Quantitative assessment of vegetation layers in tropical evergreen forests of Arunachal Pradesh, Eastern Himalaya, India

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The present study deals with first-hand information on quantitative assessments of different vegetation layers (viz. trees, saplings, seedlings, shrubs and herbs) collected from 57 permanent plots (size 400 m^2), established for long-term monitoring of biodiversity and study of functional aspects in Namdapha National Park (NPP), Arunachal Pradesh, Eastern Himalaya, India during 2017. We grouped all the plots into six clusters as study sites. A total of 60 taxa of trees, 67 shrubs and 81 herbs were recorded within 57 plots during the study. The average species richness per site for trees was 20.83 ± 1.62, saplings 16.0 ± 1.15, seedlings 15.83 ± 1.35, shrubs 23.83 ± 1.58 and herbs 32.67 ± 0.92. Total stem density varied from 117.5 to and 181 ha^{-1} (152.58 ± 10.04 ha^{-1}) for trees (circumference ≥ 31.5 cm), 881 to 3000 ha^{-1} (1652.17 ± 317.61 ha^{-1}) for shrubs and from 76750 to 98545 ha^{-1} (92032.17 ± 3246.60 ha^{-1}) for herbs. Tree regeneration status at all the six study sites was 'good' (i.e. density of seedlings > saplings > trees). The distribution of tree stems (circumference ≥ 31.5 cm) into different size classes showed highest relative density in the lowest stem size class (10–20 cm diameter) which also indicates good tree regeneration in the study area. *Dipterocarpus retusus* Blume was the most dominant tree species in the core zone area of NNP with 'good' regeneration status.

Keywords: Biodiversity, *Dipterocarpus retusus*, regeneration status, tropical evergreen forests, vegetation layers.

Introduction

QUANTIFIABLE analysis of community composition is a prerequisite for the precise evaluation of biodiversity, and it plays a central role in conservation biology[1–4]. Quantification of the contemporary composition of Himalayan forests is crucial in order to assess the role of climate change on future species coexistence and to provide baseline data for the long-term monitoring processes and species shift in the Himalayan ranges[5,6]. There is a dearth of studies reporting floristic composition and community structure in tropical evergreen forests of Eastern Himalaya, India. Therefore, a detailed ecological study in these forests is necessary to generate baseline data to assess the different ecological consequences of ongoing and future climate change[6].

A comprehensive floristic account of the Namdapha National Park (NPP), Arunachal Pradesh was made by Chauhan *et al.*[7]. This was later supplemented by some notable discoveries, i.e. *Sapria himalayana, Begonia tessaricarpa, Ceropegia lucida* and *Bretschneidera sinensis*[8–11]. Nath *et al.*[12] analysed the vegetation and tree population structure in a few selected sites of NNP, while Deb and Sundriya[13,14] observed the tree species gap phase performance, tree regeneration and seedling survival pattern, especially in the buffer zone of the Park. Barbhuiya *et al.*[15] studied the leaf litter decomposition of dominant tree species in NPP. Sarmah *et al.*[16,17] documented the ethno-botanical knowledge and natural resource utilization pattern of the tribal living in and around NNP. Besides, plant community structure and tree regeneration from different districts of Arunachal Pradesh were studied by several researchers[18–25]. The aim of this study was to evaluate the species composition, richness, density, basal area and dominance of trees, saplings, seedlings, shrubs and herbs in the western part of NNP.

Materials and methods

Study area

The experimental site is situated in the western part of Arunachal Pradesh near the international border of India and Myanmar. The Park occupies an area of 1985 km^2 and lies between 27°23′–27°39′N lat. and 96°15′–96°58″E long. with altitude ranging from 200 to

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Table 1. General details of the study sites in Namdapha National Park, Eastern Himalaya, India

