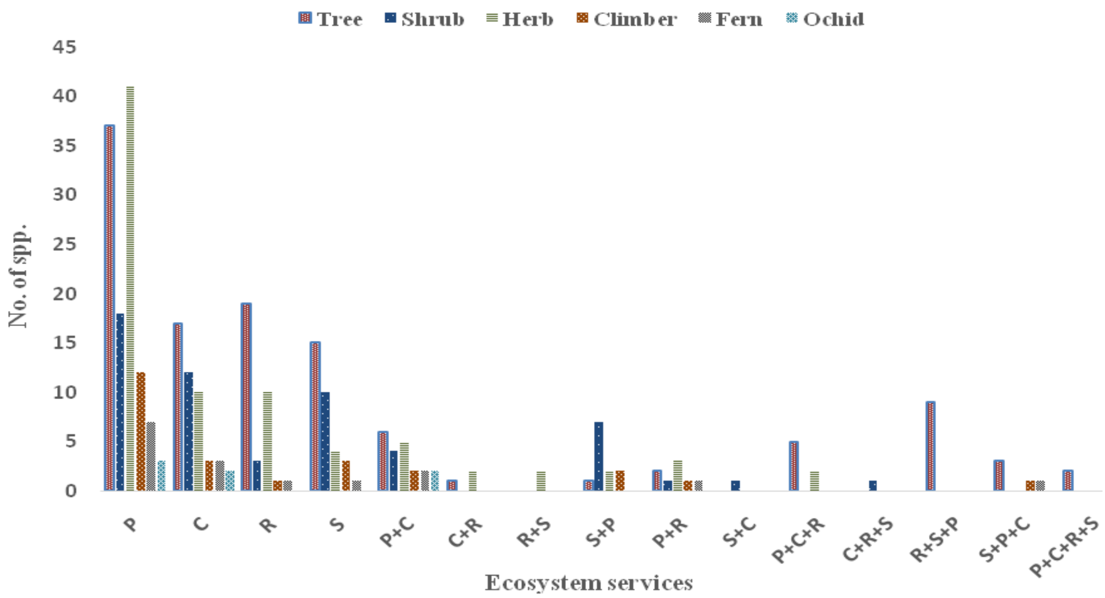
The documented plant species were also classified based on their ecosystem services i.e. provisional (P), regulatory (R), supportive (S) and cultural (C) service (fig. 7). Overall, in the large cardamom based traditional agroforestry farming systems 120, 47, 34 and 33 species were classified to provide provisional, cultural, regulatory and supporting ecosystem services, respectively including 56 species classified only as provisionary, two species as only cultural and one species as only regulatory while, others were classified providing two (47 species), three (22 species) or entire four services i.e. only two species (fig. 7).



P = Provisional; C = Cultural; R = Regulatory; S = Supportive

Fig. 7. Ecosystem services of overall documented plant species

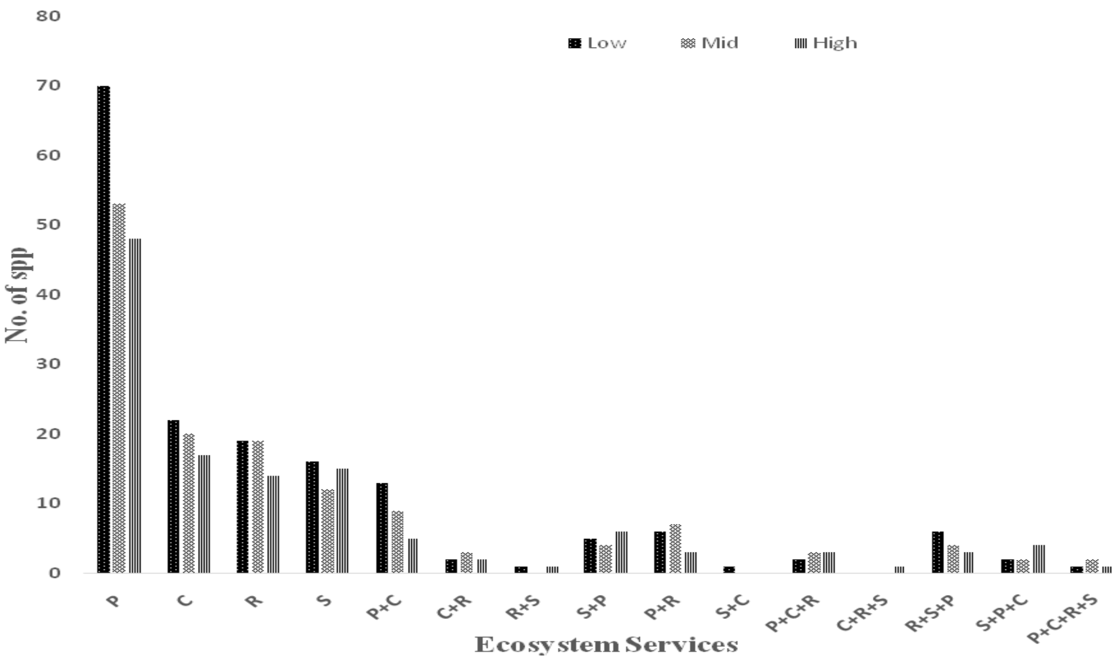
Similarly, the trees (37, 19, 15 & 17 species, respectively); shrubs (18, 3, 10 & 12 species, respectively); herbs (41, 10, 4 & 10 species, respectively); climbers (12, 1, 3 & 3 species, respectively); ferns (7, 1, 1 & 3 species respectively) and orchids (3, 0. 0 & 2 species, respectively) documented from the large cardamom based traditional agroforestry systems in Darjeeling Himalayas were also classified as provisional, regulatory, supportive and cultural ecosystem services (fig. 8; Vineeta *et al*., 2021).



P = Provisional; C = Cultural; R = Regulatory; S = Supportive

Fig. 8. Ecosystem services of overall documented plant life forms

In low-, mid- and high-altitude class 70, 53 & 48 species respectively were found as provisionary; 22, 20 & 17 species, respectively were cultural; 19, 19 & 14 species, respectively were regulatory and 16, 12 & 15 species, respectively were supportive (fig. 9).



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

Fig. 9. Ecosystem services of the documented plant species at altitude classes

The shade trees were reported to ameliorate the microclimate of the area while, agroforestry patches along the mountain slopes regulate it at a landscape level. This system helps inthe maintenance of biological diversity by reducing deforestation and pressure on woodlands by providing fuelwood and also helps in climate regulation by sequestering carbon dioxide. So, the overall productivity of the system was reported higher without doing much effort (Singh *et al*., 2018$_a$). This under canopy forest based traditional large cardamom agroforestry system was thus found economically remunerative, ecologically adapted with comparatively high carbon sequestration potential and other ecological benefits like soil conservation, soil fertility, climate ameriolation, forest and biodiversity conservation (Sharma and Ambasht, 1984; Sharma and Sharma, 1997; Sharma *et al*., 1994, 1996, 2000, 2002, 2007, 2008, 2009$_b$, 2016$_{a-d}$; Sharma and Rai, 2012; Singh *et al*., 2018$_a$; Vineeta *et al*., 2021).

The Sorenson's similarity indexes suggest a lesser similarity for species encountered in large cardamom based traditional agroforestry systems with similarity index of only 0.18 (fig. 10) as only 17 common species were encountered throughout the altitudinal gradient (fig. 11).

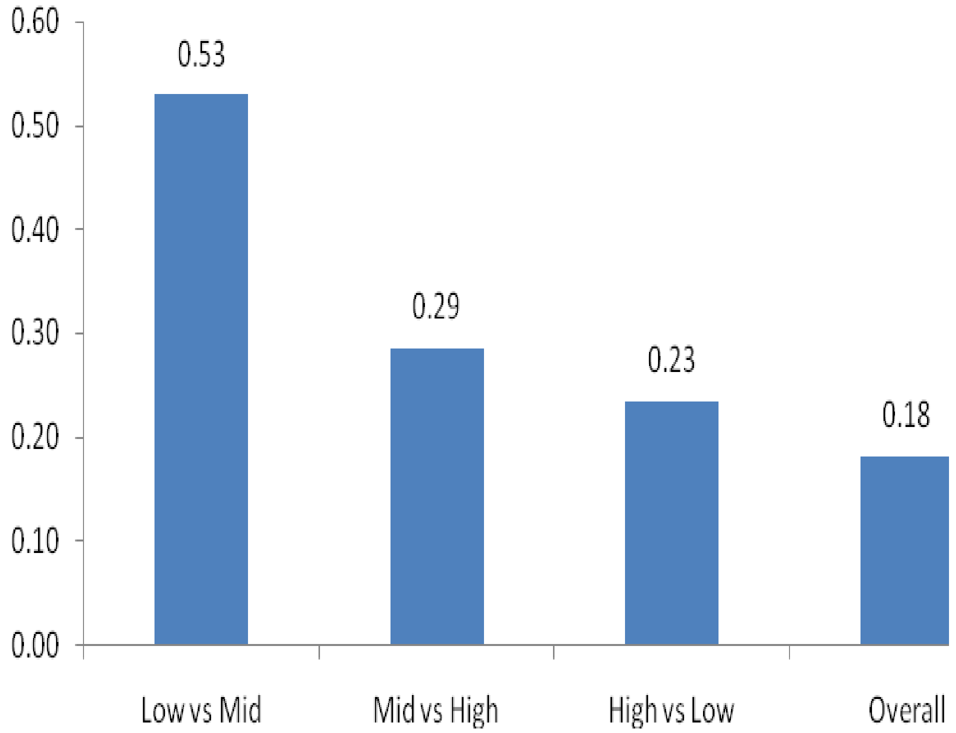


Fig. 10. Similarity index of plant species in the large cardamom based traditional agroforestry systems

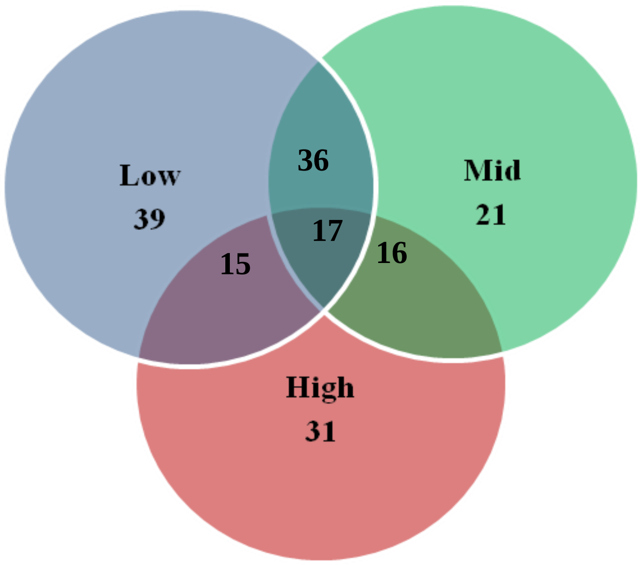


Fig. 11. Composition of specialist and generalist plant species in the large cardamom based traditional agroforestry systems

Seven species of herbs (*Amomum subulatam*, *Ageratina adenophora*, *Ageratum conyzoides*, *Ageratum houstonianum*, *Brachiaria reptans*, *Dichroa febrifuga* & *Drymaria cordata*); four species of trees (*Alnus nepalensis*, *Cryptomeria japonica*, *Cupressus cashmeriana* & *Terminalia myriocarpa*), three species of shrubs (*Boehmeria platyphylla*, *Girardinia palmata* & *Phlogacanthus thyrsiformis*); two species of ferns (*Diplazium esculentum* & *Selaginella denticulate*) and one species of climber (*Piper boehmeriaefolium*) were found in all the three altitude class (table 14).

The similarity of the species decreased gradually with increasing altitude as 36 species were common between low- and mid altitude class with similarity index of 0.53 while, only 16 species were common between mid- and high-altitude class with similarity index of 0.29 and 15 species were common between low- and high-altitude class with similarity index of 0.23 (fig. 10 and 11). In total 91 unique or specialist species were listed, of which 39, 21 and 31 species were unique to low, mid and high altitudes (fig. 11). Majority of the species documented (70 %) in the traditional large cardamom based agroforestry systems of Darjeeling Himalayas were specialists or unique with respect to the altitude class (i.e. low, mid and high). This indicates wide differences or variation among the floristic elements of these traditional systems. The entire study area sampled in the Darjeeling Himalayan zone of West Bengal varied with respect to its eco-climate zone (736-1937 m asl) from humid tropicsto temperate. Overall, the Darjeeling Himalayan forest based below canopy large cardamom farming were floristically different in terms of species composition at landscape level (across altitudinal gradient) as indicated from significant negative relationship of species richness (r = -0.648**, table 15; fig. 2) and plant population (r = -0.587**, table 15; fig. 3). This is because altitudinal or topographic factors affect the microclimate and edaphic condition across the altitudinal gradient thus influencing vegetation also (Joshi and Tiwari, 1990; Kusumlata and Bisht, 1991; Singh *et al.*, 1991; Swamy, 1998; Jha, 2001; De, 2007).

Similarly, numerous studies also had documented plant species diversity of traditional agroforestry systems across the globe (Pandey, 2007; Abebe *et al.*, 2010; Arunachalam *et al.*, 2013; Nandy and Das, 2013; Deb *et al.*, 2014; Nath *et al.*, 2016; Umrao *et al.*, 2017; Salve *et al.*, 2018$_b$; Taran and Deb, 2019; Udawatta *et al.*, 2019). Traditional agroforestry system of Darjeeling and Sikkim Himalayas was biodiversity rich due to association of shade trees (Sharma *et al.*, 1994). Large cardamom based indigenous agroforestry system was reported to supporthigher 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 TAFs of Darjeeling Himalayas are culturally associated with the local population cultivated on the leased out protected or reserved forest land where cultivators cannot cut trees or disturb the area and high rainfall make the system diverse (Nandy and Das, 2013; Sharma *et al.*, 2016$_{a\text{-}c}$; Nath *et al.*, 2016; Pandey *et al.*, 2017).

The large cardamom based traditional agroforestry of Darjeeling Himalayas like that of Sikkim Himalayas were also based on the hill slopes were very close to the natural ecosystems, thus rich in vegetation diversity particularly the trees than other agroforestry systems (Sharma and Sharma, 1997; Das *et al.*, 2012). Tree species like *Schima wallichii*, *Leucosceptrum canum*, *Ficus nemoralis*, *Ficus spp.* and *Alnus nepalensis* were also reported from the traditional large cardamom based agroforestry systems of Sikkim Himalayas (Sharma *et al.*, 1994). These traditional agroforestry systems as are very close to natural ecosystems with potential to offer 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 well-being of the society (Zomer and Menke, 1993; Nandy and Das, 2013; Iqbal *et al.*, 2014$_a$; Nath *et al.*, 2016; Pandey *et al.*, 2017; Singh *et al.*, 2018$_a$). Similar to Sikkim systems the Darjeeling Systems were also prominently providing provisionary services like supplying edible NTFPs (Sharma *et al.*, 2008, $2016_{a\text{-}c}$). Moreover, the Darjeeling large cardamom based traditional farming systems like the Sikkim systems were also observed to support variety of regional avifauna and other small wildlife species and ensuring green fodder during the lean periods as well (Pandey and Singh, 1984; (Sharma and Sharma, 1997).

On the basis of species richness and its plant population across the altitudinal gradient, large cardamom based traditional agroforestry farming systemswere grouped into six clusters illustrated with six different colours (fig. 12). Similar cluster analysis of homegardens across the altitudinal gradient in Central (Vibhuti *et al*., 2018) and Darjeeling (Sarkar, 2020) Himalayas, India were also reported.

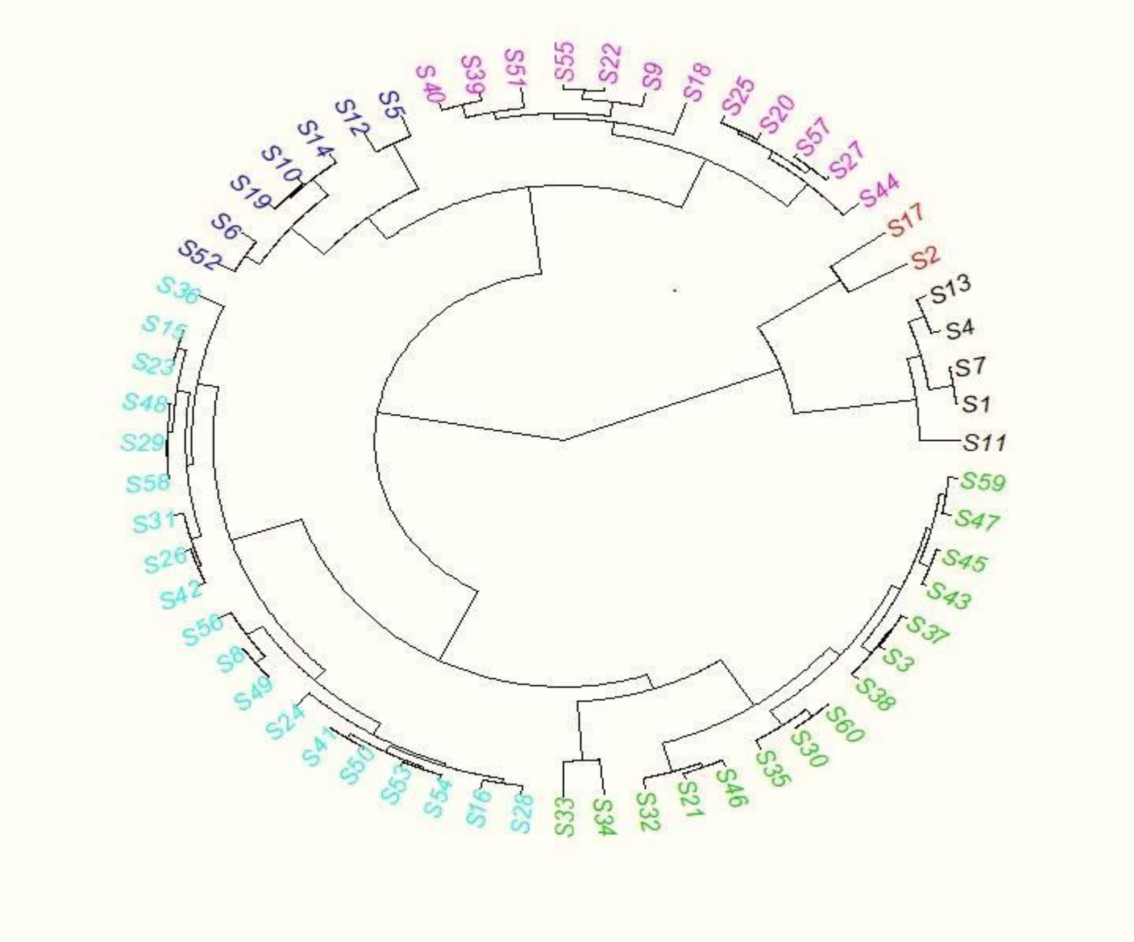


Fig. 12. Clustering based on plant species richness and population of the Darjeeling Himalayan large cardamom based traditional agroforestry systems

4.5.2. Diversity indices

The standard diversity indices like Menhinick's species diversity index, concentration of dominance, Shannon-Wiener index and evenness index estimated to analyse diversity of the Darjeeling Himalayan traditional large cardamom based agroforestry systems homegardens at different altitude class is given in table 16.

Table 16. 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

The Menhinick's species diversity index of the studied systems at Darjeeling Himalayas estimated was 1.36 while, the index estimated for the different altitude class was lesser than the overall index i.e. 1.16, 1.16 and 1.03 for low-, mid- and high-altitude class, respectively (table 16). The index decreased with increasing altitude class as was evidenced by its significant negative correlation with altitude ($r = -0.648^{**}$, table 15; fig. 13) which can be attributed to significant inverse relationship of both species richness ($r = -0.648^{**}$, table 15; fig. 2) and plant population ($r = -0.587^{**}$, table 15; fig. 3) with altitude while, also its significant direct relationship with both species richness ($r = 1.0^{**}$, table 15; fig. 14) and plant population ($r = 0.890^{**}$, table 15; fig. 15).

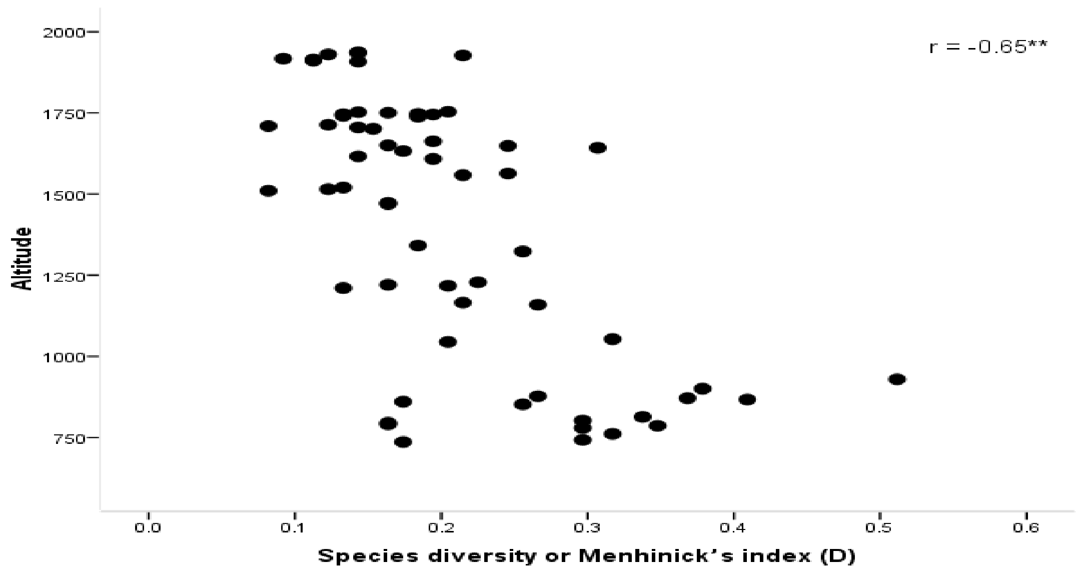


Fig. 13. Scatter plot between Menhinick's species diversity index and altitude

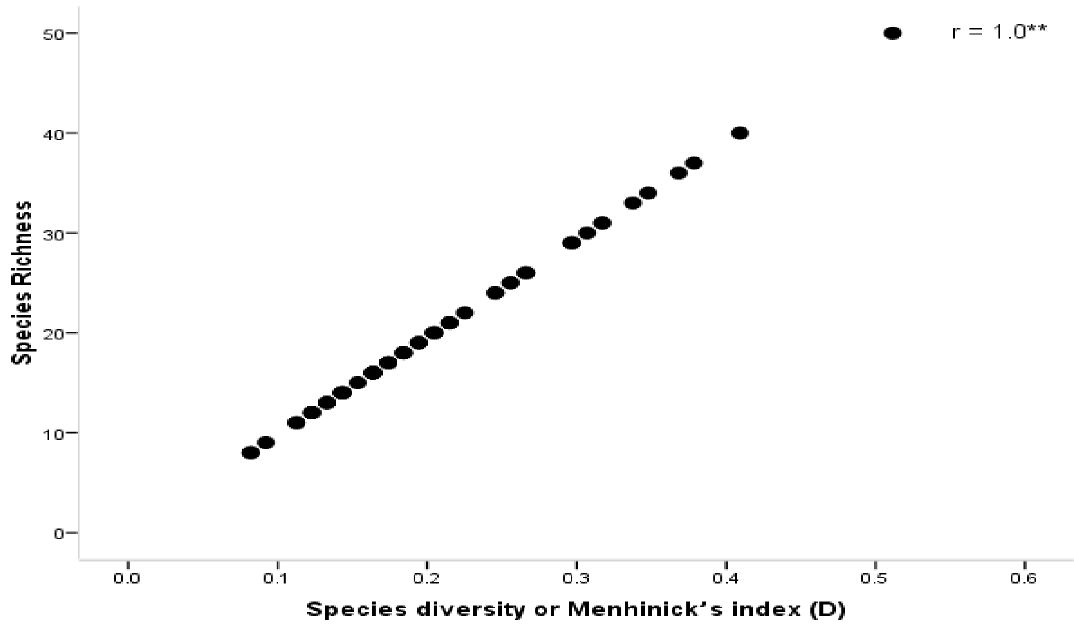


Fig. 14. Scatter plot between species richness and Menhinick's species diversity index

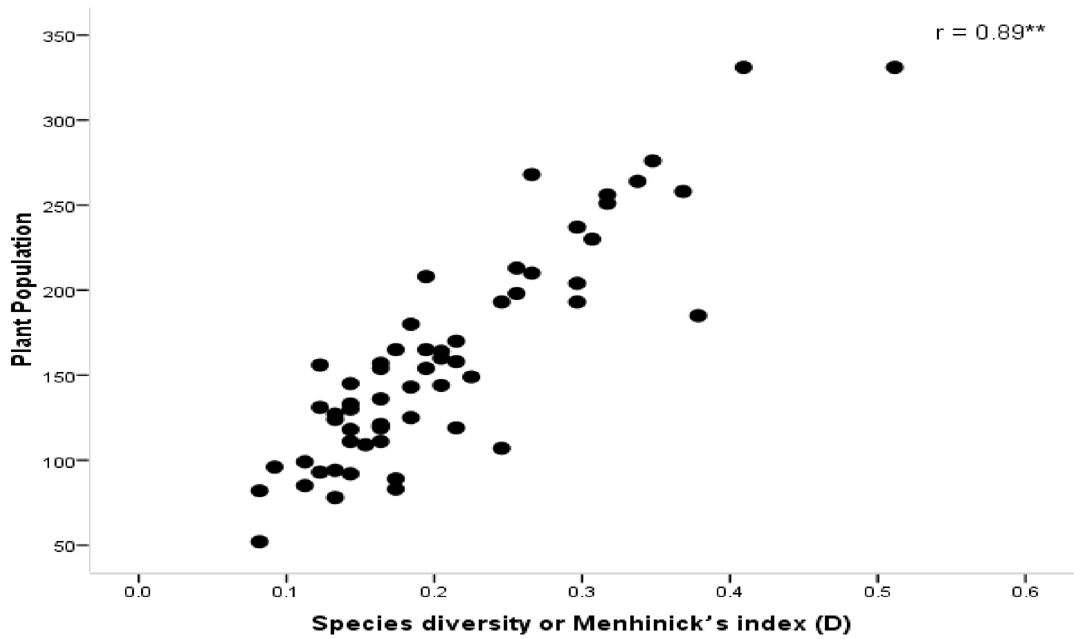


Fig. 15. Scatter plot between plant population and Menhinick's species diversity index

Higher index indicates that plant species in the high altitude class was more diverse but less frequently present than the plant species in lower altitude class. This is because the index is a function of both total number of species and total number of individuals of all the species of the sampled sites. The diversity index estimated at all the altitude class was much lesser than the other agroforestry systems of Darjeeling

Himalayas particularly the homegardens (Sarker, 2020) because the species present in the large cardamom based traditional agroforestry systems were more frequent than the species at homegardens of of Darjeeling Himalayas.

The overall concentration of dominance estimated was 0.03 and it increased with increasing altitude with values of 0.03, 0.04 and 06 for low, mid and high altitude class, respectively (table 16). Highest index value at high altitude class indicates that the chances of a species encountered during sampling in this altitude class were highest and dominance was more distributed than 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 15; fig. 16) as both species' richness and plant population also significantly decreased with altitude (r = - 0.648**, - 0.587**, respectively; table 15; fig 2 and 3). This was also because of its significant positive relationship with intensity of diversity (r = 0.893**, table 15; fig. 17), species richness (0.893**, table 15; fig. 18) and plant population (r = 0.979**, table 15; fig. 19).

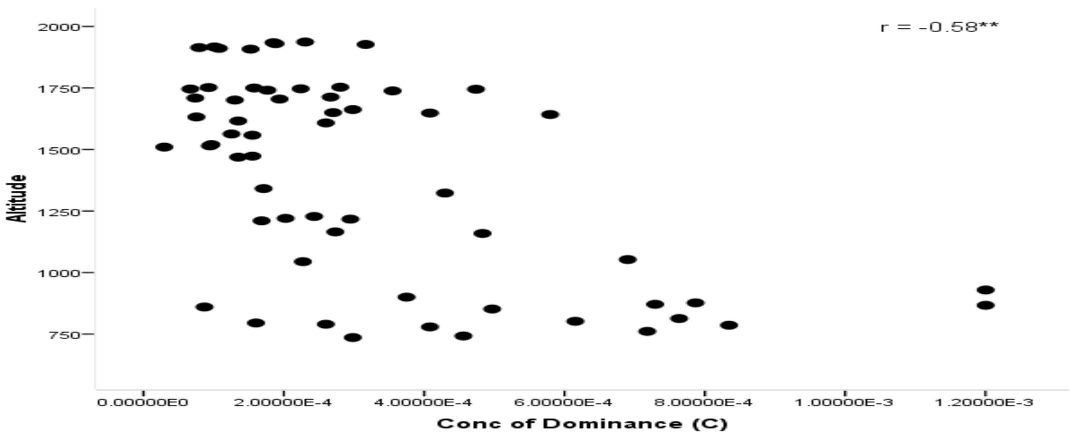


Fig. 16. Scatter plot between concentration of dominance and altitude

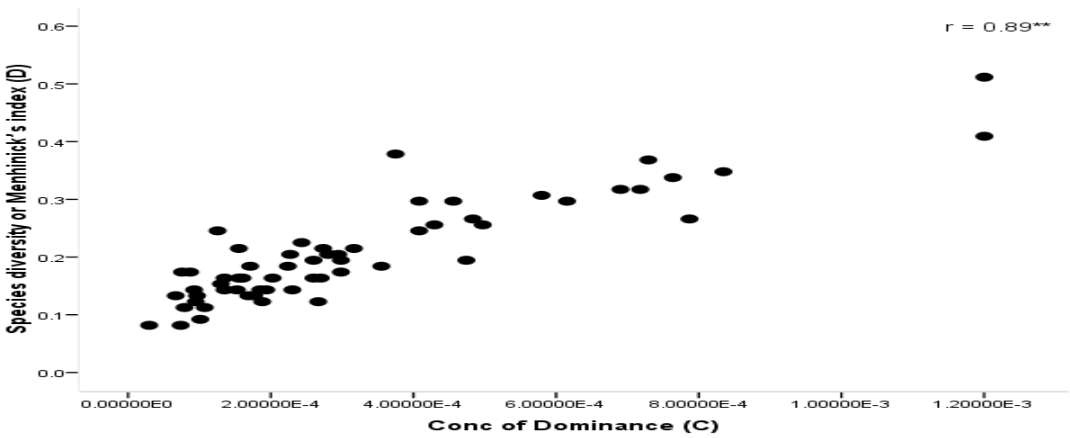


Fig. 17. Scatter plot between concentration of dominance and Menhinick's species diversity index

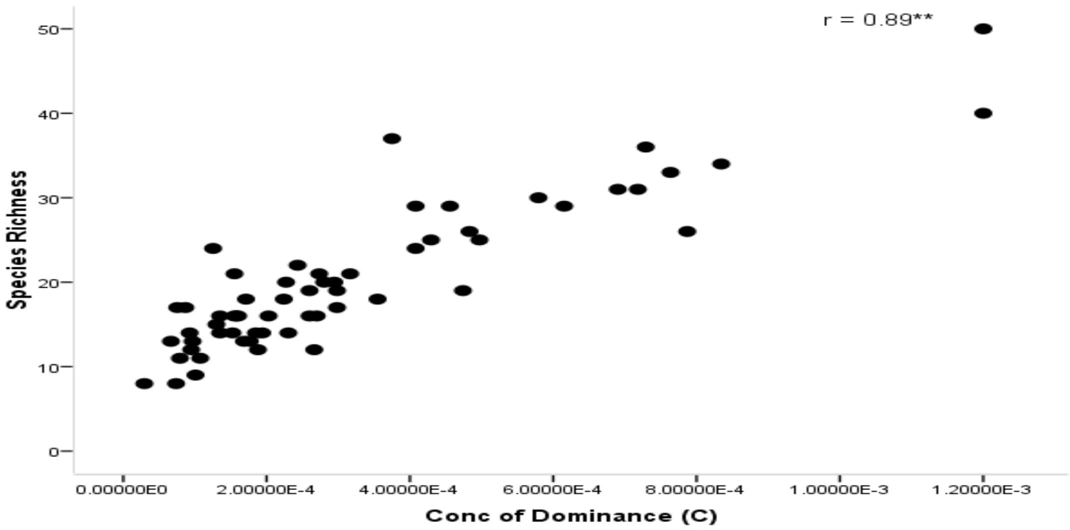


Fig. 18. Scatter plot between concentration of dominance and species richness

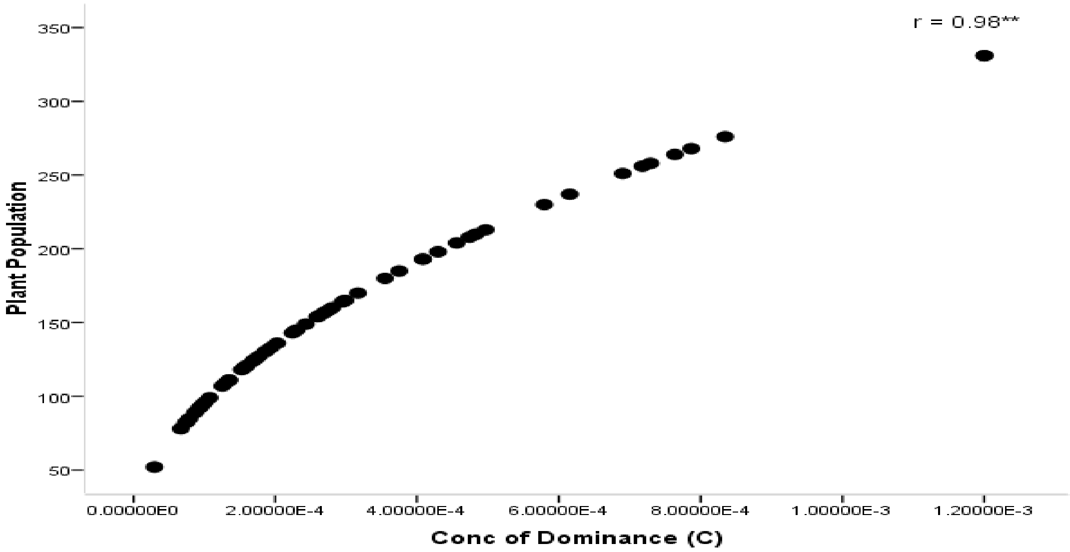


Fig. 19. Scatter plot between concentration of dominance and plant population

Shannon and Wiener index reflects diversity and the traditional large cardamom based agroforestry farming of Darjeeling Himalayas was fair enough diverse with estimated value of 4.09 (table 16) but lesser than its traditional homegardens with estimated value of 4.75 (Sarkar, 2020). Diversity decreased with altitude progressively from 3.79 for low-altitude class to 3.64 for mid-altitude class and 3.24 for high-altitude class, respectively. Altitide inversely influenced diversity as evidenced from significant negative relationship between them (- 0.582**, table 15; fig. 20).

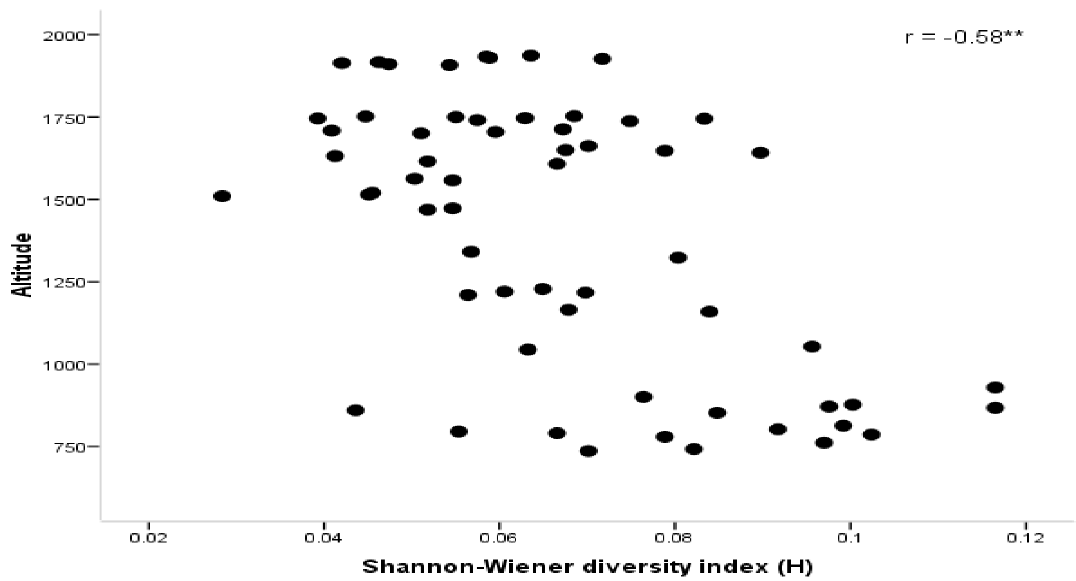


Fig. 20. Scatter plot between Shannon and Wiener index and altitude

This is because of positive relationship of Shannon-Wienerdiversity with plant species richness (0.879**, table 15; fig. 21), plant population (r = 0.997**, table 15; fig. 22), Menhinick's species diversity index (r = 0.879**, table 15; fig. 23) and concentration of dominance (r = 0.962**, table 15; fig. 24) which in turn were significant and negatively correlated with altitude (R = - 0.648**, - 0.587**, - 0. 648** and - 0.580**, respectively; table 15).

