CHAPTER 3
VEGETATION DIVERSITY

Objective I: Study on vegetation composition and identification of non-native species.

3.1 Introduction

The Himalaya is one of the global hotspots, and the Indian Himalayan region (IHR) constitutes a major component due to its ecological as well as economic values [1]. The natural vegetation of the IHR ranges from tropical forests in the foothills to alpine pastures across a span of 100-200 km [2, 3]. These wide variations of vegetation types reflect the complex interactions between plants, topography, altitude, edaphic properties, climatic conditions, and other factors. [4, 5, 6, 7, 8]. Such variations have also resulted in the development of specific phytogeographic zones with a pronounced endemism in the IHR [9, 10]. Several studies have reported altitude as the primary factor influencing the composition, structure, and distribution of vegetation [11, 12, 13, 14]. In addition to altitude, rainfall and temperature are two climatic variables that play pivotal roles in influencing the spatiotemporal distributions of vegetation [10, 15]. Topographic conditions also affect the distribution of solar radiation along with the availability of water and nutrients, leading to variations in climatic conditions that shape the vegetation patterns [7, 16, 17, 18].

However, beyond the physical and climatic determinants, the distribution, as well as the composition of plant communities, are also shaped by the competitive and facilitative interplays between the plant species [14, 19, 20, 21, 22, 23]. In forest ecosystems, the overstory and understory significantly exert mutual influence on each other's regeneration patterns, composition, and diversity [15, 24]. This is because the overstory modifies the availability of light, moisture, and nutrients through the spatial arrangement of leaves, leaf area index and amount of litter fall [14, 25, 26, 27]. The litter decomposition due to the thick canopy cover causes decreases in pH along with available nutrients [8]. As the response of the understory to the overstory can be species-specific, these modifications can either facilitate or inhibit the growth of the understory.

In the present era, the forests of the Himalayan region are threatened by invasive non-native plants [1, 28]. The invasions by non-native plants lead to alterations in plant communities primarily through a reduction in the diversity of native species, consequently exerting threats to the functioning of ecosystems as well as the biodiversity of a region [29, 30]. However, they can also modify the intrinsic properties and functions of a community without altering the diversity [8, 31]. The observable impacts of non-native plants are not limited to alterations in communities but also on the physicochemical properties and microbial diversity of soil, as well as biogeochemical cycles [28, 32, 33, 34]. To explain the transformation of non-native plants from introduction to invasion, several hypotheses have been suggested. The life history hypothesis by Elton [35], evolution of increased competition ability by Blossey and Nötzold [36] and later modified by Joshi and Vrieling [37], enemy release hypothesis by Keane and Crawley [38], empty niche hypothesis by Stachowicz and Tilman [39], propagule pressure hypothesis by Simberloff [40] and novel weapon hypothesis by Callaway and Ridenour [41] and Vilcinskas [42] are some of the notable ones. Additionally, studies have often associated several intrinsic traits such as high reproductive ability, strong competitive ability, high phenotypic and functional plasticity, etc. with the invasiveness of non-native plants [8, 43]. Hufbauer et al. [44] suggested that the similarity in soil, climate and disturbances between the native and introduced regions can facilitate the successful establishment and successive invasion by non-native plants. Even so, studies have often cited disturbances in habitats as one of the primary facilitators of the dispersal and establishment of non-native plants [8, 43, 45, 46, 47]. Therefore, this study aimed to determine the vegetation composition of the study site and identify the native and non-native plant species.

3.2 Methodology

3.2.1 Study site

The study was conducted in Sonai Rupai Wildlife Sanctuary located at 26°54'41.814" N and 92°29'53.502" E (Fig.. 3.1), Sonitpur district of Assam, covering an area of 220 km^2 with elevation ranging from 125 m to 480 m. The sanctuary was established in the year 1998 and is situated at the foothills of the Eastern Himalayas along the border of Assam-Arunachal Pradesh in Northeast India. The vegetation of the study site is characterized by a tropical semi-evergreen forest [48, 49]. However, there are scrub patches within the sanctuary dominated by grasses.

The Southwest monsoon which is characterized by the movement of moisture-laden winds from the Indian Ocean towards the Himalayas causes precipitation in the form of rainfall over the northeastern region during the period from June to September [50]. The period from November to February is characterized by low temperatures and minimal rainfall. During the study period, the highest rainfall was recorded in June (Fig.. 3.2). The highest mean monthly temperature (25.15 °C) was recorded in July 2023, while the lowest mean monthly temperature (11.20 °C) was observed in February 2022 (Fig.. 3.2).

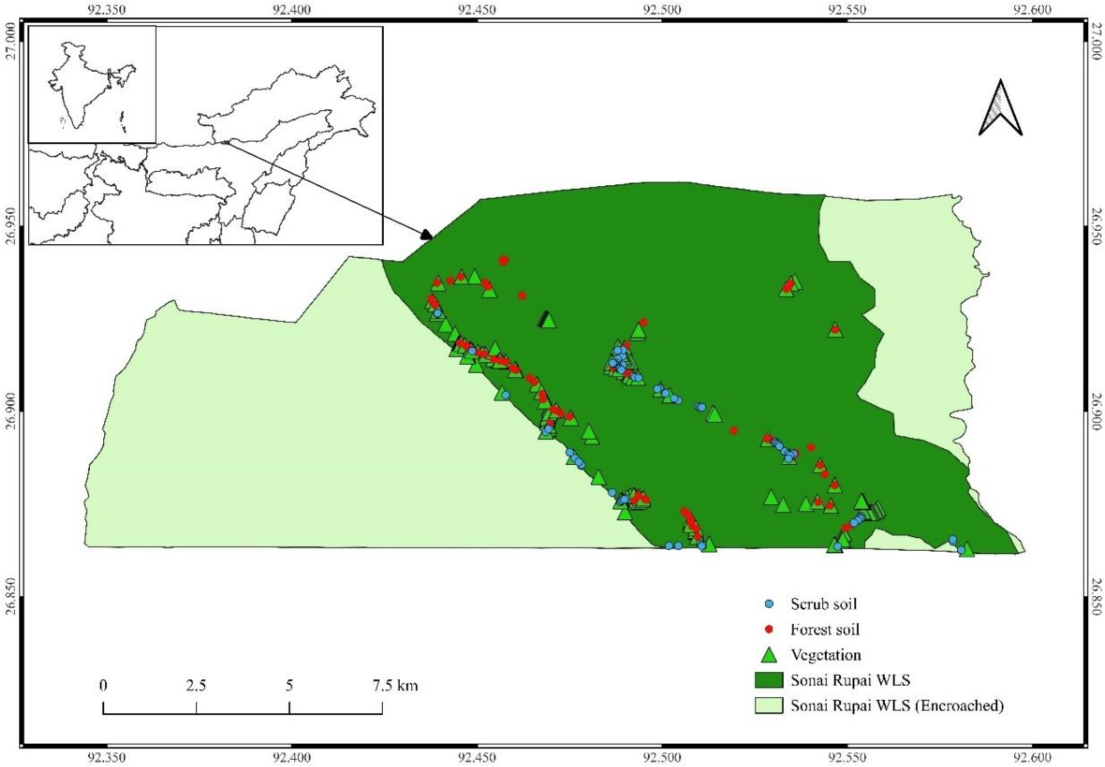

Fig. 3.1: Map displaying the location of the Sonai Rupai Wildlife Sanctuary, Assam, India

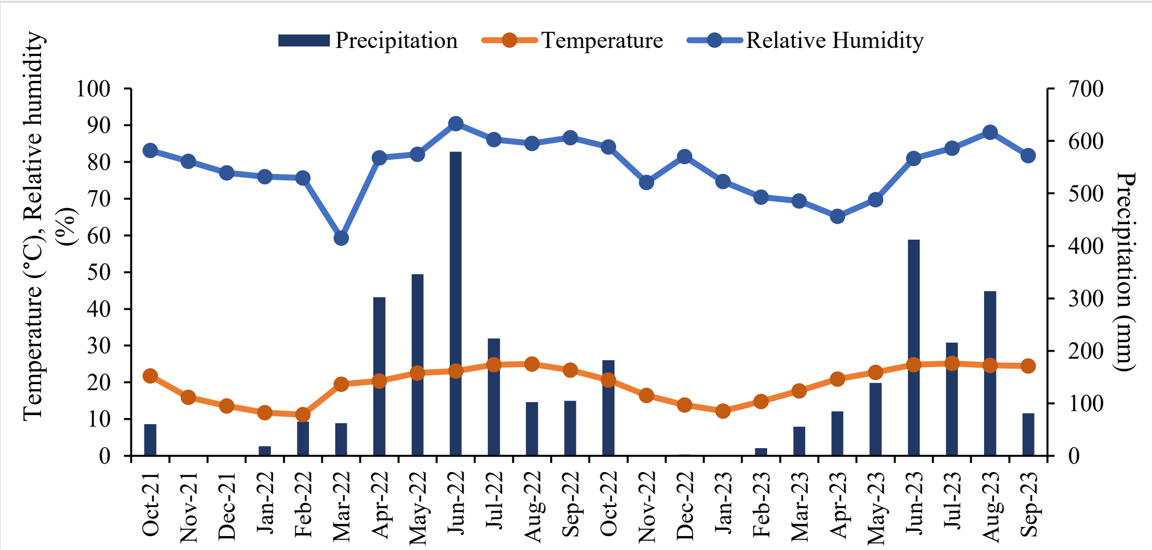

Fig. 3.2 The monthly variations in climatic variables recorded in study area, Sonai Rupai Wildlife Sanctuary during the study period (Source: NASA POWER).