Forest stand or trail	Code given	Coordinates	Altitude (m amsl)
Haldibari – Hornbill	B1	27°31′25.68″–27°31′36.89″N, 96°23′45.37″–96°24′59.45″E	460–591
Hornbill – Bulbuliya	B2	27°31′47.35″–27°32′20.79″N, 96°29′13.31″–96°27′29.81″E	560–745
25 mile – 19 mile (west)	C1	27°27′33.19″–27°27′56.13″N, 96°24′35.03″–96°25′30.25″E	485–612
25 mile – Goodbye point (uphill)	C2	27°27′09.64″–27°27′43.52″N, 96°25′39.44″–96°25′53.90″E	586–951
25 mile – 27 mile (east)	C3	27°27′49.31″–27°27′49.31″N, 96°26′02.60″–96°26′26.50″E	542–589
25 mile – riverside (downhill)	C4	27°27′52.62″–27°29′23.23″N, 96°24′17.63″–96°27′49.64″E	331–487

4571 m amsl. The Park exhibits high diversity of flora[7] and fauna[26], and is well known as one of India's pristine biodiversity regions. The vegetation of the Park ranges from lowland tropical forests to alpine scrubs. The lowland tropical rainforest of Namdapha represents the largest remaining *Dipterocarpus* forests in India[13,27]. NNP exhibits tropical climate experiencing typical monsoon with prolonged rainy season[13]. At lower altitudes, temperature varies from 5°C to 35°C, while it falls to 0° or below at higher elevations. The annual precipitation ranges from a minimum of 1400 mm to a maximum of 2500 mm, 75% of which falls between April and October[28]. The average relative humidity remains high (>60%) round the year, except during the dry season (November–January).

Methodology

Experimental sites and field work: The present study was conducted in the western part of NNP that serves as a gateway for visitors, forest personnel and residents of Gandhigram and Vijanagar villages (both villages are located on the eastern fringe of the Park). The under-storey vegetation of the study site exhibits dense naturalized bamboo, banana, zingiber, ferns, etc. The high density of the understorey vegetation is one of the major constrains for sampling. Therefore, we adopted stratified random sampling method to study vegetation along six trails (each being 2.5–3 km long) denoted as B1, B2, C1, C2, C3 and C4. Of these, four sites (C1, C2, C3 and C4) belong to the core zone, while two (B1 and B2) fall in the buffer zone of the Park. In the core zone, sites C1–C4 begin from the '25 mile base camp' area towards four directions, i.e. uphill (C2), downhill (C4), east (C3) and west (C1). B1 represents Haldibari–Hornbill area, while B2 represents Bulbuliya–Hornbill area. Sampling plots (long-term monitoring plots) were established, mapped (GPS) and marked along the track route in each site with a distance of 200–250 m. Table 1 provides details of each site.

Data collection: The field data on different vegetation layers, viz. trees, saplings, seedlings, shrubs and herbs were collected using quadrat method in 2017. The entire monitoring plot of size 400 m² was considered as a quadrat for tree vegetation. Within each tree quadrat, four sub-quadrats were nested for saplings (size 25 m²), four for seedlings (size 1 m²), four for shrubs (size 25 m²) and five for herbs (size 1 m²). Circumference (*C*) was used to differentiate tree life stages into mature trees ($C \geq 31.5$ cm at 1.37 m above ground level), saplings ($C = 10.5$–31.4 cm) and seedlings ($C < 10.5$ cm). The number of individuals of each species was counted within the respective quadrats and noted on their respective field-data sheets (separate sheets for trees, saplings, seedlings, shrubs and herbs). Circumference was measured with the help of graduated tape or diameter with callipers. Species occurring within each plot were collected, processed and preserved according to standard protocol[29].

Data analysis: The collected plant specimens were identified with help of the literature[7,30–33] and on consultation of different herbaria (ASSAM, ARUN, CAL). The quantifiable data of different vegetation layers of each site were computed for density, basal area and importance value index (IVI) following Misra[34]. In the present study, IVI of herbs was calculated by summing relative frequency and relative density following Rasingam and Parthasarathy[35]. Various diversity indices, viz. dominance index[36], diversity index[37], evenness index[38], Margalef index[39] and Fisher alpha[40] were calculated for each site. Individual trees were divided into eight diameter at breast height (DBH) classes, i.e. 10–20, 21–30, 31–40, 41–50, 51–60 cm, and so on. The density–diameter distribution of trees was calculated to understand the pattern of regeneration and structure of each forest stand. The dominance–diversity curves (*d–d* curves) for six sites were derived from IVI values of different vegetation layers. The regeneration status of tree species was determined on the basis of population size of seedlings and saplings, following Shankar[41]. The statistical analysis was performed using MS Excel and SPSS.