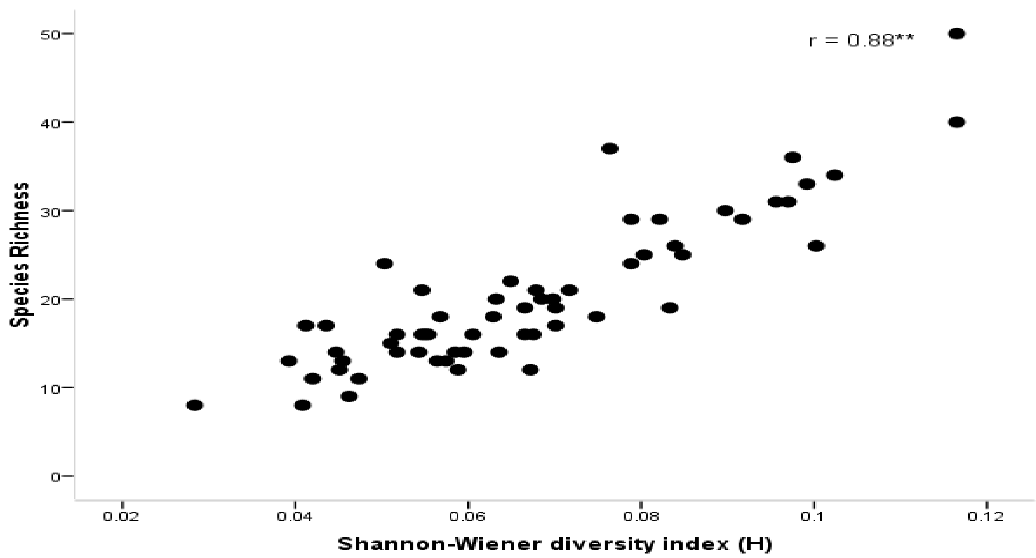


Fig. 21. Scatter plot between Shannon and Wiener index and species richness

Fig. 22. Scatter plot between Shannon and Wiener index and plant population

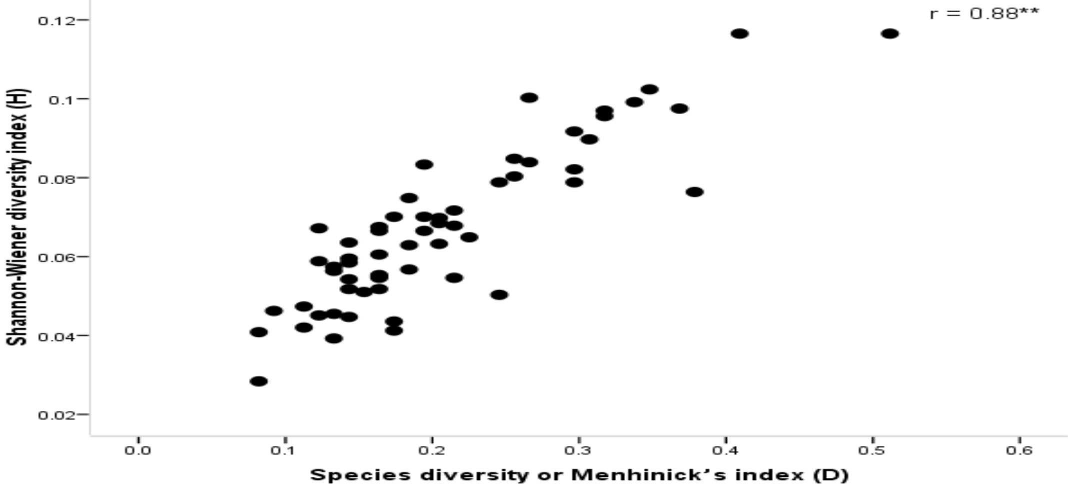


Fig. 23. Scatter plot between Shannon and Wiener index and Menhinick's species diversity index

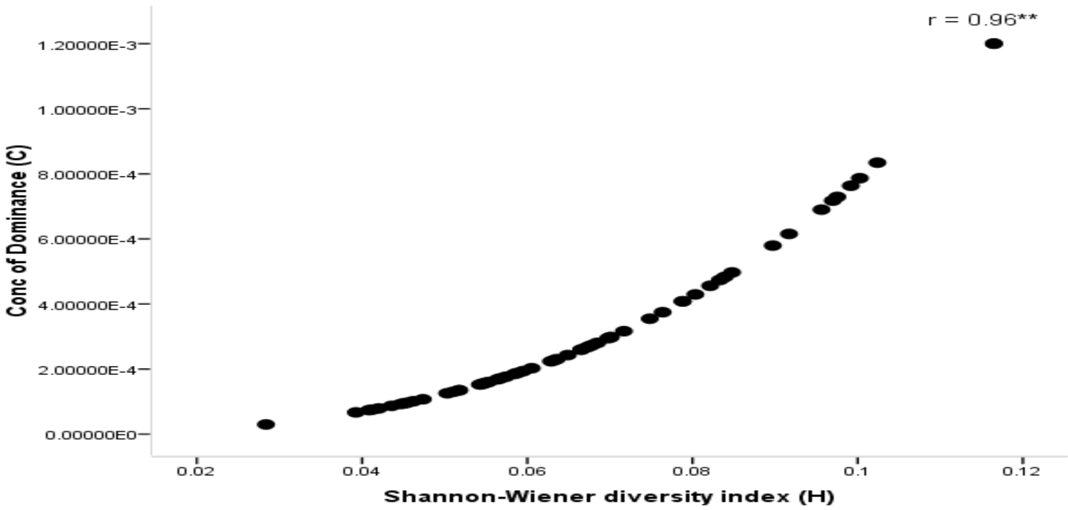


Fig. 24. Scatter plot between Shannon and Wiener index and concentration of dominance

The plant assemblages in the Darjeeling Himalayan traditional large cardamom based agroforestry systems were slightly less more evenly distributed (0.45) than the its traditional homegardens with evenness index value of 0.51 (Sarkar, 2020). The plant species in the large cardamom systems were more or less similarly evenly distributed at the altitudinal classes but evenness of species was inversely related with altitude exhibiting significant negative correlation beteeen the two (r = - 0.582**, table 15; fig. 25) as the index is also positively and significantly correlated with species richness (r = 0.879**, table 15; fig. 26), plant population (r = 0.997**, table 15; fig. 27), Menhinick's species diversity index (r = 0.879**, table 15; fig. 28), concentration of dominanace (r = 0.962**, table 15; fig. 29) and Shannon-Wiener diversity index (r = 1.0, table 15; fig. 30).

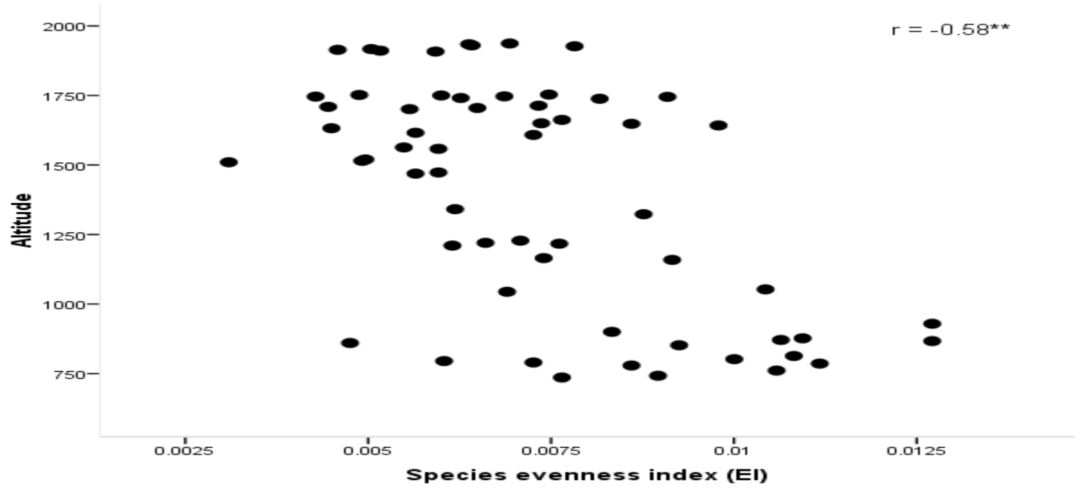


Fig. 25. Scatter plot between species evenness index and altitude

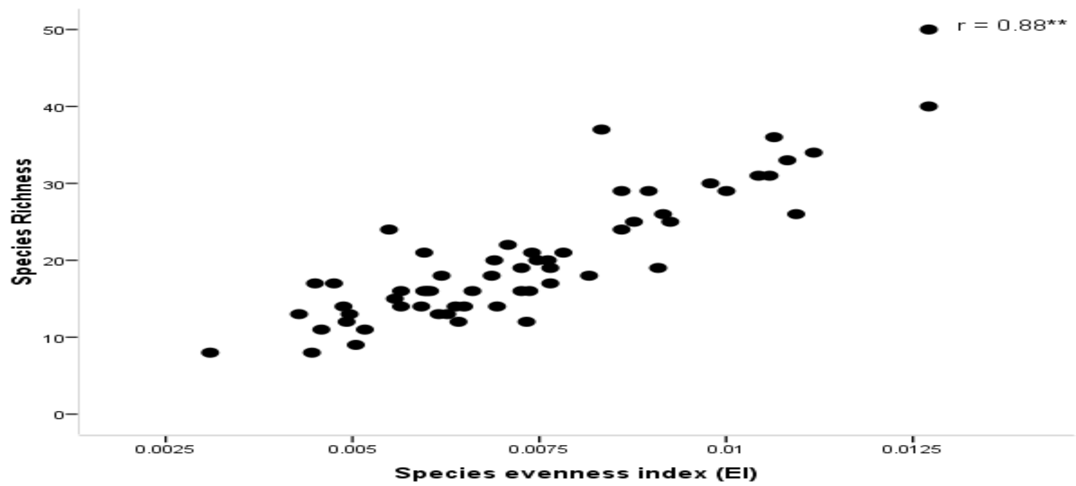


Fig. 26. Scatter plot between species evenness index and species richness

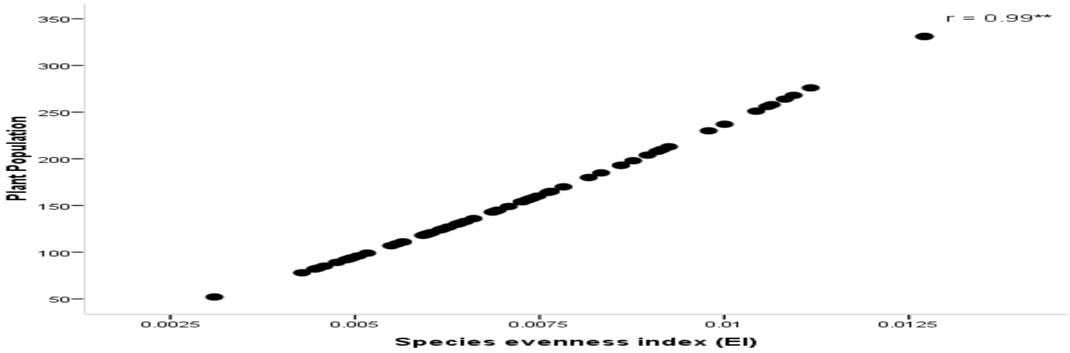


Fig. 27. Scatter plot between species evenness index and plant population

Fig. 28. Scatter plot between species evenness index and Menhinick's speciesdiversity index

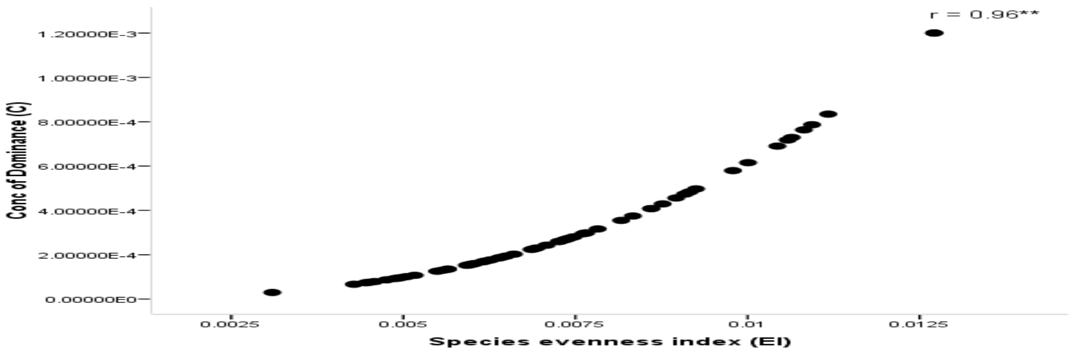


Fig. 29. Scatter plot between species evenness index and concentration of dominanace

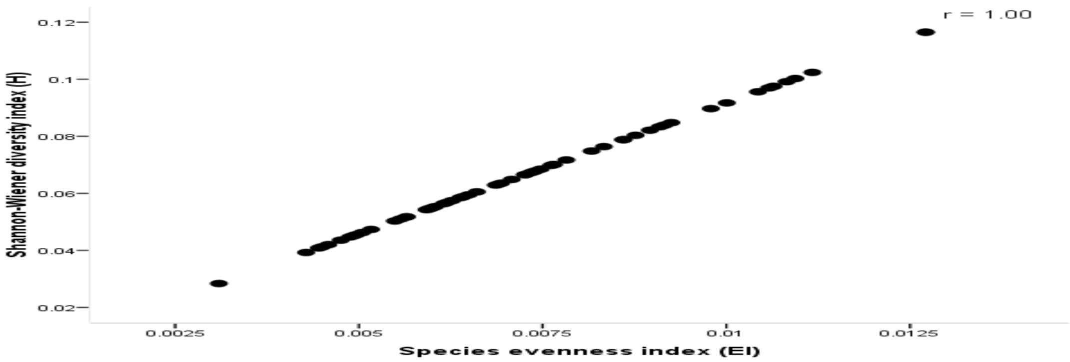


Fig. 30. Scatter plot between species evenness index and Shannon-Wiener diversity index

Similarly, the diversity indices of trees, shrubs, herbs, climbers, orchids and ferns estimated at different altitude class is given in table 17.

Table 17. Diversity indices of various plant forms in large cardamom based traditional agroforestry systems

LF	A	D	C	H′	EI
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**

LF- Life form; A- altitude (low- 700-1200 m asl, mid- 1200-1700 m asl; high- > 1700 m asl); D- Menhinick's species diversity index; C- Concentration of dominance; H′- Shannon-Wiener diversity index; EI- Evenness index

Herbs were most diverse than any other life forms as they were also recorded with higher richness and population thus also estimated with highest Shannon-Wiener diversity index throughout the study area (3.43) and also at different altitude classes

(3.03, 2.97 & 2.59, respectively) as compared to other plant forms. Following herbs, trees were estimated withoverall 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. Diversity of herbs, trees, climbers and orchids decreased gradually with increasing altitude class but diversity of shrubs and ferns increased with increasing altitude class.

Orchids were the least diverse among the plant forms with overall Shannon-Wiener diversity index of 1.06 and at low- and high-altitude class the values were 0.68 and 0.63, respectively. No orchids were found in the mid-altitude class. 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 & 1.12, respectively) than the shrubs, climbers, herbs, orchids and ferns. Ferns and orchids were most frequently present life form throughout the altitudinal gradient of Darjeeling Himalayas in the large cardamom based traditional agroforestry systems and therefore the dominance of the species in their respective life forms species was most distributed with high estimated values of concentration of dominance (0.27 and 0.36, respectively). Trees were most evenly distributed with highest evenness index (with overall value of 0.49 and at low-, mid- and high-altitude class with values of 0.49, 0.49 & 0.46, respectively) followed by shrubs, herbs, climbers, orchids and ferns. The diversity and dominance of species in the large cardamom based traditional agroforestry sysyems was lesser than the homegardens at all altitude classes (Sarkar, 2020). Comparable 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 (Tangjang *et al.*, 2004; 2007, 2014; Pandey, 2007; Nandy and Das, 2013; Nath *et al.*, 2016; Saikia and Khan, 2016; Umrao *et al.*, 2017; Salve *et al.*, 2018_b; Taran and Deb, 2019) and outside India (Abebe *et al.*, 2010; Bardhan *et al.*, 2012;Udawatta *et al.*, 2019; Wari *et al.*, 2019).

4.5.3. Vegetation analysis

Frequency, occurrence, Raunkiaer's frequency class, density and abundance estimated for the large cardamom based traditional agroforestry systems at different altitude classes of Darjeeling Himalayas are given in table 18. The frequency of species irrespective of altitude classes documented was 1.7-100.0. The most frequent species was *Amomum subulutum* and the least frequent species was *Litsea glutinosa*.

Table 18. Frequency, occurrence, Raunkiaer's frequency class, density and abundance of plant species in large cardamom based traditional agroforestry systems

Plant species	F				O				RFC				D_y				A_d			
	O_a	L	M	H	O_a	L	M	H	O_a	L	M	H	O_a	L	M	H	O_a	L	M	H
C. geniculate	10.0	30.0	-	-	r	o	-	-	A	B	-	-	0.1	0.4	-	-	1.3	1.3	-	-
M. micrantha	13.3	40.0	-	-	s	o	-	-	A	B	-	-	0.0	0.3	-	-	0.7	0.7	-	-
P. chinesis	6.7	20.0	20.0	-	r	s	s	-	A	A	B	-	0.2	1.4	0.3	-	7.0	7.0	3.8	-
P. attenuatum	6.7	20.0	-	-	r	s	-	-	A	A	-	-	0.1	0.4	-	-	2.1	2.1	-	-
P. boehmeriaefolium	23.3	30.0	20.0	20.0	s	o	s	s	B	B	B	B	0.2	0.5	0.2	0.2	2.2	1.7	2.5	2.8
P. peepuloides	8.3	25.0	-	-	r	s	-	-	A	B	-	-	0.1	0.7	-	-	2.7	2.7	-	-
S. amplexicaulis	8.3	25.0	-	-	r	s	-	-	A	B	-	-	0.0	0.3	-	-	1.2	1.2	-	-
S. japonica	13.3	40.0	-	-	s	o	-	-	A	B	-	-	0.2	1.2	-	-	2.9	2.9	-	-
A. capillus	16.7	50.0	55.0	-	s	o	o	-	A	C	C	-	0.7	2.1	2.0	-	4.2	4.2	3.7	-
A. drege	3.3	10.0	-	-	s	r	-	-	A	A	-	-	0.0	0.0	-	-	0.3	0.3	-	-
D. esculentum	33.3	10.0	25.0	65.0	o	r	s	o	B	A	B	D	1.3	0.5	0.8	2.7	4.0	5.4	3.0	4.1
L. japonicum	28.3	40.0	45.0	-	o	o	o	-	B	B	C	-	0.7	0.9	1.1	-	2.4	2.3	2.4	-
M. struthiopteris	28.3	40.0	45.0	-	o	o	o	-	B	B	C	-	0.3	0.5	0.5	-	1.2	1.3	1.1	-
N. cordifolia	36.7	55.0	55.0	-	o	o	o	-	B	C	C	-	0.9	1.3	1.5	-	2.5	2.4	2.7	-
A. uliginosa	13.3	40.0	-	-	r	o	-	-	A	B	-	-	0.4	1.2	-	-	3.1	3.1	-	-
A. adenophora	53.3	95.0	35.0	30.0	o	f	o	o	C	E	B	B	0.8	1.9	0.3	0.3	1.6	2.0	0.9	1.1
A. conyzoides	36.7	55.0	20.0	40.0	o	o	o	o	B	C	A	B	1.0	1.4	0.2	1.5	2.7	2.5	0.9	3.7
A. houstonianum	33.3	35.0	45.0	20.0	o	o	s	s	B	B	C	A	0.7	0.8	0.5	0.8	2.1	2.3	1.2	3.8
A. subulatum	**100.0**	**100.0**	**100.0**	**100.0**	**f**	**f**	**f**	**f**	**E**	**E**	**E**	**E**	**1.5**	**1.5**	**1.5**	**1.4**	**1.5**	**1.5**	**1.5**	**1.4**
A. vulgaris	20.0	40.0	20.0	-	s	o	s	-	A	B	A	-	0.3	0.7	0.1	-	1.4	1.8	0.6	-
B. pilosa	20.0	60.0	-	-	s	o	-	-	A	C	-	-	0.7	2.2	-	-	3.7	3.7	-	-
B. cylindrica	5.0	15.0	-	-	r	s	-	-	A	A	-	-	0.0	0.1	-	-	0.9	0.9	-	-
B. reptans	36.7	50.0	20.0	40.0	o	o	s	o	B	C	A	B	1.2	1.4	0.6	1.8	3.4	2.8	2.9	4.4
D. febrifuga	8.3	10.0	25.0	15.0	r	r	s	s	A	A	B	A	0.1	0.1	0.7	0.2	1.0	1.0	2.9	1.0
D. cordata	35.0	30.0	35.0	40.0	s	o	o	o	B	B	B	B	1.3	1.2	1.0	1.6	3.6	4.1	2.8	3.9
E. arvense	8.3	25.0	-	-	r	s	-	-	A	B	-	-	0.1	0.2	-	-	1.0	1.0	-	-
E. debile	23.3	40.0	30.0	-	s	o	o	-	B	B	B	-	0.5	0.7	0.6	-	1.9	1.8	2.1	-
F. scandens	11.7	35.0	-	-	s	o	-	-	A	B	-	-	0.4	1.2	-	-	3.4	3.4	-	-

Oa- overall (700-1930 m asl); L- low (700-1200 m asl); M- mid (1200-1700 m asl); H- high (> 1700 m); F- frequency; O- occurrence or presence on basis of frequency (r- very less/rare i.e. F ≤ 10 %, s- seldom present/less frequent i.e. F = 10-25 %, o- often present/frequent i.e. F = 25-75 %, f = mostly or generally present/abundant i.e. F = ≥ 75 %); RFC- Raunkiaer's frequency class (A i.e. F = 0-20 %; B i.e. F = 20-40 %; C i.e. F= 40-60 %; D i.e. F = 60-80 %; E i.e. F=80-100%); D_y- density; A_d- abundance

Table 18 contd.

Plant species	F				O				RFC				D_y				A_d			
	O_a	L	M	H	O_a	L	M	H	O_a	L	M	H	O_a	L	M	H	O_a	L	M	H
J. prostrata	16.7	15.0	35.0	-	s	s	o	-	A	A	B	-	0.1	0.0	0.1	-	0.4	0.3	0.4	-
L. incurva	20.0	25.0	30.0	-	s	s	o	-	A	B	B	-	0.3	0.5	0.5	-	1.5	1.8	1.6	-
L. grandiflora	15.0	20.0	26.0	-	s	s	o	-	A	A	B	-	0.3	0.3	0.4	-	1.7	1.7	1.7	-
O. corniculata	20.0	60.0	-	-	s	o	-	-	A	C	-	-	0.8	2.3	-	-	3.8	3.8	-	-
O. latifolia	8.3	25.0	-	-	r	s	-	-	A	B	-	-	0.2	0.5	-	-	1.8	1.8	-	-
O. martiana	18.3	55.0	-	-	s	o	-	-	A	C	-	-	0.7	2.0	-	-	3.7	3.7	-	-
P. capitata	6.7	20.0	-	-	r	s	-	-	A	A	-	-	0.2	0.6	-	-	2.8	2.8	-	-
P. dorsiflora	8.3	25.0	-	-	r	s	-	-	A	B	-	-	0.2	0.5	-	-	1.8	1.8	-	-
P. cordifolia	6.7	20.0	-	-	r	s	-	-	A	A	-	-	0.1	0.4	-	-	1.8	1.8	-	-
P. zeylanica	10.0	30.0	-	-	r	o	-	-	A	B	-	-	0.2	0.7	-	-	2.3	2.3	-	-
S. exserta	16.7	20.0	25.0	-	s	s	s	-	A	A	B	-	0.3	0.4	0.6	-	1.9	1.9	2.3	-
S. nodiflora	8.3	25.0	-	-	r	s	-	-	A	B	-	-	0.1	0.2	-	-	0.7	0.7	-	-
T. latifolia	6.7	25.0	-	-	r	s	-	-	A	B	-	-	0.1	0.4	-	-	1.4	1.6	-	-
V. pedata	6.7	20.0	-	-	r	s	-	-	A	A	-	-	0.1	0.3	-	-	1.4	1.4	-	-
S. denticulata	78.3	100.0	70.0	65.0	f	f	o	o	D	E	D	D	3.2	4.3	2.3	3.2	4.1	4.3	3.3	4.9
G. oblongifolia	8.3	25.0	-	-	r	s	-	-	A	B	-	-	0.1	0.3	-	-	1.3	1.3	-	-
S. plicata	11.7	15.0	-	20.0	s	s	-	s	A	A	-	A	0.2	0.2	-	0.3	1.4	1.5	-	1.3
B. platyphylla	16.7	25.0	25.0	25.0	s	s	s	s	A	B	B	B	0.6	1.0	0.3	0.7	3.4	3.8	1.2	2.9
B. suaveolens	3.3	10.0	-	-	r	r	-	-	A	A	-	-	0.1	0.2	-	-	1.5	1.5	-	-
C. caudatus	5.0	15.0	-	-	r	s	-	-	A	A	-	-	0.3	0.9	-	-	6.0	6.0	-	-
D. lancifolia	5.0	15.0	-	-	r	s	-	-	A	A	-	-	0.2	0.5	-	-	3.0	3.0	-	-
F. nubicola	28.3	55.0	30.0	-	o	o	o	-	B	C	B	-	0.6	3.0	0.6	-	2.1	5.4	2.1	-
G. palmata	15.0	5.0	15.0	25.0	s	r	s	s	A	A	A	B	0.3	0.1	0.1	0.6	1.9	2.0	0.5	2.7
H. phyllostachya	16.7	50.0	-	-	s	o	-	-	A	C	-	-	0.4	1.3	-	-	2.6	2.6	-	-
L. camara	20.0	30.0	30.0	-	s	o	o	-	A	B	B	-	0.7	1.1	1.0	-	3.6	3.8	3.4	-
P. thyrsiformis	16.7	25.0	25.0	25.0	s	s	s	s	A	B	B	B	0.4	0.6	0.5	0.6	2.2	2.5	1.8	2.5
V. negundo	11.7	35.0	-	-	s	o	-	-	A	B	-	-	0.1	0.2	-	-	0.6	0.6	-	-
A. odoratissima	21.7	45.0	-	-	s	o	-	-	B	C	-	-	0.4	1.1	-	-	1.7	2.4	-	-

Oa- overall (700-1930 m asl); L- low (700-1200 m asl); M- mid (1200-1700 m asl); H- high (> 1700 m); F- frequency; O- occurrence or presence on basis of frequency (r- very less/rare i.e. F ≤ 10 %, s- seldom present/less frequent i.e. F = 10-25 %, o- often present/frequent i.e. F = 25-75 %, f = mostly or generally present/abundant i.e. F = ≥ 75 %); RFC- Raunkiaer's frequency class (A i.e. F = 0-20 %; B i.e. F = 20-40 %; C i.e. F= 40-60 %; D i.e. F = 60-80 %; E i.e. F=80-100%); D_y- density; A_d- abundance

Table 18 contd.

Plant species	F				O				RFC				D_y				A_d			
	O_a	L	M	H	O_a	L	M	H	O_a	L	M	H	O_a	L	M	H	O_a	L	M	H
A. procera	18.3	55.0	-	-	s	o	-	-	A	C	-	-	0.2	0.7	-	-	1.3	1.3	-	-
A. nepalensis	30.0	25.0	25.0	35.0	o	s	s	o	B	B	B	B	1.0	0.4	0.5	1.2	3.4	1.4	6.2	3.4
C. indica	11.7	40.0	-	-	s	o	-	-	A	B	-	-	0.2	0.6	-	-	1.7	1.5	-	-
C. tetrandra	10.0	30.0	-	-	r	o	-	-	A	B	-	-	0.1	0.4	-	-	1.2	1.2	-	-
Citrus spp	10.0	30.0	-	-	r	o	-	-	A	B	-	-	0.2	0.5	-	-	1.5	1.5	-	-
C. japonica	40.0	25.0	60.0	35.0	o	s	o	o	B	B	C	B	1.2	0.3	2.1	1.1	2.9	1.2	3.5	3.1
C. cashmeriana	31.7	30.0	15.0	50.0	o	o	s	o	B	B	A	C	0.8	0.6	0.4	1.5	2.5	2.0	2.3	2.9
E. variegate	23.3	40.0	30.0	-	s	o	o	-	B	B	B	-	0.3	0.5	0.5	-	1.4	1.3	1.7	-
F. auriculata	23.3	70.0	-	-	s	o	-	-	B	D	-	-	0.6	1.9	-	-	2.7	2.7	-	-
F. lacor	16.7	50.0	-	-	s	o	-	-	A	C	-	-	0.4	1.2	-	-	2.3	2.3	-	-
F. semicordata	36.7	70.0	40.0	-	o	o	o	-	B	D	B	-	0.7	1.1	0.9	-	1.8	1.6	2.1	-
F. colorata	21.7	35.0	30.0	-	s	o	o	-	B	B	B	-	0.6	1.2	0.6	-	2.7	3.4	1.8	-
J. indica	20.0	60.0	-	-	s	o	-	-	A	C	-	-	0.3	1.0	-	-	1.6	1.6	-	-
L. monopetala	13.3	40.0	-	-	s	o	-	-	A	B	-	-	0.4	1.3	-	-	3.3	3.3	-	-
M. denticulata	26.7	45.0	35.0	-	o	o	o	-	B	C	B	-	0.5	0.7	0.8	-	1.8	1.4	2.1	-
O. indicum	18.3	65.0	-	-	s	o	-	-	A	D	-	-	0.2	0.7	-	-	1.3	1.1	-	-
O. paniculata	8.3	25.0	-	-	r	s	-	-	A	B	-	-	0.1	0.4	-	-	1.4	1.4	-	-
S. wallichii	45.0	60.0	35.0	40.0	o	o	o	o	C	C	B	B	1.3	2.1	0.1	0.8	2.8	3.4	2.7	1.9
T. myriocarpa	30.0	50.0	25.0	15.0	o	o	s	s	B	C	B	A	0.6	1.1	0.5	0.4	2.1	2.1	2.0	2.3
T. ciliata	25.0	50.0	25.0	-	s	o	s	-	B	C	B	-	0.5	1.1	0.4	-	1.9	2.1	1.4	
Z. carinata	20.0	-	35.0	25.0	s	-	o	s	A	-	B	B	0.5	-	1.2	0.3	2.5	-	3.5	1.2
A. accedens	8.3	-	25.0	-	r	-	s	-	A	-	B	-	0.1	-	0.3	-	1.1	-	1.1	
B. mitis	5.0	-	15.0	-	r	-	s	-	A	-	A	-	0.3	-	0.8	-	5.3	-	5.3	
C. asiatica	23.3	-	30.0	40.0	s	-	o	o	B	-	B	B	1.0	-	1.0	1.9	4.2	-	3.3	4.8
C. oppositifolia	10.0	-	30.0	-	r	-	o	-	A	-	B	-	0.5	-	1.6	-	5.3	-	5.3	-
B. javanica	13.3	-	40.0	-	s	-	o	-	A	-	B	-	0.1	-	0.4	-	1.0	-	1.0	-
E. populnea	6.7	-	20.0	-	r	-	s	-	A	-	A	-	0.1	-	0.2	-	1.0	-	1.0	-
G. odorata	8.3	-	25.0	-	r	-	s	-	A	-	B	-	0.2	-	0.5	-	1.8	-	1.8	-
H. nepalensis	6.7	-	20.0	-	r	-	s	-	A	-	A	-	0.1	-	0.3	-	1.3	-	1.3	-

Oa- overall (700-1930 m asl); L- low (700-1200 m asl); M- mid (1200-1700 m asl); H- high (> 1700 m); F- frequency; O- occurrence or presence on basis of frequency (r- very less/rare i.e. F ≤ 10 %, s- seldom present/less frequent i.e. F = 10-25 %, o- often present/frequent i.e. F = 25-75 %, f = mostly or generally present/abundant i.e. F = ≥ 75 %); RFC- Raunkiaer's frequency class (A i.e. F = 0-20 %; B i.e. F = 20-40 %; C i.e. F= 40-60 %; D i.e. F = 60-80 %; E i.e. F=80-100%); D_y- density; A_d- abundance

Table 18 contd.

Plant species	**F**				**O**				**RFC**				**D_y**				**A_d**			
	O_a	**L**	**M**	**H**	**O_a**	**L**	**M**	**H**	**O_a**	**L**	**M**	**H**	**O_a**	**L**	**M**	**H**	**O_a**	**L**	**M**	**H**
Ficus spp.	11.7	-	35.0	-	s	-	o	-	A	-	B	-	0.1	-	0.4	-	1.1	-	1.1	-
L. canum	11.7	-	30.0	-	s	-	o	-	A	-	B	-	0.2	-	0.5	-	1.4	-	3.4	-
M. semiserrata	8.3	-	25.0	-	r	-	s	-	A	-	B	-	0.3	-	0.8	-	3.3	-	3.3	-
O. thomsonii	13.3	-	40.0	-	s	-	o	-	A	-	B	-	0.2	-	0.7	-	1.7	-	1.7	-
P. nummulariifolia	6.7	-	20.0	-	r	-	s	-	A	-	A	-	0.3	-	0.9	-	4.4	-	4.4	-
P. asiatica	15.0	-	25.0	20.0	s	-	s	s	A	-	B	A	0.2	-	0.4	0.2	1.2	-	1.5	0.9
P. auriculata	6.7	-	20.0	-	r	-	s	-	A	-	A	-	0.1	-	0.4	-	2.1	-	2.1	-
P. andersonii	6.7	-	20.0	-	r	-	s	-	A	-	A	-	0.2	-	0.7	-	3.3	-	3.3	-
P. rude	5.0	-	15.0	-	r	-	s	-	A	-	A	-	0.1	-	0.4	-	2.7	-	2.7	-
P. cerasoides	6.7	-	20.0	-	r	-	s	-	A	-	A	-	0.1	-	0.4	-	1.8	-	1.8	-
R. cordifolia	3.3	-	10.0	-	r	-	r	-	A	-	A	-	0.0	-	0.1	-	1.5	-	1.5	-
R. diffusus	10.0	-	30.0	-	r	-	o	-	A	-	B	-	0.3	-	0.8	-	2.6	-	2.6	-
Z. piperitum	5.0	-	15.0	-	r	-	s	-	A	-	A	-	0.1	-	0.2	-	1.2	-	1.2	-
M. tetracoccus	8.3	-	25.0	-	r	-	s	-	A	-	B	-	0.1	-	0.3	-	1.2	-	1.2	-
Rubus spp	5.0	-	15.0	-	r	-	s	-	A	-	A	-	0.0	-	0.1	-	0.7	-	0.7	-
C. sylvatica	11.7	-	-	35.0	s	-	-	o	A	-	-	B	0.5	-	-	1.4	3.9	-	-	3.9
C. suffruticosa	5.0	-	-	15.0	r	-	-	s	A	-	-	A	0.1	-	-	0.2	1.1	-	-	1.1
E. attenuatus	5.0	-	-	15.0	r	-	-	s	A	-	-	A	0.1	-	-	0.8	2.7	-	-	5.3
G. diversiflora	5.0	-	-	15.0	r	-	-	s	A	-	-	A	0.1	-	-	0.3	1.8	-	-	1.8
S. densiflorus	8.3	-	-	25.0	r	-	-	s	A	-	-	B	0.3	-	-	0.9	3.4	-	-	3.4
S. ovalifolia	10.0	-	-	30.0	r	-	-	o	A	-	-	B	0.0	-	-	0.1	1.0	-	-	1.0
A. triplinervis	13.3	-	-	40.0	s	-	-	o	A	-	-	B	0.6	-	-	1.7	4.3	-	-	4.3
A. macrocarpa	6.7	-	-	20.0	r	-	-	s	A	-	-	A	0.1	-	-	0.2	1.0	-	-	1.0
B. palmata	13.3	-	-	40.0	s	-	-	o	A	-	-	B	0.1	-	-	0.4	1.0	-	-	1.0
B. tessaricarpa	11.7	-	-	35.0	s	-	-	o	A	-	-	B	0.1	-	-	0.4	1.0	-	-	1.0
G. cusimbua	5.0	-	-	15.0	r	-	-	s	A	-	-	A	0.1	-	-	0.2	2.5	-	-	1.0
H. javanica	6.7	-	-	20.0	r	-	-	s	A	-	-	A	0.3	-	-	0.8	3.9	-	-	3.9
L. bulbifera	3.3	-	-	10.0	r	-	-	r	A	-	-	A	0.1	-	-	0.3	3.0	-	-	3.0
L. glutinosa	1.7	-	-	5.0	r	-	-	r	A	-	-	A	0.0	-	-	0.1	1.0	-	-	1.0

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Table 18 contd.