3.2.2 Vegetation sampling and analysis

For the purpose of vegetation sampling, quadrats of different sizes having 10m × 10m for trees, 5m × 5m for shrubs and 1m × 1m for herbs, were placed using random sampling method. A total of 398 quadrates were used for vegetation sampling, having 103 for trees, 120 for shrubs and 175 for herbs. Additionally, prior knowledge and expertise of the study were utilized to strategically determine the sampling locations, aiming to optimize the collection of useful data. For the tree species, only those individuals with girth at breast height (GBH) ≥ 30 cm were considered as adults and included in the study. For the shrubs, the girth was measured at the collar. The identifications of the plant species were done using relevant books – Flora of Assam [51], Trees of Arunachal Pradesh [52], Flowers of Himalaya [53] – and other appropriate literature. Online plant identification databases – https://www.kew.org, https://wfoplantlist.org and https://www.flowersofindia.net – were used.

The determination of the vegetation composition and diversity was performed using frequency, density, abundance, and their relative values as given by Curtis and McIntosh [54]. The basal area was calculated using the method outlined by Kanagaraj et al. [55]. For the trees and shrubs, the importance value index (IVI) was calculated by the summation of relative values of frequency, density, and dominance whereas, for the herbs instead of relative dominance, relative abundance was used [54, 56]. The diversity of the plant species was measured using the Shannon-Wiener diversity index (H′), Simpson's index of dominance (C_D), Menhinick index ($D_{Menhinick}$), Margalef's index ($D_{Margalef}$) and Pielou's evenness index (J′) [57, 58, 59, 60, 61]. For the determination of the distribution pattern of the plant species, the Whitford index was used, and the value of the index was categorized according to the scheme given by Cottam and Curtis [63] as regular (<0.025), random (0.025-0.050) and contiguous (>0.050) [62]. The formulae of the indices and their details are provided in Table 4.1

Table 3.1 Community parameters and diversity indices used for determining the community characteristics of vegetation

Community parameters	Formula	References
Frequency	$\frac{\text{No. of quadrats in which the species occurred}}{\text{Total no. of quadrats studied}} \times 100$	
Density	$\frac{\text{Total number of individuals of a species found in quadrats}}{\text{Total no. of quadrats studied}}$	
Abundance	$\frac{\text{Total number of individuals of a species found in quadrats}}{\text{Total no. of quadrats in which the species occurred}}$	Curtis and McIntosh [54]
Relative frequency	$\frac{\text{No. of occurrence of the species}}{\text{No. of occurrence of all species}} \times 100$	
Relative density	$\frac{\text{No. of individuals of the species}}{\text{No. of individuals of all species}} \times 100$	
Relative dominance	$\frac{\text{Total basal area of the species}}{\text{Total basal area of all species}} \times 100$	
Basal area	$\frac{g^2}{4\pi}$	Kanagaraj et al. [55]
Relative abundance	$\frac{\text{Abundance of a species}}{\text{Sum of abundance of all species}} \times 100$	Mishra, [56]
Importance Value Index (IVI)	For trees and shrubs, IVI = Relative frequency + Relative density + Relative dominance For herbs, IVI = Relative frequency + Relative density + Relative abundance	Mishra, [56]
Shannon-Wiener diversity index (H′)	$H' = -\sum_{i=1}^{S} p_i \ln p_i$ here, S is species richness, p_i is the proportion of individuals in the i^{th} species ($p_i = n_i/N$), N is the total number of species	Shannon-Weaver, [57]

Simpson's index of dominance (C_D)	$$C_D = -\sum_{i=1}^{S}(p_i)^2$$ here, pi is the proportion of individuals in the ith species ($p_i = n_i/N$)	Simpson [58]
Menhinick index ($D_{Menhinick}$)	$$D_{Menhinick} = \frac{S}{\sqrt{N}}$$ Here, S is the number of species and N is the total number of individuals.	Menhinick [59]
Margalef's index ($D_{Margalef}$)	$$D_{Margalef} = \frac{S-1}{\ln(N)}$$ here S is the number of species and N is the total number of individuals.	Margalef [60]
Pielou's evenness index (J′)	$$J' = \frac{H'}{\ln(S)}$$ here H′ is the Shannon-Weiner diversity index and S is the total number of species	Pielou [61]
Whitford index (WI)	WI = A/F here A is the abundance of i^{th} species and F is the frequency of the i^{th} species.	Whitford [62]

3.3 Results

The study recorded a total of 191 species under 154 genera and 57 families from the study site (Table 3.2). 68 species were found to be herbs, including both monocots and dicots, belonging to 53 genera and 17 families. 41 species were shrubs, belonging to 38 genera and 18 families; and 82 species were trees, belonging to 72 genera and 38 families. The species accumulation curve of the herbs, shrubs and trees in Sonai Rupai Wildlife Sanctuary exhibited an irregular trend with shrub displaying least growth compared to that of the herbs and trees (Fig.. 3.3). In the case of trees and herbs, the number of species increased with increase in the number of sampling quadrats. Overall, the species accumulation curve indicated the diversity of species for herbs and trees were more than that of the shrubs in the study site.

The study demonstrated that herbs exhibited the highest density (169085 individuals ha^{-1}) compared to shrubs (4670 individuals ha^{-1}) and tree species (535 individuals ha^{-1}) (Table 3.2). The basal area of trees (54.08 m^2 ha^{-1}) was comparatively higher than that of shrubs (0.34 m^2 ha^{-1}) indicating a well-established forest structure with canopy cover (Table 3.2). The higher value of Margalef's and Menhinick's index indicates the high species richness for all the communities (Table 3.3). The higher value of Margalef's index for trees indicates that the species richness is higher even with the lower number of individuals compared to herbs and shrubs. Meanwhile, the lower value of Menhinick's index for herbs indicates the dilution of species richness due to high density. This observation is also upheld by the values of Pielou's evenness index, indicating that the shrub community has lower evenness compared to the other two communities (Table 3.3). Among the three plant habits, the herbs ($H' = 3.72$) displayed the highest diversity, followed by trees ($H' = 3.57$) and shrubs ($H' = 2.72$). Shrubs displayed the lowest species richness diversity index having 2.71 and evenness index (0.73) (Table 3.3). The low values for Simpson's dominance index for herbs ($D = 0.04$) and trees ($D = 0.06$) indicate evenly distributed communities. In contrast, the higher Simpson's dominance value ($D = 0.13$) indicates that among the shrubs, several shrub species have a disproportionately higher number of individuals.

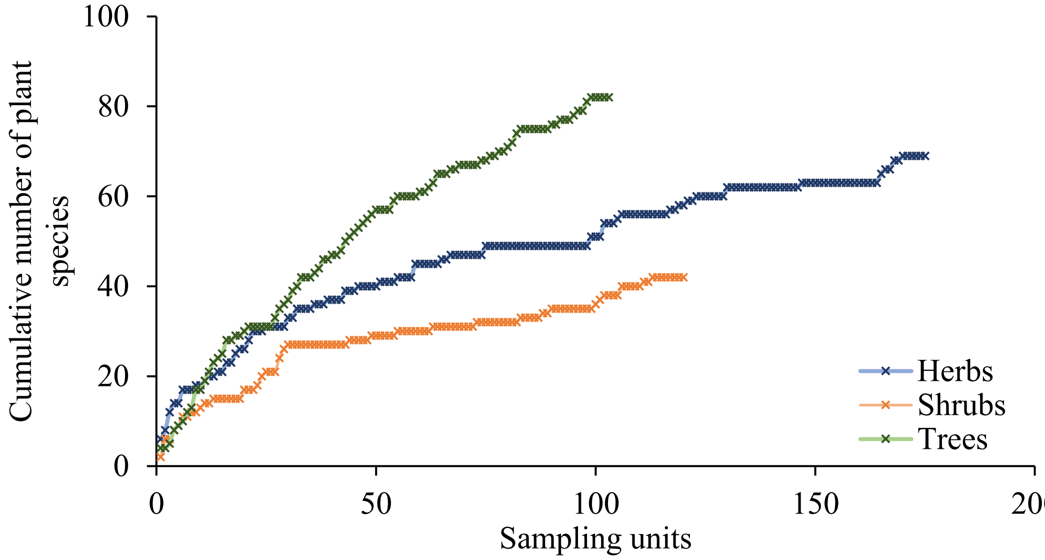

Fig. 3.3 Species accumulative curve of herbs, shrubs and trees in Sonai Rupai Wildlife Sanctuary.

In the herb community, the highest IVI was recorded for *Axonopus compressus* (32.25) followed by *Imperata cylindrica* (23.39), *Cyperus niveus* (17.70), *Cyathula prostrata*, *Ageratum houstonianum* (10.67) and others (Fig.. 3.3(a), Table 3.2). Out of the 68 herb species, 19 species were non-native to this region while the remaining 49 species were native (Fig.. 3.4). The two species with the highest IVI among the herbs i.e. *Axonopus compressus* and *Imperata cylindrica* are non-native, belonging to the family Poaceae, are dominant. In the shrub community, the highest IVI was recorded for *Chromolaena odorata* (89.83) followed by *Clerodendrum infortunatum* (52.80), *Lantana camara* (20.82), *Grewia sapida* (12.18*), Leea indica* (10.26) and others (Fig. 3.5(b), Table 3.2). Among the shrub community, 10 species were non-native and 32 species were native to this region. Significantly, both *Chromolaena odorata* and *Lantana camara* are non-native plants and dominant in the study area. In the tree community, the highest IVI was recorded for *Magnolia hodgsonii* (43.78), *Tetrameles nudiflora* (39.24), *Bauhinia purpurea* (22.68), *Bombax ceiba* (18.56), *Gmelina arborea* (11.70) and others (Fig. 3.5(c), Table 3.2). Only a single species i.e. *Senna siamea* (IVI = 2.59), out of the 82 species in the tree community was non-native. The distribution pattern obtained through Whitford's index exhibited contagiousness for all the species. There is a list of recorded plant species in Table 3.2, along with information about their status and community parameters. Table 3.3 provides details of the phytosociological attributes of the recorded plant species.

Table 3.2 List of recorded plant species along with their status, community parameters and their distribution.