Table 2. Phytosociological attributes and diversity indices for different vegetation layers at six study sites

Parameters	B1	B2	C1	C2	C3	C4	Maximum	Minimum	Mean	SE
			Study site					Statistics ($N = 6$)		
Tree										
No. of plots (size 400 m^2)	10	11	10	7	8	11	11	7	9.50	0.67
No. of taxa	21	28	20	16	19	21	28	16	20.83	1.62
No. of individuals	63	80	47	50	47	60	80	47	57.83	5.22
Total stem density (ha^{-1})	157	181	117.5	178	146	136	181	117.5	152.58	10.04
Total basal area (m^2 ha^{-1})	34.11	34.05	22.73	72.79	45.91	18.69	72.79	18.69	38.05	7.98
Dominance index	0.07	0.05	0.16	0.13	0.12	0.10	0.16	0.05	0.11	0.02
Diversity index	2.80	3.10	2.43	2.38	2.55	2.66	3.10	2.38	2.65	0.11
Evenness index	0.79	0.80	0.57	0.67	0.67	0.68	0.80	0.57	0.70	0.04
Margalef index	4.83	6.16	4.94	3.83	4.68	4.89	6.16	3.83	4.89	0.30
Fisher alpha	11.03	15.31	13.16	8.14	11.86	11.49	15.31	8.14	11.83	0.97
Tree regeneration status										
Fair	38.71	29.03	13.64	34.62	32.14	25.93	38.71	13.64	29.01	1.03
Good	16.13	25.81	22.73	15.38	14.29	29.63	29.63	14.29	20.66	2.03
New (only seedling stage)	9.68	3.23	13.64	19.23	14.29	14.81	19.23	3.23	12.48	3.03
Nil (without regeneration)	29.03	38.71	31.82	15.38	28.57	22.22	38.71	15.38	27.62	4.03
Poor	6.45	3.23	18.18	15.38	10.71	7.41	18.18	3.23	10.23	5.03
Saplings										
No. of plots (size 25 m^2)	40	44	40	28	32	44	44	28	38.00	2.68
No. of taxa	18	20	12	14	16	16	20	12	16.00	1.15
No. of individuals	37	51	40	35	32	23	51	23	36.33	3.77
Total stem density (ha^{-1})	370	463.64	400	437.5	457.14	209.09	463.64	209.09	389.56	38.91
Total basal area (m^2 ha^{-1})	0.58	0.78	0.62	0.62	0.73	0.31	0.78	0.31	0.61	0.07
Dominance index	0.08	0.08	0.21	0.12	0.1	0.08	0.21	0.08	0.11	0.02
Diversity index	2.69	2.74	1.92	2.33	2.53	2.67	2.74	1.92	2.48	0.13
Evenness index	0.82	0.78	0.57	0.73	0.79	0.9	0.9	0.57	0.77	0.05
Margalef index	4.71	4.83	2.98	3.66	4.33	4.78	4.83	2.98	4.22	0.30
Fisher alpha	13.83	12.12	5.81	8.65	12.73	23.3	23.3	5.81	12.74	2.43
Seedlings										
No. of plots (size 1 m^2)	40	44	40	28	32	44	44	28	38.00	2.68
No. of taxa	17	20	10	16	17	15	20	10	15.83	1.35
No. of individuals	79	71	64	47	35	50	79	35	57.67	6.73
Total stem density (ha^{-1})	19,750	16,136	16,000	14,687	12,500	11,363	19,750	11,363	15,072.67	1,216.51
Total basal area (m^2 ha^{-1})	1.37	0.61	1.3	0.43	1.02	0.65	1.37	0.43	0.90	0.16
Dominance index	0.09	0.19	0.26	0.14	0.1	0.11	0.26	0.09	0.15	0.03
Diversity index	2.6	2.31	1.67	2.33	2.56	2.42	2.6	1.67	2.32	0.14
Evenness index	0.79	0.5	0.53	0.64	0.76	0.75	0.79	0.5	0.66	0.05
Margalef index	3.66	4.46	2.16	3.9	4.5	3.58	4.5	2.16	3.71	0.35
Fisher alpha	6.65	9.26	3.32	8.55	13.03	7.27	13.03	3.32	8.01	1.31
Shrubs										
No. of plots (size 25 m^2)	40	44	40	28	32	44	44	28	38.00	2.68
No. of taxa	22	22	19	23	28	29	29	19	23.83	1.58
No. of individuals	135	110	300	138	137	97	300	97	152.83	30.22
Total stem density (ha^{-1})	1350	1000	3000	1725	1957	881	3000	881	1652.17	317.61
Total basal area (m^2 ha^{-1})	1.53	0.84	6.2	1.91	2.35	0.95	6.2	0.84	2.30	0.81
Dominance index	0.14	0.08	0.29	0.23	0.16	0.14	0.29	0.08	0.17	0.03
Diversity index	2.42	2.81	1.75	2.22	2.5	2.67	2.81	1.75	2.40	0.15
Evenness index	0.51	0.75	0.3	0.4	0.44	0.5	0.75	0.3	0.48	0.06
Margalef index	4.28	4.47	3.16	4.47	5.49	6.12	6.12	3.16	4.67	0.42
Fisher alpha	7.46	8.27	4.51	7.88	10.65	14.01	14.01	4.51	8.80	1.32
Herbs										
No. of plots (size 1 m^2)	50	55	50	35	40	55	55	35	47.50	3.35
No. of taxa	35	31	32	31	31	36	36	31	32.67	0.92
No. of individuals	489	542	459	307	331	443	542	307	428.50	37.39
Total stem density (ha^{-1})	97,800	98,545	91,800	76,750	94,571	92,727	98,545	76,750	92,032.17	3,246.60
Dominance index	0.13	0.09	0.06	0.07	0.06	0.06	0.13	0.06	0.08	0.01
Diversity index	2.69	2.87	3.03	2.93	3.03	3.17	3.17	2.69	2.95	0.07
Evenness index	0.42	0.57	0.65	0.6	0.67	0.66	0.67	0.42	0.60	0.04
Margalef index	5.49	4.77	5.06	5.24	5.17	5.74	5.74	4.77	5.25	0.14
Fisher alpha	8.63	7.14	7.83	8.61	8.37	9.26	9.26	7.14	8.31	0.30