Plant species	F				O				RFC				D_y				A_d			
	O_a	L	M	H	Or_a	L	M	H	O_a	L	M	H	O_a	L	M	H	O_a	L	M	H
L. flexuosum	3.3	-	-	10.0	r	-	-	r	A	-	-	A	0.0	-	-	0.0	0.8	-	-	0.8
M. edulis	8.3	-	-	25.0	r	-	-	s	A	-	-	B	0.1	-	-	0.4	1.4	-	-	1.4
M. doltsopa	3.3	-	-	10.0	r	-	-	r	A	-	-	A	0.1	-	-	0.2	1.5	-	-	1.5
M. grandiflora	5.0	-	-	15.0	r	-	-	s	A	-	-	A	0.1	-	-	0.2	1.0	-	-	1.0
M. lanuginosa	13.3	-	-	40.0	s	-	-	o	A	-	-	B	0.2	-	-	0.5	1.1	-	-	1.1
M. malabathricum	3.3	-	-	10.0	r	-	-	r	A	-	-	A	0.1	-	-	0.2	2.0	-	-	2.0
P. griffithii	6.7	-	-	30.0	r	-	-	o	A	-	-	B	0.1	-	-	0.1	1.3	-	-	0.4
P. involucrate	3.3	-	-	10.0	r	-	-	r	A	-	-	A	0.1	-	-	0.4	3.8	-	-	3.8
P. melastomoides	6.7	-	-	20.0	r	-	-	s	A	-	-	A	0.3	-	-	0.9	4.6	-	-	4.6
P. wallichiana	11.7	-	-	35.0	s	-	-	o	A	-	-	B	0.2	-	-	0.6	1.6	-	-	1.6
S. lateriflora	5.0	-	-	15.0	r	-	-	s	A	-	-	A	0.1	-	-	0.2	1.1	-	-	1.13
P. major	5.0	-	-	15.0	r	-	-	s	A	-	-	A	0.0	-	-	0.1	0.5	-	-	0.5
R. griffithianum	11.7	-	-	35.0	s	-	-	o	A	-	-	B	0.1	-	-	0.4	1.0	-	-	1.0
R. holosericeus	5.0	-	-	15.0	r	-	-	s	A	-	-	A	0.1	-	-	0.4	2.7	-	-	2.7
T. serrulatum	8.3	-	-	25.0	r	-	-	s	A	-	-	B	0.1	-	-	0.2	2.4	-	-	2.4
T. plicata	3.3	-	-	10.0	r	-	-	r	A	-	-	A	0.0	-	-	0.1	1.0	-	-	1

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The other most frequent species documented were *Selaginella denticulata* (78.3), *Ageratina adenophora* (53.3), *Schima wallichii* (45.0) and *Cryptomeria japonica* (40.0). *Girardinia palmata* (5.0) was the least frequent specieswhile; *Amomum subulatum* and *Selaginella denticulata* (100.0 each) were the most frequent species at low-altitude. At mid-altitude, the most frequent species was *Amomum subulatum* (100.0) and the least frequent species was *Rubia cordifolia* (10.0). The least frequent species at high-altitude class was *Litsea glitinosa* (5.0 each) while; *Amomum subulutum* was the most frequent species with frequency of 100.0.

The number of times a species was documented from the total sampled plots of the traditional large cardamom farming systems (N = 60 and n = 20 at each altitude class) is frequency or occupancy status of that particular species and based on the frequency the plant species documented were classified as very less/rare (documented from ≤ 10 % of the sampled plots), seldom present/less frequent (10-25 %), often present/frequent (25-75 %) and mostly or generally present/abundant (≥ 75 %; (Johnson, 1983; Gbedomon *et al*., 2017; Sarkar, 2020). Overall in the traditional large cardamom based agroforestry systems 49.23 % of the documented 130 species were rare, 36.92 % were seldom present or less frequent, 12.30 % were often present or frequentand 1.54 % was mostly or generally present/abundant (table 18). Apart from *Amomum subulatum* (100.0 %), *Selaginella denticulate* (78.3 %) was the only most abundant species with frequency of 78.3 %. The frequent species were *Ageratina adenophora* (53.3 %), *Schima wallichii* (45.0%), *Cryptomeria japonica* (40.0 %), *Nephrolepis cordifolia* (36.7 %), *Ageratum conyzoides* (36.7 %), *Brachiaria reptans* (36.7 %), *Ficus semicordata* (36.7 %), *Cupressus cashmeriana* (31.7 %), *Alnus nepalensis* (30.0), *Terminalia myriocarpa* (30.0 %) and six other species. Less frequent species documented were *Toona ciliata* (25.0 %), *Piper boehmeriaefolium* (23. 3%), *Equisetum debile* (23.3 %), *Erythrina variegate* (23.3 %), *Ficus auriculata* (23.3 %), *Centella asiatica* (23.3 %) and 23 others. Rare species listed were *Cayratiagenticulate* (10.0 %), *Pouzolzia zeylanica* (10.0 %), *Citrus spp.* (10.0 %), *Celtis tetrandra* (10.0 %), *Colebrookea oppositifolia* (10.0 %), *Rubus diffusus* (10.0 %), *Smilax ovalifolia* (10.0 %) and 57 others.

Similarly, at low-altitude class 6.57 %, 34.22 %, 55.26 %and 3.95 % of the 76 documented species were rare, less frequent, and frequent and mostly frequent, respectively while; 1.67 %, 50.0 %, 46.6 %& 1.67 % of the documented species (60 species) at mid-altitude class and 13.47 %, 46.15 %, 38.46 % & 1.92 % of the documented species (52) at high-altitude class were rare, less frequent and frequent, respectively. Apart from *Amomum subulatum* (100.0 %) which was most abundant at all altitude classes, at low-altitude class only the other most frequent species listed was *Selaginella denticulata* (100.0 %) and *Ageratina adenophora* (95.0 %). The frequnt species documented at low-altitude class was *Ficus semicordata* (70 %), *Ficus auriculata* (70.0 %), *Oroxylum indicum* (65.0 %) and 39 others. *Selaginella denticulata* (70.0 %), *Cryptomeria japonica* (60.0 %), *Nephrolepis cordifolia* (55.0 %), *Adiantum capillus* (55.0 %) and 28 others were frequent species documented at the mid-altitude class. The documented frequent species at high-altitude class were *Diplazium esculentum* (65.0 %), *Selaginella denticulata* (65.0 %), *Cupressus cashmeriana* (50.0 %) and 17 others. The less frequent species listed from the low-altitude class were *Solena amplexicaulis* (25.0 %), *Piper peeploides* (25.0 %), *Equisetum arvense* (25.0 %), *Lepidagathis incurve* (25.0 %), *Oxalis latifolia* (25.0 %), *Phaulopsisdorsiflora* (25.0 %), *Synedrella nudiflora* (25.0 %), *Thysanolaena latifolia* (25.0 %), *Goodyera oblongifolia* (25.0 %), *Boehmeria platyphylla* (25.0 %), *Phlogacanthus thyrsiformis* (25.0 %), *Alnus nepalensis* (25.0 %), *Cryptomeria japonica* (25.0 %), *Ostodes paniculata* (25.0 %) and 11 others. The species less frequently present at mid-altitude class were *Diplazium esculentum* (25.0 %), *Dichroa febrifuga* (25.0 %), *Strobilanthes exserta* (25.0 %), *Boehmeria platyphylla* (25.0 %), *Alnus nepalensis* (25.0 %), *Terminaliamyriocarpa* (25.0 %), *Toona ciliata* (25.0 %), *Acalypha accedens* (25.0 %), *Gynocardia odorata* (25.0 %), *Myrsine semiserrata* (25.0 %), *Plantago asiatica* (25.0 %), *Mallotus tetracoccus* (25.0 %) and 18 others. *Boehmeria platyphylla* (25.0 %), *Girardinia palmata* (25.0 %), *Phlogacanthus thyrsiformis* (25.0 %), *Zephyranthes carinata* (25.0 %), *Senecio densiflorus* (25.0 %), *Machilus edulis* (25.0 %) and 18 others were the less frequently species listed at hgh-altitude class. The species found rarely present at low-altitude class were *Diplazium esculentum* (10.0 %), *Dichroa febrifuga* (10.0 %), *Alsophila dregei* (10 %), *Brugmansia suaveolens* (10.0 %) and *Girardinia palmata* (5.0 %). *Rubia cordifolia* with frequency of 10 % was the only rarely present species at mid-altitude class. At high-altitude class rarely, present species were *Laportea bulbifera* (10.0 %), *Lygodium flexuosum* (10.0 %), *Magnolia doltsopa* (10.0 %), *Melastoma malabathricum* (10.0 %), *Pilea involucrate* (10.0 %), *Thuja plicata* (10.0 %) and *Litsea glutinosa* (5.0 %).

The species documented with higher occupancy status i.e. frequency exhibited wider spatial distribution at multiple altitudinal levels were widely representing biodiversity across a broad landscape (Gbedomon *et al*., 2017; Sarkar, 2020). Overall, these systems across the altitudinal gradient with varying frequencies but multi-strata vegetation with herbs, shrubs and trees were contributing heterogeneity wtith temporal and spatial dynamism. Moreover, these Darjeeling Himalayan forest based below canopy large cardamom farming systems being close to natural forest ecosystems due to minimal disturbance can be considered as efficient and viable systems of biodiversity conservation intrinsically similar to its traditional homegardens (Sarkar, 2020) and traditional homegardens elsewhere (Fernandes and Nair, 1986; Abdoellah *et al*., 1985; Coomes and Ban, 2004; Abebe *et al*., 2006, 2013; Bernholt *et al*., 2009; Cruz-Garcia and Struik, 2015; Gbedomon *et al*., 2015, 2017). The species richness of 130 documented from these large cardamoms based traditional agroforestry farming systems of Darjeeling Himalayas can be sufficient enough to represent regional species richness (van der Wal and Bongers, 2013) and thus are important to conserve regional plant diversity *in situ* (Watson and Eyzaguirre, 2002; Trinh *et al*., 2003; Kumar and Nair, 2004; Montagnini, 2006; Galluzzi *et al*., 2010; Sarkar, 2020).

The distribution of plant species in the large cardamom based traditional agroforestry systems was evaluated using Log-normal, Mandelbrot, Zipf, Null and Preemption species distribution models (SAM). The Preemption SDM was found to give best fit to the data with highest Akaike Information Criterion (AIC) score (fig. 31; annexure II).

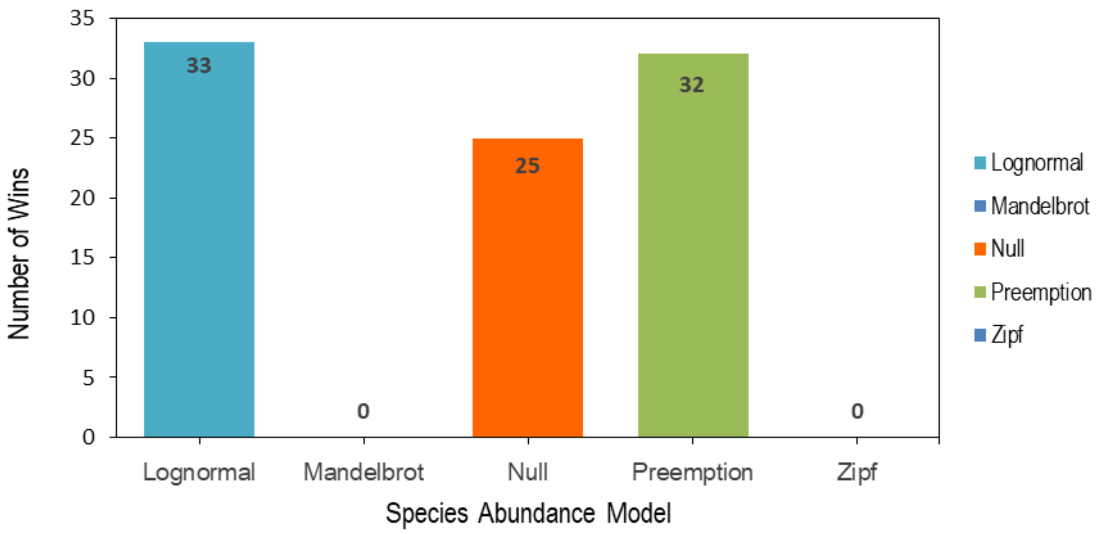

Fig. 31. Number of cases model provided best fit to plant species abundance data

Similarly, distribution of species using these species distribution models was also evaluated for the homegardens of Darjeeling Himalayas across the altitudinal gradient (Sarkar, 2020).

Among the models SAD was unable to distinguish the species with any degree of certainty due to limited information (Volkov *et al*., 2005). Therefore, it was recommended that the models should be evaluated for their their ability to simultaneously explain multiple macro-ecological data in order to obtain sufficient information on ecological processes (McGill, 2003; McGill *et al*., 2006; Newman *et al*., 2014; Xiao *et al*., 2015). The conservation status of the Darjeeling large cardamom based traditional agroforestry can be satisfactorily recognised only when its ecosystem services are fully realised in addition to factors affecting its spatial distribution, evolution and temporal resiliency understoodand regularly monitored for any evolutionary changes there in (Galluzzi *et al*., 2010; Agbogidi and Adolor, 2013). These traditional large cardamom based agroforestry systems of Darjeeling Himalayas are also diverse plant species with variable population size across the altitudinal gradient over reasonably wider landscape like many other traditional agroforestry systems (Brown and Marshall, 1995; Hodgkin, 2001; Abebe *et al*., 2013; Gebrewahid and Meressa, 2020) including its home gardens also (Sarkar, 2020).

The Darjeeling Himalayan large cardamom based traditional agroforestry systems irrespective of altitudinal classes were grouped into only three frequency classes in order A > B > C > D = E with 79.23 %, 17.69 %, 1.54 %, 0.77 % and 0.77 % of the total species, respectively (table 18) instead of five classes in the order A > B > C > D < E distributed as 0-20, 20-40, 40-60, 60-80 and 80-100 % with normal frequency distribution of 53 %, 14 %, 9 %, 8 % and 16 % of species in the respective frequency classes defined by Raunkiaer's law of frequency (Raunkiaer, 1934). Distribution of the species at low-altitude class was A (22.37 %) < B (47.37 %) > C (22.37 %) > D (3.94 %) = E (3.94).The distribution at mid-altitude class was A (26.67 %) < B (60.0 %) > C (1.92 %) > D (1.67 %) = E (1.67 %)and at high-altitude class it was A (44.23 %) < B (48.08 %) > C (1.92 %) < D (3.85 %) > E (1.92). The law doesn'thold good for the present studied traditional farming systems also as the documented species were not normally distributed to the classes defined by it. This was because of heterogeneity of the systems as indicated from the higher number of species with poor dispersion of frequencies similar to typical species-abundance distributions in tropical forests (Odum, 1971, 1983). The traditional below canopy large cardamom cultivation based on leased out forest lands with ensured minimal disturbances retains multi-storey canopy structure and heterogeneity of its original forest, thus conserving plant biodiversity to maximum possible extent as indicated by the analysis of Raunkiaer's law of frequency.

The overall numerical strength or density estimated for the documented species in Darjeeling Himalayan large cardamom based traditional agroforestry systems was in the range of 0.01-3.23quadrate^{-1} (table18). The densest species found was *Selegnella denticulata* while, *Lygodiumflexuosum* and *Alsophiladregei* were sparse. Other dense species were *Amomum subulatum* (1.47), *Diplaziumesculentum* (1.32), *Drymaria cordata* (1.27), *Schimawallichii* (1.25), *Brachiaria raptans* (1.25), *Cryptomeriajaponica* (1.17), *Alnusnepalensis* (1.03) and *Ageratinaadenophora* (1.0). Tree, shrub, herb, climber, fern and orchid density was estimated in the range of 0.017-1.25, 0.033-0.71, 0.043-1.47, 0.05-0.207, 0.01-3.23 and 0.083-0.160, respectively. The plant density estimated for low-, mid- and high-altitude class was 0.03-4.26 (*Alsophiladregei-Selegnella denticulata*), 0.06-2.30 (*Rubia cordifoliai- Selegnella denticulata*) and 0.03-3.16 (*Lygodiumflexuosum- Selegnella denticulata*), respectively while, density of *Amomum subulatum* at these classes were 1.47, 1.50 and 1.41, respectively

Abundance of the plant species in the Darjeeling Himalayan large cardamom based traditional agroforestry systems are given in table 18. Overall, abundance of species was in the range of 0.30-7.0. The least abundant species was *Alsophila dregei* and the most abundant species found was *Persicaria chinensis* while, for large cardamom the value was 1.47. Other abundant species found were *Croton caudatus* (6.0), *Brassaiopsismitis* (5.33), *Colebrookea oppositifolia*(5.25), *Pilea melastomoides* (4.63), *Pilea nummulariifolia* (4.35), *Anaphalis triplinervis* (4.28), *Adintum capillus* (4.22), *Centella asiatica* (4.16) and *Selegnella denticulata* (4.13).Overall, the most abundant tree species was *Brassaiopsis mitis* (5.33) while, *Bischofia javanica*, *Exbucklandia populnea*, *Thuja plicata*, *Magnolia grandiflora*, *Litsea glutinosa* and *Rhododendron griffithianum* were least abundant species (1.0 each). The other abundant species were *Alnus nepalensis* (3.44), *Litsea monopetela* (3.25), *Cryptomeria japonica* (2.92), *Schima wallichii* (2.78), *Firmiana colorata* (2.69) and *Cupressus cashmeriana* (2.53).

The overall abundance of large cardamom documented 1.47 while, at low-, mid- and high-altitude class was 1.47, 1.52 and 1.41, respectively. The abundance of plant species at low-altitude class was in the range of 0.27-7.0 (*Justicia prostrata-Persicaria chinensis*). The most abundant tree species at thesealtitude classes were *Firmiana* *colorata* (3.43), *Schima wallichii* (3.42) and *Litsea momonopetala* (3.25) and least abubdant were *Oroxylum indicum* (1.08), *Celtis tetrandra* (1.17), *Cryptomeria japonica* (1.20), *Erythrina variegata* (1.25) and *Albiziz procera* (1.27). The most abundant shrub was *Croton caudatus* (6.0) and the least abundant was *Vitex negundo* (0.57). *Drymaria cordata* (4.13) was the most abundant and *Justicia prostrata* (0.27) was least abundant herb. The most and least abundant ferns were *Diplazium esculentum* (5.40) and *Alsophila dregei* (0.30), respectively. Among the climbers, the most abundant was *Persicaria chinensis* (7.0) and least abundant was *Mikania micrantha* (0.69). The most and the least abundant orchid found at the low-altitude class was *Goodyera oblongifolia* (1.28) and *Spathoglottius plicata* (1.53).

At mid-altitude the abundance of species was 0.40-6.20 (*Justicia prostrata*-*Alnus nepalensis*). The most abundant tree species at this altitude class was *Alnu snepalensis* followed by *Brassaiopsis mitis* (5.33), *Cryptomeria japonica* (3.50) and the least abundtant was *Bischofia javanica* and *Exbucklandia populnea* (1.0 each) while, the most & the least abundant shrub, herb, climber and fern was *Colebrookea oppositifolia* (5.25) & *Girardinia palmata* (0.50), *Pilea nummulariifolia* (4.35) & *Justicia prostrata*, *Persicaria chinensis* (3.75) & *Rubia cordifolia* (1.50) and *Adiantum capillus* (3.65) & *Matteuccia struthiopteris* (1.13).The most and the least abundant plant species documented at the high-altitude class was *Euonymus attenuates* (5.33) and *Peliosanthes griffithii* (0.40), respectively. *Alnus nepalensis* (3.43) was the most abundant tree species found at the high-altitude class followed by *Cryptomeria japonica* (3.14), *Cupressus cashmeriana* (2.90) and least abundant were *Litsea glutinosa*, *Magnolia grandiflora*, *Thuja plicata* and *Rhododendron griffithianum* (1.0 each). *Euonymus attenuates* was the most abundant shrub found at the high-altidude class while, the least abundant shrub found at this class was *Ardisia macrocarpa* and *Gynura cusimbua* (1.0 each). *Brachiaria reptans* (4.43) & *Plantago major* (0.53), *Selaginella denticulata* (4.86) & *Diplazium esculentum* (4.09), *Piperboehmeriae folium* (2.75) & *Smilax ovalifolia* (1.0) and *Spathoglottis plicata* (1.25) & *Peliosanthes griffithii* (0.40) were the most and least herb, fern, climber and orchid species at high-altitude class.

The relative frequency (RF), relative density (RD), relative abundance (RA)and importance value index (IVI) estimated for the Darjeeling Himalayan traditional large cardamom based agroforestry systems is given in table 19. The RF, RD and RA of the systems irrespective of the altitude were estimated in the range of 0.03-7.80, 0.01-10.52 and 0.03-0.81, respectively.

Table 19. Relative frequency, relative density, relative abundance and importance value index of plant species in large cardamom based traditional agroforestry systems

Plant species	RF				RD				RA				IVI			
	O_a	L	M	H	O_a	L	M	H	O_a	L	M	H	O_a	L	M	H
C. geniculate	0.31	0.69	-	-	0.17	0.37	-	-	0.15	0.24	-	-	0.64	1.30	-	-
M. micrantha	0.42	0.92	-	-	0.12	0.26	-	-	0.08	0.12	-	-	0.62	1.30	-	-
P. chinesis	0.21	0.46	0.65	-	0.61	1.30	1.12	-	0.81	1.27	0.09	-	1.63	3.03	1.86	-
P. attenuatum	0.21	0.46	-	-	0.18	0.39	-	-	0.25	0.38	-	-	0.64	1.24	-	-
P. boehmeriaefolium	0.73	0.69	0.65	0.83	0.67	0.46	0.75	0.86	0.26	0.30	0.06	0.22	1.66	1.45	1.46	1.91
P. peepuloides	0.26	0.57	-	-	0.29	0.63	-	-	0.31	0.49	-	-	0.87	1.69	-	-
S. amplexicaulis	0.26	0.57	-	-	0.13	0.28	-	-	0.14	0.22	-	-	0.53	1.07	-	-
S. japonica	0.42	0.92	-	-	0.51	1.09	-	-	0.34	0.53	-	-	1.27	2.54	-	-
A. capillus	1.30	2.86	4.50	-	2.29	4.90	7.49	-	0.49	0.76	0.09	-	4.08	8.53	12.08	-
A. drege	0.26	0.57	-	-	0.03	0.07	-	-	0.03	0.05	-	-	0.33	0.70	-	-
D. esculentum	2.60	0.57	2.05	6.72	4.30	1.25	2.83	10.38	0.46	0.98	0.07	1.78	7.36	2.80	4.95	18.89
L. japonicum	2.21	2.29	3.68	-	2.18	2.14	4.06	-	0.27	0.42	0.06	-	4.67	4.84	7.80	-
M. struthiopteris	2.21	2.29	3.68	-	1.12	1.21	1.90	-	0.14	0.24	0.03	-	3.47	3.73	5.61	-
N. cordifolia	2.86	3.15	4.50	-	3.04	3.11	5.44	-	0.30	0.44	0.06	-	6.19	6.70	10.00	-
A. uliginosa	1.04	2.29	-	-	1.33	2.86	-	-	0.36	0.56	-	-	2.73	5.70	-	-
A. adenophora	4.16	5.44	2.86	3.10	2.70	4.32	1.12	1.29	0.18	0.35	0.02	0.82	7.04	10.11	4.00	5.21
A. conyzoides	2.86	3.15	1.64	4.14	3.25	3.13	0.67	5.74	0.32	0.44	0.02	1.10	6.43	6.73	2.33	10.97
A. houstonianum	2.60	2.00	3.68	2.07	2.28	1.88	2.01	2.93	0.24	0.42	0.03	0.55	5.12	4.30	5.72	5.54
A. subulatum	**7.80**	**5.73**	**8.18**	**10.34**	**4.77**	**3.41**	**5.66**	**5.50**	**0.17**	**0.27**	**0.04**	**2.75**	**12.74**	**9.41**	**13.88**	**18.59**
A. vulgaris	1.56	2.29	1.64	-	0.89	1.62	0.45	-	0.16	0.32	0.01	-	2.61	4.23	2.10	-
B. pilosa	1.56	3.44	-	-	2.43	5.20	-	-	0.43	0.68	-	-	4.42	9.31	-	-
B. cylindrica	0.39	0.86	-	-	0.14	0.30	-	-	0.10	0.16	-	-	0.63	1.32	-	-
B. reptans	2.86	2.86	1.64	4.14	4.06	3.25	2.12	6.91	0.39	0.51	0.07	1.10	7.31	6.62	3.83	12.14
D. febrifuga	0.65	0.57	2.05	1.55	0.27	0.23	2.68	0.59	0.12	0.18	0.07	0.41	1.04	0.99	4.80	2.55
D. cordata	2.73	1.72	2.86	4.14	4.12	2.88	3.69	6.13	0.42	0.75	0.07	1.10	7.27	5.35	6.62	11.36
E. arvense	0.65	1.43	-	-	0.26	0.56	-	-	0.11	0.17	-	-	1.02	2.16	-	-
E. debile	1.82	2.29	2.45	-	1.48	1.67	2.38	-	0.23	0.33	0.05	-	3.52	4.29	4.89	-
F. scandens	0.91	2.00	-	-	1.30	2.79	-	-	0.40	0.62	-	-	2.61	5.41	-	-

RF- Relative frequency; RD- Relative density; RA- relative abundance; IVI- Importance value index; Oa- overall (700-1930 m asl); L- low (700-1200 m asl); M- mid (1200-1700 m asl); H- high (> 1700 m)

Table 19 contd.

Plant species	RF				RD				RA				IVI			
	O_a	L	M	H	O_a	L	M	H	O_a	L	M	H	O_a	L	M	H
J. prostrate	1.30	0.86	2.86	-	0.20	0.09	0.52	-	0.04	0.05	0.01	-	1.54	1.00	3.40	-
L. incurva	1.56	1.43	2.45	-	1.00	1.04	1.75	-	0.18	0.33	0.04	-	2.74	2.80	4.24	-
L. grandiflora	1.17	1.15	2.05	-	0.81	0.77	1.56	-	0.19	0.30	0.04	-	2.18	2.21	3.65	-
O. corniculata	1.56	3.44	-	-	2.44	5.22	-	-	0.43	0.68	-	-	4.44	9.34	-	-
O. latifolia	0.65	1.43	-	-	0.50	1.07	-	-	0.21	0.33	-	-	1.36	2.83	-	-
O. martiana	1.43	3.15	-	-	2.21	4.74	-	-	0.43	0.67	-	-	4.07	8.56	-	-
P. capitata	0.52	1.15	-	-	0.61	1.30	-	-	0.32	0.51	-	-	1.45	2.95	-	-
P. dorsiflora	0.65	1.43	-	-	0.49	1.04	-	-	0.21	0.33	-	-	1.35	2.80	-	-
P. cordifolia	0.52	1.15	-	-	0.38	0.81	-	-	0.20	0.32	-	-	1.10	2.27	-	-
P. zeylanica	0.78	1.72	-	-	0.76	1.62	-	-	0.27	0.42	-	-	1.81	3.77	-	-
S. exserta	1.30	1.15	2.05	-	1.05	0.88	2.12	-	0.23	0.34	0.05	-	2.58	2.37	4.22	-
S. nodiflora	0.65	1.43	-	-	0.20	0.42	-	-	0.08	0.13	-	-	0.93	1.98	-	-
T. latifolia	0.52	1.43	-	-	0.30	0.93	-	-	0.16	0.29	-	-	0.99	2.65	-	-
V. pedata	0.52	1.15	-	-	0.30	0.65	-	-	0.16	0.25	-	-	0.99	2.05	-	-
S. denticulata	6.11	5.73	5.73	6.72	10.52	9.89	8.49	12.33	0.48	0.77	0.08	1.78	17.1	16.39	14.3	20.8
G. oblongifolia	0.65	1.43	-		0.35	0.74	-	-	0.15	0.23	-		1.15	2.41	-	-
S. plicata	0.91	0.86	-	2.07	0.52	0.53	-	0.98	0.16	0.28	-	0.55	1.59	1.67	-	3.59
B. platyphylla	0.52	0.57	0.82	1.03	0.73	0.88	0.45	1.13	0.39	0.69	0.03	0.27	1.64	2.14	1.29	2.44
B. suaveolens	0.10	0.23	-	-	0.07	0.14	-	-	0.17	0.27	-	-	0.34	0.64	-	-
C. caudatus	0.16	0.34	-	-	0.39	0.84	-	-	0.70	1.09	-	-	1.24	2.27	-	-
D. lancifolia	0.16	0.34	-	-	0.20	0.42	-	-	0.35	0.54	-	-	0.70	1.30	-	-
F. nubicola	2.21	1.26	2.45	-	1.97	2.76	2.35	-	0.25	0.98	0.05	-	4.43	5.00	4.85	-
G. palmata	0.47	0.11	0.49	1.03	0.37	0.09	0.11	1.05	0.22	0.36	0.01	0.27	1.06	0.57	0.61	2.36
H. phyllostachya	0.52	1.15	-	-	0.56	1.21	-	-	0.30	0.47	-	-	1.39	2.82	-	-
L. camara	0.62	0.69	0.98	-	0.93	1.04	1.53	-	0.42	0.68	0.08	-	1.97	2.41	2.59	-

RF- Relative frequency; RD- Relative density; RA- relative abundance; IVI- Importance value index; Oa- overall (700-1930 m asl); L- low (700-1200 m asl); M- mid (1200-1700 m asl); H- high (> 1700 m)

Table 19 contd.

Plant species	RF				RD				RA				IVI			
	O_a	L	M	H	O_a	L	M	H	O_a	L	M	H	O_a	L	M	H
P. thyrsiformis	0.52	0.57	0.82	1.03	0.47	0.58	0.67	0.98	0.25	0.45	0.04	0.27	1.24	1.61	1.53	2.28
V. negundo	0.36	0.80	-	-	0.09	0.19	-	-	0.07	0.10	-	-	0.52	1.09	-	-
A. odoratissima	0.34	0.52	-	-	0.24	0.51	-	-	0.20	0.44	-	-	0.77	1.47	-	-
A. procera	0.29	0.63	-	-	0.15	0.32	-	-	0.15	0.23	-	-	0.59	1.19	-	-
A. nepalensis	0.47	0.29	0.41	0.72	0.67	0.16	1.15	0.94	0.40	0.25	0.15	0.19	1.54	0.70	1.71	1.85
C. indica	0.18	0.46	-	-	0.13	0.28	-	-	0.20	0.27	-	-	0.51	1.01	-	-
C. tetrandra	0.16	0.34	-	-	0.08	0.16	-	-	0.14	0.21	-	-	0.37	0.72	-	-
Citrus spp	0.16	0.34	-	-	0.10	0.21	-	-	0.17	0.27	-	-	0.43	0.82	-	-
C. japonica	0.62	0.29	0.98	0.72	0.76	0.14	1.56	0.86	0.34	0.22	0.08	0.19	1.72	0.64	2.63	1.77
C. cashmeriana	0.49	0.34	0.25	1.03	0.52	0.28	0.26	1.13	0.29	0.36	0.06	0.27	1.31	0.98	0.56	2.44
E. variegate	0.36	0.46	0.49	-	0.22	0.23	0.37	-	0.17	0.23	0.04	-	0.75	0.92	0.90	-
F. auriculata	0.36	0.80	-	-	0.41	0.88	-	-	0.31	0.49	-	-	1.09	2.18	-	-
F. lacor	0.26	0.57	-	-	0.25	0.53	-	-	0.27	0.42	-	-	0.78	1.52	-	-
F. semicordata	0.57	0.80	0.65	-	0.42	0.51	0.63	-	0.21	0.28	0.05	-	1.20	1.60	1.34	-
F. colorata	0.34	0.40	0.49	-	0.38	0.56	0.41	-	0.31	0.62	0.04	-	1.03	1.58	0.94	-
J. indica	0.31	0.69	-	-	0.21	0.44	-	-	0.18	0.29	-	-	0.70	1.42	-	-
L. monopetala	0.21	0.46	-	-	0.28	0.60	-	-	0.38	0.59	-	-	0.87	1.65	-	-
M. denticulata	0.42	0.52	0.57	-	0.30	0.30	0.56	-	0.20	0.26	0.05	-	0.92	1.08	1.18	-
O. indicum	0.29	0.74	-	-	0.15	0.32	-	-	0.15	0.20	-	-	0.59	1.26	-	-
O. paniculata	0.13	0.29	-	-	0.08	0.16	-	-	0.16	0.25	-	-	0.37	0.70	-	-
S. wallichii	0.70	0.69	0.57	0.83	0.81	0.95	0.71	0.59	0.32	0.62	0.07	0.22	1.84	2.26	1.35	1.63
T. myriocarpa	0.47	0.57	0.41	0.31	0.41	0.49	0.37	0.27	0.24	0.38	0.05	0.08	1.13	1.44	0.83	0.67
T. ciliata	0.39	0.57	0.41	-	0.30	0.49	0.26	-	0.22	0.38	0.03	-	0.91	1.44	0.70	-
Z. carinata	1.56	-	2.86	2.59	1.64	-	4.51	1.17	0.29	-	0.08	0.69	3.49	-	7.46	4.44
A. accedens	0.65	-	2.05	-	0.29	-	1.01	-	0.13	-	0.03	-	1.07	-	3.08	-
B. mitis	0.08	-	0.25	-	0.17	-	0.60	-	0.62	-	0.13	-	0.87	-	0.97	-

RF- Relative frequency; RD- Relative density; RA- relative abundance; IVI- Importance value index; Oa- overall (700-1930 m asl); L- low (700-1200 m asl); M- mid (1200-1700 m asl); H- high (> 1700 m)

Table 19 contd.

Plant species	RF				RD				RA				IVI			
	O_a	L	M	H	O_a	L	M	H	O_a	L	M	H	O_a	L	M	H
C. asiatica	1.82	-	2.45	4.14	3.16	-	3.65	7.53	0.48	-	0.08	1.10	5.46	-	6.18	12.77
C. oppositifolia	0.31	-	0.98	-	0.68	-	2.35	-	0.61	-	0.13	-	1.60	-	3.46	-
B. javanica	0.21	-	0.65	-	0.09	-	0.30	-	0.12	-	0.02	-	0.41	-	0.98	-
E. populnea	0.10	-	0.33	-	0.04	-	0.15	-	0.12	-	0.02	-	0.26	-	0.50	-
G. odorata	0.13	-	0.41	-	0.10	-	0.34	-	0.21	-	0.04	-	0.44	-	0.79	-
H. nepalensis	0.52	-	1.64	-	0.27	-	0.93	-	0.14	-	0.03	-	0.94	-	2.60	-
Ficus spp.	0.18		0.57		0.09		0.30	-	0.13	-	0.03	-	0.40	-	0.90	-
L. canum	0.18	-	0.98	-	0.11	-	1.53	-	0.17	-	0.08	-	0.46	-	2.59	-
M. semiserrata	0.26	-	0.82	-	0.36	-	1.23	-	0.38	-	0.08	-	1.00	-	2.13	-
O. thomsonii	1.04	-	3.27	-	0.75	-	2.57	-	0.20	-	0.04	-	1.99	-	5.89	-
P. nummulariifolia	0.52	-	1.64	-	0.94	-	3.24	-	0.50	-	0.10	-	1.97	-	4.98	-
P. asiatica	1.17	-	2.05	2.07	0.61	-	1.42	0.70	0.14	-	0.04	0.55	1.92	-	3.50	3.32
P. auriculata	0.52	-	1.64	-	0.44	-	1.53	-	0.24	-	0.05	-	1.20	-	3.21	-
P. andersonii	0.52	-	1.64	-	0.71	-	2.42	-	0.38	-	0.08	-	1.60	-	4.14	-
P. rude	0.16	-	0.49	-	0.17	-	0.60	-	0.31	-	0.06	-	0.64	-	1.15	-
P. cerasoides	0.10	-	0.33	-	0.08	-	0.26	-	0.20	-	0.04	-	0.38	-	0.63	-
R. cordifolia	0.10	-	0.33	-	0.07	-	0.22	-	0.17	-	0.04	-	0.34	-	0.59	-
R. diffusus	0.31	-	0.98	-	0.34	-	1.15	-	0.30	-	0.06	-	0.95	-	2.20	-
Z. piperitum	0.16	-	0.49	-	0.08	-	0.26	-	0.14	-	0.03	-	0.37	-	0.78	-
M. tetracoccus	0.13	-	0.41	-	0.07	-	0.22	-	0.14	-	0.03	-	0.33	-	0.66	-
Rubus spp	0.16	-	0.49	-	0.04	-	0.15	-	0.08	-	0.02	-	0.28	-	0.66	-
C. sylvatica	0.91	-	-	3.62	1.48	-	-	5.31	0.45	-	-	0.96	2.84	-	-	9.89
C. suffruticosa	0.39	-	-	1.55	0.18	-	-	0.66	0.13	-	-	0.41	0.71	-	-	2.63
E. attenuatus	0.16	-	-	0.31	0.17	-	-	0.62	0.31	-	-	0.08	0.64	-	-	1.02
G. diversiflora	0.16	-	-	0.62	0.12	-	-	0.43	0.21	-	-	0.16	0.49	-	-	1.21

RF- Relative frequency; RD- Relative density; RA- relative abundance; IVI- Importance value index; Oa- overall (700-1930 m asl); L- low (700-1200 m asl); M- mid (1200-1700 m asl); H- high (> 1700 m)

Table 19 contd.