Name	Family	Status	Density ha^{-1}	Basal area m^2ha^{-1}	IVI	WI	Distribution pattern
Herbs							
Acanthus leucostachyus Wall. Ex Nees	Acanthaceae	Native	57	-	0.56	1.64	Contagious
Acmella oleracea (L.) R.K.Jansen	Asteraceae	Non-native	343	-	2.22	9.84	Contagious
Acmella paniculata (Wall. Ex DC.) R.K.Jansen	Asteraceae	Native	1714	-	4.16	0.61	Contagious
Ageratum conyzoides L.	Asteraceae	Non-native	4400	-	7.67	0.64	Contagious
Ageratum houstonianum Mill.	Asteraceae	Non-native	7200	-	10.70	0.72	Contagious
Alpinia nigra (Gaertn.) Burtt	Zingiberaceae	Native	171	-	1.23	4.92	Contagious
Alternanthera ficoidea (L.) P.Beauv	Amaranthaceae	Non-native	857	-	2.58	1.54	Contagious
Alternanthera sessilis (L.) DC.	Amaranthaceae	Native	3886	-	6.79	1.12	Contagious
Arthraxon lancifolius (Trin.) Hochst.	Poaceae	Native	3143	-	6.40	3.61	Contagious
Arundinella hirta (Thunb.) Tanaka	Poaceae	Non-native	57	-	0.56	1.64	Contagious
Arundinella nepalensis Trin.	Poaceae	Native	686	-	2.25	1.23	Contagious

Arundinella pumila (Hochst. ex A.Rich.) Steud.	Poaceae	Native	857	-	2.72	2.73	Contagious
Axonopus compressus (Sw.) P.Beauv.	Poaceae	Non-native	35829	-	38.30	0.38	Contagious
Boehmeria virgata (G.Forst.) Guill.	Urticaceae	Native	914	-	2.69	1.05	Contagious
Bonnaya ciliata (Colsm.) Spreng.	Convolvulaceae	Non-native	229	-	1.20	1.64	Contagious
Camonea umbellate (L.) A.R.Simões & Staples	Poaceae	Native	171	-	1.02	1.23	Contagious
Centotheca lappacea (L.) Desv.	Poaceae	Native	571	-	2.05	1.82	Contagious
Chrysopogon aciculatus (Retz.) Trin.	Commelinaceae	Native	1657	-	4.10	0.59	Contagious
Commelina diffusa Burm.f.	Fabaceae	Native	229	-	1.56	6.56	Contagious
Crotalaria evolvuloides Wight	Asteraceae	Non-native	286	-	1.89	8.20	Contagious
Cuphea carthagenensis (Jacq.) J.F.Macbr.	Zingiberaceae	Native	2400	-	5.35	0.48	Contagious
Curcuma aromatica Salisb.	Amaranthaceae	Native	57	-	0.56	1.64	Contagious
Cyanthillium cinereum (L.) H.Rob.	Poaceae	Native	10571	-	15.15	0.39	Contagious
Cyathula prostrata (L.) Blume	Poaceae	Native	4400	-	7.47	0.88	Contagious

Cynodon dactylon (L.) Pers.	Poaceae	Native	629	-	2.14	1.13	Contagious
Cyperus mindorensis (Steud.) Huygh	Poaceae	Native	12743	-	17.73	0.34	Contagious
Cyperus niveus Retz.	Poaceae	Native	800	-	2.58	2.55	Contagious
Cyperus odoratus Burm.f.	Poaceae	Native	800	-	2.50	0.92	Contagious
Cyperus rotundus L.	Acanthaceae	Native	171	-	1.23	4.92	Contagious
Desmostachya bipinnata (L.) Stapf	Poaceae	Native	686	-	4.21	19.68	Contagious
Dicliptera paniculata (Forssk.) I.Darbysh.	Poaceae	Native	686	-	2.67	4.92	Contagious
Digitaria ciliaris (Retz.) Koeler	Pontederiaceae	Non-native	1600	-	4.47	5.10	Contagious
Digitaria longiflora (Retz.) Pers.	Poaceae	Native	1371	-	3.51	0.80	Contagious
Eleusine indica (L.) Gaertn.	Poaceae	Native	400	-	2.55	11.48	Contagious
Eragrostis japonica (Thunb.) Trin	Poaceae	Native	171	-	1.23	4.92	Contagious
Eragrostis unioloides (Retz.) Nees ex Steud.	Convolvulaceae	Non-native	286	-	1.89	8.20	Contagious
Evolvulus nummularius (L.) L.	Poaceae	Native	171	-	1.23	4.92	Contagious
Fimbristylis dichotoma (L.) Vahl	Fabaceae	Native	114	-	0.90	3.28	Contagious

Grona trifloral (L.) H.Ohashi & K.Ohashi	Poaceae	Non-native	17829	-	23.42	0.28	Contagious
Imperata cylindrica (L.) Raeusch.	Poaceae	Native	4800	-	7.90	0.96	Contagious
Isachne globosa (Thunb.) Kuntze	Lamiaceae	Native	57	-	0.56	1.64	Contagious
Leucas aspera (Willd.) Link	Linderniaceae	Native	286	-	1.89	8.20	Contagious
Mikania micrantha Kunth	Asteraceae	Non-native	1029	-	3.34	0.36	Contagious
Mitracarpus hirtus (L.) DC.	Rubiaceae	Non-native	1143	-	3.07	1.31	Contagious
Murdannia triquetra (Wall. ex C.B.Clarke) G.Brückn.	Commelinaceae	Native	2400	-	5.21	0.57	Contagious
Oplismenus burmanni (Retz.) P.Beauv.	Poaceae	Native	1429	-	4.06	4.56	Contagious
Oplismenus compositus (L.) P.Beauv.	Poaceae	Native	400	-	2.55	11.48	Contagious
Oplismenus undulatifolius (Ard.) P.Beauv.	Poaceae	Native	5029	-	8.16	1.78	Contagious
Oxalis debilis Kunth.	Oxalidaceae	Non-native	971	-	2.99	3.10	Contagious
Paederia foetida L.	Rubiaceae	Native	400	-	1.83	0.46	Contagious
Panicum jahnii Steud.	Poaceae	Native	1257	-	4.51	9.02	Contagious
Paspalum distichum L.	Poaceae	Non-native	343	-	2.22	9.84	Contagious

Paspalum conjugatum P.J.Bergius	Poaceae	Non-native	229	-	1.56	6.56	Contagious
Persicaria hydropiper (L.) Delarbre	Polygonaceae	Native	1029	-	3.78	7.38	Contagious
Persicaria strigose (R.Br.) H.Gross	Polygonaceae	Native	514	-	1.91	1.64	Contagious
Phyllanthus amarus Schumach. & Thonn.	Phyllanthaceae	Non-native	229	-	1.20	1.64	Contagious
Pontederia crassipes Mart.	Pontederiaceae	Native	1429	-	5.06	10.25	Contagious
Pontederia vaginalis Burm.f.	Lamiaceae	Native	800	-	2.58	2.55	Contagious
Premna herbacea Roxb.	Acanthaceae	Native	171	-	1.23	4.92	Contagious
Rungia pectinata (L.) Nees	Poaceae	Native	4629	-	7.66	1.10	Contagious
Saccharum spontaneum L.	Rubiaceae	Non-native	5657	-	8.79	1.34	Contagious
Spermacoce latifolia Aubl.	Poaceae	Native	743	-	2.86	5.33	Contagious
Sporobolus diandrus (Retz.) P.Beauv.	Poaceae	Native	571	-	2.05	1.82	Contagious
Sporobolus piliferus (Trin.) Kunth	Asteraceae	Non-native	2286	-	5.55	0.33	Contagious
Synedrella nudiflora (L.) Gaertn.	Menispermaceae	Native	171	-	1.23	4.92	Contagious

Tinospora cordifolia (Willd.) Hook.f. & Thomson	Linderniaceae	Native	171	-	1.23	4.92	Contagious
Torenia asiatica L.	Urticaceae	Native	1029	-	3.12	3.28	Contagious
Urtica dioica L.	Asteraceae	Native	171	-	1.02	1.23	Contagious
Shrubs							
Abelmoschus manihot (L.) Medik.	Malvaceae	Native	7	0.00	0.90	2.40	Contagious
Antidesma acidum Retz.	Phyllanthaceae	Native	3	0.00	1.05	1.20	Contagious
Buddleja asiatica Lour.	Scrophulariaceae	Native	10	0.00	0.78	3.60	Contagious
Chromolaena odorata (L.) R.M.King & H.Rob.	Asteracee	Non-native	1630	0.10	89.83	0.10	Contagious
Citrus medica L.	Rutaceae	Native	20	0.02	6.19	0.45	Contagious
Clerodendrum infortunatum L.	Lamiaceae	Native	803	0.07	52.80	0.14	Contagious
Coffea benghalensis B.Heyne ex Roth	Rubiaceae	Native	13	0.00	1.09	1.20	Contagious
Croton caudatus Geiseler	Euphorbiaceae	Native	77	0.01	6.95	0.77	Contagious
Desmodium gangeticum (L.) DC.	Fabaceae	Native	63	0.00	3.89	0.47	Contagious
Flemingia strobilifera (L.) W.T.Aiton	Fabaceae	Native	97	0.01	7.53	1.39	Contagious
Glochidion ellipticum Wight	Phyllanthaceae	Native	17	0.00	1.44	0.67	Contagious