Results and discussion

The variation in phytosociological attributes of different Himalayan forests is driven by environmental variables, including soil condition, slope angles, species composition, elevation, regional climate and topography. In the present study, we found slight to noticeable variations in the phytosociological attributes and diversity indices of all the five vegetation layers, viz. trees, saplings, seedlings, shrubs and herbs from one site to another. The hierarchical cluster analysis (using the Bray–Curtis similarity, single linkage) is depicted in Figure 1 using tree species composition in 57 plots nested across the six sites. Two sites in the buffer zone area, viz. B1 and B2 showed maximum similarity in tree species composition, while maximum dissimilarity was observed between two sites in the core zone area, viz. C1 and C2. A total of 60

species of trees, 67 shrubs and 81 herbs were recorded from the 57 plots. The species richness (SR) among the sites varied from 16 to 28 for trees, 19 to 29 for shrubs, 12 to 20 for saplings, 10 to 20 for seedlings and 31 to 36 for herbs (Table 2), which was much higher than the SR reported by Das *et al.*[24] for shrubs, saplings, seedlings and herbs (except trees layers that were found to be similar) from *Pinus merkusii*-dominated forests of Anjaw, Arunachal Pradesh. Behera and Kushwaha[18] observed high SR for trees (cbh $\geq$ 15 cm) from Subansiri district, Arunachal Pradesh than that in the present study (trees, cbh $\geq$ 31.5 cm).
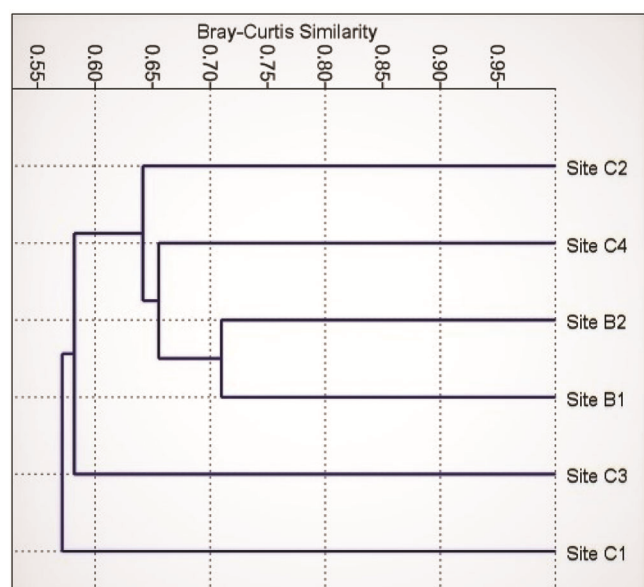

Figure 1. Hierarchical cluster analysis (Bray–Curtis, single linkage) of six study sites using tree species composition.
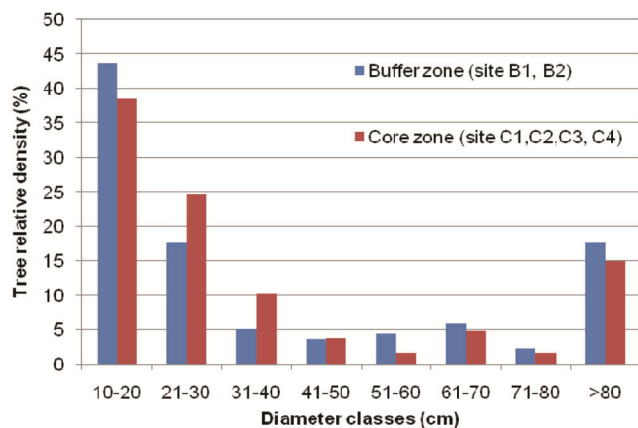

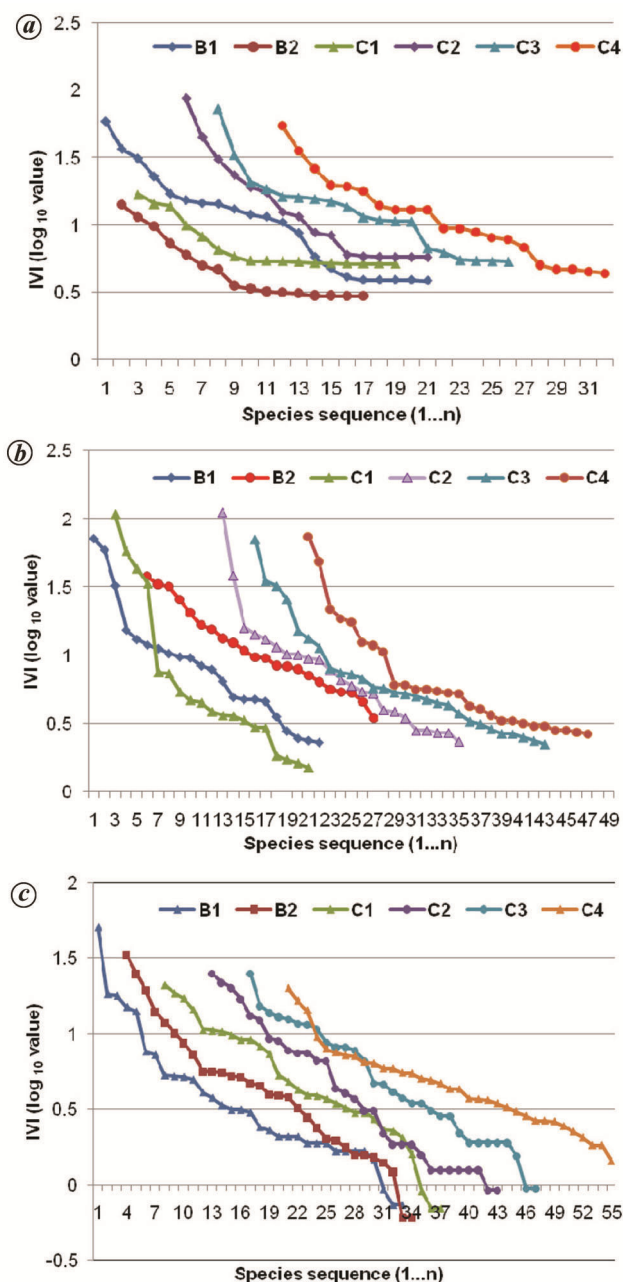**Figure 2.** Distribution of trees into different size classes.