Plant species	RF				RD				RA				IVI			
	O_a	L	M	H	Or_a	L	M	H	O_a	L	M	H	O_a	L	M	H
S. densiflorus	0.26	-	-	1.03	0.37	-	-	1.33	0.39	-	-	0.27	1.02	-	-	2.64
S. ovalifolia	0.31	-	-	1.24	0.13	-	-	0.47	0.12	-	-	0.33	0.56	-	-	2.04
A. triplinervis	1.04	-	-	4.14	1.86	-	-	6.67	0.50	-	-	1.10	3.39	-	-	11.91
A. macrocarpa	0.21	-	-	0.83	0.09	-	-	0.31	0.12	-	-	0.22	0.41	-	-	1.36
B. palmata	1.04	-	-	4.14	0.44	-	-	1.60	0.12	-	-	1.10	1.60	-	-	6.84
B. tessaricarpa	0.91	-	-	3.62	0.38	-	-	1.37	0.12	-	-	0.96	1.41	-	-	5.95
G. cusimbua	0.16	-	-	1.55	0.16	-	-	0.59	0.29	-	-	0.41	0.61	-	-	2.55
H. javanica	0.52	-	-	2.07	0.85	-	-	3.04	0.45	-	-	0.55	1.82	-	-	5.66
L. bulbifera	0.10	-	-	0.41	0.13	-	-	0.47	0.35	-	-	0.11	0.58	-	-	0.99
L. glutinosa	0.03	-	-	0.10	0.01	-	-	0.04	0.12	-	-	0.03	0.15	-	-	0.17
L. flexuosum	0.10	-	-	0.41	0.03	-	-	0.12	0.09	-	-	0.11	0.22	-	-	0.64
M. edulis	0.13	-	-	0.52	0.08	-	-	0.27	0.16	-	-	0.14	0.37	-	-	0.93
M. doltsopa	0.05	-	-	0.21	0.03	-	-	0.12	0.17	-	-	0.05	0.26	-	-	0.38
M. grandiflora	0.08	-	-	0.31	0.03	-	-	0.12	0.12	-	-	0.08	0.23	-	-	0.51
M. lanuginosa	0.21	-	-	0.83	0.10	-	-	0.35	0.13	-	-	0.22	0.44	-	-	1.40
M. malabathricum	0.10	-	-	0.41	0.09	-	-	0.31	0.23	-	-	0.11	0.42	-	-	0.84
P. griffithii	0.52	-	-	3.10	0.27	-	-	0.47	0.14	-	-	0.82	0.94	-	-	4.39
P. involucrata	0.10	-	-	0.41	0.16	-	-	0.59	0.43	-	-	0.11	0.70	-	-	1.11
P. melastomoides	0.21	-	-	0.83	0.40	-	-	1.44	0.54	-	-	0.22	1.15	-	-	2.49
P. wallichiana	0.18	-	-	0.72	0.12	-	-	0.43	0.18	-	-	0.19	0.48	-	-	1.35
S. lateriflora	0.39	-	-	1.55	0.18	-	-	0.66	0.13	-	-	0.41	0.71	-	-	2.63
P. major	0.39	-	-	1.55	0.09	-	-	0.31	0.06	-	-	0.41	0.54	-	-	2.28
R. griffithianum	0.18	-	-	0.72	0.08	-	-	0.27	0.12	-	-	0.19	0.37	-	-	1.19
R. holosericeus	0.16	-	-	0.62	0.17	-	-	0.62	0.31	-	-	0.16	0.64	-	-	1.41
T. serrulatum	0.26	-	-	1.03	0.26	-	-	0.94	0.28	-	-	0.27	0.80	-	-	2.25
T. plicata	0.05	-	-	0.21	0.02	-	-	0.08	0.12	-	-	0.05	0.19	-	-	0.34

RF- Relative frequency; RD- Relative density; RA- relative abundance; IVI- Importance value index; Oa- overall (700-1930 m asl); L- low (700-1200 m asl); M- mid (1200-1700 m asl); H- high (> 1700 m)

The RF estimated for trees, shrubs, herbs, ferns, climbers and orchids was 0.05-0.70, 0.10-2.21, 0.39-7.80, 0.10-6.11, 0.10-0.73 and 0.52-0.91, respectively while, RD and RA values estimated for these plant forms was 0.012-0.81, 0.04-1.97, 0.09-4.77, 0.03-10.52, 0.07-0.67 & 0.27-0.52 and 0.12-0.40, 0.07-0.70, 0.06-0.43, 0.03-0.49, 0.08-0.81 & 0.14-0.16, respectively. The range of these relative values estimated at low altitude class was 0.11-5.73, 0.07-9.89 and 0.05-1.27, respectively.At mid-altitude class the range of RF, RD and RA was 0.25-8.18, 0.11-8.49 and 0.01-0.15, respectively and at high-altitude class these values were 0.10-10.34, 0.04-12.33 and 0.03-2.75, respectively. The RF, RD and RA estimated for large cardamom irrespective of altitude class was 7.80, 4.77 and 0.17; respectively while, at low-, mid- and high-altitude class RF was 5.73, 8.18 and 10.34, respectively; RD was 3.41, 5.66 and 5.50, respectively and RA was 0.27, 0.04 and 2.75, respectively.

The important value index (IVI) of the documented species at the studied systems varied from 0.15-17.11 irrespective of altitude classes (table 19). IVI estimated for large cardamom was 12.74 while, at low-, mid- and high-altitude class it was 9.41, 13.88 and 18.59, respectively. Overall, IVI estimated across these altitude classes for trees, shrubs, herbs, ferns, climbers and orchids was 0.19-1.84 (*Thuja plicata-Schima wallichi*), 0.28-4.43 (*Rubus spp.-Fragaria nudicola*), 0.54-12.74 (*Plantago major-Amomum subulatum*), 0.22-17.11 (*Lygodium flexuosum-Selaginella denticulata*), 0.34-1.63 (*Rubia cordifolia-Piper boehmeriaefolium*) and 0.94-1.59 (*Peliosanthes griffithii-Spathoglottis plicata*). This means at large cardamom based traditional agroforestry systems of Darjeeling Himalayas the most important species based on IVI was a fern followed by a herb i.e. *Amomum subulatum*, a fern *Diplazium esculentum* (7.36), a herb *Brachiaria reptans* (7.31), a herb *Drymaria cordata* (7.27), a herb *Ageratina adenophora* (7.04), a herb *Ageratumconyzoides* (6.43), a fern *Nephrolepsis cordifolia* (6.19), a herb *Centella asiatica* (5.46), a herb *Ageratum houstonianum* (5.12), a fern *Lycopodium japonicum* (4.67), a herb *Oxalis corniculata* (4.44), a shrub *Fragaria nudicola* (4.43), a herb *Biden spilosa* (4.42), a fern *Adiantum* capillus (4.08) and a herb *Oxalis martiana* (4.07). The least important species based on IVI was a tree *Litsea glutinosa* (0.15). The other less important species were *Thuja plicata* (a tree- 0.19), *Lygodium flexuosum* (a fern- 0.22), *Magnolia grandiflora* (a tree- 0.23), *Magnolia doltopsa* (a tree- 0.26), *Exbucklandia populnea* (a tree- 0.26) and *Rubus spp*. (a shrub- 0.28). The most important trees following *Schima* wallichii in the system were *Cryptomeria japonica* (1.72), *Alnus nepalensis* (1.54), *Cupressus cashmeriana* (1.31), *Ficus semicordata* (1.20), *Terminalia myriocarpa* (1.13), *Ficus auriculata* (1.09) and *Firmiana colorata* (1.03).

The IVI of species estimated for low-altitude class was 0.57-16.39. The most important species based on IVI at this altitude was a fern *Selaginella denticulata* followed by an herb *Ageratina adenophora* (10.11), *Amomum subulatum* (9.41), an herb *Oxalis corniculata* (9.34), an herb *Bidens pilosa* (9.31), an herb *Oxalis martiana* (8.56), a fern *Adiantum capillus* (8.53) and the least important was a shrub *Girardinia palmata* (0.57). Among the tree species, most important at this altitude class was *Schimawallichii* (2.26) followed by *Ficus auriculata* (2.18) and the least was *Alnus nepalensis* (0.70) and *Ostodes paniculata* (0.70). The IVI of shrubs, herbs, ferns, climbers and orchids estimated at the low-altitude class was 0.57-5.0 (*Girardinia palmata-Fragaria nubicola*), 0.99-10.11 (*Dichroa febrifuga-Ageratina adenophora*), 0-79-16.39 (*Alsophila dregei-Selaginella denticulata*), 1.07-2.54 (*Solena amplexicaulis-Stephania japonica*) and 1.67-2.41 (*Spathoglottis plicata-Goodyera oblongifolia*).

At mid-altitude class the IVI estimated was in the range of 0.50- 14.30. The most important species based on IVI at this altitude found was a fern *Selaginella denticulata* followed by an herb *Amomum subulatum* (13.88), a fern *Adiantum capillus* (12.08), a fern *Nephrolepsis cordifolia* (10.0), a fern *Lycopodium japonicum* (7.80), a heb *Zephyranthes carinata* (7.46) and the least important species was atree *Exbucklandia populnea* (0.50).Important tree species found at this altitude were *Cryptomeria japonica* (2.63), *Alnus nepalensis* (1.71), *Schima wallichii* (1.35), *Ficus semicordata* (1.34) and *Macaranga denticulata* (1.18). IVI estimated for the shrubs, herbs, ferns and climbers at mid-altitude class was in the range of0.61-4.85 (*Girardinia palamata-Colebrookia oppositifolia*), 2.10-13.88 (*Artemesia vulgaris-Amomum subulatum*), 4.95-14.30 (*Diplazium esculentum-Selaginella denticulata*), 0.59-1.86 (*Rubia cordifolia- Persicaria chinesis*).

Similarly, IVI estimated for high-altitude class 0.17-20.84. The most important species found at this altitude class was a fern *Selaginella denticulata* followed by a fern *Diplazium esculentum* (18.89), an herb *Amomum subulatum* (18.59), an herb *Centella asiatica* (12.77), an herb *Brachiaria reptans* (12.14) and the least important specis was a tree *Litsea glutinosa* (0.17). The important tree species of the high-altitude class found were *Cupressus cashmeriana* (2.44), *Alnus nepalensis* (1.85), *Cryptomeria japonica* (1.77), *Schima wallichii* (1.63), *Magnolia lanuginose* (1.40), *Pinus wallichiana* (1.35) and *Rhododendron griffithianum* (1.19). The IVI estimated for shrubs, herbs, ferns, climbers and orchids at high-altitud class was in the range of 0.84-2.64 (*Melastoma malabathricum-Senecio densiflorus*), 2.28-18.59 (*Plantago major-Amomum subulatum*), 0.64-20.84 (*Lygodium flexuosum-Selaginella denticulata*), 1.91-2.25 (*Piper boehmeriaefolium-Tetrastigma serrulatum*) and 3.59-4.39 (*Spathoglottis plicata-Peliosanthes griffithii*).

In terms of IVI, the plant species in the large cardamom based traditional; agroforestry systems of Darjeeling Himalayas at low-, mid- and high-altitude class were more or less similarly distributed. Species estimated with higher IVI signifies its ecological importance in the system. The species growing at a particular altitude in the Darjeeling Himalayas was primarily influenced by site factors and ecological conditions that they best adapted the natural selection and evolution (Odum, 1971). Similar vegetation analysis with comparable density, abundance, frequency and IVI of traditional agroforestry systems was reported in earlier studies also (Deb *et al*., 2014; Taran and Deb, 2019; Sarkar, 2020). Phyto-sociology of the plant communities vary with agroforestry systems, slope and land quality (Sharma *et al.*, 2010_a).

4.6. Soils Parameters

4.6.1. Soil electrical conductivity, pH and moisture

Soil pH, electrical conductivity (EC) and moisture of largecardamom based traditional agroforestry systems quantified are given in table 20.

Table 20. Soil pH, electrical conductivity and moisture of large cardamom based traditional agroforestry systems at altitude classes and soil depths

AC/D	0-20 cm	20-40 cm	40-60 cm	Mean
pH				
Low	5.41	5.28	5.31	**5.33**
Mid	5.37	5.23	5.29	**5.30**
High	5.36	5.22	5.29	**5.29**
Mean	**5.38**	**5.25**	**5.30**	
$LSD_{0.05}$	**A = 0.015**	**D = 0.015**	**A × D = 0.026**	
Electrical conductivity (m mhos cm^{-1})				
Low	0.55	0.53	0.51	**0.53**
Mid	0.54	0.52	0.62	**0.56**
High	0.59	0.57	0.55	**0.57**
Mean	**0.56**	**0.54**	**0.56**	
$LSD_{0.05}$	**A = 0.061**	**D = 0.061**	**A × D = 0.106**	
Moisture (%)				
Low	21.94	17.83	14.13	**17.96**
Mid	21.72	17.17	13.97	**17.62**
High	22.10	17.48	13.64	**17.74**
Mean	**21.92**	**17.49**	**13.91**	
$LSD_{0.05}$	**A = 0.554**	**D = 0.554**	**A × D = 0.959**	

AC- Altitude class (low- 700-1200 m asl; mid- 1200-1700 m asl; high-> 1700 m asl); D- soil depth

All these parameters were significantly influenced by both altitude class and soil depth along with their interaction. The soil of the large cardamom based traditional agroforestry systems at low, mid and high-altitude class were acidic in nature with mean pH of 5.33, 5.30 and 5.29, respectively which decreased gradually and significantly with altitude class. This was further evidenced from the negative mild correlationship between pH and altitude (r= - 0.22, table 21; fig. 32).

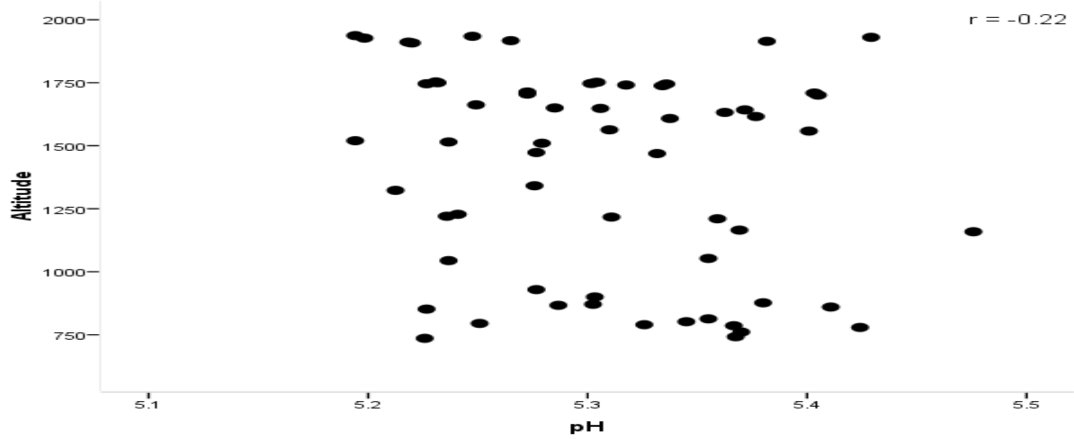

Fig. 32. Scatterred plot between soil pH and altitude

Similarly, pH also decreased significantly with increasing soil depth and the mean pH at these depths estimated was 5.38, 5.25 and 5.30, respectively. EC also significantly increased with altitude class but no trend was observed with soil depth though the differences between the depths were significant. However, non-significant correlationship was observed between EC and altitude (r = 0.154, fig. 33; table 21).

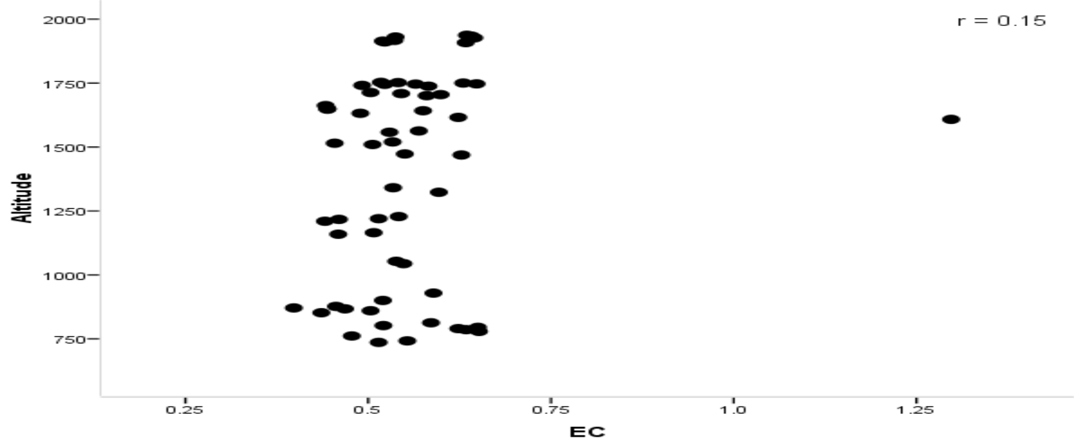

Fig. 33. Scatterred plot between soil electrical conductivity and altitude

The mean EC estimated at these altitudinal classes was 0.53, 0.56 and 0.57 m mhos cm^{-1}, respectively while, at different soil depth the mean EC estimated was 0.56, 0.54 and 0.56 m mhos cm^{-1}, respectively.

Table 21. Pearson correlation matrix of plant diversity of large cardamom based traditional agroforestry systems and altitude

	A	SR	PP	pH	EC	M	N	P	K	Ca	Mg	Al	SOC	PB
A	**1**													
SR	- 0.65**	**1**												
PP	- 0.59**	0.89**	**1**											
pH	- 0.22	0.19	0.16	**1**										
EC	0.15	-0.08	-0.10	- 0.01	**1**									
M	- 0.42	0.09	0.18	- 0.05	0.05	**1**								
N	0.15	-0.11	-0.08	0.07	0.07	0.43**	**1**							
P	- 0.46**	0.16	0.07	0.13	- 0.02	- 0.07	0.04	**1**						
K	0.06	0.31*	0.23	0.08	0.15	- 0.13	0.07	- 0.12	**1**					
Ca	- 0.48**	0.20	0.14	- 0.11	- 0.05	- 0.09	- 0.39**	0.37**	- 0.12	**1**				
Mg	- 0. 40**	0.33*	0.07	0.12	- 0.11	- 0.16	- 0.11	0.33*	0.06	0.47**	**1**			
Al	0.04	-0.1	-0.11	- 0.05	0.01	- 0.01	0.15	- 0.07	0.05	- 0.01	- 0.05	**1**		
SOC	0.70**	-0.55**	-0.52**	- 0.15	0.14	- 0.09	- 0.06	- 0.34**	0.01	- 0.12	-0.1	0.01	**1**	
PB	- 0.25*	0.45**	0.42**	0.23	-0.03	0.16	0.22	0.17	0.21	0.08	0.14	-0.03	- 0.05	**1**

****Significant at 0.01 level; *Significant at 0.05 level; A- altitude; SR- species richness; PP- plant population; EC- electrical conductivity (m mhos cm^{-1}); M- moisture (%); N- nitrogen (Kg ha^{-1}); P- phosphorus (Kg ha^{-1}); K- potassium (Kg ha^{-1}); Ca- calcium (ceq/kg); Mg- magnesium (ceq/kg); Al- aluminium (ceq/kg); SOC- soil organic carbon (%); PB- plant biomass (Mg ha^{-1})**

Soil moisture also decreased consistently and significantly with increasing soil depth. However, decrease in soil moisture was inconsistent with increasing altitude class because of non-significant correlationship between the two (r = -0.42, table 21; fig. 34).

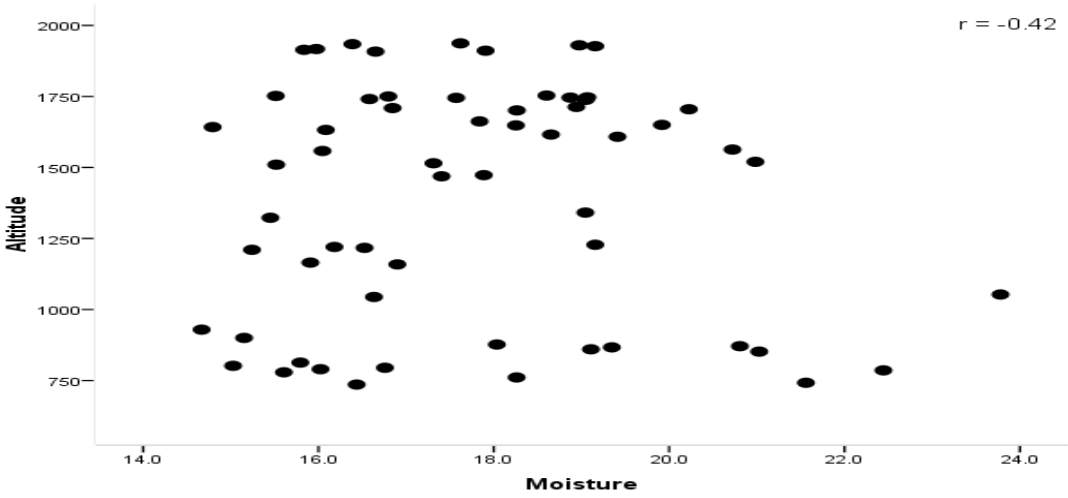

Fig. 34. Scatterred plot between soil moisture and altitude

Soil moisture initially decreased from low- to mid-altitude class but thereafter increased from mid- to high-altitude class though lesser than the moisture at low-altitude class. The mean soil moisture estimated at low-, mid- and high-altitude class was 17.96 %, 17.62 % and 17.74 %, respectively while, it was 21.92 %, 17.49 % and 13.91 % at 0-20 cm, 20-40 cm and 40-60 cm soil depth.

Soil pH, EC and moisture regime in a tree based land use system is function of biotic and abiotic factors like rainfall, amount of radiation received, temperature, structure and function of the system (Pande, 2001; Lepcha and Devi, $2020_{a,\ b}$; Sarkar, 2020). Similar soil pH, EC and moisture condition of forest based under canopy large cardamom cultivation system was also reported from Sikkim Himalayas also (Singh *et al*., 2018_a). Under canopy large cardamom cultivation is forest based in Darjeeling Himalayas also which is a high rainfall area with average annual rainfall of 270-310 cm and soils of forests at high rainfall areas are acidic (Shukla and Chakravarty, 2012_a; Shukla *et al*., 2017_a; Subba *et al*., 2018_a; Rai *et al*., 2021; Sarkar, 2020; Tamang *et al*., 2021). Forests or tree based land uses were generally reported with higher organic matter build up in its soil responsible for increasing acidity in such soils (Sharma *et al*., 2000; Koul *et al*., 2011; Koul and Panwar, 2012; Shukla and Chakravarty, 2012_a; Shukla *et al*., 2014, 2017_a, 2018; Shukla and Chakravarty, 2018; Singh *et al*., 2018_a; Lepcha and Devi, $2020_{a,\ b}$; Sarkar, 2020; Rai *et al*., 2021; Tamang *et al*., 2021).

The under-canopy forest based large cardamom farming systems due to its heterogenous vegetation composition aid in higher soil organic matter production (Fisher *et al*., 1994). Organic matter in soil was reported predominantly accountable to regulate both of physical and chemical properties of the soil (Woomer *et al*., 1994). Moreover, in acidic soil of tree based systems, release of humic matter as root exudates form complex with the aluminium which further regulates its pH (Young, 1997).High soil organic carbon in these tree based systems due to higher organic input in form of litter and root debris increase leaching of bases with enhanced weathering through litter decomposition. The traditional sysem of large cardamom cultivation in Darjeeling Himalayas is under canopy of reserved forest with very less disturbance and thus similar soil pH, electrical conductivity and moisture was recorded to that of forests and other tree based land use systems in high rainfall areas (de Hann, 1977; Robertson and Vitousek, 1981; Adams and Sidle, 1987; Chavan *et al*., 1995;Contractor and Badnur, 1996; Chakravarty and Barthakur, 1997; Sharma and Sharma, 1997; Young, 1997; Sharma *et al*., 2000; Khera *et al*., 2001; Raina *et al*., 2001; Paudel and Sah, 2003; Chaudhuri *et al*., 2005, 2009; Bagherzadeh *et al*., 2008; Chandran *et al*., 2009; Sheikh and Kumar, 2010; Panwar *et al*., 2011; Gairola *et al*., 2012_a; Rai *et al*., 2021; Tamang *et al*., 2021).

The Darjeeling Himalaya has humid climatic condition and receivehigh rainfallwhile, closer vegetation canopy of the system reduced evaporation rate and higher organic matter increased water holdingcapacity of the system, thus estimated with higher soil moisture (Jose, 2009; Devi and Sherpa, 2019; Lepcha and Devi, $2020_{a, b}$; Sarkar, 2020). Soil with highr organic matter can absorb substantial quantities of water in it (Stevenson, 1994). Land use systems with closed canopy restrict prevent the incoming solar radiation to penetrate the soil surface reducing surface evaporation (Sharma *et al*. 2007, 2008; Shukla and Chakravarty, 2012_a; Singh *et al*., 2018_a; Lepcha and Devi, $2020_{a, b}$; Sarkar *et al*., 2020; Rai, *et al*., 2021; Tamang *et al*., 2021). Higher soil moisture and EC of the under-canopy forest based large cardamom farming of Darjeeling Himalayas also lowered its soil pH (Robertson and Vitousek, 1981; Adams and Sidle, 1987; Chakravarty and Barthakur, 1997; Khera *et al*., 2001; Pande, 2001; Paudel and Sah, 2003).

4.6.2. Soil organic carbon

Oxidizable soil organic carbon (SOC) at different altitude classess and soil depthsof the large cardamom based traditional agroforestry systems in Darjeeling Himalayas are given in table 22.

Table 22. Oxidizable soil organic carbonof large cardamom based traditional agroforestry systemsat altitude classes and soil depths

AC/D	0-20 cm	20-40 cm	40-60 cm	Mean
Content (%)				
Low	1.11	1.09	1.06	**1.09**
Mid	1.40	1.37	1.35	**1.37**
High	1.65	1.63	1.62	**1.63**
Mean	**1.39**	**1.36**	**1.34**	
$LSD_{0.05}$	**A = 0.01**	**D = 0.01**	**A × D = 0.02**	
Amount ($Mg\ ha^{-1}$)				
Low	22.77	22.33	21.82	**22.31**
Mid	28.92	28.48	28.05	**28.48**
High	34.24	33.79	33.45	**33.83**
Mean	**28.64**	**28.20**	**27.77**	
$LSD_{0.05}$	**A = 0.534**	**D = 0.534**	**A × D = 0.924**	

AC- Altitude class (low- 700-1200 m asl; mid- 1200-1700 m asl; high- > 1700 m asl); D- soil depth

Mean soil organic carbon content estimated for low-, mid- and high-altitude class was 1.09, 1.37 and 1.63 %, respectively which amounted to 22.31, 28.48 and 33.83 Mg ha^{-1}, respectively. Total SOC stock of 66.93-101.49 up to 60 cm soil depth estimated in the present study is within the range of 8.9 to 851.9 Mg C ha^{-1}estimated for various tropical and sub-tropical forests (Yadav and Sharma, 1968; Chaudhri *et al*., 1977; Banerjeeand Badola, 1980; Banerjee *et al*., 1981, 1990; Das and Roy, 1982; Singh *et al*., 1982, 1987, 1991; Singhal *et al*., 1982; Singh and Datta, 1983; Banerjee *et al*., 1990; Gupta and Singh, 1990; Bhattacharyya *et al*., 2000; Chhabra *et al*., 2003; Ramachandran *et al*., 2007; Sheikh *et al*., 2009; Li *et al*., 2010; Mohanraj *et al*., 2011; Sharma *et al*., 2011; Negi *et al*., 2013; Guerra-Santos *et al*., 2014; Shukla *et al*., 2014, 2017$_{a}$, 2018; Bazezew *et al*., 2015; Borah *et al*., 2015; Gurung *et al*., 2015; Choudhary *et al*., 2016$_{a,b}$; Pandey and Bhusal, 2016; Paudel *et al*., 2016; Tashi *et al*., 2016; Tran and Dargusch, 2016; Abere *et al*., 2017; Anon., 2017$_{b}$; Barré *et al*., 2017; Castillo *et al*., 2017; Krishan *et al*., 2017; Kumar and Gupta, 2017; Shukla and Chakravarty, 2018;

Simon *et al*., 2018; Chettri, 2020; Pala *et al*., 2020; Rai *et al*., 2021; Tamang *et al*., 2021).

SOC content significantly increased with increasing altitudeclass and so was the amount estimated. Significant positive relationship between altitude and SOC content was also observed (r = 0.699**, table 21; fig. 35). Distribution and composition of vegetation is greatly influence by altitude as temperature decreases with increasing altitude which reduces the diversity and population thus regulating carbon (Shedayi *et al*., 2016) as altitude was found prime determinant of ecosystem properties and processes in the mountainneous regions (He *et al*., 2016).

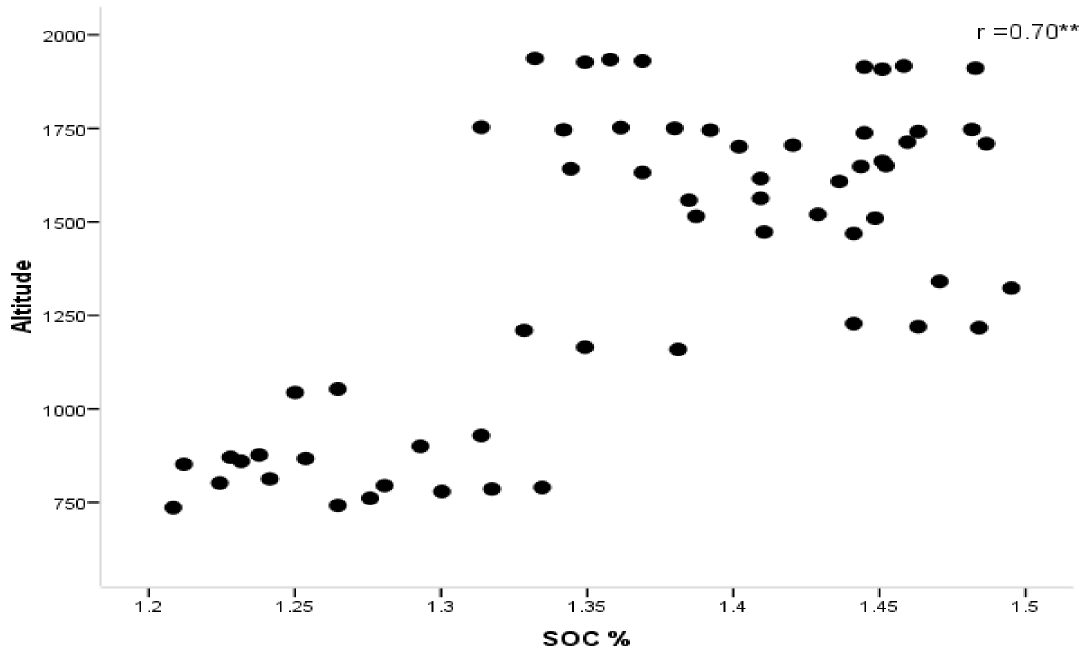

Fig. 35. Scatterred plot between SOC and altitude

However, increasing soil depth significantly decreased SOC contentand amount. Mean SOC content at 0-20 cm, 20-40 cm and 40-60 cm soil depth estimated was 1.39 %, 1.36 % and 1.34 % which amounted to 28.64, 28.20 and 27.77 Mg ha^{-1}, respectively. The soil of the large cardamom based traditional agroforestry systems of Darjeeling Himalayan homegardens was high in availability of organic carbon at all altitude class (Tandon, 2005).

Soil carbon is regulated by its structure, species composition, management,organic matter input, locality factors (climatic, soil and topographic variables), land use and management (Chakravorty and Chakravarti, 1980; Batjes, 1996; Banerjee *et al*., 1998; Jobbágy and Jackson 2000; Maikhuri *et al*., 2000; Lal, 2004, 2015; Lemenih and Itanna, 2004; Litton *et al*., 2004; Polyakov and Lal, 2004; Bunker *et* *al*., 2005; Raich *et al*., 2006; Paul *et al*., 2008; Henry *et al*., 2009; Kaul *et al*., 2009; Li *et al*., 2010; Martin *et al*., 2010, 2011; Sharma *et al*., 2011; Muñoz-Rojas *et al*., 2012; Negash, 2013; Banerjee, 2014; Scharlemann *et al*., 2014; Schrumpf *et al*., 2014; Dar and Sundarapandian, 2015; Bao *et al*., 2016; Bhardwaj *et al*., 2016; Newaj *et al*. 2016; Tashi*et al*., 2016; Barré *et al*., 2017; Sanderman *et al*., 2017; Liu *et al*., 2018; Ma *et al*., 2018; Simon *et al*., 2018; Devi and Sherpa, 2019). SOC in a tree based land use system largely depend on quality and quantity of organic matter accumulated into its soil (Tans *et al*., 1990; Woomer *et al*., 1997; Fenton *et al*., 1999; Bhattacharyya *et al*., 2001; Kimble *et al*., 2007; John, 2010; Koul *et al*., 2011; Gairola *et al*., 2012_a; Shukla and Chakravarty, $2012_{a,\ b}$; Scotti *et al*., 2015). In Darjeeling Himalayas, traditional below canopy forest based large cardamom agroforestry systems entire system vegetation were contributing to soil organic carbon build up like that of its homegardens (Sarkar, 2020) which was not the case of agroforestry system at agricultural landscapes where trees were reported as a major contributor of soil organic matter to the system (Chivaura-Masusa *et al*., 2000; Santhoshkumar and Ichikawa, 2010; Bishaw *et al*., 2013). In a heterogenous system like the traditional large cardamom forest based agroforestry system or homegardens of Darjeeling Himalayas, entire vegetation acts as a source of soil organic matter to build up SOC and nutrients as vegetation of a land use system was reported prime and basic to build-up soil carbon and nutrients rather than the source *par se* (Hawke and O'Connor, 1993; Wendt *et al*., 1996; Garg, 1998; Rowland, 1998; Akinnifesi *et al*., 1999; Beets *et al*., 2002; Zhang and Zhang, 2003; Mutuo *et al*., 2005; Makumba *et al*., 2007; Vallejo *et al*., 2010; Schmidt *et al*., 2011; Anon., 2017_a; Sarkar, 2020; Choudhury *et al*., 2021).

The SOC content of the present study was comparable with homegardens of Terai Zone of West Bengal (Subba *et al*., 2017_d, 2018_a), and large cardamom based agroforestry and other tree based systems of Sikkim (Das *et al*., 2017; Singh *et al*., 2018_a; Lepcha and Devi, $2020_{a,\ b}$; Choudhury*et al*., 2021) but lesser than temperate forest of Garhwal region (Saha *et al*., 2018) and higher than the homegardens of Darjeeling Himalayas (Sarkar, 2020). SOC significantly increased with increasing altitude due to slower decomposition rates. This is evidenced from significant positive relationship between altitude and SOC content ($r = 0.699^{**}$, table 21; fig. 35). However, significant negative corrlationship of SOC content with species richness ($r = -\ 0.551^{**}$, table 21; fig. 36) and plant population ($r = -\ 0.524^{**}$, table 21; fig. 37) was observed because both species richness (r = - 0.648**, fig. 2; table 15) and plant population (r = - 0.587**, fig. 3; table 15) were significantly and negatively correlated with altitude.

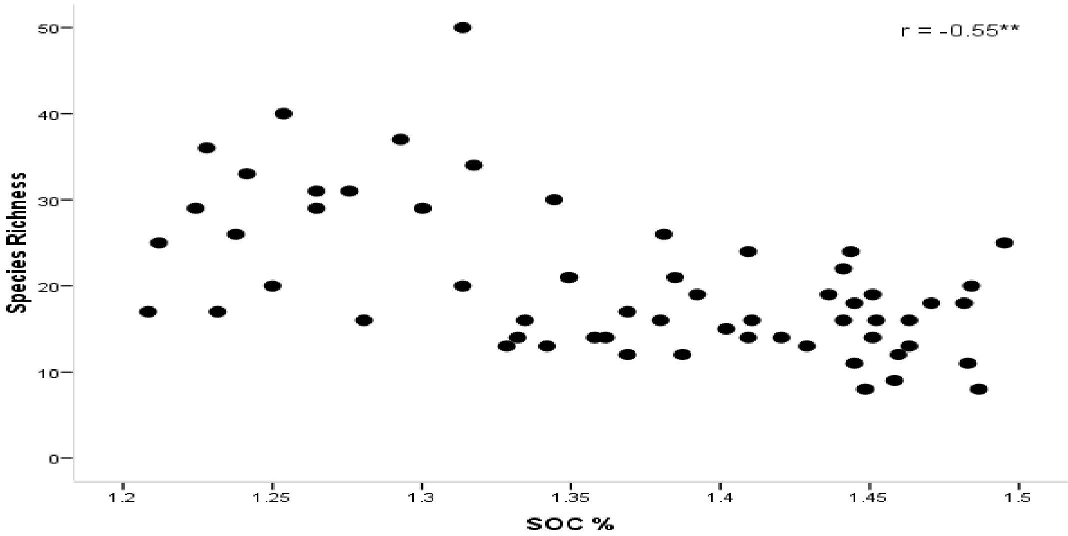

Fig. 36. Scatterred plot between SOC and species richness

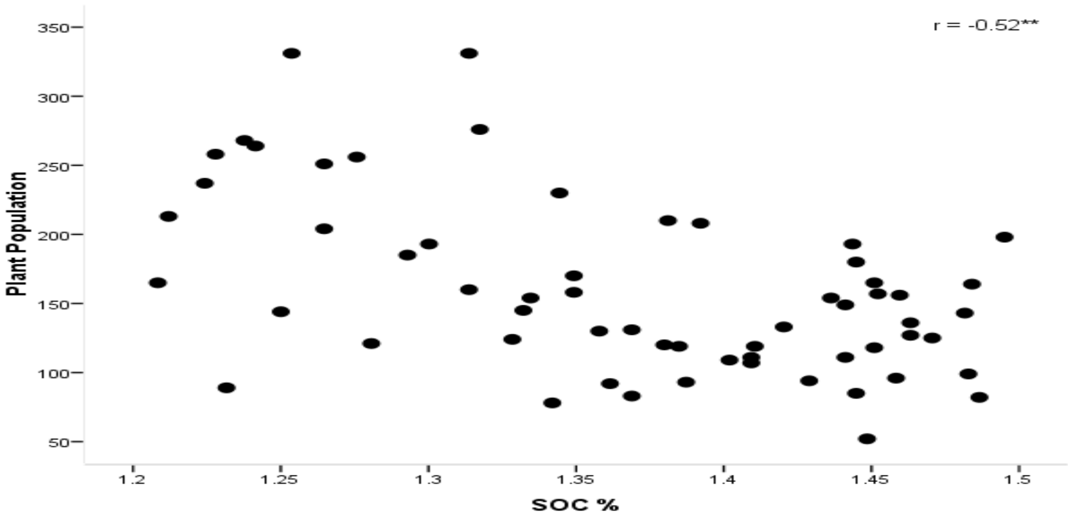

Fig. 37. Scatterred plot between SOC and plant population

Similar significant direct relationship of SOC with species richness was also reported from Sikkim large cardamom agroforestry systems (Lepcha and Devi, 2020_a), homegardens of Darjeeling Himalayas (Sarkar, 2020) and other different land-uses elsewhere (Shrestha *et al*., 2004; Ramesh *et al*., 2015; Chaudhary *et al*., 2016). Lower temperature at higher altitude decreases decomposition due to increasing soil acidity and anaerobic conditions which inhibit the decomposition process thereby cumulating the build up of undecomposed organic matter annually (Dimri *et al*., 1997; Djukic *et al*., 2010; Martin *et al*., 2010; Banerjee, 2014; Tashi *et al*. 2016; Simon *et al*., 2018; Devi and Sherpa, 2019; Lepcha and Devi, 2020_a; Choudhury *et al*., 2021). This is because fresh annual builds up of organic matter in the soil doesn't get decomposed and mineralised by the soil microbes (Fontaine *et al*., 2004). The soil carbon stock of the Eastern Himalayan region is thus prominently organic as compared to prominent inorganic soil carbon stock in the Western Himalayas (Sreenivas *et al*., 2016; Devi and Sherpa, 2019) as was also estimated in the present study.