Glycosmis pentaphylla (Retz.) DC.	Rutaceae	Native	7	0.00	0.49	2.40	Contagious
Grewia sapida Roxb. ex DC.	Malvaceae	Native	300	0.00	12.18	0.42	Contagious
Ipomoea carnea Jacq.	Convolvulaceae	Non-native	77	0.00	3.78	1.73	Contagious
Ixora acuminata Thwaites	Rubiaceae	Native	13	0.01	3.68	1.20	Contagious
Jasminum grandiflorum L.	Oleaceae	Native	7	0.00	0.90	0.60	Contagious
Jasminum multiflorum (Burm.f.) Andrews	Oleaceae	Native	7	0.00	0.85	2.40	Contagious
Lantana camara L.	Verbenaceae	Non-native	230	0.03	20.82	0.19	Contagious
Leea indica (Burm.f.) Merr.	Vitaceae	Native	203	0.01	10.26	0.43	Contagious
Melastoma malabathricum L.	Melastomataceae	Native	67	0.01	5.74	1.50	Contagious
Mimosa himalayana Gamble	Fabaceae	Native	33	0.00	2.78	0.33	Contagious
Mimosa pudica L.	Fabaceae	Non-native	53	0.00	2.95	0.77	Contagious
Mussaenda roxburghii Hook.f.	Rubiaceae	Native	23	0.00	1.91	2.10	Contagious
Nyctanthes arbor-tristis L.	Oleaceae	Native	23	0.01	2.62	8.40	Contagious
Ohwia caudata (Thunb.) H.Ohashi	Fabaceae	Native	17	0.00	0.87	6.00	Contagious
Osbeckia nepalensis Hook.	Melastomataceae	Native	83	0.00	5.37	0.61	Contagious
Persicaria orientalis (L.) Spach	Polygonaceae	Native	43	0.00	1.44	15.60	Contagious
Phlogacanthus thyrsiformis (Roxb. ex Hardw.) Mabb.	Acanthaceae	Native	13	0.02	4.92	4.80	Contagious

Phyllanthus reticulatus Poir.	Phyllanthaceae	Native	3	0.00	0.71	1.20	Contagious
Rotheca serrata (L.) Steane & Mabb.	Lamiaceae	Native	83	0.01	6.71	0.83	Contagious
Senna hirsuta (L.) H.S.Irwin & Barneby	Fabaceae	Non-native	3	0.00	0.44	1.20	Contagious
Senna occidentalis (L.) Link	Fabaceae	Non-native	27	0.00	1.08	9.60	Contagious
Senna tora (L.) Roxb.	Fabaceae	Non-native	60	0.00	2.96	1.35	Contagious
Sida acuta Burm.f.	Malvaceae	Native	100	0.00	5.67	0.44	Contagious
Solanum torvum Sw.	Solanaceae	Non-native	57	0.00	3.88	0.57	Contagious
Solanum viarum Dunal	Solanaceae	Non-native	23	0.00	1.70	0.93	Contagious
Stachytarpheta cayennensis (Rich.) Vahl	Verbenaceae	Non-native	143	0.00	6.24	0.81	Contagious
Tabernaemontana divaricata (L.) R.Br. ex Roem. & Schult.	Apocynaceae	Native	77	0.01	6.93	0.34	Contagious
Thunbergia grandiflora Roxb.	Acanthaceae	Native	7	0.00	0.83	0.34	Contagious
Triumfetta pentandra A.Rich.	Malvaceae	Native	27	0.00	1.34	0.34	Contagious
Urena lobata L.	Malvaceae	Native	117	0.00	7.50	0.34	Contagious
Trees							
Actinodaphne obovata (Nees) Blume	Lauraceae	Native	1	0.02	0.59	1.03	Contagious
Aesculus assamica Griff.	Sapindaceae	Native	6	0.05	1.56	6.18	Contagious

Aglaia edulis (Roxb.) Wall.	Meliaceae	Native	4	0.72	2.43	4.12	Contagious
Aglaia spectabilis (Miq.) S.S.Jain & S.Bennet	Meliaceae	Native	12	0.86	6.42	0.25	Contagious
Ailanthus integrifolia Lam.	Simaroubaceae	Native	1	0.08	0.71	1.03	Contagious
Alangium chinense (Lour.) Harms	Cornaceae	Native	2	0.02	0.78	2.06	Contagious
Albizia procera (Roxb.) Benth.	Fabaceae	Native	5	0.51	3.75	0.21	Contagious
Alstonia scholaris (L.) R.Br.	Apocynaceae	Native	4	0.06	1.98	0.46	Contagious
Aphanamixis polystachya (Wall.) R.Parker	Meliaceae	Native	11	0.41	4.28	0.71	Contagious
Aristolochia cathcartii Hook.f.	Aristolochiaceae	Native	1	0.01	0.58	1.03	Contagious
Artocarpus chama Buch.-Ham.	Moraceae	Native	3	1.87	5.15	0.34	Contagious
Azadirachta indica A.Juss.	Meliaceae	Native	1	0.01	0.59	1.03	Contagious
Baccaurea ramiflora Lour.	Phyllanthaceae	Native	11	0.28	4.03	0.71	Contagious
Balakata baccata (Roxb.) Esser	Euphorbiaceae	Native	1	0.08	0.70	1.03	Contagious
Bauhinia purpurea L.	Fabaceae	Native	64	1.47	22.68	0.15	Contagious
Beilschmiedia assamica Meisn.	Lauraceae	Native	1	0.07	0.70	1.03	Contagious
Bombax ceiba L.	Malvaceae	Native	12	6.80	18.56	0.12	Contagious
Bridelia assamica Hook.f.	Phyllanthaceae	Native	1	0.01	0.59	1.03	Contagious
Canarium bengalense Roxb.	Burseraceae	Native	1	0.01	0.57	1.03	Contagious
Canarium strictum Roxb.	Burseraceae	Native	2	0.15	1.40	0.52	Contagious

Casearia glomerata Roxb.	Salicaceae	Native	1	0.02	0.59	1.03	Contagious
Castanopsis tribuloides (Sm.) A.DC.	Fagaceae	Native	1	0.17	0.87	1.03	Contagious
Ceriscoides campanulata (Roxb.) Tirveng.	Rubiaceae	Native	3	0.03	0.98	3.09	Contagious
Chisocheton cumingianus (C.DC.) Harms	Meliaceae	Native	4	0.04	1.93	0.46	Contagious
Chukrasia tabularis A.Juss.	Meliaceae	Native	7	0.56	4.59	0.20	Contagious
Cinnamomum bejolghota (Buch.-Ham.) Sweet	Lauraceae	Native	1	0.01	0.58	1.03	Contagious
Cinnamomum glaucescens (Nees) Hand.-Mazz.	Lauraceae	Native	1	0.02	0.59	1.03	Contagious
Cordia dichotoma G.Forst.	Boraginaceae	Native	1	0.10	0.74	1.03	Contagious
Cryptocarya amygdalina Nees	Lauraceae	Native	16	0.29	5.35	0.66	Contagious
Dalrympelea pomifera Roxb.	Staphyleaceae	Native	3	0.03	1.36	0.77	Contagious
Dendrocnide sinuata (Blume) Chew	Urticaceae	Native	2	0.33	1.73	0.52	Contagious
Dillenia indica L.	Dilleniaceae	Native	15	1.22	9.15	0.13	Contagious
Dipterocarpus retusus Blume	Dipterocarpaceae	Native	2	0.31	1.32	2.06	Contagious

Dysoxylum gotadhora (Buch.-Ham.) Mabb.	Meliaceae	Native	2	0.05	1.21	0.52	Contagious
Ehretia acuminata R.Br.	Boraginaceae	Native	1	0.01	0.58	1.03	Contagious
Elaeocarpus aristatus Roxb.	Elaeocarpaceae	Native	2	0.36	1.42	2.06	Contagious
Elaeocarpus serratus L.	Elaeocarpaceae	Native	9	0.35	4.57	0.26	Contagious
Endospermum chinense Benth.	Euphorbiaceae	Native	1	0.06	0.69	1.03	Contagious
Ficus auriculata Lour.	Moraceae	Native	8	0.07	4.05	0.52	Contagious
Ficus nervosa Roth	Moraceae	Native	7	0.58	3.88	0.80	Contagious
Gmelina arborea Roxb. ex Sm.	Lamiaceae	Native	29	0.79	11.70	0.26	Contagious
Gynocardia odorata R.Br.	Achariaceae	Native	2	1.12	1.31	0.52	Contagious
Heteropanax fragrans (Roxb.) Seem.	Rhamnaceae	Native	2	0.10	0.79	2.06	Contagious
Hovenia acerba Lindl.	Rhamnaceae	Native	7	0.02	2.79	0.80	Contagious
Ilex hookeri King	Aquifoliaceae	Native	7	0.20	3.14	0.45	Contagious
Knema erratica (Hook.f. & Thomson) J.Sinclair	Myristicaceae	Native	2	0.19	0.90	2.06	Contagious
Kydia calycina Roxb.	Malvaceae	Native	2	0.08	1.80	0.52	Contagious
Lagerstroemia speciosa (L.) Pers.	Lythraceae	Native	3	0.36	1.47	3.09	Contagious
Litsea glutinosa (Lour.) C.B.Rob.	Malvaceae	Native	2	0.29	0.89	2.06	Contagious

Litsea monopetala (Roxb.) Pers.	Lythraceae	Native	7	0.01	3.88	0.45	Contagious
Litsea salicifolia (Roxb. ex Nees) Hook.f.	Lauraceae	Native	1	0.08	0.57	1.03	Contagious
Macaranga denticulata (Blume) Müll.Arg.	Euphorbiceae	Native	2	0.59	0.84	2.06	Contagious
Macaranga indica Wight	Euphorbiceae	Native	1	0.05	0.57	1.03	Contagious
Machilus gamblei King ex Hook.f.	Lauraceae	Native	1	0.01	0.80	1.03	Contagious
Magnolia hodgsonii (Hook.f. & Thomson) H.Keng	Magnoliaceae	Native	126	0.13	43.38	0.11	Contagious
Mallotus nudiflorus (L.) Kulju & Welzen	Euphorbiaceae	Native	1	3.50	0.59	1.03	Contagious
Mesua ferrea L.	Calophyllaceae	Native	7	0.01	2.61	0.80	Contagious
Meyna laxiflora Robyns	Rubiaceae	Native	1	0.11	0.62	1.03	Contagious
Monoon simiarum (Buch.-Ham. ex Hook.f. & Thomson) B.Xue & R.M.K.Saunders	Annonaceae	Native	5	0.03	2.08	1.29	Contagious
Morus macroura Miq.	Moraceae	Native	2	0.22	1.36	2.06	Contagious
Mucuna macrocarpa Wall.	Fabaceae	Native	1	0.33	0.62	1.03	Contagious

Neolamarckia cadamba (Roxb.) Bosser	Rubiaceae	Native	1	0.03	0.77	1.03	Contagious
Oroxylum indicum (L.) Kurz	Bignoniaceae	Native	6	0.11	2.49	0.69	Contagious
Phyllanthus emblica L.	Phyllanthaceae	Native	3	0.14	1.41	0.77	Contagious
Premna punduana Wall. ex Schauer	Lamiaceae	Native	1	0.04	0.63	1.03	Contagious
Pterospermum acerifolium (L.) Willd.	Malvaceae	Native	7	0.06	2.52	0.80	Contagious
Pterospermum lanceifolium Roxb. ex DC.	Malvaceae	Native	4	0.20	1.85	1.03	Contagious
Pterygota alata (Roxb.) R.Br.	Malvaceae	Native	4	1.70	4.62	1.03	Contagious
Pyrenaria barringtoniifolia (Griff.) Seem.	Theaceae	Native	5	0.04	2.51	0.32	Contagious
Castanopsis indica (Roxb. ex Lindl.) A.DC.	Fagaceae	Native	3	1.48	4.42	0.34	Contagious
Senna siamea (Lam.) H.S.Irwin & Barneby	Fabaceae	Non-native	8	0.20	2.59	2.06	Contagious
Sterculia villosa Roxb. ex Sm.	Malvaceae	Native	14	2.37	9.59	0.29	Contagious
Stereospermum colais (Buch.-Ham. ex Dillwyn) Mabb.	Bignoniaceae	Native	2	0.08	1.28	0.52	Contagious
Syzygium cumini (L.) Skeels	Myrtaceae	Native	4	0.07	1.62	1.03	Contagious

Syzygium formosum (Wall.) Mason	Myrtaceae	Native	5	0.53	3.03	0.57	Contagious
Tectona grandis L.f.	Lamiaceae	Native	3	0.17	1.24	3.09	Contagious
Tetrameles nudiflora R.Br.	Tetramelaceae	Native	10	18.39	39.24	0.13	Contagious
Toona ciliata M.Roem.	Meliaceae	Native	12	0.82	6.73	0.19	Contagious
Trema orientale (L.) Blume	Cannabaceae	Native	4	0.18	1.81	1.03	Contagious
Vallaris solanacea (Roth ex Roem. & Schult.) Kuntze	Apocynaceae	Native	4	0.02	1.52	1.03	Contagious
Vitex quinata (Lour.) F.N.Williams	Lamiaceae	Native	1	1.09	2.59	1.03	Contagious
Zanthoxylum rhetsa (Roxb.) DC.	Rutaceae	Native	1	0.02	0.60	1.03	Contagious

Table 3.3 Phytosociological attributes of the angiosperms of Sonai Rupai Wildlife Sanctuary

Community parameters	Herbs	Shrubs	Trees
Richness (S)	68	41	82
Number of families	17	18	38
Number of genera	53	38	72
Density (individuals ha^{-1})	169085	4670	535
Basal area (m^2ha^{-1})	-	0.34	54.08
Margalef's index ($D_{Margalef}$)	8.45	5.52	12.83
Menhinick's index ($D_{Menhinick}$)	1.29	1.09	3.49
Shannon-Wiener diversity index (H′)	3.72	2.72	3.57
Simpson dominance index (D)	0.04	0.13	0.06
Pielou's evenness index (J)	0.88	0.73	0.81

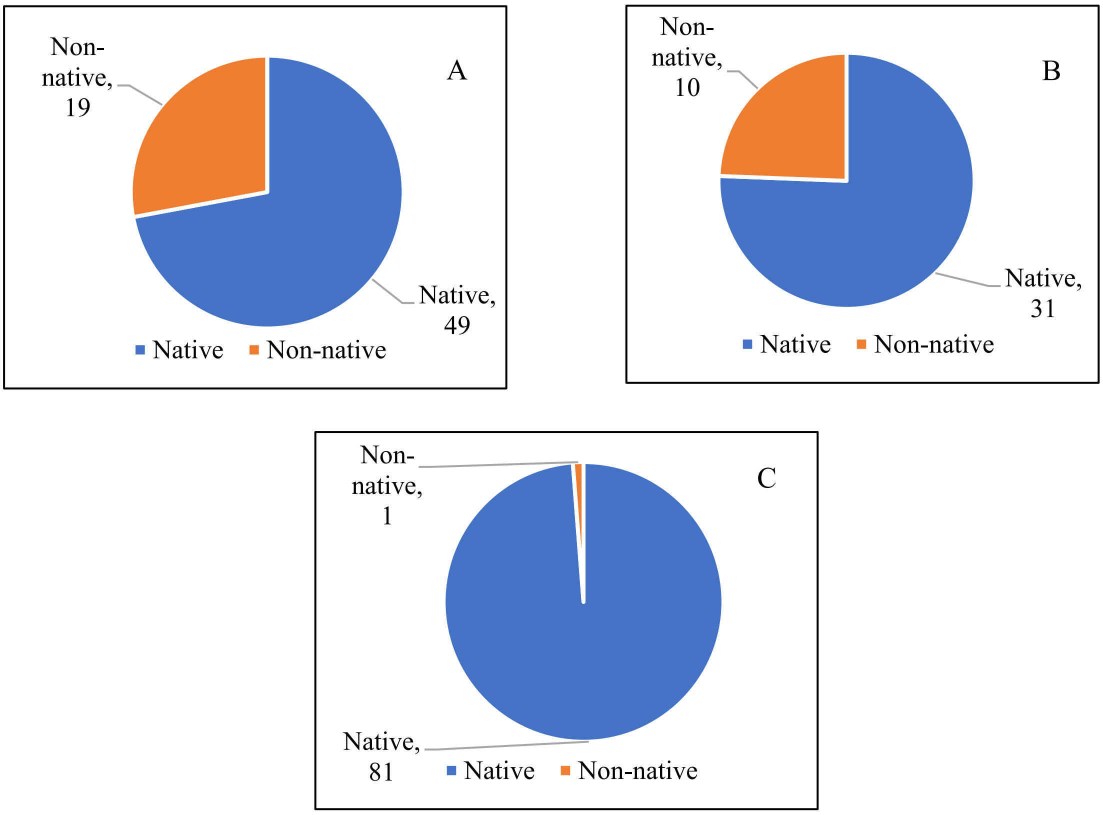

Fig. 3.4: Number of native and non-native plants for herbs (A), shrubs (B), and trees(C)

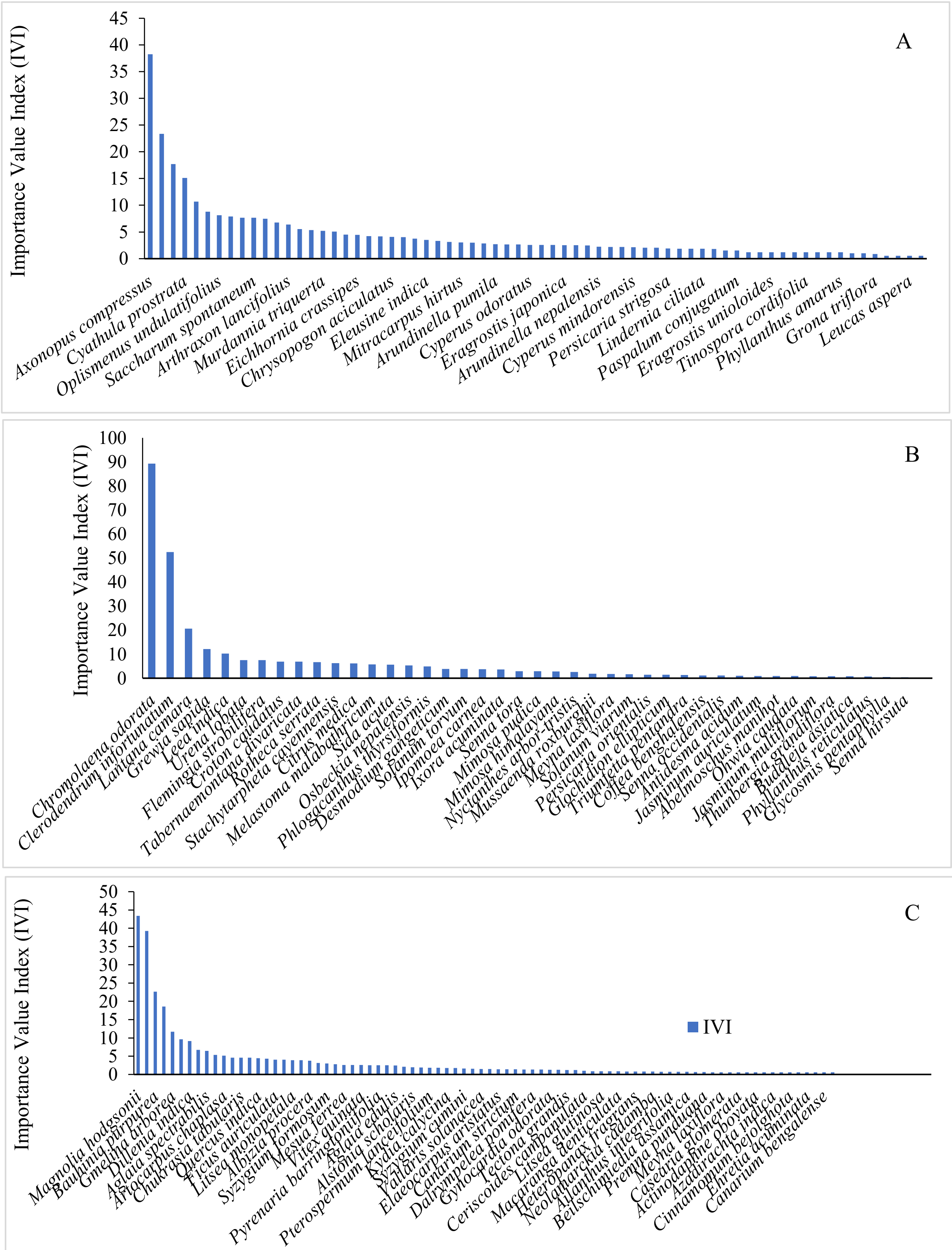

Fig. 3.5. Importance Value Index (IVI) of herb (A), shrub (B), and tree (C) species recorded in Sonai Rupai Wildlife Sanctuary