As a general trend, SOC decreases with increasing soil depth due to reducing organic matter input (Upadhyay and Singh 1989; Devi and Yadava 2006; Bargali *et al*., 2018; Devi and Sherpa, 2019; Lepcha and Devi, 2020_a; Sarkar, 2020; Choudhury*et al*., 2021) and particularly the hilly soils have been reported to contain more organic carbon on the surface layers than the sub-surface layers (Velayutham *et al*., 2000). Continuous addition of vegetation detritus enriches the top most soil horizon or 'O' horizon with organic matter resulting to hgher SOC on it (Dimri *et al*., 1997; Binkley and Giardina, 1998; Kaye *et al*., 2005; Golubiewski, 2006; Raciti *et al*., 2011; Edmondson *et al*., 2014; Bae and Ryu, 2015; Livesley *et al*., 2016). Moreover, drilosphere activity (mainly earthworms and soil bacteria) was also observed higher on the top most soil layer of the systems due to its higher organic matter which in turn also resulted into its higher SOC content (Isaac, 2001; Rahman *et al*., 2012) then the lower soil layers. Further, scarcity of moisture except during rainy season along with low air and soil temperatures in the dry winter months in Darjeeling Himalayas inhibits microbial activities which continuously increased the surface humus layer (Upadhyay and Singh 1989; Devi and Yadava, 2006; Banerjee, 2014; Tashi *et al*., 2016; Bargali *et al*., 2018; Devi and Sherpa, 2019). The SOC content though decreased with increasing soil depth but the availability remained high (Tandon, 2005). This is because of heterogeneity of the system which produced high root biomass distributed throughout soil profile. High root biomass produced high amount of root detritusthroughout the soil profile building up enough organic matter for high availability of permanent continuous carbon even at deeper layers with lesser net emission (Fisher *et al*., 1994; Johnson *et al*., 2006; Wutzler and Reichstein, 2007; Meinen *et al*., 2009; Saha *et al*., 2009; Nair *et al*., 2010; Schmidt *et al*., 2011; Stockmann *et al*., 2013; Mbow *et al*., 2014).

The SOC stock also significantly increased with increasing altitudeclass and decreased significantly with decreasing soil depth (table 22) which was due to similar trend of SOC content with altitude and soil depth. Inspite of significant changes of SOC content with changing altitude the change in SOC stock was non-significant which might be due to significant inverse relationship of bothspecies' richness ($r = -0.648^{**}$, fig. 2; table 15) and plant population ($r = -0.587^{**}$, fig. 3; table 15) with altitude. Comparable SOC stock was reported from other agroforestry systems (Nair *et al*., 2010). Sikkim Himalayan large cardamom based traditional agroforestry systems (Singh *et al*., 2018_a; Lepcha and Devi, $2020_{a,\ b}$), natural forest, managed plantation and jhum fallows of Tripura, North-East India (Chaudhary *et al*., 2016),Montane forest (Singh *et al*., 1987; Devi and Sherpa, 2019) and homegardens (Sarkar, 2020) of Darjeeling Himalayas.Many Himalayan studies and studies from other parts of India and outside Indiaalso has reported reduction in SOC stock with increasing soil depth due to similar reduction in its content (Jobbágy and Jackson, 2000; He *et al*., 2013, 2016; Dar and Somaiah, 2015;Dar and Sundarapandian, 2015; Choudhury *et al*., $2016_{a,\ b}$; Tashi *et al*., 2016; Saha *et al*., 2018; Singh *et al*., $2018_{a,\ b}$; Devi and Sherpa, 2019; Soleimani *et al*., 2019; Lepcha and Devi, 2020_a; Sarkar, 2020; Rai *et al*., 2021; Tamang *et al*., 2021).

The altitudinal gradient particularly in the tropics has been a priority area of research to study ecosystem and climate change (Malhi *et al*., 2010). Traditional tree based land use systems like homegardens (Sarkar, 2020) and under canopy forest based large cardamom agroforestry systems can be a climate change mitigation option in Darjeeling Himalayasdue to their soil carbon sequestrationpotential to increase carbon footprint for land use productivity and sustainability. This is because tree based land use systems were always reported with higher soil carbon content than any other land uses with possibility of higher net gains in carbon stocks (Lal, 2000; Andren *et al*., 2001; Goel, 2007; Kimble *et al*., 2007; Jacobson, 2009; Chauhan *et al*., 2009; Calfapietra *et al*., 2010; Kumar and Nair, 2011; Rizvi *et al*., 2011; Hergoualc'h *et al.*, 2012; Abdul Haris *et al*., 2013; Kanime *et al*., 2013; Nielsen *et al*., 2014; Chauhan *et al*., 2015, 2019; Kane, 2015; Kutsokon *et al*., 2015; Choudhury *et al*., $2016_{a,\ b}$; Newaz *et al*., 2016; Panwar *et al*., 2017; Jha, 2018; Dar *et al*., 2019; Das *et al*., 2019).

4.6.3. Soil available nitrogen, phosphorus and potassium

Soil available nitrogen, phosphorus and potassium in large cardamom based traditional agroforestry system as influenced by altitude classesand soil depths along with their interaction are given in table 23. Based on the availability of these soil primary nutrients, the large cardamom based traditional agroforestry system of

Darjeeling Himalaya was medium in available nitrogen and phosphorus at all altitude classes up to 60 cm soil depth and high in available potassium (Tandon, 2005).

Table 23. Available nitrogen, phosphorus and potassium of large cardamom based traditional agroforestry systems at altitude classes and soil depths

AC/D	0-20 cm	20-40 cm	40-60 cm	Mean
Available nitrogen (kg ha^{-1})				
Low	277.22	257.19	238.10	**257.51**
Mid	279.73	260.01	241.16	**260.30**
High	284.85	263.58	243.67	**264.03**
Mean	**280.60**	**260.26**	**240.98**	
LSD$_{0.05}$	**A= 3.99**	**D= 3.98**	**A×D= 6.91**	
Available phosphorus (kg ha^{-1})				
Low	14.15	13.75	13.32	**13.74**
Mid	13.35	12.95	12.57	**12.95**
High	12.96	12.45	12.00	**12.46**
Mean	**13.48**	**13.04**	**12.63**	
LSD$_{0.05}$	**A= 0.16**	**D= 0.16**	**A×D= 0.29**	
Available potassium (kg ha^{-1})				
Low	234.04	229.21	226.01	**229.75**
Mid	231.66	228.02	224.32	**227.99**
High	235.41	231.03	227.30	**231.25**
Mean	**233.70**	**229.42**	**225.86**	
LSD$_{0.05}$	**A= 2.34**	**D= 2.34**	**A×D= 4.06**	

AC- Altitude class (low- 700-1200 m asl; mid- 1200-1700 m asl; high- > 1700 m asl); D- soil depth

The order of available soil primary nutrients found was N> K > P which was also reported from many other tree based land use systems (Pande, 2001; Shukla *et al.*, 2017$_a$; Sarkar, 2020; Rai *et al.*, 2021; Tamang *et al.*, 2021).The mean available nitrogen, phosphorus and potassium quantified was 257.51, 260.30 & 264.03 Kg N ha^{-1}; 13.74, 12.95 & 12.46 Kg P ha^{-1} and 229.75, 227.99 & 231.25 Kg K ha^{-1} at low-, mid- and high-altitude classes, respectively with continuous significant increasing trend from lower to higher altitude class except potassium with no discreet trend. Comparable amount of soil available primary nutrients were also reported from other tree based land use systems in earlier studies (Kumar *et al.*, 2004; Semwal, 2006; Sharma *et al.*, 2010$_a$; Shukla *et al.*, 2014, 2017$_a$; Saha *et al.*, 2018; Shukla and Chakravarty, 2018; Sarkar, 2020). Vegetation also influences the availability of soil primary nutrients (Gairola *et al*., 2012_b) due to variation in absorption and return to the soil by differenttree species (Singh *et al*., 1986_b).

Contrarily, non-significant relationship of available nitrogen (r = 0.152, table 21; fig. 38) and potassium (r = 0.05, table 21; fig. 39) with altitude along with mild inverse significant relationship between phosphorus and altitude (r = - 0. 458**, table 21; fig. 40) was observed.

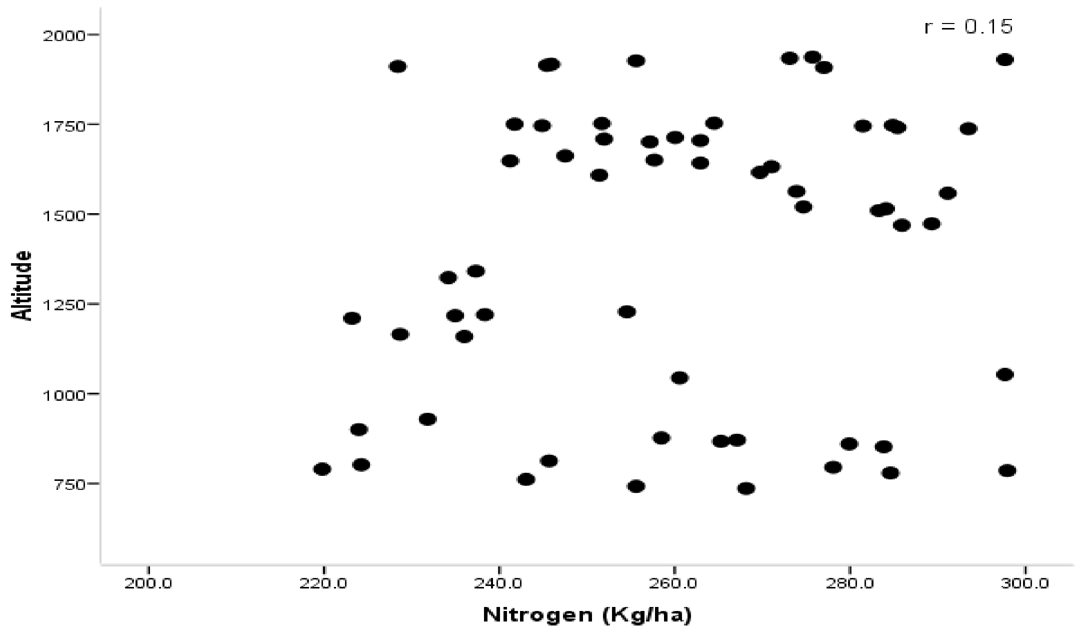

Fig. 38. Scatterred plot between soil available nitrogen and altitude

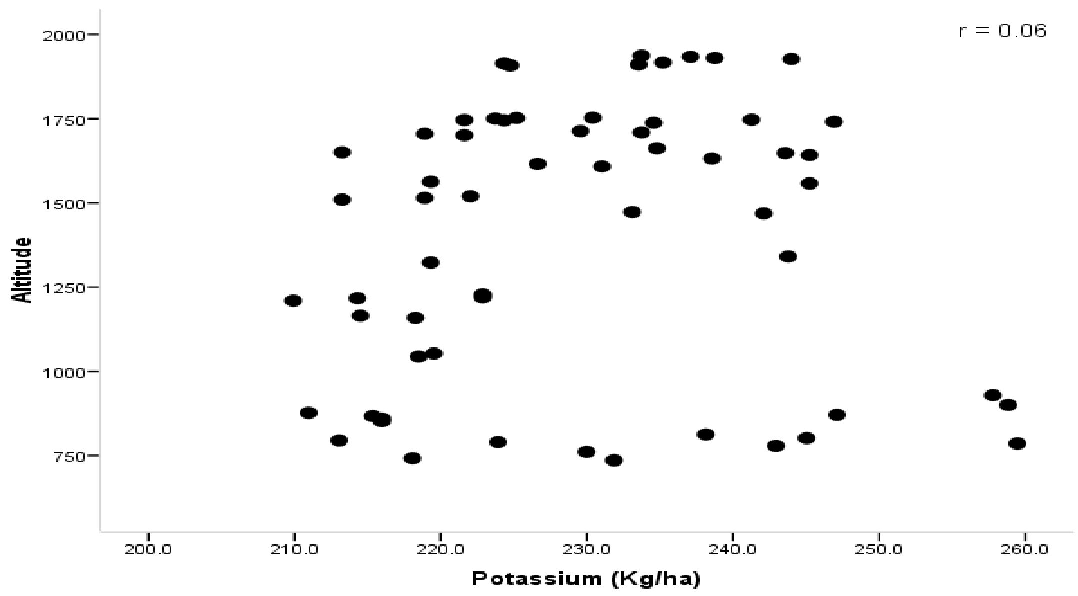

Fig. 39. Scatterred plot between soil available potassium and altitude

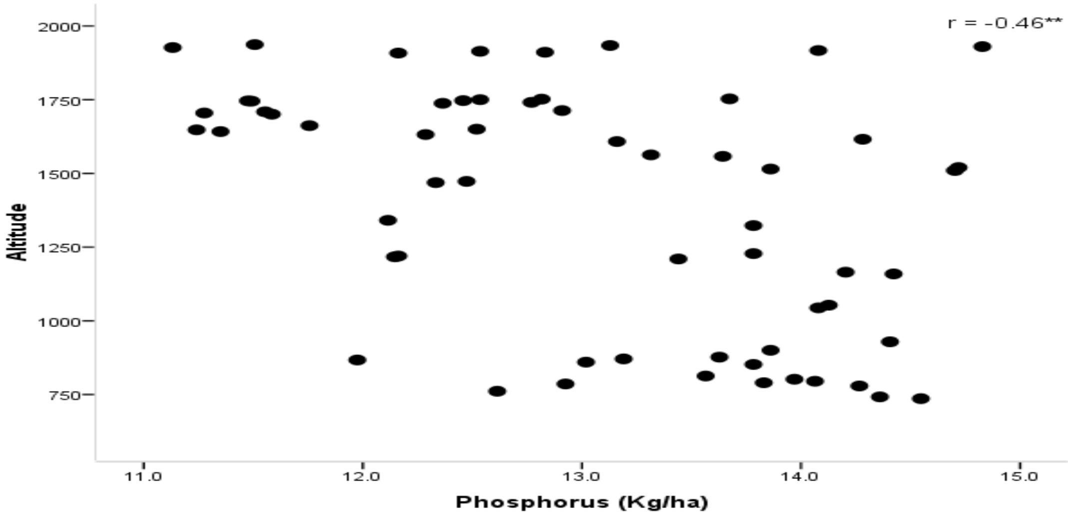

Fig. 40. Scatterred plot between soil available phosphorus and altitude

Similar trends of soil available nutrients with altitude were also observed in earlier studies (Vincent *et al*., 2014; Saha *et al*., 2018; Sarkar, 2020). Studies have reported influence of forest type, elevation and soil depth on nitrogen stock (Tashi *et al*., 2016; Simon *et al*., 2018; Devi and Sherpa, 2019). Such relationship of soil available primary nutrients with altitude might also be due to very weak and non-significant correlation of soil available nitrogen & phosphorus with species richness (r = - 0.133, table 21; fig. 41 & r = 0.160, table 21; fig. 42, respectively) and plant population (r = - 0.099, table 21; fig. 43 & r = 0.082, table 21; fig. 44, respectively) while, mild significant relationship of soil available potassium with species richness ($r = 0.349^{**}$, table 21; fig. 45) but non-significant relationship with plant population (r = 0.244, table 21; fig. 46).

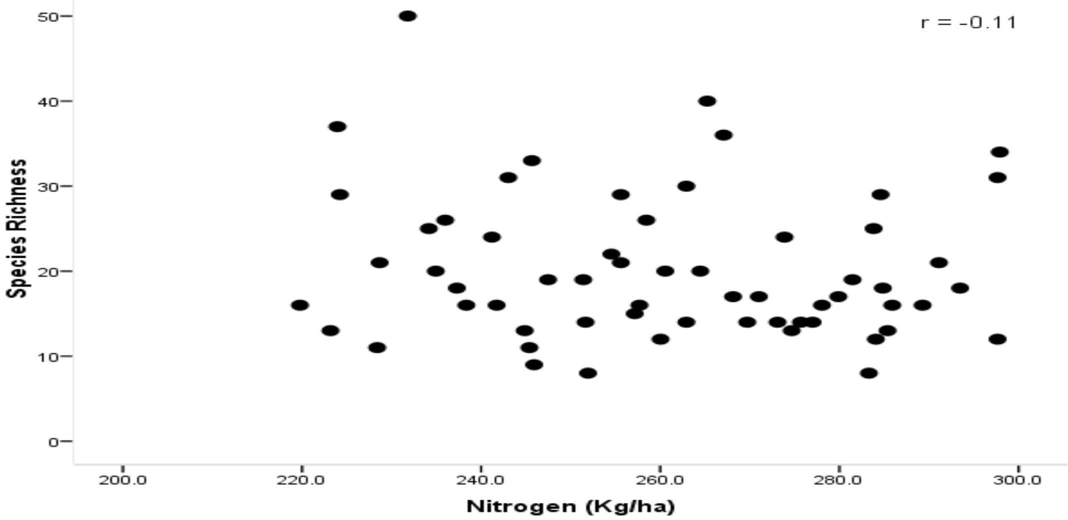

Fig. 41. Scatterred plot between soil available nitrogen and species richness

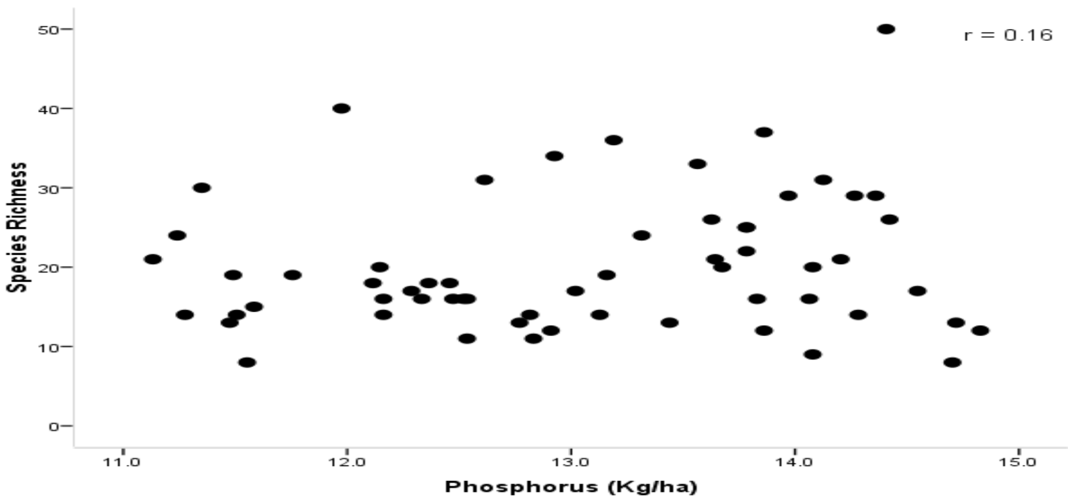

Fig. 42. Scatterred plot between soil available phosphorus and species richness

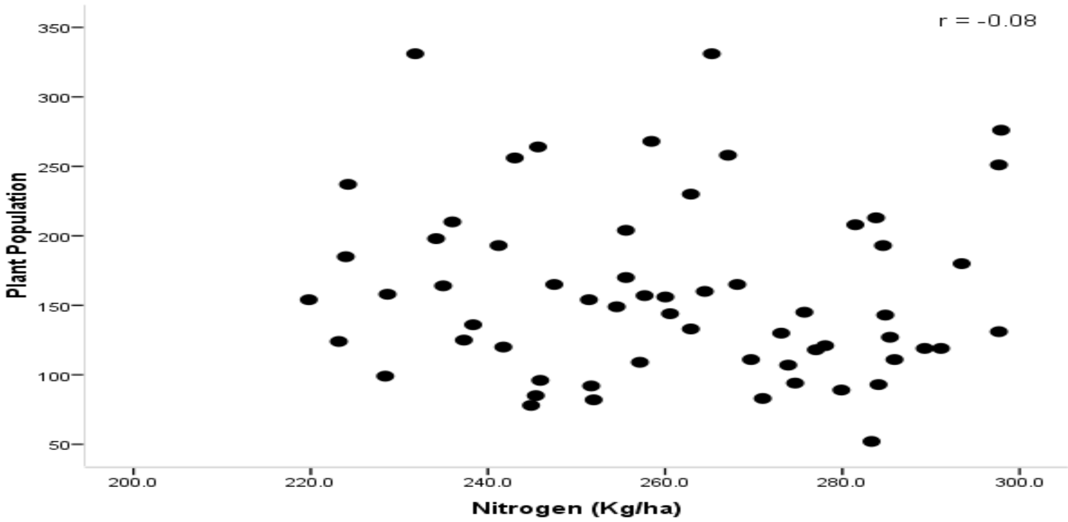

Fig. 43. Scatterred plot between soil available nitrogen and plant population

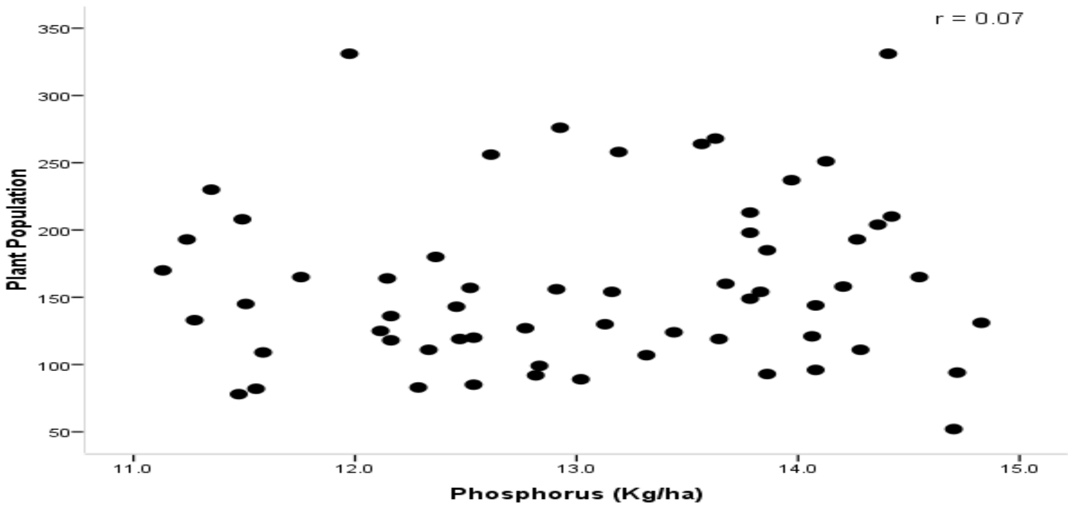

Fig. 44. Scatterred plot between soil available phosphorus and plant population

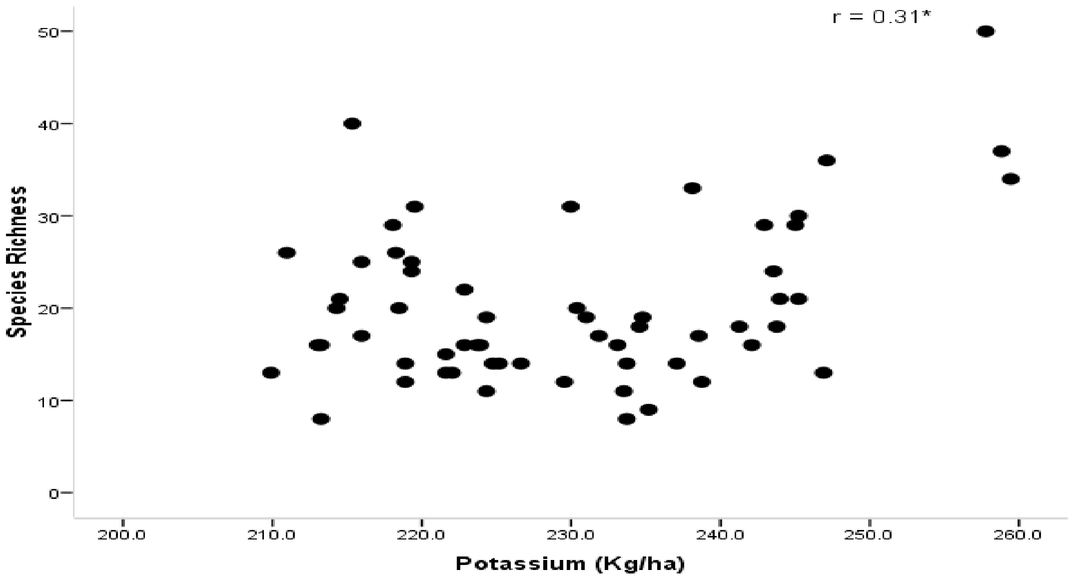

Fig. 45. Scatterred plot between soil available potassium and species richness

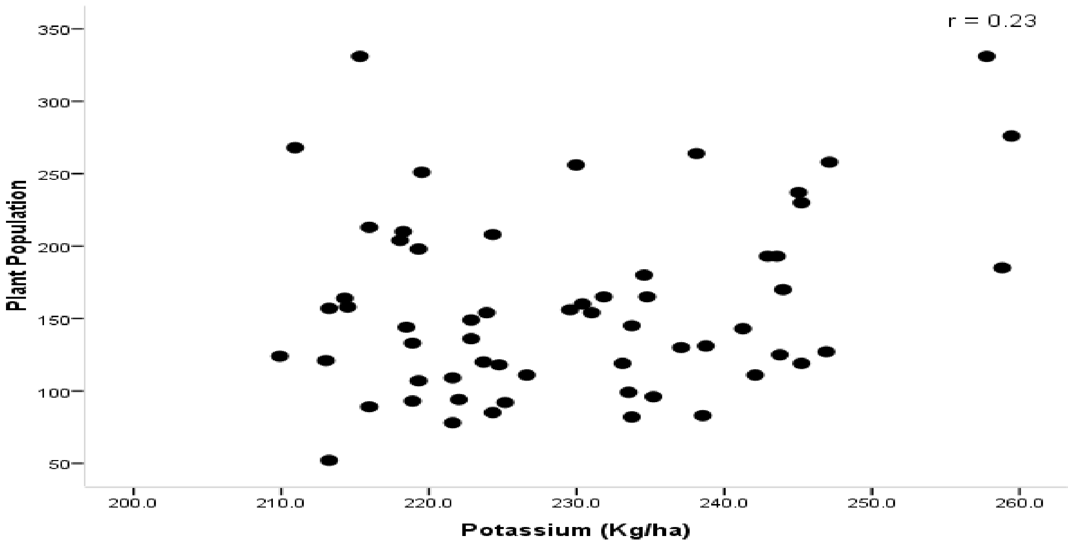

Fig. 46. Scatterred plot between soil available potassium and plant population

Consequent of these observed relationships of soil available primary nutrients with plant species and population in relation to altitude, the relationship of soil available nitrogen (r = - 0.057, table 21; fig. 47) and potassium (r = 0.006, table 21; fig. 48) was also weak and non-significant while, relationship between soil available phosphorus and SOC was inverse, mild and significant ($r = -0.343^{**}$, table 21; fig. 49).

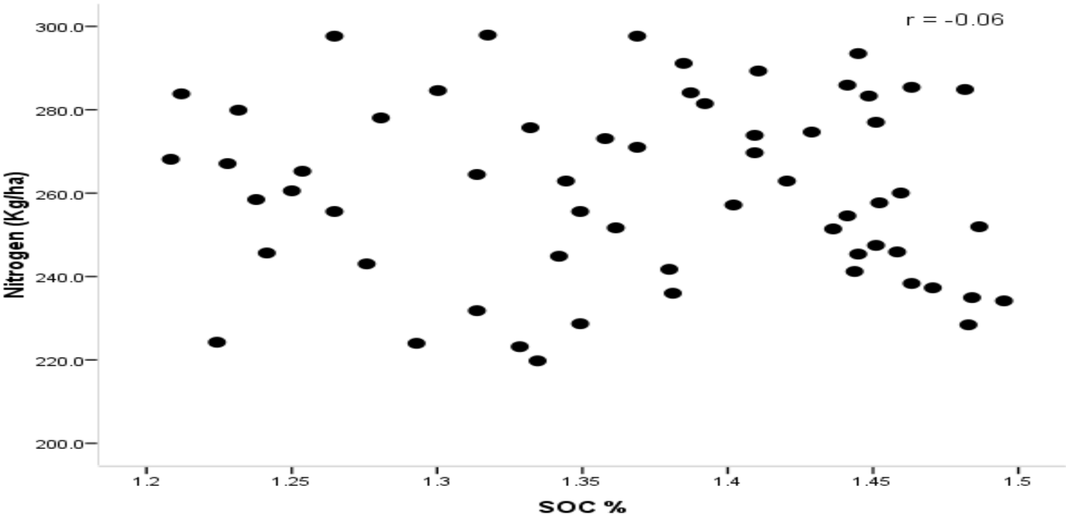

Fig. 47. Scatterred plot between soil available nitrogen and SOC

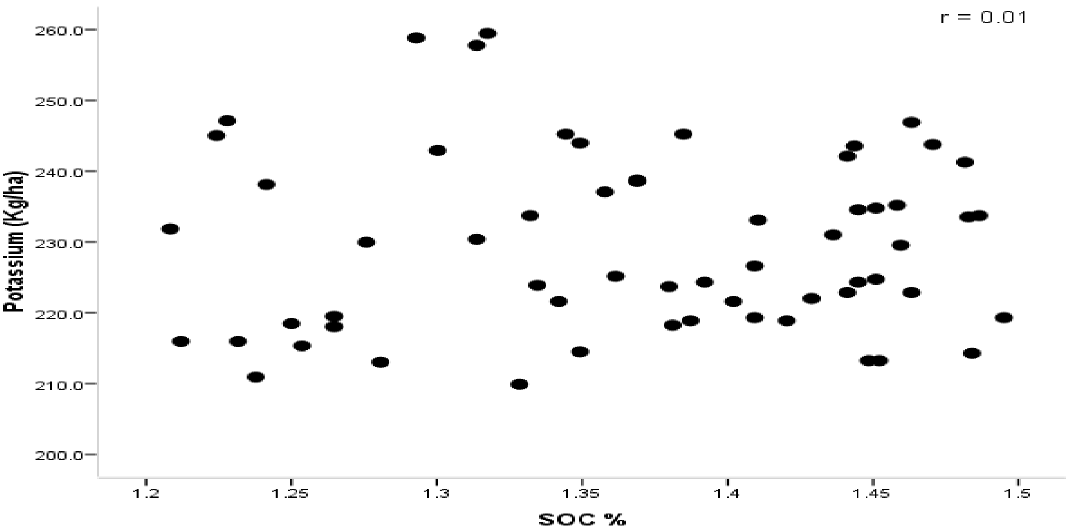

Fig. 48. Scatterred plot between soil available potassium and SOC

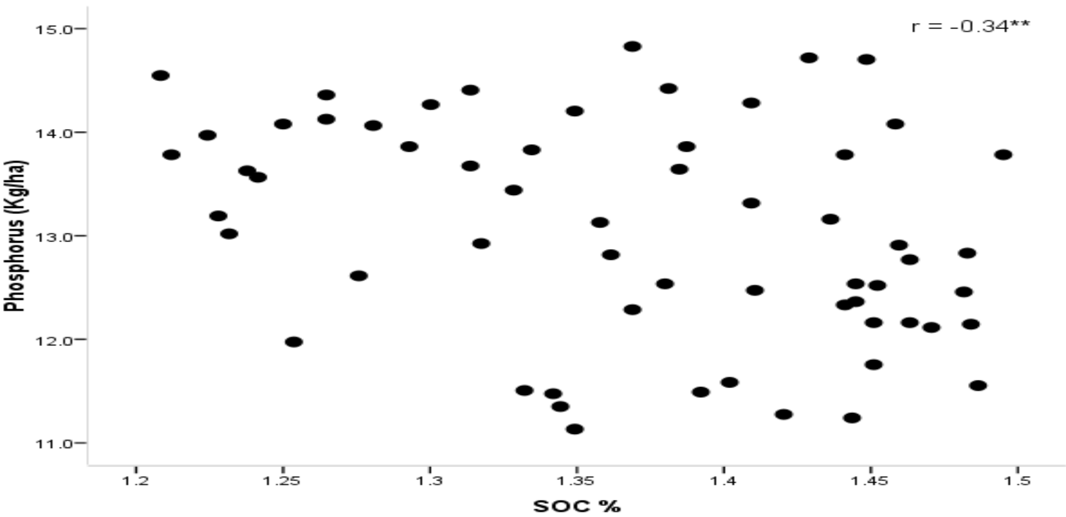

Fig. 49. Scatterred plot between soil available phosphorus and SOC

Soil available phosphorus exhibited a different relationship with respect to soil available nitrogen and potassium because of its significant mild inverse relationship with altitude ($r = -0.458^{**}$, table 21; fig. 40) while, both soil available nitrogen ($r = 0.152$, table 21; fig. 38) and potassium ($r = 0.059$, table 21; fig. 39) exhibited non-significant very weak relationship with altitude. However, irrespective of altitude and vegetation composition, it was reported that amount of organic matter *par se* accumulated in a tree based land use system directly influences the availability of soil primary nutrients (Prescott, 2002; Jerabkova *et al*., 2006; Banerjee, 2014; Tashi *et al*., 2016; Simon *et al*., 2018; Choudhury *et al*., 2021) as it is the source SOC that ultimately describes the soil physical, chemical, and biological properties (Johnston, 1986; Tans *et al*., 1990; Woomer *et al*., 1994; Fenton *et al*., 1999; Bhattacharyya *et al*., 2001; Kimble *et al*., 2007; Gupta and Sharma, 2008; John, 2010; Koul *et al*., 2011; Gairola *et al*., 2012_{a}; Shukla and Chakravarty, $2012_{a, b}$; Scotti *et al*., 2015; He *et al*., 2016; Saha *et al*., 2018; Lepcha and Devi, $2020_{a, b}$). In spite of high oxidizable SOC (table 22), the under canopy forest based traditional large cardamom agroforestry systems of Darjeeling Himalayas were estimated with medium available nitrogen and phosphorus. This is because SOC in addition to vegetation and soil factors soil also depend on topography and climatic condition of the area particularly the rainfall (Paudel and Sah, 2003). Darjeeling Himalayas receives high annual rainfall leading to nutrient run off down the slope.

However, the quantity of all these available primary nutrients decreased but non-significantly with increasing soil depth and the amount estimated at 0-20 cm, 20-40 cm and 40-60 cm soil depth was 280.60, kg Nha^{-1}, 260.26 kgN ha^{-1}& 240.98 $kgNha^{-1}$; 13.48 kg P ha^{-1}, 13.04 kg P ha^{-1}& 12.63 kg P ha^{-1} and 233.7 kg K ha^{-1}, 229.42 kg K ha^{-1}& 225.86 kg K ha^{-1}, respectively. Avalibility of primary nutrients decreased with increasing soil depth due to buildup these nutrients on the surface soil layer owing to continuous accumulation of organic matter on this layer (Juo and Lal, 1977; Srinivasanand Caulfield, 1989; Liu and Wang, 2010; He *et al*., 2016).

4.6.4. Exchangeable calcium, magnesium and aluminium

Altitude class and soil depth of large cardamom based traditional agroforestry systems along with their interaction significantly influenced its soil exchangeable calcium, magnesium and aluminium (table 24).