3.4 Discussion

The forest ecosystems, characterized by their diverse floristic components and species richness, serve as an important model for both biodiversity as well as numerous ecosystem functions associated with the conservation values [3, 14]. In the study, high diversity and richness of angiosperms were observed in the Sonai Rupai Wildlife Sanctuary. Begum et al. [64] reported that the floristic composition of the Sonai Rupai Wildlife Sanctuary resembled that of the tropical semi-evergreen forest of Nameri National Park The tropical semi-evergreen forest was characterized by the presence of trees like *Bombax ceiba, Dillenia indica*, *Gmelina arborea, Magnolia hodgsonii*, *Sterculia villosa*, *Tetrameles nudiflora*, etc., meanwhile, the understory comprised of plants like *Alpinia nigra, Clerodendrum infortunatum, Phlogacanthus thysiflorus*, etc. [64]. Similar species composition and diversity were observed in various studies conducted in the lower-elevation regions of the Eastern Himalaya. A study by Borah et al., [65] in the Behali reserve forest of Biswanath district, Assam found that the herbaceous plants are primarily comprised of species like *Axonopus compressus, Ageratum conyzoides, Cynodon dactylon, Eleusine indica, Oplismenus burmannii Cuphea carthagenensis* and others species with highest density displayed by *Cynodon dactylon* and *Ageratum conyzoides*. Similar observations were reported by Malunguja et al. [66] where the dominance of *Axonopus compressus, Imperata cylindrica,* and *Cynodon dactylon* contributed significantly to the density of herbs in Balipara and Bhomoraguri reserve forests.

The presence of non-native plants – *Ageratum houstonianum*, *Axonopus compressus*, *Chromolaena odorata*, *Imperata cylindrica*, and *Lantana camara* – with IVI values that are same or higher than the native plants indicates that these plants have either successfully establishment themselves or initiated the invade of the Wildlife Sanctuary. Several studies have reported the presence of these species within the protected areas and their detrimental effects on the ecosystems [67, 68, 69, 70]. According to Ram et al. [71], disturbances allow the regeneration of the understory plants as the open canopy allows more light penetration and more available resources. However, it is observed that the non-native plants that are invasive grow best in areas with high to moderate disturbances, such as forest edges and degraded forests [1, 72]. Several studies have reported that landscape passages e.g. trails, roads, waterways, etc. facilitate their proliferation [3, 46, 47]. By comparison, the protected areas characterized by undisturbed forests tend to exhibit lower susceptibility to invasions. In this study it was also observed that several non-native plants have low IVI compared to the native plants. According to the biotic resistance hypothesis states that forests that are undisturbed are likely to be lower susceptibility because of their species richness and intrinsic structure and functions of the communities which work collectively to hinder the biological invasion [73, 74, 75, 76]. However, non-native plants can rapidly acclimatize to their new habitats if they have traits like reproductive potential, uniparental reproduction, rapid dispersal and establishment, high growth, phenotypic plasticity, etc., [28, 43]. In this study it was observed that the non-native species like *Axonopus compressus* and *Imperata cylindrica* contributed significantly to the total density of herbs which was recorded as 169085 ha^{-1}. Similarly, Gogoi and Sahoo [77] reported that in parts of Jeypore reserve forest where anthropogenic disturbances were recorded, the density of herbs was 166000 ha^{-1} while the density was 36500 ha^{-1} in the undisturbed parts. These findings imply that disturbances facilitate the proliferation and growth of herbs. Similarly, in case of shrubs, Gogoi and Sahoo [77] observed that the basal area was 0.60 m^2 ha^{-1} and 2.41 m^2 ha^{-1} for undisturbed and highly disturbed parts of Jeypore reserve forest. As a result, even though the presence of non-native plants can be considered a consequence of the disturbance and degradation of the natural forests, they can promptly act as catalysts for degradation through rapid disruptions of the regeneration of both overstory and understory layers [76, 78, 79].

The tree species richness recorded in this study aligns with studies conducted by Sarkar and Devi [80], Yumnam and Deori [81], Buragohain et al. [82] and Baidya et al. [83]. The higher number of tree species compared to that of shrubs and herbs in the studied protected area is consistent with the findings of the study conducted by Rajbonshi and Islam [84] in Jeypore Reserve Forest. Kalita and Yumnam [85] reported from a study conducted in Gotanagar Reserve Forest of Assam that the Shannon-Weaver diversity index was 3.50 and *Gmelina arborea* displayed the highest dominance with an IVI of 20.65. Similary, Joshi et al. [86] observed that the undisturbed forest stands tend to have a higher diversity compared to the disturbed ones. Yuman and Deori [81] reported that the tree species in the interior of Poba Reserve Forest of Assam, at the foothills of Himalaya exhibited Shannon-Weiner index of 3.94, Simpson's index of 0.02 and Margalef's richness index of 11.79. Buragohain et al. [82] observed that in two moderately disturbed forests with 55 and 48 tree species respectively, the densities of trees were 582 and 446 individuals ha^{-1}, and the values of Shannon-Weiner index were 3.55 and 3.68, indicating a diverse composition. The tree species composition of this study was fairly comparable to the composition of species in the tropical semi-evergreen forest of Nambor characterized by the presence of *Alstonia scholaris, Dillenia indica, Balakata baccata, Bombax ceiba, Canarium bengalense, Litsea* *glutinosa, Syzygium cumini, Trema orientalis,* etc. [87]. Additionally, Barua et al. [88, 89] observed that the tree density, diversity and evenness varied with the presence and absence of non-native species in a given area. The presence of non-native species causing invasion can also favor and promote the recruitment of deciduous trees like *Alangium chinense, Bombax ceiba, Lagerstroemia speciosa*, etc. with an affinity towards sunlight [89]. The distribution of trees, shrubs and herbs irrespective of native or non-native origin were found to be contagious. According to Odum [90], the most common distribution in nature is contagious followed by random and regular. The presence of contagious distribution of tree species indicates minimum disturbances in the tropical semi-evergreen forest. Similar observations were made by Meshram and Khobragade [91] and Behera et al. [92], where majority of the trees displayed contagious distribution. Similar trend was reported for shrubs by Behera et al. [92] where the contagious distribution was the most prevalent type followed by random. However, the contagious distribution of non-native shrubs indicates the presence of disturbance within the study site which can further facilitate their spreading and establishments subsequently leading to invasion [93]. Similarly, the prevalence of contagious distributions among herbaceous species indicates presence of site-level disturbances and environmental heterogeneity that influence their spatial arrangement [91]. Therefore, the presence of non-native plants with the significant species diversity, low dominance, and evenness, indicates the occurrences of disturbances in the forest within the study site.

3.5 Conclusion

In this study, it is observed that the forest type is a tropical semi-evergreen forest that comprises both evergreen and deciduous tree species. Furthermore, the phytosociological analyses revealed species diversity encompasses both native and non-native species of herbs, shrubs and trees exhibiting the forest of Sonai Rupai wildlife sanctuary support rich diversity of plant species, which provides various ecological services. There are a few non-native plants had higher IVI than the native plants. This suggests that plants like *Axonopus compressus, Chromolaena odorata, Imperata cylindrica, Lantana camara, Mikania micrantha*, etc. have successfully established themselves post their introduction. Although the extent of invasion by the non-native plants in the protected area is not explored, over time their presence could significantly alter the phytosociological structure through the selective recruitment of the plant species within the study site.

3.6 References

[1] Pathak, R., Negi, V. S., Kumar Yadava, A., and Bhatt, I. D. Distribution Pattern of Dominant Invasive Alien Plants in Forests of Kumaon Region in West Himalaya. *International Journal of Ecology and Environmental Sciences*, 47(4):325-332, 2021.

[2] Zobel, B.D. and Singh, S.P. Himalayan Forests and Ecological Generalizations. *Bio Science*, 47 (11):735-745, 1997.

[3] Mehra, A., Tewari, L. M., and Rawal, R. S. Structure and Composition of Vegetation and Status of Invasion in Different Forest Types of Western Himalaya. *Advances in Zoology and Botany*, 11(1):12-29, 2023.

[4] Ahmad SS, Erum S, Khan SM, Nawaz M (2014) An appraisal of ecological distribution of herbaceous flora at Changa Manga park Lahore, Pakistan. *Pakistan Journal of Botany*, 46:19–25

[5] Mandal, G., and Joshi, S. P. Analysis of vegetation dynamics and phytodiversity from three dry deciduous forests of Doon Valley, Western Himalaya, India. *Journal of Asia-Pacific Biodiversity*, 7(3):292-304, 2014.

[6] Abdo HG, Almohamad H, Al Dughairi AA, Al-Mutiry M (2022) GIS-based frequency ratio and analytic hierarchy process for forest fire susceptibility mapping in the western region of Syria. *Sustainability* 14(8):4668, 2022.

[7] Ali, H., Muhammad, Z., Majeed, M., Aziz, R., Khan, A., Mangrio, W. M., Abdo, H. G., Almohamad, H., Abdullah, A., and Dughairi, A. Vegetation diversity pattern during spring season in relation to topographic and edaphic variables in sub - tropical zone. Botanical Studies, 20232023.

[8] Dar, A. A., Parthasarathy, N., and Dar, A. A. Herb stratum diversity and community structure in Gurez valley of Kashmir Himalaya : application of multivariate techniques in community analyses Himalaya : application of multivariate techniques in community analyses. Geology, Ecology, and Landscapes, 00(00):1-17, 2023.

[9] Singh, J.S., and Singh, S.P. Forest vegetation of the Himalaya. *The Botanical Review* 53:80–192, (1987).

[10] Ramachandran, R. M., and Roy, P. S. Vegetation response to climate change in Himalayan hill ranges: a remote sensing perspective. *Plant Diversity in the Himalaya Hotspot Region*, I(Vol. I):998, 2018.

[11] Wang, C.T., Long, R.J., Wang, Q.J., Ding, L.M., and Wang, M.P. Effects of altitude on plant-species diversity and productivity in an alpine meadow, Qinghai–Tibetan plateau. *Australian Journal of Botany*, 55, 110-117, 2007.

[12] Sinha, S., Badola, H. K., Chhetri, B., Gaira, K. S., Lepcha, J., and Dhyani, P. P. Effect of altitude and climate in shaping the forest compositions of Singalila National Park in Khangchendzonga Landscape, Eastern Himalaya, India. *Journal of Asia-Pacific Biodiversity*, 11(2):267-275, 2018.

[13] Maletha, A., Maikhuri, R. K., Bargali, S. S., Sharma, A., Negi, V. S., and Rawat, L. S. Vegetation dynamics and soil nutrient availability in a temperate forest along altitudinal gradient of Nanda Devi Biosphere Reserve, Western Himalaya, India. *PLoS ONE*, 17(10 October):1-22, 2022.

[14] Sangry, S., Kumar, P., Bhardwaj, D. R., and Dogra, K. S. Abundance , diversity and composition of understory plants along the altitudinal gradient and dominant overstory composition types in the temperate Himalayan region. *Frontiers in Forests and Global Change*, (August), 2024.

[15] Dubey, P., Raghubansh, A., and Singh, J.S. Temporal variability of herbaceous vegetation diversity in rainy season in a tropical dry deciduous forest. *Proceedings of The National Academy Of Sciences India Section B-Biological Sciences*, 81, 396-403, 2011.

[16] Khan, A. M., Qureshi, R., Saqib, Z., Munir, M., Shaheen, H., Habib, T., Dar, M. E. U. I., Fatimah, H., Afza, R., and Hussain, M. A. A first ever detailed ecological exploration of the western himalayan forests of sudhan gali and ganga summit, azad Jammu and Kashmir, Pakistan. *Applied Ecology and Environmental Research*, 17(6):15477-15505, 2019.

[17] Abdo, H. G. Impacts of war in Syria on vegetation dynamics and erosion risks in Safita area, Tartous, Syria. *Regional Environmental Change*, 18(6):1707-1719, 2018.

[18] Caballero-Serrano, V., McLaren, B., Carrasco, J. C., Alday, J. G., Fiallos, L., Amigo, J., and Onaindia, M. Traditional ecological knowledge and medicinal plant diversity in Ecuadorian Amazon home gardens. *Global Ecology and Conservation*, 17:e00524, 2019.

[19] Gracia, M., Montané, F., Piqué, J., and Retana, J. Overstory structure and topographic gradients determining diversity and abundance of understory shrub species in temperate forests in central Pyrenees (NE Spain). *Forest Ecology and Management*, 242(2):391-397, 2007.

[20] Barbier, S., Gosselin, F., and Balandier, P. Influence of tree species on understory vegetation diversity and mechanisms involved—A critical review for temperate and boreal forests. *Forest Ecology and Management*, 254(1):1-15, 2008.

[21] Cavard, X., Bergeron, Y., Chen, H. Y. H., and Paré, D. Effect of forest canopy composition on soil nutrients and dynamics of the understorey: Mixed canopies serve neither vascular nor bryophyte strata. *Journal of Vegetation Science*, 22(6):1105-1119, 2011.

[22] Zhang et al., 2016Zhang, W., Huang, D., Wang, R., Liu, J., and Du, N. Altitudinal patterns of species diversity and phylogenetic diversity across temperate mountain forests of northern China. *PLoS One* 11:e-015995, 2016.

[23] Kumar, P., Chen, H. Y. H., Searle, E. B., and Shahi, C. Dynamics of understory biomass, production and turnover associated with long-term overstory succession in boreal forest of Canada. *Forest Ecology and Management*, 427:152–161, 2018.

[24] Thrippleton, T., Bugmann, H., Kramer-Priewasser, K., and Snell, R. S. (2016). Herbaceous understorey: An over-looked player in forest landscape dynamics? *Ecosystems*, 19(7), 1240–1254, 2016.

[25] Ishii, H., Azuma, W., and Nabeshima, E. The need for a canopy perspective to understand the importance of phenotypic plasticity for promoting species coexistence and light-use complementarity in forest ecosystems. *Ecological Research*, 28(2):191-198, 2013.

[26] Tinya, F., and Ódor, P. Congruence of the spatial pattern of light and understory vegetation in an old-growth, temperate mixed forest. Forest *Ecology and Management*, 381:84-92, 2016.

[27] Tonteri, T., Salemaa, M., Rautio, P., Hallikainen, V., Korpela, L., and Merilä, P. Forest management regulates temporal change in the cover of boreal plant species. *Forest Ecology and Management*, 381:115-124, 2016.

[28] Khatri, K., Negi, B., Bargali, K., and Bargali, S. S. Trait plasticity : a key attribute in the invasion success of Ageratina adenophora in different forest types of Kumaun. *Environment, Development and Sustainability*, 26(8):21281-21302, 2024.

[29] Jhariya et al., 2022[1] , S., and Bargali, S. S. Species invasion and ecological risk. In Jhariya, M.K., Meena, R.S., Banerjee, A., Meena, S.N. editors, *Natural Resources Conservation and Advances for Sustainability*, pages 503-531. Elsevier, 2022

[30] Paudel, C. K., Tiwari, A., Baniya, C. B., and Shrestha, B. B. High Impacts of Invasive Weed Lantana camara on Plant Community and Soil Physico-Chemical Properties across Habitat Types in Central Nepal. 20242024.

[31] Tilman, D., Knops, J., Wedin, D., Reich, P., Ritchie, M., and Siemann, E. The influence of functional diversity and composition on ecosystem processes. *Science,* 277 (5330), 1300–1302, 1997.

[32] Ehrenfeld, J.G. Ecosystem consequences of biological invasions. *Annual Review of Ecology, Evolution, and Systematics*, 41, 59–80, 2010.

[33] Martin, P. H., Canham, C. D., and Marks, P. L. Why forests appear resistant to exotic plant invasions: Intentional introductions, stand dynamics, and the role of shade

[34] Vilà, M., Espinar, J. L., Hejda, M., Hulme, P. E., Jarošík, V., Maron, J. L., Pergl, J., Schaffner, U., Sun, Y., and Pyšek, P. Ecological impacts of invasive alien plants: A meta-analysis of their effects on species, communities and ecosystems. *Ecology Letters*, 14(7):702-708, 2011.

[35] Elton, C.S. *The Ecology of Invasions by Animals and Plants*. University of Chicago Press, 1958.

[36] Blossey, B. and Nötzold, R. Evolution of increased competitive ability in invasive non indigenous plants: a hypothesis. *Journal of Ecology*, 83, 887–889, 1995.

[37] Joshi, J. & Vrieling, K. The enemy release and EICA hypothesis revisited: incorporating the fundamental difference between specialist and generalist herbivores. *Ecology Letters*, 8:704–714, 2005.

[38] Keane, R.M. and Crawley, M.J. Exotic plant invasions and the enemy release hypothesis. *Trends in Ecology & Evolution*, 17:164-170, 2002.

[39] Stachowicz, J. and Tilman, D. Species invasions and the relationships between species diversity, community saturation, and ecosystem functioning. In Sax, D.F., Stachowicz, J J., and Gaines, S.D., editors, *Species Invasions: Insights into Ecology, Evolution, and Biogeography*, pages 41-64. Sinauer Associates, inc. Sunderland, Massachusetts, 2005.

[40] Simberloff, D. The role of propagule pressure in biological invasions. *Annual Review of Ecology, Evolution, and Systematics*, 40:81-102, 2009.

[41] Callaway, R.M. and Ridenour, W.M. Novel weapons: invasive success and the evolution of increased competitive ability. *Frontiers in Ecology and the Environment*, 2:436–443. 2004.

[42] Vilcinskas, A. Pathogens as biological weapons of invasive species. *PLoS Pathogens*, 11, e1004714, 2015.

[43] Chabrerie, O., Massol, F., Facon, B., Thevenoux, R., Hess, M., Ulmer, R., Pantel, J. H., Braschi, J., Amsellem, L., Tasiemski, A., Grandjean, F., Gibert, P., Picardie, U. De, Verne, J., and Edysan, U. M. R. C. *Biological Invasion Theories : Merging Perspectives from Population , Community and Ecosystem Scales*. (October)2019.

[44] Hufbauer, R.A., Facon, B., Ravigne, V., Turgeon, J., Foucaud, J., Lee, C.E., Rey, O. and Estoup, A. Anthropogenically induced adaptation to invade (AIAI): contemporary adaptation to human-altered habitats within the native range can promote invasions. *Evolutionary Applications*, 5:89-101, 2012.

[45] Lozon, J.D. and MacIsaac, H.J. Biological invasions: are they dependent on disturbance? *Environmental Reviews*, 5:131-144, 1997.

[46] Liedtke, R., Barros, A., Essl, F., Lembrechts, J. J., Wedegärtner, R. E. M., Pauchard, A., and Dullinger, S. Hiking trails as conduits for the spread of non-native species in mountain areas. *Biological Invasions*, 22(3):1121-1134, 2020.

[47] Wedegärtner, R. E. M., Lembrechts, J. J., van der Wal, R., Barros, A., Chauvin, A., Janssens, I., and Graae, B. J. Hiking trails shift plant species' realized climatic niches and locally increase species richness. *Diversity and Distributions*, 28(7):1416-1429, 2022.

[48] Champion, H.G., and Seth, S.K. *A Revised Survey of the Forest Types of India*, Manager of Publications, Government of India, Delhi, 1968.