Table 24. Exchangeable calcium, magnesium and aluminium of large cardamom based traditional agroforestry systems at altitude classes and soil depths

AC/D	0-20 cm	20-40 cm	40-60 cm	Mean
Exchangeable calcium (c mol Kg^{-1})				
Low	0.94	0.83	0.78	**0.85**
Mid	0.93	0.75	0.72	**0.80**
High	0.64	0.63	0.39	**0.55**
Mean	**0.84**	**0.73**	**0.63**	
$LSD_{0.05}$	**A= 0.054**	**D= 0.054**	**A×D= 0.093**	
Exchangeable magnesium (c molKg^{-1})				
Low	0.48	0.52	0.42	**0.47**
Mid	0.63	0.50	0.54	**0.56**
High	0.36	0.25	0.22	**0.28**
Mean	**0.49**	**0.42**	**0.39**	
$LSD_{0.05}$	**A= 0.046**	**D= 0.046**	**A×D= 0.080**	
Exchangeable aluminium(c mol Kg^{-1})				
Low	1.37	1.36	1.33	**1.35**
Mid	1.44	3.09	1.41	**1.98**
High	1.43	1.38	1.40	**1.40**
Mean	**1.41**	**1.94**	**1.38**	
$LSD_{0.05}$	**A= 0.914**	**D= 0.914**	**A×D= 1.584**	

AC- Altitude class (low- 700-1200 m asl; mid- 1200-1700 m asl; high- > 1700 m asl); D- soil depth

Soil exchangeable calcium significantly decreased with both increasing altitude class and soil depth. Both soil exchangeable magnesium and aluminium exhibited incosistent trend with increasing altitude class but differences between the classes were significant while, with increasing soil depth soil exchangeable magnesium significantly decreased and soil exchangeable aluminium exhibited inconsistent trend but with significant difference between the soil depths. This was also evidenced from the significant inverse relationship of soil exchangeable calcium ($r = -0.477^{**}$, table 21; fig. 50) and magnesium ($r = -0.403^{**}$, table 21; fig. 51) along with non-significant relationship between soil exchangeable aluminium with altitude (r = 0.040, table 21; fig. 52). Similar behaviour of these exchangeable cations in forest soil and other tree based land use systems was also reported in earlier studies (Panwar *et al*., 2011; Choudhury *et al*., 2017; Shukla and Behera, 2017, 2019; Rai *et al*., 2021).

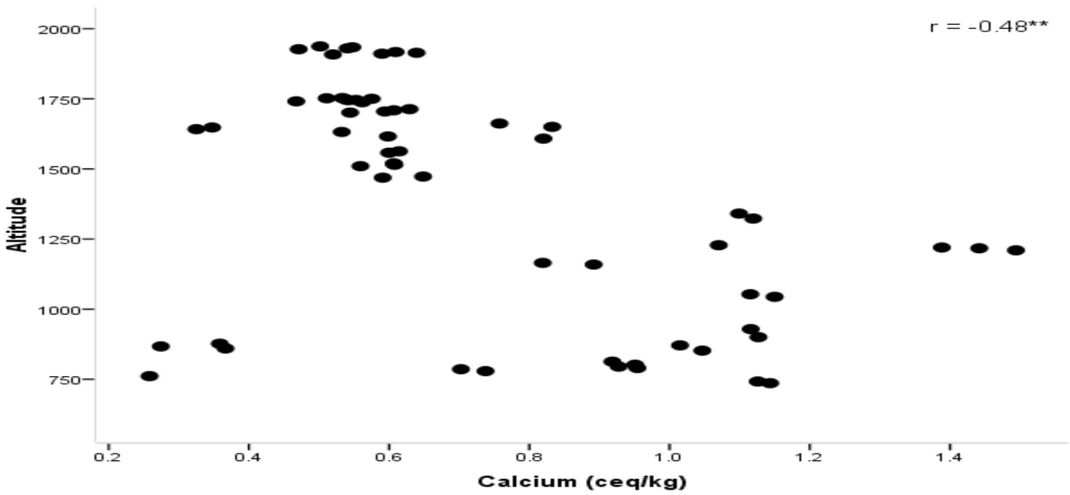

Fig. 50. Scatterred plot between soil exchangeable calcium and altitude

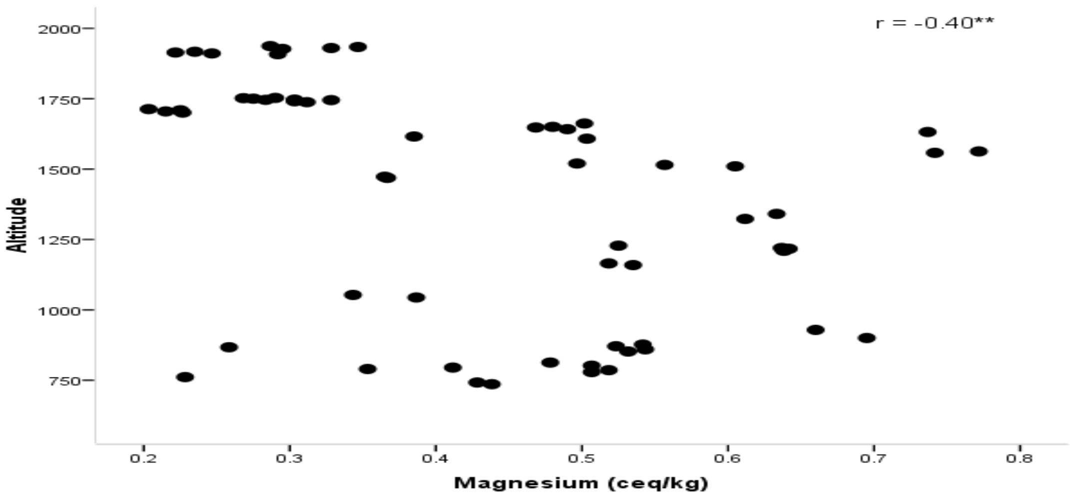

Fig. 51. Scatterred plot between soil exchangeable magnesium and altitude

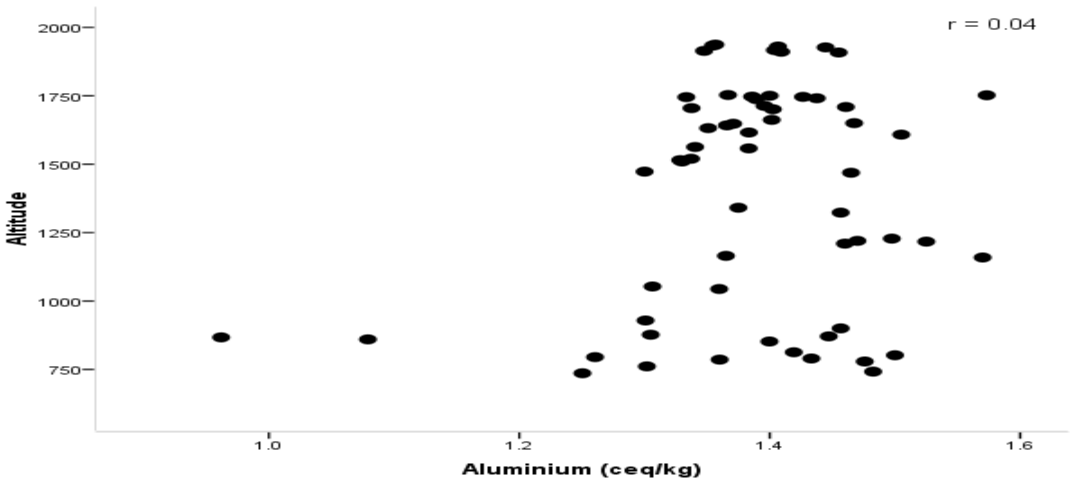

Fig. 52. Scatterred plot between soil exchangeable aluminium and altitude

4.6.5. Soil fertility indices

Soil fertility index (SFI) and soil evaluation factor (SEF) that evaluate soil fertility is significantly influenced by both altitude class and soil depth along with their interaction (table 25).

Table 25. Soil fertility indices of large cardamom based traditional agroforestry systems at altitude classes and soil depths

AC/D	0-20 cm	20-40 cm	40-60 cm	Mean
Soil fertility index				
Low	21.43	21.34	21.10	**21.29**
Mid	23.21	21.65	21.42	**22.09**
High	22.05	21.21	20.14	**21.13**
Mean	**21.75**	**20.97**	**20.89**	
$LSD_{0.05}$	**A= 0.47**	**D= 0.32**	**A×D= 0.62**	
Soil evaluation factor				
Low	6.21	6.12	5.98	**6.10**
Mid	6.35	5.73	5.99	**6.02**
High	5.63	5.45	4.95	**5.34**
Mean	**6.06**	**5.77**	**5.65**	
$LSD_{0.05}$	**A= 0.03**	**D= 0.06**	**A×D= 0.04**	

AC- Altitude class (low- 700-1200 m asl; mid- 1200-1700 m asl; high- > 1700 m asl); D- soil depth

Among the fertility indices SFI exhibited inconsistent trend with increasing altitude class though with significant difference among the classes and SEF significantly consistently decreased with increasing altitude class while both the indices significantly decreased with increasing soil depth. Soil fertility indices were significantly influenced by altitude class and soil depth because the pH, EC, moisture and availability of primary nutrients were also significantly influenced by the altitude class and soil depth (Reza *et al*., 2011; Rai *et al*., 2021).The indices estimated for the under canopy forest based large cardamom traditional agroforestry systems were comparable with different land use systems (Moran *et al*., 2000; De M Sá *et al*., 2001; Lu *et al*., 2002; Panwar *et al*., 2011) and higher than forest plantations (Rai *et al*., 2021) at terai zone of West Bengal.

This means that soil fertility of large cardamom based traditional agroforestry systems was comparably higher than forest plantations. Higher the fertility of a tree based land use system, higher is its productivity indicated (Panwar *et al*., 2011). This may be attributed to the quantity of organic matter added to the system through litter fall (de Hann, 1977; Pande, 2001; Pande and Sharma, 1993; Scott and Binkley, 1997; Panwar *et al*., 2011; Uriarte *et al*., 2015; Rai *et al*., 2021).The under canopy forest based large cardamom traditional agroforestry systems of Darjeeling Himalayas due to their vegetation heterogeneity might have added higher organic matter into the system through litter fall which is evidenced from its high oxidizable SOC content (table 22). Improved soil fertility under trees based systems was reported by many studies(Pandey *et al*., 2000; Panwar *et al*., 2011; Rai *et al*., 2021; Tamang *et al*., 2021).Variability of soilnutrients in tree based land use systems across an altitudinal gradient was reported due to variability of altitude mediated climatic factors like rainfall, temperature and vegetation composition (Rajput *et al*., 2015, 2017; Bargali *et al*., 2018; Manral *et al*., 2020; Choudhury *et al*., 2021) which creates variation in soil physico-chemical properties (Choudhury *et al*., 2013; 2016; Bargali *et al*., 2019).

4.6.6. Tree biomass and carbon stock

The amount of overall and tree species biomass and carbon estimated for low, mid and high-altitude class of large cardamom based traditional agroforestry systems of Darjeeling Himalaya is given in table 26 and 27.

Table 26. Tree biomass and biomass carbon (Mg ha^{-1}) of large cardamom based traditional agroforestry systems at altitude classes

AC	AGB	BGB	TB	AGC	BGC	TC
Low	504.14	126.03	630.17	236.94	59.24	296.18
Medium	317.64	79.41	397.05	149.29	37.32	186.61
High	252.63	63.16	315.78	118.73	29.68	148.42
Mean	**358.14**	**89.53**	**447.67**	**168.32**	**42.08**	**210.40**
LSD$_{0.05}$	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

AC- Altitude class (Low- 700-1200 m asl; Mid- 1200-1700 m asl; High- > 1700 m asl); AGB- Above ground biomass; BGB- Below ground biomass; TB- Total biomass; AGC- Above ground carbon; BGC- Below ground carbon; TC- Total carbon

The tree biomass and carbon accumulated was 447.67 & 210.40 Mg ha^{-1} while, at low-, mid- and high-altitude class it was 630.17 & 296.18 Mg ha^{-1}, 397.05 & 186.61 Mg ha^{-1} and 315.78 & 148.42 Mg ha^{-1}, respectively (table 26). The contribution of the above ground biomass (AGB) was 80 % at all the altitude classes. The tree biomass accumulated in the systems decreased gradually with increasing altitude class by 36.99 % from low- to mid-altitude, 20.47 % from mid- to high-altitude class and 49.89 % from low- to high-altitude class due to variation in tree population, richness and diameter at breast height or dbh (table 27).

Table 27. Biomass and carbon accumulation by tree species in large cardamom based traditional agroforestry systems

Species	D	H	Dy	AGB	BGB	TB	AGC	BGC	TC
Low-altitide class									
A. nepalensis	39.5	39.3	35	23.3	5.8	29.2	11.0	2.7	13.7
O. indicum	20.7	32.6	70	11.6	2.9	14.5	5.4	1.4	6.8
C. tetrandra	16.9	22.9	35	3.7	0.9	4.6	1.7	0.4	2.2
T. myriocarpa	23.9	35.0	105	23.6	5.9	29.6	11.1	2.8	13.9
C. cashmeriana	18.8	41.1	60	8.	2.0	10.1	3.8	0.9	4.7
J. indica	24.8	29.9	95	23.3	5.8	29.1	10.9	2.7	13.7
C. japonica	54.8	44.5	30	40.6	10.1	50.7	19.1	4.8	23.8
M. denticulata	26.7	15.8	65	18.7	4.7	23.4	8.8	2.2	11.0
O. paniculata	19.7	30.5	35	5.2	1.3	6.5	2.5	0.6	3.1
A. odoratissima	28.7	18.3	110	36.7	9.2	45.9	17.3	4.3	21.6
E. variegate	31.2	27.4	50	20.1	5.0	25.1	9.4	2.4	11.8
A. procera	23.2	18.3	70	14.9	3.7	18.6	7.0	1.7	8.7
C. indica	18.1	26.8	60	7.5	1.9	9.3	3.5	0.9	4.4
L. monopetala	24.8	27.1	130	31.9	8.0	39.8	15.0	3.7	18.7
T. ciliata	24.5	27.4	105	25.0	6.3	31.3	11.8	2.9	14.7
F. auriculata	19.7	36.6	190	28.4	7.1	35.5	13.3	3.3	16.7
F. lacor	16.6	27.1	115	11.7	2.9	14.7	5.5	1.4	6.9
F. semicordata	29.9	27.4	110	40.3	10.1	50.4	19.0	4.7	23.7
Citrus spp	12.7	23.4	45	2.6	0.6	3.3	1.2	0.3	1.5
F. colorata	24.8	27.4	120	29.4	7.3	36.8	13.8	3.5	17.3
S. wallichii	33.7	29.9	205	97.5	24.4	121.8	45.8	11.45	57.3
Mean	**25.4**	**29.0**	**88**	**24.0**	**6.0**	**30.0**	**11.3**	**2.8**	**14.1**
Mid-altitude class									
A. nepalensis	29.9	39.3	155	56.8	14.2	71.2	26.7	6.7	33.4
B. javanica	22.9	33.5	40	8.2	2.1	10.3	3.9	1.0	4.8
B. mitis	21.7	10.4	80	14.6	3.6	18.2	6.8	1.7	8.6
C. japonica	32.5	44.5	210	91. 9	23.0	114.9	43.2	10.8	54.0
C. cashmeriana	17.5	41.1	35	4.0	1.0	5.0	1.9	0.5	2.4
E. variegate	24.2	27.4	50	11.6	2.9	14.5	5.4	1.4	6.8
E. populnea	22.3	15.2	20	3.9	1.0	4.8	1.8	0.5	2.3
F. semicordata	21.7	27.4	85	15.5	3.9	19.4	7.3	1.8	9.1
Ficus spp.	23.6	23.5	40	8.7	2.2	11.0	4.1	1.0	5.1
F. colorata	16.9	27.4	55	5.8	1.5	7.3	2.7	0.7	3.4
G. odorata	22.3	19.8	45	8.7	2.2	10.9	4.1	1.0	5.1
L. canum	8.0	29.9	50	1.0	0.3	1.3	0.5	0.1	0.6
M. denticulata	28.0	15.8	75	23.9	6.0	29.8	11.2	2.8	14.0
M. tetracoccus	24.8	37.8	30	7.3	1.8	9.2	3.5	0.9	4.3
P. cerasoides	21.3	9.7	35	6.2	1.5	7.7	2.9	0.7	3.6
S. wallichii	28.7	29.9	95	31.7	7.9	39.6	14.9	3.7	18.6

D- Diameter at breast height (cm); H- height (m); Dy- Density (trees ha^{-1}); AGB- Above ground biomass (Mg ha^{-1}); BGB- Below ground biomass (Mg ha^{-1}); TB- Total biomass (Mg ha^{-1}); AGC- Above ground carbon (Mg ha^{-1}); BGC- below ground carbon (Mg ha^{-1}); TC- Total carbon (Mg ha^{-1})

Table 27 contd.

Species	D	H	Dy	AGB	BGB	TB	AGC	BGC	TC
T. myriocarpa	12.7	35.0	50	2.9	0.7	3.6	1.4	0.3	1.7
T. ciliata	31.8	27.4	35	14.7	3.7	18.3	6.9	1.7	8.6
Mean	**43.2**	**52.1**	**124.7**	**25.1**	**8.4**	**41.8**	**15.7**	**3.9**	**19.6**
High-altitude class									
A. nepalensis	27.1	39.3	120	35.4	8.8	44.3	16.6	4.2	20.8
C. japonica	28.7	44.50	110	36.7	9.2	45.9	17.3	4.3	21.6
C. cashmeriana	33.1	41.1	145	66.2	16.5	82.7	31.1	7.8	38.9
E. attenuatus	28.0	10.7	80	25.4	6.4	31.8	12.0	3.0	15.0
L. glutinosa	21.3	33.5	5	0.9	0.2	1.1	0.4	0.1	0.5
M. edulis	21.0	17.1	35	6.0	1.5	7.5	2.8	0.7	3.5
M. doltsopa	22.3	15.8	15	2.9	0.7	3.6	1.4	0.3	1.7
M. grandiflora	18.1	23.8	15	1.9	0.5	2.3	0.9	0.2	1.1
M. lanuginosa	22.9	15.8	45	9.3	2.3	11.6	4.4	1.1	5.4
P. wallichiana	14.0	36.0	55	3.9	1.0	4.9	1.8	0.5	2.3
R. griffithianum	20.4	33.8	35	5.6	1.4	7.0	2.6	0.7	3.3
S. wallichii	38.2	29.9	75	46.6	11.6	58.3	21.9	5.5	27.4
T. myriocarpa	26.4	35.0	35	9.8	2.4	12.3	4.6	1.1	5.8
T. plicata	22.6	10.7	10	2.0	0.5	2.5	0.9	0.2	1.2
Mean	**45.9**	**51.6**	**104.0**	**33.7**	**8.4**	**42.1**	**15.8**	**4.0**	**19.8**

D- Diameter at breast height (cm); H- height (m); Dy- Density (trees ha^{-1}); AGB- Above ground biomass (Mg ha^{-1}); BGB- Below ground biomass (Mg ha^{-1}); TB- Total biomass (Mg ha^{-1}); AGC- Above ground carbon (Mg ha^{-1}); BGC- below ground carbon (Mg ha^{-1}); TC- Total carbon (Mg ha^{-1})

Similarly, the relationship between tree biomass accumulation and altitude was also inverse and significant (r = - 0.255*, table 21). Similar non-significant effect of altitude on forest biomass and carbon was earlier reported (Cavanaugh *et al*., 2014; Mensah *et al*., 2016; Wondimu *et al*., 2021) while on the contrary, either direct or inverse relationshipsbetween elevation and biomass or carbon stock also exist (Moser *et al*., 2007; Zhu *et al*., 2010; Ensslin *et al*., 2015; Zhang *et al*., 2018). Varied relationship on biomass and biomass carbon found was attributed to varied range of altitude considered in the studies (Wondimu *et al*., 2021). The large cardamom based traditional agroforestry systems at low altitude-class accumulated highest biomass and carbon unit area due to highest number of trees and tree species followed by mid-altitude class and the least at high-altitude class.

This was evidenced from direct relationship of tree biomass accumulation with species richness (r = 0.450**, table 21) and plant population (r = 0.421**, table 21). Similarly, relationship between tree biomass/tree biomass carbon and tree density was also reported from large cardamom basd traditional agroforestry systems from Sikkim Himalayas (Lepcha and Devi, 2020_a). Significant and positive influence ofspecies richness on forest biomass and biomass carbon after the effect's altitude was also accounted for in many studies (Ruiz-Jaen and Potvin, 2010; Vance-Chalcraft *et al*., 2010; Wang *et al*., 2011; Barrufol *et al*., 2013; Mandal *et al*., 2013; Cavanaugh *et al*., 2014; Ruiz-Benito *et al*., 2014; Wu *et al*., 2015, 2017; Mensah *et al*., 2016; Wondimu *et al*., 2021). Direct relationship of biomass or carbon accumulation with species richnesswas attributed to various biotic interactions like facilitation e.g., improving soil fertility by atmospheric nitrogen fixing, litter fall and many more which explains land uses with heterogeneous vegetation or forests with higher productivity than homogenous vegetation (Ruiz-Benito *et al*., 2014; Mensah *et al*., 2016, 2018; Sarkar, 2020; Rai *et al*., 2021; Wondimu *et al*., 2021). However, inverse or no relationship of biomass and carbon with species richness was also reported (Whittaker andHeegaard, 2003; Ruiz-Jaen and Potvin, 2011; Zhang *et al*., 2014) indicating that biomass and carbon not only is influenced by species diversity of the system but also on-site quality factors, succession stages the ofthe forests and specific dimension of the diversity measure used (Vance-Chalcraft *et al*., 2010; Lasky *et al*., 2014; Wu *et al*., 2015).

Total tree biomass and tree biomass carbon in this study was much higher than what was quantified for Sikkim Himalayan systems (Lepcha and Devi, 2020_a), homegardens of terai zone and Darjeeling Himalayas West Bengal (Subba *et al*., 2017_d, 2018_a; Pala *et al*., 2020; Sarkar, 2020) and elsewhere (Takimoto *et al*., 2008; Nair *et al*., 2010; Rizvi *et al*., 2011; Prasad *et al*., 2012; Kalita *et al*., 2016; Xie *et al*., 2017; Yadav *et al*., 2017) while, comparable to different subtropical forest ecosystems (Borah *et al*., 2013, 2015; Chaudhary *et al*., 2016). The variation in biomass and carbon accumulation amongst these studies was due to variation in geographical location (site quality, topography, climate, edaphic conditions), plant species and species diversity (stem density, stem size distribution, age, density, diameter, canopy height and wood density), management practices and disturbance history (Swamy and Puri, 2005; Do *et al*., 2010; Con *et al*., 2013; Goswami *et al*., 2013; Kanime *et al*., 2013; Ngo *et al*., 2013; Slik *et al*., 2013; Karthick and Pragasan, 2014; Liu *et al*., 2015; Mohandass *et al*., 2016; Sarkar, 2020; Rai *et al*., 2021; Tamang *et al*., 2021). High total tree biomass and tree biomass carbon storage coincides with high tree densities and diameter similar to tea agroforestry system of Assam (Kalita *et al*., 2016) but contrast to *Dipterocarpus* forest of Manipur where tree carbon densities increased with increase in girth size that may be related to the difference in the carbon capture pattern of different species (Devi and Yadava, 2016). This was also evidenced from linear regression models between tree density and tree diameter (r^2 = 0.05863, P < 0.05; fig. 53) and tree biomass density and tree diameter (r^2 = 0.407, P < 0.01; fig. 53).

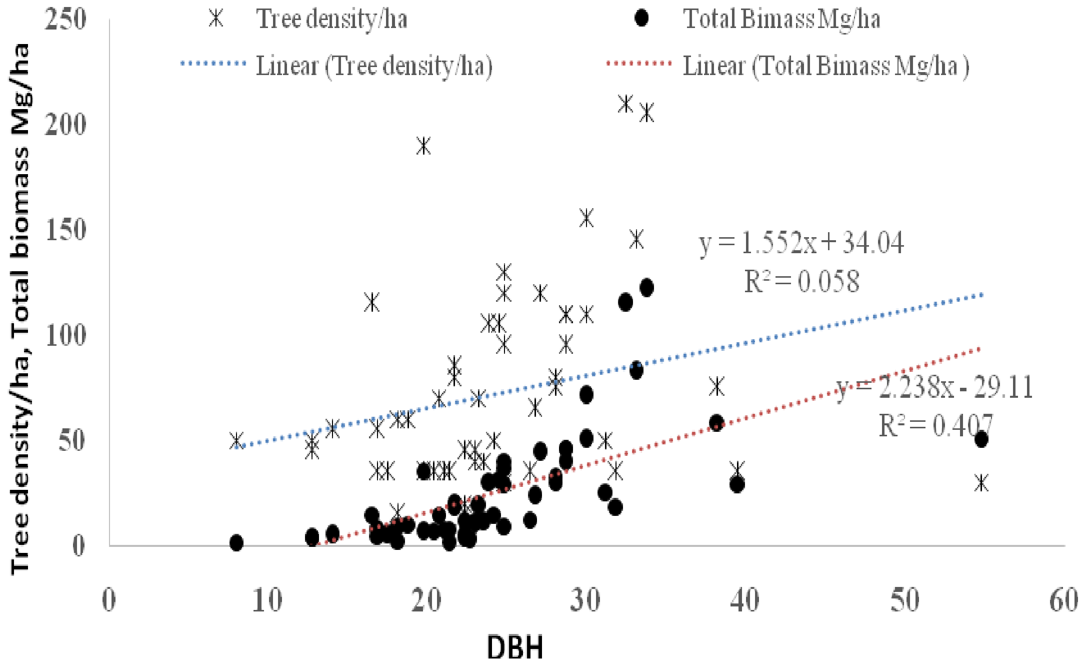

Fig. 53. Regression models tree density and tree diameter and tree biomass density and tree diameter

Similar regression models were also reported for large cardamom systems of Sikkim Himalayas (Lepcha and Devi, 2020_a), Darjeeling Himalayan homegardens (Sarkar, 2020) and for different subtropical ecosystems of Northeast India (Borah *et al*., 2015; Chaudhary *et al*., 2016).Studies had established very negligible contribution of under storey vegetation to total biomass accumulated by any forests or other tree based land use systems (Rawat and Negi, 2004; Shukla and Chakravarty, 2012_a; Giri and Rawat, 2013; Shukla *et al*., 2014, 2017_a, 2018; Subba *et al*., 2017_d, 2018_a; Shukla and Chakravarty, 2018; Sarkar, 2020; Rai *et al*., 2021; Tamang *et al*., 2021). Therefore, this study also ignored the biomass contribution by shrubs and herbs in the system.

Biomass and carmulation accumulation of species varied from species to species and also from altitude class to altitude class due to variation in tree density and diameter at breast height (table 27). At low-altitude class the most prominent tree species in terms of biomass accumulation was *Schima wallichii* with estimated biomass of 121.8 Mg ha^{-1} with average dbh of 33.7 cm and density of 205 trees ha^{-1}. *Schima wallichii* was followed by *Cryptomeria japonica* with estimated biomass of 50.7 Mg ha^{-1}, dbh 54.8 cm & density 30 trees ha^{-1} and *Ficus semicordata* with biomass of 50.4 Mg ha^{-1} with dbh 29.9 cm & density 110 trees ha^{-1}. The prominent tree species at mid-altitude class were *Cryptomeria japonica* with biomass of 114.9 Mg ha^{-1}, dbh of 32.5 cm & density of 210 trees ha^{-1}, *Alnus nepalensis* with biomass of 71.2 Mg ha^{-1} with dbh 29.9 cm & density 155 trees ha^{-1} and *Schimawallichii* with biomass of 39.6 Mg ha^{-1} with dbh 28.7 cm & density 95 trees ha^{-1}. *Cupressus cashmeriana*, *Schimawallichii*, *Cryptomeria japonica*and *Alnus nepalensis*were prominent tree species found at high-altitude class with biomass accumulation of 82.7, 58.3, 45.9 & 44.3 Mg ha^{-1} with dbh of 33.1, 38.2, 28.7 & 27.1 cm and density of 145, 75, 110 and 120 trees ha^{-1}, respectively.

Average diameter at breast height for the trees recorded in the system was in the range of 7.96-39.49 cm (*Leucosceptrum canum-Alnus nepalensis*) and average height of the trees measured was in the range of 9.75-44.50 m (*Prunus cerasoides-Cryptomeria japonica*). Average diameter (at breast height) recorded at low-, mid- and high-altitude class was 12.74-44.50 cm (*Citrus spp.-Alnus nepalensis*), 7.96-32.48 cm (*Leucosceptrum canum-Cryptomeria japonica*) and 14.01-38.22 cm (*Pinus wallichiana-Schima wallichii*). Tree height measured at these altitude classes was 10.67-44.47 (*Thuja plicata-Cryptomeria japonica*), 9.75-44.45 (*Prunus cerasoides-Cryptomeria japonica*) and 15.85-44.50 (*Macaranga denticulata-Cryptomeria japonica*), respectively. Tree density estimated for the system was 5.0-210.0 trees ha^{-1} (*Litsea glutinosa-Cryptomeria japonica*. Other prominent tree species with higher population density documented in the system were *Schima wallichii* (205 trees ha^{-1}), *Ficus auriculata* (190trees ha^{-1}), *Alnus nepalensis* (155trees ha^{-1}), *Cupressus cashmeriana* (145 trees ha^{-1}), *Litsea monopetela* (130 trees ha^{-1}) *Ficus colorata* (120 tree ha^{-1}), *Ficus lacor* (115 trees ha^{-1}), *Ficus semicordata* (110 trees ha^{-1}), *Albizia odoratissima* (110 trees ha^{-1}), *Terminalia myriocarpa* (105 trees ha^{-1}) and *Toona ciliata* (105 trees ha^{-1}). Tree density estimated at low-altitude class was in the range of 30-205 trees ha^{-1} (*Cryptomeria japonica-Schima wallichi*). Other denser tree species at this class documented were *Ficus auriculata* (190 trees ha^{-1}), *Litsea monopetela* (130 trees ha^{-1}), *Ficus colorata* (120 trees ha^{-1}), *Ficus lacor* (115 trees ha^{-1}), *Ficus semicordata* (110 trees ha^{-1}), *Albizia odoratissima* (110 trees ha^{-1}), *Terminalia myriocarpa* (105 trees ha^{-1}) and *Toona ciliata* (105 trees ha^{-1}). The densest tree species documented at the mid-altitude class was *Cryptemoria japonica* (210trees ha^{-1}) followed by *Alnus nepalensis* (155trees ha^{-1}), *Schima wallichii* (95trees ha^{-1}), *Ficus semicordata* (85 trees ha^{-1}), *Brassaiopsis mitis* (80 trees ha^{-1}) and the sparse tree species was *Eubacklandia populnea* (20 trees ha^{-1}). Highest tree population density at high-altitude class estimated was 145 trees ha$^{−1}$ for *Cupressus cashmeriana*, followed by 120 trees ha$^{−1}$ for *Alnus nepalensis*, 110 trees ha$^{−1}$ for *Cryptomeria japonica*, 80 trees ha^{-1} for *Euonymus attenuates*, 75 trees ha^{-1} for *Schima wallichi* and five trees ha^{-1} for *Litsea glutinosa*.

In contrast to the Sikkim Himalayan large cardamom based traditional agroforestry systems where *Alnus nepalensis* was prominent shade tree with density of 80.13 tree ha$^{−1}$ (Lepcha and Devi, 2020$_a$), prominent trees found in the Darjeeling Himalayan systems were *Schima wallichi* with density of 205.0 trees ha$^{−1}$, at low-altitude class, *Cryptemoria japonica*with density of 210 trees ha$^{−1}$ at mid-altitude class and *Cupressus cashmeriana* with density 145 trees ha$^{−1}$ at high-altitude class. In this study *Alnus nepalensis* was found with density of only 35 trees ha$^{−1}$ at low altitude class while, at mid- and high-altitude classthe species followed *Cryptemoria japonica* and *Cupressus cashmeriana* with density of 155 and 120 trees ha$^{−1}$, respectively. However, the density of *Alnus nepalensis* estimated at mid- and high-altitude class in the present study is 39.87-74.87 trees ha$^{−1}$than estimated at Sikkim Himalayas (80.13 trees ha$^{−1}$) in the altitude of 1350 to 1619 m above mean sea level. This was because the studied systems at Sikkim Himalayaswere in the agricultural landscape planted 20 years ago where the growers preferred *Alnus nepalensis* to maintain soil fertility andproductivity as it can fix atmospheric nitrogen (Sharma *et al*., 1994). In contrast, the Darjeeling systems were cultivated under canopy of leased out forest land by the growers with no rights to change the natural species composition of the forest. However, total tree density estimated in this study (105.33 trees ha$^{−1}$) was lesser than the Sikkim Himalayan studies (124.19 trees ha$^{−1}$) because the Darjeeling Himalayan systems were forest based (Sharma *et al*., 2007) where dominance of the species were distributed as compared to the Sikkim Himalayan system which were planted at an agricultural landscape where preferred species were planted and allowed to grow.

The tree density of Darjeeling Himalayan system was also either comparable or higher than the poplar agroforestryof Northwestern India (Rizvi *et al*., 2011), jhum fallow agroforestry of Tripura (Chaudhary *et al*., 2016), homegardens of terai region and Darjeeling Himalayas of West Bengal (Subba *et al*., 2017$_b$; Sarkar, 2020), poplar agroforestry systems of China (Fang *et al*., 2010) and coffee agroforestryof Guatemala (Schmitt-Harsh *et al*., 2012).This indicates that the under canopy forest based traditional large cardamom agroforestry systems were promoting harbouring and maintaining diverse tree species with higher overall population because of their retained structure and composition of the original forest promoteand encourage higher tree growth and is very closelysimilar to a natural forest (Sharma *et al*., 2007). However, the basal area of the systems estimated in the range of 4.46-18.27 m^2 ha^{-1} with an average of 13.31 m^2 ha^{-1} was lesser than the Sikkim systems (Lepcha and Devi, 2020_a), tea agroforestry of Assam (Kalita *et al*., 2016), managedplantation and jhum fallow agroforestry of Tripura(Chaudhary *et al*., 2016) and homegardens of may be due to young age of thetrees in the agroforestry system terai region and Darjeeling Himalayas of West Bengal (Subba *et al*., 2017_b; Sarkar, 2020). This is because of higher heterogeneity of the Darjeeling systems in terms of its structure and composition where dominance by the species was distributed with higher inter- and intra-specific competition (Odum, 1971, 1983).

In contrast to maximum biomass and carbon stock by *Alnus nepalensis* at Sikkim Himalayan systems, the maximum biomass and carbon stock estimated in this study was by *Schima wallichii* at low-altitude class, *Cryptomeria japonica*at mid-altitude class and *Cupressus cashmeriana* at high-altitude class but highest biomass and carbon accumulation in this study was also found corresponding with highest tree density and diameter at breast height or basal area similar to the Sikkim study (Lepcha and Devi, 2020_a). However, the tree biomass and carbon storage estimated for different species in this study a was inconsistent with diameter at breast height of the trees but largely consistent with the tree density similar to studies reported for large cardamom systems of Sikkim Himalayas (Lepcha and Devi, 2020_a), homegardens of Darjeeling Himalayas (Sarkar, 2020) and tea agroforestry system of Assam (Kalita *et al*., 2016) while, was contrast to *Dipterocarpus* forest of Manipur (Devi and Yadava, 2016). Similarly above and below ground biomass allocation of many individual tree species were reported with major contribution by above ground biomass (Rana and Singh, 1990; Tandon *et al*., 1991; Bargali *et al*., 1992; Shrestha *et al*., 2000; Koul, 2011; Rawat and Negi, 2004; Subedi, 2004; Swami *et al*., 2006; Liu and Yu, 2009; Singh and Lodhiyal, 2009; Zhang *et al*., 2009; Sharma *et al*., 2010_b; Yadava, $2010_{a,\ b}$; Rizvi *et al*., 2011; Giri and Rawat, 2013; Kanime *et al*., 2013;Ali *et al*., 2014;Arora *et al*., 2014; Iqbal *et al*., 2014_b; Behera and Mohapatra, 2015; Justine *et al*., 2015; Singh and Singh, 2017). Large cardamom based traditional agroforestry systems in the present study found many including *Alnus nepalensis*which provide multiple ecosystem services from provisions like fuelwood and fodder to regulatory like maintaining soil fertility andproductivity (Sharma *et al*., 1994; Anitha and Hore, 2018; Lepcha and Devi, $2020_{a,\ b}$; Cyamweshi*et al*., 2021; Vineeta *et al*., 2021). However, *Alnus nepalensis* was reported as dominant shade tree species in large cardamom based traditional agroforestry systems of Sikkim Himalayas (Sharma and Ambasht, 1984; Sharma *et al*., 1994; Sharma and Sharma, 1997; Sharma *et al*., 2007; Anitha and Hore, 2018; Singh *et al*., 2018$_a$; Lepcha and Devi, 2020$_{a,\ b}$; Vineeta *et al*., 2021) but in present study the species was present but not as a dominant shade tree species.