[49] Bahuguna, V. K., Swaminath, M. H., Tripathi, S., Singh, T. P., Rawat, V. R. S., and Rawat, R. S. Revisiting forest types of India. *International Forestry Review*, 18(2):135-145, 2016.

[50] Aravind, N. A., Ganeshaiah, K. N., and Shaanker, R. U. Indian monsoons shape dispersal phenology of plants. *Biology Letters*, 9(6), 2013.

[51] Kanjilal, U.N., Kanjilal, P.C. and Das, A. *Flora of Assam*, Vol. 2. Assam Govt. Press, Shillong. 1938

[52] Page, N., Datta, A., and Basu, B. *Trees of Arunachal Pradesh*. Nature Conservation Foundation, Mysore, India 1st edition, 2022.

[53] Singh, P., Dash, S.S., and Sinha, B.K. *Plants of Indian Himalayan Region*. Botanical Survey of India, Kolkata, India, 2019.

[54] Curtis, J., and McIntosh, R. The interrelations of certain analytic and synthetic phytosociological characters. *Ecology*, 31(3):434-455, 1950

[55] Kanagaraj, S., Selvaraj, M., Das Kangabam, R., and Munisamy, G. Assessment of tree species diversity and its distribution pattern in Pachamalai Reserve Forest, Tamil Nadu. *Journal of Sustainable Forestry*, 36(1):32-46, 2017.

[56] Misra, K. *Mannual of Plant Ecology*. 3rd ed. New Delhi: Oxford and IBH Publishing Co. Pvt. Ltd., 1989.

[57] Shannon, C.E., and Weaver, W. *The Mathematical Theory of Communication. Urbana*. IL. University if Illinois Press, p. 117, 1949

[58] Simpson, E.H. Measurement of diversity. *Nature*, 163(4148):688, 1949.

[59] Menhinick, E.F. A Comparison of Some Species-Individuals Diversity Indices Applied to Samples of Field Insects. *Ecology*, 45:859-861, 1964.

[60] Margalef, R. Perspectives in ecological theory. Univ. Chicago Press, Chicago. *Limnology and Oceanography*, 14(2):313-315, 1969.

[61] Pielou, E.C. Species-diversity and pattern-diversity in the study of ecological succession. *Journal of Theoretical Biology*, 10(2):370-383, 1966.

[62] Whitford, P.B. Distribution of woodland plants in relation to succession and clonal growth. *Ecology*, 30:199-208, 1949.

[63] Cottam, G. and Curtis, J.T. The use of distance measures in phytosociological sampling. *Ecology*, 37(3):451-460, 1956.

[64] Begum, S. S., Roy, H., Nath, M., and Borthakur, S. K. A sketch of the flora of Nameri National Park , Assam : II. Phytogeography. Pleione, 5(1):10-22, 2011.

[65] Borah, D., Paul, B., Mipun, P., and Tangjang, S. Diversity and composition of herbaceous component in Behali Reserve Forest of Biswanath District, Assam, India. *Indian Journal of Ecology*, 48(5): 1335-1342, 2021.

[66] Malunguja, G. K., Thakur, B., and Devi, A. Relationship between forest biodiversity attributes and potential carbon stocks in dry tropical reserve forests of Assam, northeast India. *Environmental and Experimental Biology*, 19(4):231-243, 2021.

[67] Dogra, K. S., Kohli, R. K., Sood, S. K., and Dobhal, P. K. Impact of Ageratum conyzoides L . on the diversity and composition of vegetation in the Shivalik hills of Himachal Pradesh (Northwestern Himalaya), India. *International Journal of Biodiversity and Conservation*, 1(4):135-145, 2009.

[68] Lahkar, B., Talukdar, B., and Sarma, P. Invasive species in grassland habitat: an ecological threat to the greater one-horned rhino (*Rhinoceros unicornis*). *Pachyderm*, 49: 33-39, 2011.

[69] Choudhury, M. A. R. A. Y. C., Eb, P. A. D., and Ingha, H. I. S. Status of Invasive Plant Species in the Dry Savanna Grasslands of Rajiv Gandhi Orang National Park , Assam. 43(3):245-250, 2017.

[70] Sengupta, R., and Dash, S. S. Predicting the Potential Invasion Hotspots of Chromolaena odorata under Current and Future Climate Change Scenarios in Heterogeneous Ecological Landscapes of Mizoram, India. *Research in Ecology*, 5(4):1–12, 2023.

[71] Ram, J., Singh, S. P., and Singh, J. S. Community level phenology of grassland above treeline in central Himalaya, India. *Arctic & Alpine Research*, 20(3):325-332, 1988.

[72] Thapa et al., 2018; Thapa, S., Chitale, V., Rijal, S.J., Bisht, N., and Shrestha, B.B. Understanding the dynamics in distribution of invasive alien plant species under predicted climate change in Western Himalaya. *PLoS ONE*, 13(4): e0195752, 2018.

[73] Henriksson, A., Yu, J., Wardle, D.A., Trygg, J., and Englund, G. Weighted species richness outperforms species richness as predictor of biotic resistance. *Ecology,* 97:262–271, 2016.

[74] Howeth, J.G. Native species dispersal reduces community invasibility by increasing species richness and biotic resistance. *The Journal of animal ecology*, 86:1380–1393, 2017.

[75] Beaury, E.M., Finn, J.T., Corbin, J.D., Barr, V., and Bradley, B.A. Biotic resistance to invasion is ubiquitous throughout ecosystems of the United States. *Ecology Letters*, 23:476–482, 2020.

[76] Sarkar, S., and Deb, P. Community - level impacts of plant invasion in tropical forests of Northeast India. Plant Ecology, 225(10):1079-1094, 2024.

[77] Gogoi, A., and Sahoo, U. K. Impact of anthropogenic disturbance on species diversity and vegetation structure of a lowland tropical rainforest of eastern Himalaya, India. Journal of Mountain Science, 15(11):2453-2465, 2018.

[78] Pathak, R., Negi, V. S., Rawal, R. S., and Bhatt, I. D. Alien plant invasion in the Indian Himalayan Region: state of knowledge and research priorities. *Biodiversity and Conservation*, 28(12):3073-3102, 2019.

[79] Larigauderie, A., Larigauderie, J. K., And Kummerow, A., Larigauderie, A., and Kummerow, J. The Sensitivity of Phenological Events to Changes in Nutrient Availability for Several Plant Growth Forms in the Arctic. *Frontiers in Plant Science*, 14, 1991.

[80] Sarkar, M., and Devi, A. Assessment of diversity, population structure and regeneration status of tree species in Hollongapar Gibbon Wildlife Sanctuary, Assam, Northeast India. *Tropical Plant Research*, 1(2):26-36, 2014.

[81] Yumnam, J.Y., Deori, H. Edge-interior disparities in tree species and structural composition of Poba Reserve Forest (PRF), Assam at the foothills of Himalayas. Vegetos 37: 277–285, 2024)

[82] Buragohain, M. K., Dar, A. A., Babu, K. N., and Parthasarathy, N. Tree community structure, carbon stocks and regeneration status of disturbed lowland tropical rain forests of Assam, India. *Trees, Forests and People*, 11(November 2022):100371, 2023.

[83] Baidya, S., Sumant, S., Bhuyan, A., Hazarika, N. J., Thakur, B., Gogoi, N., Parkash, A., Handique, S., and Devi, A. Tree Population Structure and Carbon Stock of Tropical Wet Evergreen Forest in Dehing Patkai National Park, Assam, Northeast India. *International Journal of Ecology and Environmental Sciences*, 50(2 SE-Articles):303-313, 2024.

[84] Rajbonshi, B. and Islam, M. Plant Diversity of Jeypore Reserve Forest, of Upper Assam, North East India. *International Journal of Advance Research and Development*, 132-139, 2018.

[85] Kalita, P., Yumnam, J.Y. Tree diversity and community characteristics of a tropical moist deciduous forest of Assam, India. *Vegetos* (2024).

[86] Joshi et al. [2020] Joshi, R.K. Tree species diversity and biomass carbon assessment in undisturbed and disturbed tropical forests of Dibru-Saikhowa biosphere reserve in Assam North-East India. *Vegetos,* 33, 516–537 (2020).

[87] Giri, K., Buragohain, P., Konwar, S., Pradhan, B., Mishra, G., and Meena, D. K. Tree Diversity and Ecosystem Carbon Stock Assessment in Nambor Wildlife Sanctuary, Assam. *Proceedings of the National Academy of Sciences India Section B - Biological Sciences*, 89(4):1421-1428, 2019.

[88] Barua, K. N., Gogoi, G., and Hazarika, P. Comparative study on structural composition and community association of Nambor Wildlife Sanctuary and its South-Westward extended Bornewria forest, Assam, India. *Tropical Plant Research*, 5(2):233-242, 2018.

[89] Barua, K. N., and Hazarika, P. Floristic composition and natural regeneration status in Abhoypur reserve forest of Assam following Mikania micrantha Kunth. ex. H.B.K. invasion. *Tropical Plant Research*, 7(2):460-471, 2020.

[90] Odum, E. P. *Fundamentals of Ecology*. W. B. Saunders, Philadelphia, 1971.

[91] Meshram, M., and Khobragade, N. D. Study on plants diversity in Chhindwara district of Madhya Pradesh. *International Journal of Agriworld*, 2(1), 6-23, 2021.

[92] Behera, M. C., Sahoo, U. K., Mohanty, T. L., Prus, P., Smuleac, L., and Pascalau, R. Species Composition and Diversity of Plants along Human-Induced Disturbances in Tropical Moist Sal Forests of Eastern Ghats, India. *Forests* 14, 1931, 2023.

[93] Pathak, R., Negi, V. S., Yadava, A. K., and Bhatt, I. D. Distribution pattern of dominant invasive alien plants in forests of Kumaon region of West Himalaya. *International Journal of Ecology and Environmental Sciences* 47, 325-332, 2021.