Biomass quantification and allocation by the shade trees of large cardamom based traditional agroforestry system will improve our understanding its life history strategies like nutrient cycling, carbon stocks, fuel property and potential to offset carbon dioxide emission (Mary *et al*., 2001; Westoby *et al*., 2002; Wright *et al*., 2004; Pickup *et al*., 2005; Niinemets *et al*., 2007; Mandal and Joshi, 2014). Such understanding will aid in developing sustainable land management options for the Darjeeling Himalayas (Kumar and Nair, 2011; Nair, 2012$_{a,\ b}$; Schoeneberger *et al*., 2012; Murthy *et al*., 2013; Cubbage*et al*., 2013; Lorenz and Lal, 2014; Nair and Nair, 2014; Possu *et al*., 2018; Shukla and Chakravarty, 2018; Sarkar, 2020; Rai *et al*., 2021; Tamang *et al*., 2021). Further understanding the quantum of biomass accumulation and allocation of the system was used to quantify the productivity of dominant tree species in the system. Dominant tree species in the system are crucial while managing the system sustainably because they regulate the magnitude and pattern of energy flow and material cycle between biotic and abiotic components of the system (Devi and Yadava, 2009). Quantified biomass of the system will be helpful to understand the contribution of the shade tree species and the system as a whole towards net carbon emission along with their potential to sequester carbon which can be used for planning viable options to mitigate climate change locally, regionally and globally as well as (Chhabra and Dadhwal, 2004). This is because large cardamom based traditional agroforestry systems are sequestering carbon permanently because the system is forest based that too on reserved forests where the shade tree species will never ever be totally removed like other traditional agroforestry systems (Kumar *et al*., 1994; Kumar, 2006$_{a,\ b}$; Henry *et al*., 2009; Nair *et al*., 2010; Saha *et al*., 2009, 2010; Chakravarty *et al*., 2017$_{a,\ b}$; Coelho, 2017; Shukla *et al*., 2017$_a$; Subba *et al*., 2017$_d$, 2018$_a$; Kumar *et al*., 2018; Dar *et al*., 2019; Das *et al*., 2019; Mengistu and Asfaw 2019; Pala *et al*., 2020; Sarkar, 2020; Rai *et al*., 2021; Tamang *et al*., 2021; Vineeta *et al*., 2021).

4.6.7. Ecosystem carbon stock

Ecosystem carbonstock of large cardamom based traditional agroforestry system in Darjeeling Himalaya is given in fig. 54.

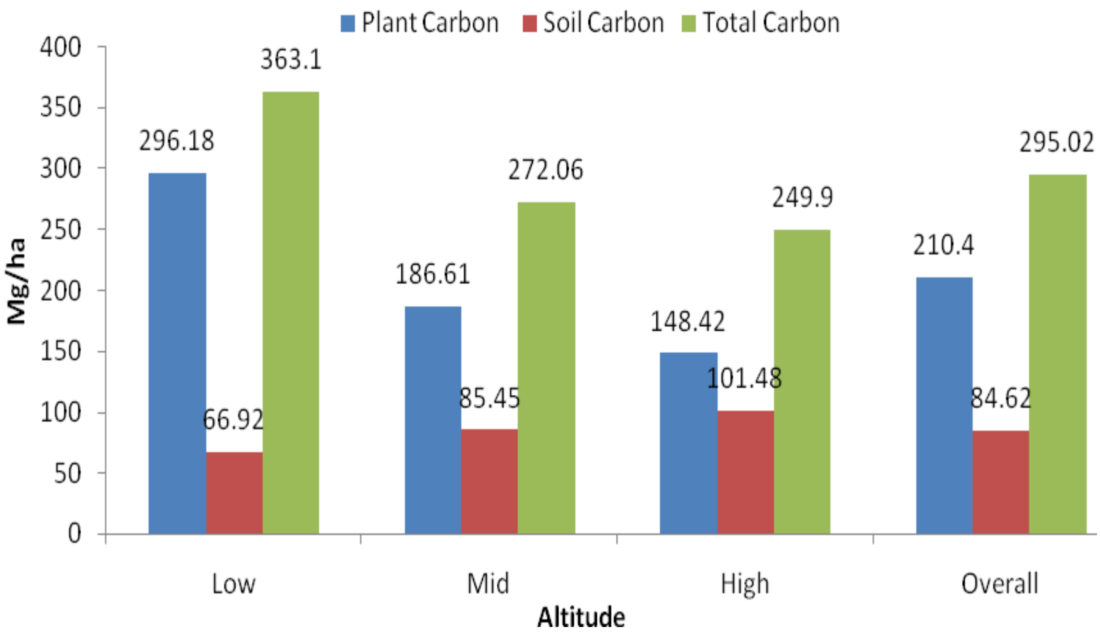

Fig. 54. Ecosystem carbon stock of large cardamom based traditional agroforestry system in Darjeeling Himalayas

The overall ecosystem carbon stock estimated in the large cardamom based traditional agroforestry systems of Darjeeling Himalayas was 295.02 Mgha^{-1}. The contribution of tree biomass carbon to the stock was 71.32 % and 28.68% was contributed by the soil. The ecosystem carbon stock at low-, mid- and high-altitude class systems estimated was 363.10 Mg ha^{-1}, 272.06 Mg ha^{-1} and 249.90 Mg ha^{-1}, respectively. The contribution by the tree biomass carbon to the ecosystem carbon stock of the system at these respective altitude classes was 81.57 %, 68.59 % and 59.39 % while, soil carbon contributed the rest. Contribution of SOCto ecosystem carbon stock increased with increasing altitude but contribution by tree biomass carbon decreased with increasing altitude class because SOC stock of the system gradually increased with increasing altitude class and reverse was true for the tree biomass carbon. The ecosystem carbon stock estimated for the low-altitude class systems was 36.43 % and 45.30 % more than the mid- and high-altitude class systems, respectively while, mid-altitude class systems were estimated with 8.87 % more ecosystem carbon stock than high-altitude class systems.

Ecosystem carbon stock estimated for the Darjeeling Himalayan under canopy forest based large cardamom traditional agroforestry systems estimatedwas higher than the stock estimated for traditional homegardens, farm forestry and forestry plantations

(Dissanayake*et al*., 2009; Kumar and Takeuchi, 2009; Saha *et al*., 2009; Kumar, 2011; Bikila and Zebene, 2019; Dar *et al*., 2019; Mengistu and Asfaw, 2019; Mulatu, 2019; Semere, 2019; Siyum and Tassew, 2019; Betemariyam*et al*., 2020; Chettri, 2020; Sarkar, 2020, Rai *et al*., 2021; Tamang *et al*., 2021). Carbon sequestration potential of tree based land use systems varies with geographical location, nature of species, species richness and age of the tree (Liu *et al*., 2015). Moreover, the amount of carbon stored in large cardamom based traditional agroforestry system was reported predominantly dependenton its structure and function and which in turn were influenced by community and culture of the region (Sharma *et al*., 2000, 2007; Singh *et al*., 2018_{a}; Lepcha and Devi, $2020_{a,\ b}$). Both higher biomass carbon stock and SOC stock can efficiently and permanently manage the ecosystem carbon pool in the large cardamom based traditional agroforestry systems (Mathew *et al*., 2016). This is because of higher carbon net gain by the heterogenous vegetation composition of the under canopy forest based large cardamom traditional agroforestry systems which were undisturbed owing to their reserved forest status as compared to any other land usesustems in an agricultural landscape (Winjum *et al*., 1992; Albrecht and Kandji, 2003; Kumar and Nair, 2004, 2011; Montagnini and Nair, 2004; Panwar *et al*., 2017; Jha, 2018; Dar *et al*., 2019; Das *et al*., 2019; Sarkar, 2020). The under canopy forest traditional large cardamom farming systems are diverse both structurally and compositionally and being reserved forest biomass removal were restricted which make the system permanent, stable, resilient and productive (Findlay, 1985; Roy, 1999; Albrecht and Kandji, 2003; Kumar, 2006_{b}; Montagnini, 2006; Henry *et al*., 2009;Folke *et al*., 2010; Nair *et al*., 2010; Saha *et al*., 2009, 2010; Nair, 2011; Chakravarty *et al*., $2017_{a,\ b}$; Shukla *et al*., 2017_{b}; Subba *et al*., 2015, 2016, $2017_{a\text{-}d}$, $2018_{a,\ b}$).

The quantified amount of ecosystem carbon stock in the large cardamom based traditional agroforestry systems of Darjeeling Himalayas indicate that the system is a prospective carbon sink both in vegetation and soil due to its higher tree density and natural resource conservation based traditional farming practices. This traditional practice of under canopy large cardamom cultivation below the forest canopy can be an efficient adaptation option at Darjeeling Himalayas to mitigate climate change locally and regionally because of its permanent nature with potential for net net gain and high ecosystem carbon balance besides the provision of livelihood and ecological benefits to the locals (Kumar and Nair, 2004; Montagnini and Nair, 2004; Kumar, 2006_{b}; $2008_{a\text{-}d}$, 2011; Nath *et al*., 2008; Panwar and Chakravarty, 2010; Aertsens *et al*., 2013; Verma *et* *al*., 2014; Kim *et al*., 2016; Madalcho and Tefera, 2016; Chakravarty *et al*., 2017$_{a, b}$, 2018$_{a, b}$, 2019, 2020; Coelho, 2017; Hart *et al*., 2017;Kumar *et al*., 2018; Mengistu and Asfaw, 2019; Dar *et al*., 2019; Das *et al*., 2019, Chettri, 2020; Lepcha and Devi, 2020$_{a, b}$; Sarkar, 2020, Rai *et al*., 2021; Tamang *et al*., 2021, Vineeta *et al*., 2021). This Darjeeling traditional under forest canopy large cardamom farming system thus is a viable option to offset carbon emission in conformity of the Kyoto Protocol under article 3.3 (Anon., 2001, 2014; Roshetko *et al*., 2002$_{a}$; Watson and Eyzaguirre, 2002; Smith *et al*., 2007; Nair *et al*., 2009$_{a}$; Nath and Das, 2011). Managing soil and biomass carbon in this traditional system will both be an avoided emission and net addition of carbon to terrestrial pool thereby fulfilling the global 4 per mille initiative (Sanderman and Baldock, 2010; Powlson*et al*., 2011; Lal, 2016; Minasny *et al*., 2017).

Chapter 5

SUMMARY AND CONCLUSION

The present study entitled, "**Variations in Vegetational Diversity and Carbon Stock in Large Cardamom based Traditional Agroforestry System across Altitudinal Gradient in Darjeeling Himalayas**" was carried out in Darjeeling Himalayan region of West Bengal, India from January, 2019 to January, 2021.

5.1. Site Description

The study site was Darjeeling Himalayas in the state of West Bengal comprising districts of Kalimpong and Darjeeling exclusive the plain or Terai region of Darjeeling district i.e. Siliguri sub-division. Narrow valleys with precipices and ridges stretch from north to south and from south west to north east are prominent features of the study site. The slopes are both covered with forests and tea gardens. Five seasons experienced in the study area are spring (March-April), summer (May-June), monsoon (June-August), autumn (September-November) and winter (December-February). The region is humid and sub-tropical to sub-alpine with dry winter where normal temperature of coldest month is -3-18°C and warmest month is above 22°C. The population is diverse with marginally agrarian communities like Nepalis, Limbus, Lepchas, Tamang, Bhutia, and tea plantation labourers cultivating paddy, maize, millet, chilies, ginger, orange, large cardamom, flowers, orchids and other vegetables.

5.2. Material and Methods

The traditional large cardamom cultivation in Darjeeling Himalayas was found 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. A total of 25 traditional large cardamom based agroforestry holdings found during the reconnaissance survey of the study area were distributed in the elevations between 700-2000 m, of which 17 were in Kalimpong district and only eight were in Darjeeling district. The available traditional large cardamom holdings in the study area was also classified into three altitude class as low (700-1200 m asl), mid (1200-1700 m asl) and high (> 1700 m asl) with eleven, nine and five holdings, respectively. All the large cardamom holdings were analyzed for their phyto-sociological, diversity, physical (biomass) and edaphic attributes adopting stratified random nested quadrate sampling method. In these large cardamom holdings 1-4 quadrates were laid for vegetation and soil analysis depending on its size. All the growers or owners of the holdings were interviewed for their perception on ecosystem service and performance of their traditional large cardamom based agroforestry farming system. Two main sources of information were used for the collection of data; first one was growers through interview and second one was through focused group discussions. Ecosystem services provided by every species documented from the traditional large cardamom based agroforestry system was collected following Millennium Ecosystem Assessment guidelines. The important statistical measures that are used to analyze the survey or research data are frequency, per cent, range, mean, standard deviation, coefficient of variation, Karl Pearson's coefficient of correlation and multiple regressions with analysis of variance.

5.3. Socio-economic Profile of the Large Cardamom Growers

Most of the growers were in the age group of 40-60 years, mostly represented other backward community, attended mostly up to five years of formal education and depended mostly on farming activities. Most of them had land of less than 100 decimal and most of them had total monthly household income of less than INR ₹ one lakh, of which contribution by the large cardamom to the household monthly income was 39.78-47.70 %.

5.4. Grower's View on Traditional Large Cardamom Farming

The growers held their large cardamom farming system as traditional and cultural pride that was heir loomed over from generation to generation. The growers also acknowledged the declining productivity and failure of their large cardamom farming system to sustain household livelihood. The growers instead giving priority to economic worth of the large cardamom farming system were valuing cultural and traditional worth of associated with the system. Majority of the growers justified their continued loyalty towards their traditional large cardamom farming because of the provisionary services they receive from the system. The growers also justified their continued cultivation of large cardamom due to its ease of cultivation with minimum inputs and efforts and high economic value but felt the need for improvement or rejuvenation of their diminishing traditional farming system through improved or superior varieties and also expected institutional support with availability of quality planting material and capacity building to bail out their ailing traditional large cardamom farming system.

5.5. Grower's Perception on Constraints of Large Cardamom Farming

According to the total weighted scores estimated for the statements of problems faced by the large cardamom growers, the prominent was increased infestation of disease and pests including decreased pollinator population followed by unavailability of market, shrinking cropping area, improper system management, absence of extension and supporting services and least prominent was unavailability of quality planting material. The growers believed that the problems of pest and disease infestation along with decreased population of bumble bee, the pollinator of their large cardamom crop was due to increasing temperature over the years in their area which they didn't faced a few decades earlier. The growers perceived these problems as the major cause of decline in their large cardamom productivity.

5.6. Grower's Perception on Solution for Problems of Large Cardamom Farming

Most prominent solution to the problems perceived by the traditional large cardamom growers was the need for proper and timely extension services with adequate institutional support. The growers expected themselves to be capacity build so that they can efficiently and properly manage their large cardamom to realise the full potential of the system. The other important solutions perceived by the growers were value adding large cardamom for more consumer preference and more income, rejuvenation of their traditional agroforestry system, assured marketing of their product and assured supply of quality large cardamom planting material.

5.7. Species Richness

The large cardamom based traditional agroforestry systems of the Darjeeling Himalayas were documented with 130 species represented by 63 families and 107 genera, of which 37 were tree species (23 families & 30 genera), 25 shrub species (15 families & 21 genera), 46 herb species (23 families & 38 genera), eight fern species (eight families & eight genera), 11 climber species (eight families & nine genera) and three orchid species (two families & three genera). Low (700-1200 m asl), mid (1200-1700 m asl) and high (< 1700 m asl) altitudinal class was listed with 76 (63 genera & 43 families), 60 (57 genera & 40 families) and 52 (45 genera & 35 families) plant species, respectively. The overall range of plant species richness range recorded was 8-50 species with 16-50 species at low altitude class, 8-30 species richness at mid-altitude class and 9-21 species at high altitude class.

The richness of trees documented at low-, mid- and high-altitude class was 21 (14 families & 18 genera), 18 (15 families & 17 genera) and 14 (11 families & 13 genera) species, respectively; shrub richness was 10 (nine families & 10 genera), 10 (eight families & nine genera) and 11 (six families & nine genera), respectively; herb richness was 28 (13 families & 24 genera), 23 (17 families & 22 genera) and 19 (13 families & 16 genera), respectively; fern richness was seven (seven families & seven genera), six (six families & six genera) and three (three families & three genera) species, respectively; climber richness was eight (six families & six genera), three (three families & three genera) and three (three families & three genera) species, respectively and orchid richness was two (one family & two genera), zero and two (two families & two genera) species, respectively. The dominant plant form found in all the altitude class was herbs followed by trees, shrubs, climbers, ferns and least was orchids.

Among the documented species from the large cardamom based traditional agroforestry systems at Darjeeling Himalayas (130 species) following the ICUN conservation status of plant species, 89 species were data deficit, 38 species were least concerned; two species (*Cryptomeria japonica* and *Cupressus cashmeriana*) were near threatened and one species (*Brugmansia suaveolens*) was extinct in the wild. Highest number (47 and 26 species, respectively) of data deficit and least concerned species was recorded from the low-altitude, followed by mid-altitude (41 and 17 species, respectively) and high altitude (35 and 15 species, respectively. The two documented IUCN near to threatened species was found throughout the altitudinal classes while, IUCN extinct in wild species was found only at the low-altitude class.

Overall, in the large cardamom based traditional agroforestry farming systems 120, 47, 34 and 33 species were classified to provide four types of ecosystem services, respectively including 56 species classified only as provisionary, two species as only cultural and one species as only regulatory while, others were classified providing two (47 species), three (22 species) or entire four services i.e. only two species. Similarly, the trees (37, 19, 15 & 17 species, respectively); shrubs (18, 3, 10 & 12 species, respectively); herbs (41, 10, 4 & 10 species, respectively); climbers (12, 1, 3 & 3 species, respectively); ferns (7, 1, 1 & 3 species respectively) and orchids (3, 0. 0 & 2 species, respectively) documented from the large cardamom based traditional agroforestry systems in Darjeeling Himalayas were also classified as provisional, regulatory, supportive and cultural ecosystem services. In low-, mid- and high-altitude class 70, 53 & 48 species respectively were found as provisionary; 22, 20 & 17 species, respectively were cultural; 19, 19 & 14 species, respectively were regulatory and 16, 12 & 15 species, respectively were supportive.

The Sorenson's similarity indexes suggest a lesser similarity for species encountered in large cardamom based traditional agroforestry systems with similarity index of only 0.18.Only 17 common species were common in the entire altitudinal classes with seven species of herbs, four species of trees, three species of shrubs, two species of ferns and one species of climber. The similarity of the species decreased gradually with increasing altitude as 36 species were common between low- and mid-altitude class with similarity index of 0.53 while, only 16 species were common between mid- and high-altitude class with similarity index of 0.29 and 15 species were common between low- and high-altitude class with similarity index of 0.23. In total 91 unique or specialist species were listed, of which 39, 21 and 31 species were unique to low, mid and high altitudes. Majority of the species documented (70 %) in the traditional large cardamom based agroforestry systems of Darjeeling Himalayas were specialists or unique with respect to the altitude class.

5.8. Diversity Indices

The Menhinick's species diversity index of the studied systems at Darjeeling Himalayas estimated was 1.36 while, the index estimated for the different altitude class was lesser than the overall index i.e. 1.16, 1.16 and 1.03 for low-, mid- and high-altitude class, respectively. The overall concentration of dominance estimated was 0.03 and it increased with increasing altitude with values of 0.03, 0.04 and 06 for low, mid and high-altitude class, respectively. The large cardamom based traditional agroforestry farming systems of Darjeeling Himalayas was fair enough diverse with estimated Shannon and Wiener index of 4.09. Diversity decreased with altitude progressively from 3.79 for low-altitude class to 3.64 for mid-altitude class and 3.24 for high-altitude class, respectively. The plant assemblages in these systems were less evenly distributed (0.45) than the traditional homegardens of Darjeeling Himalayas. The plant species in the large cardamom systems were more or less similarly evenly distributed at the altitudinal classes.

Herbs were most diverse than any other life forms as they were also recorded with higher richness and population thus also estimated with highest Shannon-Wiener diversity index throughout the study area (3.43) and also at different altitude classes (3.03, 2.97 & 2.59, respectively). Following herbs, trees were estimated with 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. Diversity of herbs, trees, climbers and orchids decreased gradually with increasing altitude class but diversity of shrubs and ferns increased with increasing altitude class. Orchids were the least diverse among the plant forms with overall Shannon-Wiener diversity index of 1.06 and at low- and high-altitude class the values were 0.68 and 0.63, respectively. No orchids were found in the mid-altitude class. 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 & 1.12, respectively) than the shrubs, climbers, herbs, orchids and ferns. Ferns and orchids were most frequently present life form throughout the altitudinal gradient of Darjeeling Himalayas in the large cardamom based traditional agroforestry systems and therefore the dominance of the species in their respective life forms species was most distributed with high estimated values of concentration of dominance (0.27 and 0.36, respectively). Trees were most evenly distributed with highest evenness index (with overall value of 0.49 and at low-, mid- and high-altitude class with values of 0.49, 0.49 & 0.46, respectively) followed by shrubs, herbs, climbers, orchids and ferns.

5.9. Vegetation Analysis

The frequency of species irrespective of altitude classes documented was 1.7-100.0. *Amomum subulatum* and *Selaginella denticulata* (100.0 each) were the most frequent species at low-altitude. At mid-altitude, the most frequent species was *Amomum subulatum* (100.0) and the least frequent species was *Rubia cordifolia* (10.0). The least frequent species at high-altitude class was *Litsea glutinosa* (5.0 each) while; *Amomum subulatum* was the most frequent species with frequency of 100.0. Overall in the traditional large cardamom based agroforestry systems 49.23 % of the documented 130 species were rare, 36.92 % were seldom present or less frequent, 12.30 % were often present or frequent and 1.54 % was mostly or generally abundant. Similarly, at low-altitude class 6.57 %, 34.22 %, 55.26 % and 3.95 % of the 76 documented species were rare, less frequent, and frequent and mostly frequent, respectively while; 1.67 %, 50.0 %, 46.6 % & 1.67 % of the documented species (60 species) at mid-altitude class and 13.47 %, 46.15 %, 38.46 % & 1.92 % of the documented species (52) at high-altitude class were rare, less frequent and frequent, respectively.The distribution of plant species in the large cardamom based traditional agroforestry systems evaluated was compared using Log-normal, Mandelbrot, Zipf, Null and Preemption species distribution models (SAM). The Preemption SDM was found to give best fit to the data with highest Akaike Information Criterion (AIC) score.

The Darjeeling Himalayan large cardamom based traditional agroforestry systems irrespective of altitudinal classes were grouped into only three frequency classes in order A > B > C > D = E with 79.23 %, 17.69 %, 1.54 %, 0.77 % and 0.77 % of the total species, respectively. Distribution of the species at low-altitude class was A (22.37 %) < B (47.37 %) > C (22.37 %) > D (3.94 %) = E (3.94). The distribution at mid-altitude class was A (26.67 %) < B (60.0 %) > C (1.92 %) > D (1.67 %) = E (1.67 %) and at high-altitude class it was A (44.23 %) < B (48.08 %) > C (1.92 %) < D (3.85 %) > E (1.92). The law doesn't hold good for the present studied traditional farming systems.

The overall numerical strength or density estimated for the documented species in Darjeeling Himalayan large cardamom based traditional agroforestry systems was in the range of 0.01-3.23 quadrate^{-1}. Tree, shrub, herb, climber, fern and orchid density was estimated in the range of 0.017-1.25, 0.033-0.71, 0.043-1.47, 0.05-0.207, 0.01-3.23 and 0.083-0.160, respectively. The plant density estimated for low-, mid- and high-altitude class was 0.03-4.26, 0.06-2.30 and 0.03-3.16, respectively while, density of *Amomum subulatum* at these classes were 1.47, 1.50 and 1.41, respectively. Overall, abundance of species was in the range of 0.30-7.0. The overall abundance of large cardamom documented 1.47 while, at low-, mid- and high-altitude class was 1.47, 1.52 and 1.41, respectively. The abundance of plant species at low-altitude class was in the range of 0.27-7.0. At mid-altitude the abundance of species was 0.40-6.20 while, at high-altitude class it was 0.40-5.33.

The relative frequency (RF), relative density (RD) and relative abundance (RA) of the systems irrespective of the altitude were estimated in the range of 0.03-7.80, 0.01-10.52 and 0.03-0.81, respectively. The RF estimated for trees, shrubs, herbs, ferns, climbers and orchids was 0.05-0.70, 0.10-2.21, 0.39-7.80, 0.10-6.11, 0.10-0.73 and 0.52-0.91, respectively while, RD and RA values estimated for these plant forms was 0.012-0.81, 0.04-1.97, 0.09-4.77, 0.03-10.52, 0.07-0.67 & 0.27-0.52 and 0.12-0.40, 0.07-0.70, 0.06-0.43, 0.03-0.49, 0.08-0.81 & 0.14-0.16, respectively. The range of these relative values estimated at low altitude class was 0.11-5.73, 0.07-9.89 and 0.05-1.27, respectively. At mid-altitude class the range of RF, RD and RA was 0.25-8.18, 0.11-8.49 and 0.01-0.15, respectively and at high-altitude class these values were 0.10-10.34, 0.04-12.33 and 0.03-2.75, respectively. The RF, RD and RA estimated for large cardamom irrespective of altitude class was 7.80, 4.77 and 0.17; respectively while, at low-, mid- and high-altitude class RF was 5.73, 8.18 and 10.34, respectively; RD was 3.41, 5.66 and 5.50, respectively and RA was 0.27, 0.04 and 2.75, respectively.

The important value index (IVI) of the documented species at the studied systems varied from 0.15-17.11 irrespective of altitude classes. IVI estimated for large cardamom was 12.74 while, at low-, mid- and high-altitude class it was 9.41, 13.88 and 18.59, respectively. Overall, IVI estimated across these altitude classes for trees, shrubs, herbs, ferns, climbers and orchids was 0.19-1.84, 0.28-4.43, 0.54-12.74, 0.22-17.11, 0.34-1.63 and 0.94-1.59, respectively. The most important trees following *Schima wallichii* in the system were *Cryptomeria japonica*, *Alnus nepalensis*, *Cupressus cashmeriana*, *Ficus semicordata*, *Terminalia myriocarpa*, *Ficus auriculata* and *Firmiana colorata*. The IVI of species estimated for low-altitude class was 0.57-16.39. The most important tree species at this altitude class was *Schima wallichii* and *Ficus auriculata*. At mid-altitude class the IVI estimated was in the range of 0.50- 14.30. Important tree species found at this altitude were *Cryptomeria japonica*, *Alnus nepalensis*, *Schima wallichii*, *Ficus semicordata* and *Macaranga denticulata*. Similarly, IVI estimated for high-altitude class 0.17-20.84. The important tree species of the high-altitude class found were *Cupressus cashmeriana*, *Alnus nepalensis*, *Cryptomeria japonica*, *Schima wallichii*, *Magnolia lanuginose*, *Pinus wallichiana* and *Rhododendron griffithianum*.

5.10. Soil Electrical Conductivity, pH and Moisture

Soil pH, electrical conductivity (EC) and moisture of large cardamom based traditional agroforestry systems were significantly influenced by both altitude class and soil depth along with their interaction. The soil of the large cardamom based traditional agroforestry systems at low, mid and high-altitude class was acidic in nature with mean pH of 5.33, 5.30 and 5.29, respectively. Similarly, pH also decreased significantly with increasing soil depth and the mean pH at these depths estimated was 5.38, 5.25 and 5.30, respectively. The mean EC estimated at these altitudinal classes was 0.53, 0.56 and 0.57 m mhos cm^{-1}, respectively while, at different soil depth the mean EC estimated was 0.56, 0.54 and 0.56 m mhos cm^{-1}, respectively. The mean soil moisture estimated at low-, mid- and high-altitude class was 17.96 %, 17.62 % and 17.74 %, respectively while, it was 21.92 %, 17.49 % and 13.91 % at 0-20 cm, 20-40 cm and 40-60 cm soil depth, respectively.

5.11. Oxidizable SOC

Mean soil organic carbon content estimated for low-, mid- and high-altitude class was 1.09, 1.37 and 1.63 %, respectively which amounted to 22.31, 28.48 and 33.83 Mg ha^{-1}, respectively. SOC content significantly increased with increasing altitude class and so was the amount estimated. Mean SOC content at 0-20 cm, 20-40 cm and 40-60 cm soil depth estimated was 1.39 %, 1.36 % and 1.34 % which amounted to 28.64, 28.20 and 27.77 Mg ha^{-1}, respectively.

5.12. Soil Available Nitrogen, Phosphorus and Potassium

Based on the availability of nitrogen, phosphorus and potassium, the large cardamom based traditional agroforestry system of Darjeeling Himalaya was medium in available nitrogen and phosphorus at all altitude classes up to 60 cm soil depth and high in available potassium. The order of available soil primary nutrients found was N> K > P. The mean available nitrogen, phosphorus and potassium quantified was 257.51, 260.30 & 264.03 Kg N ha^{-1}; 13.74, 12.95 & 12.46 Kg P ha^{-1} and 229.75, 227.99 & 231.25 Kg K ha^{-1} at low-, mid- and high-altitude classes, respectively. However, the quantity of all these available primary nutrients decreased but non-significantly with increasing soil depth and the amount estimated at 0-20 cm, 20-40 cm and 40-60 cm soil depth was 280.60, kg N ha^{-1}, 260.26 kg N ha^{-1}& 240.98 kg Nha^{-1}; 13.48 kg P ha^{-1}, 13.04 kg P ha^{-1}& 12.63 kg P ha^{-1} and 233.7 kg K ha^{-1}, 229.42 kg K ha^{-1}& 225.86 kg K ha^{-1}, respectively.

5.13. Exchangeable Calcium, Magnesium and Aluminium

Altitude class and soil depth of large cardamom based traditional agroforestry systems along with their interaction significantly influenced its soil exchangeable calcium, magnesium and aluminium. Soil exchangeable calcium significantly decreased with both increasing altitude class and soil depth.

5.14. Soil Fertility Indices

Soil fertility index (SFI) and soil evaluation factor (SEF) that evaluate soil fertility is significantly influenced by both altitude class and soil depth along with their interaction. Among the fertility indices SFI exhibited inconsistent trend with increasing altitude class though with significant difference among the classes and SEF significantly consistently decreased with increasing altitude class while both the indices significantly decreased with increasing soil depth.

5.15. Tree Biomass and Carbon Stock

The tree biomass and carbon accumulated in the large cardamom based agroforestry systems of Darjeeling Himalayas was 447.67 & 210.40 Mg ha^{-1} while, at low-, mid- and high-altitude class the biomass estimated was 630.17 & 296.18 Mg ha^{-1}, 397.05 & 186.61 Mg ha^{-1} and 315.78 & 148.42 Mg ha^{-1}, respectively. The contribution of the above ground biomass (AGB) was 80 % at all the altitude classes. The tree biomass accumulated in the systems decreased gradually with increasing altitude class by 36.99 % from low- to mid-altitude, 20.47 % from mid- to high-altitude class and 49.89 % from low- to high-altitude class. The large cardamom based traditional agroforestry systems at low altitude-class accumulated highest biomass and carbon unit area due to highest number of trees and tree species followed by mid-altitude class and the least at high-altitude class.

At low-altitude class the most prominent tree species in terms of biomass accumulation was *Schima wallichii* with estimated biomass of 121.8 Mg ha^{-1} with average dbh of 33.7 cm and density of 205 trees ha^{-1}. *Schima wallichii* was followed by *Cryptomeria japonica* with estimated biomass of 50.7 Mg ha^{-1}, dbh 54.8 cm & density 30 trees ha^{-1} and *Ficus semicordata* with biomass of 50.4 Mg ha^{-1} with dbh 29.9 cm & density 110 trees ha^{-1}. The prominent tree species at mid-altitude class were *Cryptomeria japonica* with biomass of 114.9 Mg ha^{-1}, dbh of 32.5 cm & density of 210 trees ha^{-1}, *Alnus nepalensis* with biomass of 71.2 Mg ha^{-1} with dbh 29.9 cm & density 155 trees ha^{-1} and *Schima wallichii* with biomass of 39.6 Mg ha^{-1} with dbh 28.7 cm & density 95 trees ha^{-1}. *Cupressus cashmeriana*, *Schima wallichii*, *Cryptomeria japonica* and *Alnus nepalensis* were prominent tree species found at high-altitude class with biomass accumulation of 82.7, 58.3, 45.9 & 44.3 Mg ha^{-1} with dbh of 33.1, 38.2, 28.7 & 27.1 cm and density of 145, 75, 110 and 120 trees ha^{-1}, respectively.

Average diameter at breast height for the trees recorded in the system was in the range of 7.96-39.49 cm and average height of the trees measured was in the range of 9.75-44.50 m. Average diameter (at breast height) recorded at low-, mid- and high-altitude class was 12.74-44.50 cm, 7.96-32.48 cm and 14.01-38.22 cm. Tree height measured at these altitude classes was 10.67-44.47, 9.75-44.45 and 15.85-44.50, respectively. Tree density estimated for the system was 5.0-210.0 trees ha^{-1}. Tree density estimated at low-, mid- and high-altitude class was in the range of 30-205, 20-210 and 5-145 trees ha^{-1}.

5.16. Ecosystem Carbon Stock

The overall ecosystem carbon stock estimated in the large cardamom based traditional agroforestry systems of Darjeeling Himalayas was 295.02 Mg ha^{-1}. The ecosystem carbon stock at low-, mid- and high-altitude class systems estimated was 363.10 Mg ha^{-1}, 272.06 Mg ha^{-1} and 249.90 Mg ha^{-1}, respectively. Contribution of SOC to ecosystem carbon stock increased with increasing altitude but contribution by tree biomass carbon decreased with increasing altitude class because SOC stock of the system gradually increased with increasing altitude class and reverse was true for the tree biomass carbon. The ecosystem carbon stock estimated for the low-altitude class systems was 36.43 % and 45.30 % more than the mid- and high-altitude class systems, respectively while, mid-altitude class systems were estimated with 8.87 % more ecosystem carbon stock than high-altitude class systems.

5.17. Conclusion

The growers of the Darjeeling Himalayas were aware about the ecosystem services and declining productivity of their under canopy forest based traditional large cardamom agroforestry farming systems along with the cause of this decline and the possible solutions for revival of their system. The growers valued this farming system as their cultural identity linked with their ancestors and thus were continuing the tradition of large cardamom farming in spite of its declining productivity and failure to sustain their livelihood and expected institutional interventions for revival of their dying system. The altitudinal location was found significantly influencing the diversity (species richness, population and diversity indices), soil parameters (pH, electrical conductivity, moisture, available primary nutrients and available organic carbon) and fertility (soil fertility index and soil evaluation factor) but didn't significantly influenced the biomass and carbon stock of the system though biomass and carbon stock of the system decreased gradually with increasing altitude. The diversity, soil parameters and soil evaluation factor decreased gradually with increasing altitude while, oxidizable SOC increased gradually with increasing altitude and soil fertility index was inconsistent with altitude. The large cardamom farming system is forest based below canopy cultivation with no rights to cut trees by the growers, thus were diverse and heterogeneous. The heterogeneity of the system can be attributed to richness of 130 plant species represented by 63 families and 107 genera, of which 37 were tree species, 25 shrub species, 46 herb species; eight fern species, 11 climber species and three orchid species including 68.46 % species data deficit, 29.23 % least concerned, 1.54 % near threatened and 0.77 % extinct in the wild status species according ICUN conservation status. Documentation of ICUN red listed species indicate that this forest based traditional large cardamom based agroforestry farming system is playing an important role of harbouring and conserving the regional plant diversity. Moreover, the system was found offering variety of ecosystem services from provisional to cultural like NTFPs, biodiversity conservation, water regulation and purification, production, economic yield, carbon sequestration, nutrient cycling and socio-cultural service for the well-being of the society with prominence of provisionary services from 120 species followed by 47 species of cultural ecosystem services, 34 species of regulatory services and 33 species of supporting ecosystem services. The system was highly heterogeneous due to higher diversity of species with lesser similarity of floristic element as evidenced from higher diversity indices, lower Sorenson's similarity index and only 17 common species among the altitude classes.The farming systems also varied on the basis of their species richness and plant population which were grouped into six clusters. Based on the distribution of plant species in the system five species distribution models (SDM) were evaluated and the Preemption SDM was found to give best fit to the data with highest Akaike Information Criterion (AIC) score. The soil fertility of the system was higher as indicated from higher soil fertility indices because of medium to high available primary nutrients, higher concentration of exchangeable cations and high oxidizable SOC. The tree biomass, tree biomass carbon, SOC (up to 60 cm soil depth) and ecosystem carbon stock estimated was 447.67, 210.40, 84.62 & 295.02 Mg ha^{-1}, respectively. The below canopy forest based large cardamom cultivation due to traditional practice of natural resource conservation has denser and diverse plant population and higher soil fertility with higher soil organic and biomass carbon is build-up of permanent carbon pool in the region. Carbon sequestration with higher possibility of net gains in carbon stocks by this system can be a significant climate change mitigation option by increasing the carbon footprint in the Darjeeling Himalayan region. Therefore, taking cognisance of Darjeeling farmer's effort to preserve their traditional large cardamom based agroforestry system with their attitude to empower themselves through capacity building, the study recommends intervention of scientists, government and non-government agents with research, extension, technological, policy and financial support to bail out this dying tradition which will not only improve the livelihood of the growers but also will be a step forward fulfilling the global 4 per mille initiative.

5.18. Future Research Scope and Recommendations

More exploration and research are required to inventorize the importance of the under canopy forest based large cardamom traditional agroforestry systems in comparison to the large cardamom farming system or any other tree based land use system at agricultural landscapes and also with natural forests of Darjeeling Himalayas for its sustainable utilization and management. Inclusive and comparative research is required to analyse the ecosystem services of the system. In depth analysis of structure and composition with respect to altitudinal location will generate more information on functional diversity, structure, composition and productivity. The study recommends adequate and effective institutional interventions for socio-ecological framework and pro-growers-based policy support for bailing out this dying traditional farming system empowering the growers, ensuring bio-cultural approach and formalizing traditional practices into site specific planning. Such pro-people approach will help to understand grass root level problems and aspiration holistically including local concerns of climate change and their interaction with other local dynamics to create proper human-environment interaction.

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ANNEXURE- I

PERSONAL INTERVIEW SCHEDULE

General Information:

1. Name of the respondent: M/F..… Age..
2. Name of the Village: ………………Total households in village………………….
3. Block………………………Dist.…………
4. Latitude……………………Longitude………………………Altitude……………….
5. Caste – ST, SC , OBC, Gen ………………
6. Religion- Hindu [ ] Christian [ ] Muslim [ ] Buddhist [ ] Others [ ]
7. Primary occupation ………………………..Secondary occupation …………………
8. Total land holding/Possession…………..
9. Total monthly household income……………… Education of respondent…………………………

Features of Traditional Agroforestry System (TAF)

10. Land area under TAF….………Age of TAF ………….
11. Maintenance of Traditional AF by…………………Working hour…………Labour………….
12. Percentage of household income byTAF ……………
13. Is your TAFnow bigger or smaller than before? [ ] bigger [ ] smaller [ ] same
14. What are the reasons behind this change?

    Income generation [1] Family partition [2] Not Interested [3] Soil fertility problem[4] labour problem[5] Time problem [6] other [7] ……………………………………
15. **Tree Association with Cardamom:**

Local name of species	Parts use	Uses

16. Why do you prefer those trees species?...
17. Major problems for practicing TAF?

    …………………………………………………………………………………………
18. Estimate the percentage of these products that are used for home consumption? ……………%
19. Do you estimate that this % varies from season to season? Yes [ ] NO [ ]
20. In which season you will get the maximum? **………………………………………**
21. Why did you select these particular plants? (Individual preferences)

    Economical- [ ], Nutritional- [ ], Easy to grow- [ ], Easy available- [ ],Other (……………..)
22. How much do you pay to obtain these seedlings or seeds.

Name of species	Price per gm/kg	Spp. Varieties

23. Who supplies your seedlings?

…………………………………………………………………………………………….

24. Where do you obtain your desired variety of seedling/seed?

Gift [ ]..... Trade [ ]…... KVK [ ], Other …………… (Please specify)

25. Do you believe that certain varieties are better than others? Which and Why?

High Yield [ ] Diseases resistance [ ] Insect resistance [ ] Susceptible to env. [ ]

Others [ ] ………………………………

26. Do you plan on leaving this garden to your children? Yes [ ] No [ ]

27. Do you believe that this TAF system will be of economic worth to the inheritor?Yes [ ] No [ ]

28. Does this TAF system help to improve health care/ nutritional security of your family?Yes [ ] No [ ]

Marketing

Species	**Input Cost**	**Production (in kg)**	**Producer selling price (Per/kg)**	**Middle man price (per/kg)**	**Retailer price (per/kg)**	**Consumer price (per/kg)**

29. How far is main market from here (km)..................................

30. Mode of transportation? Walking [1] Cart [2] Bicycle [3] Motor bike [4] Local vehicles [5]

31. What are the major problems for marketing that you are facing now?

Communication [ ] Transportation [ ] Not getting actual price [ ] No problem [ ]

32. Does you are getting any type of help from the govt. agencies for marketing?

Yes [ ] No [ ] ……………………………………………………………………………….

Understanding of ecosystems services

Provisioning:

33. How much essential is to grow tree species for fuel wood and fodder?

----- Invaluable ------Very important ------ Somewhat important------ Neutral ------Not very important

Provisioning services	Food, fibre, fuel, genetic resources, natural medicines, ornamental resources and fresh water.

Regulatory:

34. Do you feel the pattern of weather is generally changing? Yes [ ] No [ ] Don't Know [ ]
35. Have you heard of climate change? Yes [ ] No [ ] Don't Know [ ]
36. How important is the issue of climate change to you personally?
    Very important [ ] Quite important [ ] Not very important [ ] Not at all important [ ]
37. Global warming is an effect of climate change? Yes [ ] No [ ] Don't know [ ]
38. Do you ever feel that crop sowing and harvesting time are changing? Yes [ ] No [ ] Don't know [ ]
39. Do you ever feel that climate change can change the crop composition? Yes [ ] No [ ] Don't know []
40. Do you feel the season indicator like butterflies, insect and birds are changing their visiting period?
    Yes [ ] No [ ] Don't Know [ ]
41. How important is it to obtain shade for your livestock?

----- Invaluable ------Very important ------ Somewhat important------ Neutral ------Not very important

42. TAF system regulates Temperature/prevent blowing hot air or cold air, how much it is essential?
    ----- Invaluable ------Very important ------ Somewhat important------ Neutral ------Not very important

41. How much it is essential to maintain TAF systemto get a pure fresh air for respiration?
    ----- Invaluable ------Very important ------ Somewhat important------ Neutral ------Not very important

42. How much it is essential to grow plant for to control soil erosion, air quality and retain water table?
    ----- Invaluable ------Very important ------ Somewhat important ------ Neutral ------Not very important

    Do you believe that this system contribute to the empowerment of women? Yes [ ] No [ ]

Supporting:

43. How much essential is to grow plant species to augment soil physico-chemical properties?
    ----- Invaluable ------Very important ------ Somewhat important------ Neutral ------Not very important
44. How much it is essential to maintain TAF to improve nutrient cycle?
    ----- Invaluable ------Very important ------ Somewhat important------ Neutral ------Not very important
45. Vegetation can retain soil erosion
    ……… Strongly agree ………….Agree ……….Neutral………… Not very important

Cultural:

46. Do you think this TAF system is essential to your lifestyle? Yes [ ] No [ ]
47. How important is it to obtain aesthetic and ornamentation benefits from your system?

----- Invaluable ------Very important ------ Somewhat important------ Neutral ------Not very important

48. Do you perform your religious/ puja/festivals/marriage ceremonies/gathering etc. activities in this system
    Yes [ ] No [ ]
49. Design of your AF is culturally developed? Yes [ ] No [ ]

Signature of Farmers **Signature of Student**

Annexure-II

```
[1] "S1"

RAD models, family poisson
No. of species 33, total abundance 260

           par1      par2         par3         Deviance AIC      BIC
Null                                              8.9655 127.1960
127.1960
Preemption  0.088002                              3.7016 123.9322
125.4287
Lognormal   1.7583    0.80473                     9.0733 131.3039
134.2969
Zipf        0.14341  -0.68514                    29.8524 152.0830
155.0760
Mandelbrot    Inf    -2.1651e+07  2.3842e+08      3.0598 127.2904
131.7799
[1] "S2"

RAD models, family poisson
No. of species 38, total abundance 310

           par1      par2         par3         Deviance AIC      BIC
Null                                             14.8178 147.1343
147.1343
Preemption  0.087334                              5.9299 140.2465
141.8840
Lognormal   1.7378    0.87299                    28.8339 165.1505
168.4256
Zipf        0.13938  -0.7009                     67.9602 204.2768
207.5519
Mandelbrot    Inf    -1.9143e+06  2.1068e+07      5.6189 143.9354
148.8482
[1] "S3"

RAD models, family poisson
No. of species 15, total abundance 87

           par1     par2         par3         Deviance AIC     BIC
Null                                             3.6626  52.4270 52.4270
Preemption  0.18402                              2.3215  53.0859 53.7940
Lognormal   1.4544   0.82491                     5.7032  58.4676 59.8837
Zipf        0.23618 -0.79611                    12.7974  65.5618 66.9779
Mandelbrot    Inf   -2.6832e+06  1.3381e+07      2.1115  56.8759 59.0000
[1] "S4"

RAD models, family poisson
No. of species 28, total abundance 271

           par1     par2         par3         Deviance AIC      BIC
Null                                            12.6973 116.8866 116.8866
```

```
Preemption  0.10494                           7.0381 113.2274 114.5596
Lognormal   1.9674   0.80375                 21.2345 129.4238 132.0882
Zipf        0.15329 -0.68285                 50.5566 158.7459 161.4103
Mandelbrot    Inf   -1.7158e+06  1.5671e+07   6.4540 116.6433 120.6399
[1] "S5"

RAD models, family poisson
No. of species 32, total abundance 233

           par1        par2     par3    Deviance AIC      BIC
Null                                     20.6766 125.3878 125.3878
Preemption  0.12199                       5.6809 112.3922 113.8579
Lognormal   1.4905      1.0306           25.1217 133.8330 136.7644
Zipf        0.1942     -0.84863          50.6429 159.3541 162.2856
Mandelbrot  1.2813e+63 -27.746   201.72   5.5379 116.2492 120.6464
[1] "S6"

RAD models, family poisson
No. of species 26, total abundance 206

           par1     par2     par3        Deviance AIC      BIC
Null                                       4.2169  94.4033  94.4033
Preemption  0.12691                        3.0983  95.2847  96.5428
Lognormal   1.6673   0.93257               8.5590 102.7454 105.2616
Zipf        0.19563 -0.80978              26.6929 120.8793 123.3955
Mandelbrot    Inf   -85008    6.2956e+05   2.9141  99.1005 102.8748
[1] "S7"

RAD models, family poisson
No. of species 32, total abundance 259

           par1      par2        par3        Deviance AIC      BIC
Null                                           6.6614 120.5435
120.5435
Preemption  0.094434                           7.5346 123.4167
124.8824
Lognormal   1.7499    0.85165                  8.8382 126.7203
129.6518
Zipf        0.15627  -0.72443                 30.1603 148.0424
150.9739
Mandelbrot    Inf    -8.6142e+05  8.7778e+06   7.0524 126.9345
131.3317
[1] "S8"

RAD models, family poisson
No. of species 19, total abundance 142

           par1     par2        par3        Deviance AIC     BIC
Null                                          2.8763  69.3070 69.3070
```

```
Preemption  0.15074                         4.3399  72.7707 73.7151
Lognormal   1.6743   0.86131                3.6767  74.1074 75.9963
Zipf        0.21783 -0.8044                13.2947  83.7255 85.6143
Mandelbrot    Inf   -1.7612e+06  1.0915e+07  4.0339  76.4647 79.2980
[1] "S9"

RAD models, family poisson
No. of species 17, total abundance 166

           par1     par2        par3        Deviance AIC     BIC
Null                                       14.3060  79.1921 79.1921
Preemption  0.14082                         8.6244  75.5105 76.3437
Lognormal   2.0667   0.68267               13.3105  82.1966 83.8630
Zipf        0.17809 -0.63299               28.3768  97.2629 98.9293
Mandelbrot    Inf   -8.0624e+07  5.5267e+08  7.5171  78.4032 80.9028
[1] "S10"

RAD models, family poisson
No. of species 25, total abundance 193

           par1     par2        par3        Deviance AIC      BIC
Null                                         8.6230  97.3759  97.3759
Preemption  0.11302                          4.5081  95.2610  96.4799
Lognormal   1.7496   0.79519                10.3284 103.0813 105.5191
Zipf        0.1666  -0.70261                26.5467 119.2996 121.7374
Mandelbrot    Inf   -6.6966e+05  5.6715e+06   3.9880  98.7410 102.3976
[1] "S11"

RAD models, family poisson
No. of species 33, total abundance 249

           par1     par2     par3    Deviance AIC      BIC
Null                                 10.7402 122.7573
122.7573
Preemption  0.10943                  10.3530 124.3701
125.8666
Lognormal   1.5433   1.0112           8.6551 124.6721
127.6652
Zipf        0.19266 -0.84981         25.2957 141.3127
144.3057
Mandelbrot  665.84  -3.0593   15.233   7.3287 125.3458
129.8353
[1] "S12"

RAD models, family poisson
No. of species 27, total abundance 225

           par1        par2    par3    Deviance AIC      BIC
Null                                     7.6163 100.6266 100.6266
```

```
Preemption  0.1331                       7.2797 102.2900 103.5859
Lognormal   1.6378      1.0227           7.7399 104.7502 107.3419
Zipf        0.21552    -0.8798          25.4868 122.4971 125.0888
Mandelbrot  5.1669e+13 -8.5314  49.848   6.8433 105.8536 109.7411
[1] "S13"

RAD models, family poisson
No. of species 31, total abundance 268

           par1      par2     par3    Deviance AIC      BIC
Null                                   14.0270 129.9871 129.9871
Preemption  0.083241                   10.5595 128.5196 129.9536
Lognormal   1.8918    0.74956           2.1025 122.0626 124.9305
Zipf        0.14226  -0.66649          14.6104 134.5704 137.4384
Mandelbrot  60.683   -2.2871   15.464   8.0722 130.0322 134.3342
[1] "S14"

RAD models, family poisson
No. of species 30, total abundance 194

           par1      par2        par3       Deviance AIC      BIC
Null                                          7.0079 108.5064 108.5064
Preemption  0.097467                          1.8236 105.3221 106.7233
Lognormal   1.5612    0.80624                 8.7846 114.2831 117.0855
Zipf        0.15136  -0.69229                25.3644 130.8629 133.6653
Mandelbrot    Inf    -3.6473e+05  3.604e+06   1.3803 108.8788 113.0824
[1] "S15"

RAD models, family poisson
No. of species 16, total abundance 121

           par1     par2       par3        Deviance AIC     BIC
Null                                         5.6305  60.4428 60.4428
Preemption  0.19116                          4.5853  61.3976 62.1701
Lognormal   1.6478   0.91775                 8.9579  67.7702 69.3154
Zipf        0.2536  -0.8714                 18.8802  77.6925 79.2377
Mandelbrot    Inf   -4.504e+05  2.1374e+06  4.4427  65.2550 67.5727
[1] "S16"

RAD models, family poisson
No. of species 16, total abundance 133

           par1     par2        par3       Deviance AIC     BIC
Null                                        11.8792  65.4821 65.4821
Preemption  0.2224                           4.9517  60.5546 61.3272
Lognormal   1.6363   1.0445                 15.5983  73.2012 74.7464
```

```
Zipf        0.28636 -0.97187               28.9039  86.5068 88.0520
Mandelbrot    Inf   -5.8272e+07  2.321e+08  4.9084  64.5113 66.8290
[1] "S17"

RAD models, family poisson
No. of species 50, total abundance 332

           par1      par2        par3        Deviance AIC     BIC
Null                                          15.648  178.004 178.004
Preemption  0.071656                          10.898  175.254 177.166
Lognormal   1.4638    0.94804                 21.554  187.910 191.734
Zipf        0.13559   -0.74                   58.324  224.680 228.504
Mandelbrot    Inf    -7.1232e+05  9.6135e+06  10.696  179.052 184.788
[1] "S18"

RAD models, family poisson
No. of species 34, total abundance 175

           par1       par2     par3    Deviance AIC      BIC
Null                                    12.1415 115.1385 115.1385
Preemption  0.10432                      4.7237 109.7207 111.2471
Lognormal   1.2123     0.95267          14.5481 121.5451 124.5978
Zipf        0.17222   -0.79096          30.6961 137.6931 140.7459
Mandelbrot  1.433e+59 -25.636   220.41   4.5694 113.5665 118.1455
[1] "S19"

RAD models, family poisson
No. of species 26, total abundance 197

           par1         par2     par3    Deviance AIC      BIC
Null                                        4.9988  97.2876  97.2876
Preemption  0.1096                          2.3362  96.6250  97.8831
Lognormal   1.7182       0.81159            5.0276 101.3164 103.8326
Zipf        0.16897     -0.72071           18.9606 115.2493 117.7655
Mandelbrot  9.3459e+210 -75.353   648.05   1.8251 100.1138 103.8881
[1] "S20"

RAD models, family poisson
No. of species 19, total abundance 154

           par1     par2        par3        Deviance AIC     BIC
Null                                          9.9151  79.5311 79.5311
Preemption  0.12721                           5.2955  76.9115 77.8559
Lognormal   1.8695   0.69711                  6.7292  80.3452 82.2341
Zipf        0.17323 -0.65023                 18.0951  91.7111 93.6000
Mandelbrot    Inf   -7.4989e+06  5.7314e+07  4.2796  79.8956 82.7289
```

```
[1] "S21"

RAD models, family poisson
No. of species 11, total abundance 96

           par1     par2        par3        Deviance AIC     BIC
Null                                         8.6186  50.5132 50.5132
Preemption  0.18473                          4.2114  48.1060 48.5039
Lognormal   1.999    0.61937                 2.3001  48.1947 48.9905
Zipf        0.22937 -0.65984                 6.9272  52.8218 53.6176
Mandelbrot    Inf   -1.7865e+06  9.5482e+06  2.8277  50.7223 51.9160
[1] "S22"

RAD models, family poisson
No. of species 21, total abundance 172

           par1      par2        par3       Deviance AIC      BIC
Null                                         23.7366 103.5552 103.5552
Preemption  0.098124                          5.4662  87.2848  88.3294
Lognormal   1.9512    0.57138                 1.2801  85.0988  87.1878
Zipf        0.14046  -0.55329                 7.5195  91.3382  93.4272
Mandelbrot    Inf    -1.3961e+05  1.502e+06   2.4774  88.2960  91.4296
[1] "S23"

RAD models, family poisson
No. of species 16, total abundance 121

           par1     par2     par3        Deviance AIC     BIC
Null                                     15.4899  74.4718 74.4718
Preemption  0.1274                        5.9854  66.9673 67.7399
Lognormal   1.8712   0.57787              3.6679  66.6498 68.1950
Zipf        0.16703 -0.56957              9.8601  72.8420 74.3872
Mandelbrot    Inf   -59624    4.8473e+05  3.9413  68.9232 71.2410
[1] "S24"

RAD models, family poisson
No. of species 19, total abundance 127

           par1     par2        par3        Deviance AIC     BIC
Null                                         4.6527  68.5446 68.5446
Preemption  0.15962                          2.6404  68.5324 69.4768
Lognormal   1.5441   0.88542                 7.0651  74.9571 76.8459
Zipf        0.22237 -0.81908                16.9249  84.8168 86.7057
Mandelbrot    Inf   -6.8593e+07  3.9767e+08  2.4600  72.3519 75.1852
[1] "S25"
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RAD models, family poisson
No. of species 22, total abundance 156

	par1	par2	par3	Deviance	AIC	BIC
Null				4.9487	80.6157	80.6157
Preemption	0.14062			1.7426	79.4095	80.5006
Lognormal	1.5952	0.89032		6.2465	85.9134	88.0955
Zipf	0.20805	-0.81046		16.3551	96.0220	98.2041
Mandelbrot	1.7364e+13	-8.3665	46.903	1.2804	82.9474	86.2205

[1] "S26"

RAD models, family poisson
No. of species 17, total abundance 111

	par1	par2	par3	Deviance	AIC	BIC
Null				9.2774	63.8831	63.8831
Preemption	0.19709			4.3650	60.9707	61.8039
Lognormal	1.4582	0.96755		13.4345	72.0402	73.7066
Zipf	0.25621	-0.89609		24.1836	82.7894	84.4558
Mandelbrot	Inf	-2.3017e+06	1.0521e+07	4.2994	64.9051	67.4048

[1] "S27"

RAD models, family poisson
No. of species 18, total abundance 158

	par1	par2	par3	Deviance	AIC	BIC
Null				9.1416	76.8156	76.8156
Preemption	0.13301			4.3133	73.9874	74.8778
Lognormal	1.949	0.69901		4.7976	76.4716	78.2524
Zipf	0.1813	-0.66322		15.4551	87.1292	88.9099
Mandelbrot	Inf	-3.2344e+07	2.3601e+08	3.2330	76.9070	79.5781

[1] "S28"

RAD models, family poisson
No. of species 13, total abundance 136

	par1	par2	par3	Deviance	AIC	BIC
Null				6.4503	57.0726	57.0726
Preemption	0.1857			3.8731	56.4954	57.0603
Lognormal	2.1101	0.73316		6.2449	60.8672	61.9971
Zipf	0.23222	-0.7349		15.9274	70.5497	71.6796
Mandelbrot	Inf	-2.9696e+06	1.4932e+07	3.1299	59.7522	61.4471

[1] "S29"

RAD models, family poisson
No. of species 16, total abundance 118

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           par1     par2     par3    Deviance AIC     BIC
Null                                  4.6157  60.7708 60.7708
Preemption  0.18272                   3.5665  61.7216 62.4942
Lognormal   1.635    0.90205          3.2836  63.4387 64.9839
Zipf        0.25979 -0.89079          6.9125  67.0676 68.6128
Mandelbrot  64.938  -2.687    7.3678  1.8512  64.0064 66.3241
[1] "S30"

RAD models, family poisson
No. of species 12, total abundance 75

           par1     par2        par3        Deviance AIC     BIC
Null                                         1.8678  41.6070 41.6070
Preemption  0.23499                          2.2164  43.9555 44.4404
Lognormal   1.4717   0.91413                 2.3467  46.0858 47.0557
Zipf        0.30336 -0.94113                 6.3039  50.0431 51.0129
Mandelbrot    Inf   -4.0838e+05  1.5398e+06  2.0879  47.8271 49.2818
[1] "S31"

RAD models, family poisson
No. of species 16, total abundance 114

           par1       par2     par3    Deviance AIC     BIC
Null                                    2.8821  58.7687
58.7687
Preemption  0.17283                     1.6561  59.5426
60.3152
Lognormal   1.6471     0.84034          2.7375  62.6241
64.1693
Zipf        0.23775   -0.8208           8.8499  68.7365
70.2816
Mandelbrot  2.513e+98 -42.311   219.39  1.3677  63.2543
65.5720
[1] "S32"

RAD models, family poisson
No. of species 15, total abundance 100

           par1         par2     par3    Deviance AIC     BIC
Null                                      3.1813  53.7099 53.7099
Preemption  0.19883                       1.5879  54.1165 54.8246
Lognormal   1.5322       0.90738          4.6528  59.1815 60.5976
Zipf        0.26439     -0.88692         10.7600  65.2887 66.7048
Mandelbrot  3.8439e+214 -83.635   373.93  1.4502  57.9789 60.1030
[1] "S33"

RAD models, family poisson
No. of species 9, total abundance 54
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           par1     par2     par3    Deviance AIC      BIC
Null                                  3.12493 34.03120
34.03120
Preemption  0.2512                    1.91547 34.82174
35.01897
Lognormal   1.547    0.80667          0.99470 35.90097
36.29542
Zipf        0.32025 -0.89059          1.24580 36.15207
36.54652
Mandelbrot  1.5983  -1.5586   1.9264  0.99911 37.90538
38.49705
[1] "S34"

RAD models, family poisson
No. of species 8, total abundance 39

           par1     par2        par3        Deviance AIC     BIC
Null                                         1.7483  26.6639 26.6639
Preemption  0.31355                          1.7522  28.6678 28.7473
Lognormal   1.2653   0.93942                 1.9970  30.9126 31.0714
Zipf        0.36991 -1.0066                  3.8252  32.7408 32.8997
Mandelbrot    Inf   -1.5022e+09  4.0556e+09  1.6495  32.5651 32.8034
[1] "S35"

RAD models, family poisson
No. of species 11, total abundance 71

           par1     par2        par3        Deviance AIC     BIC
Null                                         3.7969  40.4036 40.4036
Preemption  0.26583                          1.9969  40.6036 41.0015
Lognormal   1.4824   0.94785                 4.3496  44.9563 45.7521
Zipf        0.33089 -0.99922                 7.3958  48.0025 48.7983
Mandelbrot    Inf   -3.0272e+06  9.8627e+06  1.9140  44.5207 45.7144
[1] "S36"

RAD models, family poisson
No. of species 25, total abundance 117

           par1        par2     par3   Deviance AIC      BIC
Null                                    4.29851 82.21922 82.21922
Preemption  0.1121                      1.30205 81.22275 82.44163
Lognormal   1.2441      0.80211         2.63641 84.55711 86.99486
Zipf        0.17324    -0.72593         9.26416 91.18486 93.62261
Mandelbrot  5.9057e+14 -8.6584   63.84  0.86766 84.78836 88.44499
[1] "S37"

RAD models, family poisson
No. of species 18, total abundance 87
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           par1     par2        par3        Deviance AIC     BIC
Null                                         6.2520  62.4749 62.4749
Preemption  0.14483                          3.2299  61.4527 62.3431
Lognormal   1.3217   0.74644                 6.7073  66.9301 68.7109
Zipf        0.19076 -0.69723                13.8000  74.0228 75.8035
Mandelbrot    Inf   -1.6779e+06  1.0978e+07  2.8839  65.1067 67.7778
[1] "S38"

RAD models, family poisson
No. of species 18, total abundance 84

           par1     par2        par3        Deviance AIC     BIC
Null                                         5.2812  61.0930 61.0930
Preemption  0.147                            2.4826  60.2944 61.1848
Lognormal   1.2753   0.76324                 5.5374  65.3492 67.1300
Zipf        0.19638 -0.71696                11.9619  71.7737 73.5544
Mandelbrot    Inf   -5.3839e+06  3.4584e+07  2.1798  63.9916 66.6627
[1] "S39"

RAD models, family poisson
No. of species 26, total abundance 179

           par1      par2        par3        Deviance AIC      BIC
Null                                           8.1480  99.2237
99.2237
Preemption  0.099169                           5.4765  98.5521
99.8102
Lognormal   1.6706    0.7438                   3.7036  98.7793
101.2955
Zipf        0.15427  -0.66793                 15.0619 110.1376
112.6538
Mandelbrot    Inf    -7.0675e+06  6.9673e+07   4.5904 101.6661
105.4403
[1] "S40"

RAD models, family poisson
No. of species 23, total abundance 177

           par1     par2        par3        Deviance AIC      BIC
Null                                        11.3566  94.9835  94.9835
Preemption  0.10478                          6.6424  92.2692  93.4047
Lognormal   1.814    0.69816                 4.1697  91.7965  94.0675
Zipf        0.15622 -0.64246                14.7892 102.4160 104.6870
Mandelbrot    Inf   -4.8787e+05  4.6003e+06   5.3675  94.9943  98.4008
[1] "S41"

RAD models, family poisson
No. of species 13, total abundance 128
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           par1     par2     par3  Deviance AIC     BIC
Null                                4.2275  52.4000 52.4000
Preemption  0.21552                 4.8014  54.9740 55.5389
Lognormal   1.9509   0.87678        7.5514  59.7240 60.8539
Zipf        0.27329 -0.87142       17.5638  69.7364 70.8663
Mandelbrot                              NA       NA      NA
[1] "S42"

RAD models, family poisson
No. of species 15, total abundance 109

           par1     par2    par3    Deviance AIC     BIC
Null                                13.0470  63.6031 63.6031
Preemption  0.22412                 10.5242  63.0803 63.7884
Lognormal     1.5    1.0503         10.7801  65.3362 66.7523
Zipf        0.3122  -1.0322         13.8193  68.3755 69.7916
Mandelbrot  55.364  -2.8122  5.6776  8.0014  64.5575 66.6817
[1] "S43"

RAD models, family poisson
No. of species 8, total abundance 82

           par1     par2        par3        Deviance AIC     BIC
Null                                         5.4965  35.3685 35.3685
Preemption  0.33896                          4.4783  36.3503 36.4297
Lognormal   1.9574   1.0155                  6.9854  40.8574 41.0163
Zipf        0.38697 -1.0631                 12.5821  46.4541 46.6129
Mandelbrot    Inf   -1.5542e+06  3.7857e+06  4.3635  40.2355 40.4738
[1] "S44"

RAD models, family poisson
No. of species 12, total abundance 156

           par1     par2        par3        Deviance AIC     BIC
Null                                        12.1398  59.1940 59.1940
Preemption  0.25437                          7.3500  56.4041 56.8890
Lognormal   2.1751   0.95168                17.1628  68.2169 69.1867
Zipf        0.30853 -0.95734                29.5696  80.6238 81.5936
Mandelbrot    Inf   -7.3021e+07  2.5008e+08  7.2086  60.2627 61.7174
[1] "S45"

RAD models, family poisson
No. of species 10, total abundance 81

           par1     par2        par3        Deviance AIC      BIC
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Null                                          1.13525 36.98368 36.98368
Preemption  0.2656                            1.00964 38.85807 39.16066
Lognormal   1.7621   0.93067                  2.19702 42.04544 42.65061
Zipf        0.32239 -0.93891                  7.25406 47.10249 47.70766
Mandelbrot    Inf   -5.6292e+06  1.8475e+07  0.82852 42.67695 43.58471
[1] "S46"

RAD models, family poisson
No. of species 11, total abundance 99

           par1     par2     par3        Deviance AIC     BIC
Null                                      2.8807  44.2205 44.2205
Preemption  0.21828                       2.7927  46.1325 46.5304
Lognormal   1.9349   0.77959              1.6693  47.0090 47.8048
Zipf        0.27898 -0.8321               6.1285  51.4682 52.2640
Mandelbrot    Inf   -33112    1.3853e+05  2.2954  49.6351 50.8288
[1] "S47"

RAD models, family poisson
No. of species 8, total abundance 88

           par1     par2        par3        Deviance AIC     BIC
Null                                         2.8351  33.7590 33.7590
Preemption  0.3238                           1.9285  34.8524 34.9319
Lognormal   2.0661   0.95915                 4.4009  39.3249 39.4838
Zipf        0.37135 -1.0114                  9.9513  44.8753 45.0342
Mandelbrot    Inf   -1.1543e+09  2.9859e+09  1.7486  38.6726 38.9109
[1] "S48"

RAD models, family poisson
No. of species 14, total abundance 118

           par1     par2        par3        Deviance AIC     BIC
Null                                         4.6942  56.7171 56.7171
Preemption  0.18261                          2.4216  56.4445 57.0835
Lognormal   1.849    0.7983                  1.5888  57.6118 58.8899
Zipf        0.25094 -0.82284                 4.8202  60.8431 62.1212
Mandelbrot    Inf   -2.6251e+07  1.3323e+08  1.9589  59.9819 61.8990
[1] "S49"

RAD models, family poisson
No. of species 18, total abundance 143

           par1     par2        par3        Deviance AIC     BIC
Null                                        12.4524  73.3868 73.3868
Preemption  0.19175                          5.4528  68.3872 69.2776
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Lognormal   1.6385   0.98378                18.1183  83.0528 84.8335
Zipf        0.25155 -0.89662                32.9563  97.8908 99.6715
Mandelbrot    Inf   -2.5236e+06  1.1887e+07  5.3839  72.3183 74.9894
[1] "S50"

RAD models, family poisson
No. of species 13, total abundance 127

           par1     par2       par3        Deviance AIC     BIC
Null                                        8.6586  57.7607 57.7607
Preemption  0.20251                         6.3816  57.4837 58.0486
Lognormal   1.9963   0.80197               11.0829  64.1850 65.3149
Zipf        0.25182 -0.80133               20.5495  73.6516 74.7815
Mandelbrot    Inf   -9.599e+05  4.3183e+06  5.9955  61.0976 62.7924
[1] "S51"

RAD models, family poisson
No. of species 19, total abundance 185

           par1     par2     par3        Deviance AIC      BIC
Null                                      7.3409  76.1510  76.1510
Preemption  0.17582                       5.0789  75.8889  76.8334
Lognormal   1.8438   0.97919             11.4207  84.2308  86.1197
Zipf        0.24584 -0.89274             27.8435 100.6535 102.5424
Mandelbrot    Inf   -99663    5.1736e+05   4.9560  79.7661  82.5994
[1] "S52"

RAD models, family poisson
No. of species 19, total abundance 208

           par1     par2        par3       Deviance AIC      BIC
Null                                        14.7019  87.9969  87.9969
Preemption  0.1499                           9.6436  84.9386  85.8830
Lognormal   2.0881   0.81812                19.1795  96.4745  98.3633
Zipf        0.20278 -0.75457                36.8381 114.1330 116.0219
Mandelbrot    Inf   -1.8339e+07  1.144e+08   9.1772  88.4722  91.3055
[1] "S53"

RAD models, family poisson
No. of species 12, total abundance 131

           par1     par2        par3        Deviance AIC     BIC
Null                                          6.5533  52.2571 52.2571
Preemption  0.22049                           6.2308  53.9346 54.4195
Lognormal   2.0999   0.8168                  11.7244  61.4283 62.3981
Zipf        0.26292 -0.81037                 24.4305  74.1343 75.1042
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Mandelbrot    Inf   -2.3614e+05  9.6336e+05  5.8707  57.5745 59.0293
[1] "S54"

RAD models, family poisson
No. of species 14, total abundance 130

           par1     par2    par3    Deviance AIC     BIC
Null                                14.3877  65.4853 65.4853
Preemption  0.22467                 13.0407  66.1384 66.7774
Lognormal   1.7894   1.0029         11.8963  66.9939 68.2721
Zipf        0.31186 -1.013          14.1347  69.2323 70.5104
Mandelbrot  9.9637  -2.2727  3.8649  9.1289  66.2266 68.1437
[1] "S55"

RAD models, family poisson
No. of species 20, total abundance 170

           par1     par2     par3    Deviance AIC     BIC
Null                                  13.228   85.136  85.136
Preemption  0.14878                   13.582   87.490  88.485
Lognormal   1.7824   0.88601          13.694   89.602  91.594
Zipf        0.22079 -0.82738          22.709   98.617 100.608
Mandelbrot  1367.9  -3.3623   13.467  12.190   90.098  93.085
[1] "S56"

RAD models, family poisson
No. of species 13, total abundance 141

           par1        par2     par3    Deviance AIC     BIC
Null                                    10.9271  60.8680 60.8680
Preemption  0.2179                       8.1878  60.1287 60.6936
Lognormal   2.0462      0.87859         12.9010  66.8419 67.9718
Zipf        0.27878    -0.88897         20.9231  74.8640 75.9939
Mandelbrot  2.8591e+70 -33.475   132.03  7.9221  63.8630 65.5579
[1] "S57"

RAD models, family poisson
No. of species 19, total abundance 160

           par1     par2       par3        Deviance AIC     BIC
Null                                        6.7687  74.4512 74.4512
Preemption  0.15612                         5.9099  75.5925 76.5369
Lognormal   1.7893   0.86704               10.9393  82.6219 84.5107
Zipf        0.21629 -0.79941               24.2521  95.9346 97.8235
Mandelbrot    Inf   -3.396e+06  2.0201e+07  5.6421  79.3246 82.1579
[1] "S58"
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RAD models, family poisson
No. of species 15, total abundance 118

	par1	par2	par3	Deviance	AIC	BIC
Null				7.8745	60.3914	60.3914
Preemption	0.20097			9.4560	63.9728	64.6809
Lognormal	1.6552	0.96084		6.1637	62.6805	64.0966
Zipf	0.28644	-0.95501		9.5706	66.0874	67.5035
Mandelbrot	4.8996	-1.9788	3.5065	6.7790	65.2958	67.4200

[1] "S59"

RAD models, family poisson
No. of species 12, total abundance 87

	par1	par2	par3	Deviance	AIC	BIC
Null				2.5157	43.0847	43.0847
Preemption	0.2546			1.4742	44.0431	44.5280
Lognormal	1.5705	0.97771		4.0528	48.6218	49.5916
Zipf	0.31911	-0.99029		9.9535	54.5224	55.4922
Mandelbrot	Inf	-2.535e+05	8.6725e+05	1.3959	47.9649	49.4196

[1] "S60"

RAD models, family poisson
No. of species 12, total abundance 76

	par1	par2	par3	Deviance	AIC	BIC
Null				8.2090	46.0953	46.0953
Preemption	0.29795			4.1702	44.0564	44.5413
Lognormal	1.2582	1.1812		4.0433	45.9296	46.8994
Zipf	0.38889	-1.2015		5.9598	47.8460	48.8158
Mandelbrot	137.79	-3.3278	5.0715	2.8095	46.6958	48.1505

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Ph.D. (Forestry)	Uttar Banga Krishi Viswavidyalaya	2020	

Title of M. Sc. thesis: Rooting behavior of *Terminalia bellerica* Roxb. under controlled conditions through vegetative propagation method

Title of Ph. D. dissertation: Variations in Vegetational Diversity and Carbon Stock in Large Cardamom Based Traditional Agroforestry System across Altitudinal Gradient in Darjeeling Himalayas

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W	URL: http://internal.khntusg.com.ua/fulltext/Springer/2017_Book_Agroforestry.pdf Fetched: 2021-07-05T19:36:00.9300000	2
W	URL: https://www.researchgate.net/figure/Emission-factors-tonnes-CO-2-C-ha-1-yr-1-for-sites-IP1-6-and-DP1-3_tbl1_281813214 Fetched: 2021-08-10T06:30:00.0000000	1
W	URL: http://mzuir.inflibnet.ac.in:8080/jspui/bitstream/123456789/200/1/Alfred%20Malsawmsanga%20%28EVS%29%20-%202011.pdf Fetched: 2021-01-29T15:53:11.7670000	1
W	URL: https://www.researchgate.net/publication/343544421_Species_diversity_population_structure_and_regeneration_status_of_trees_in_Fakim_Wildlife_Sanctuary_Nagaland_Northeast_India Fetched: 2021-03-05T08:03:50.9800000	1
W	URL: https://repository.tribal.gov.in/bitstream/123456789/74176/1/IIPA_2019_research_0057.pdf Fetched: 2021-07-27T14:57:34.2770000	2
W	URL: https://www.mdpi.com/2073-445X/10/4/387/pdf Fetched: 2021-06-21T12:35:12.0900000	6
W	URL: https://www.mdpi.com/2073-445X/10/4/435/pdf Fetched: 2021-05-14T11:23:14.3030000	2