Figure 3. Dominance–diversity curves for different sites (*a*) tress, (*b*) shrubs and (*c*) herbs.

Table 3. Four dominant taxa (with IVI value) at different study sites in tree, shrub and herb layers

Site	Tree layer	Shrub layer	Herb layer
B1	*Dysoxylum excelsum* Blume (58.52)	*Bambusa tulda* Roxb. (71.53)	*Amischotolype mollissima* (Blume) Hassk. (50.46)
	Mesua ferrea L. (36.58)	*Miliusa roxburghiana* Hook.f. & Thomson (59.22)	*Chloranthus elatior* Link (18.19)
	Cleidion javanicum Blume (31.16)	*Strobilanthes secunda* T. Anderson (32.37)	*Begonia palmata* D.Don (17.79)
	Dipterocarpus retusus Blume (22.88)	*Sabia lanceolata* Colebr. (15.39)	*Myrioneuron nutans* Wall. ex Hook. f. (15.01)
B2	*Altingia excelsa* Noronha (26.27)	*Boehmeria macrophylla* Hornem. (37.92)	*Elatostema sessile* J.R.Forst. & G. Forst. (24.89)
	Dysoxylum excelsum Blume (25.21)	*Saprosma ternatum* (Wall.) Hook.f. (33.18)	*Selaginella monospora* Spring (19.39)
	Colona floribunda (Wall. ex Kurz) Craib (24.02)	*Miliusa roxburghiana* Hook.f. & Thomson (31.97)	*Myrioneuron nutans* Wall. ex Hook. f. (13.93
	Dipterocarpus retusus Blume (21.45)	*Myxopyrum smilacifolium* (Wall.) Blume (25.60)	*Baliospermum calycinum* Müll. Arg. (11.73)
C1	*Dipterocarpus retusus* Blume (143.33)	*Bambusa tulda* Roxb. (108.09)	*Carex baccans* Nees (20.99)
	Mallotus roxburghianus Müll. Arg. (23.14)	*Musa velutina* H.Wendl. & Drude (58.25)	*Amischotolype mollissima* (Blume) Hassk. (18.59)
	Knema cinerea var. *glauca* (Blume) Y.H. Li (16.81)	*Calamus erectus* Roxb. (43.29)	*Pollia secundiflora* (Blume) Bakh.f. (17.23)
	Ficus altissima Blume(14.35)	*Ensete glaucum* (Roxb.) Cheesman (33.66)	*Centotheca lappacea* (L.) Desv. (14.48)
C2	*Dipterocarpus retusus* Blume (87.44)	*Bambusa tulda* Roxb. (111.95)	*Elatostema platyphyllum* Wedd. (24.95)
	Shorea assamica Dyer (45.13)	*Calamus erectus* Roxb. (38.43)	*Selaginella monospora* Spring (21.69)
	Quercus lamellosa Sm. (30.74)	*Smilax perfoliata* Lour. (15.94)	*Amischotolype mollissima* (Blume) Hassk. (20.06)
	Terminalia myriocarpa Van Heurck & Müll. Arg. (23.53)	*Strobilanthes secunda* T. Anderson (14.22)	*Begonia hatacoa* Buch.-Ham. ex D. Don (16.91)
C3	*Dipterocarpus retusus* Blume (73.02)	*Bambusa tulda* Roxb. (70.99)	*Phrynium pubinerve* Blume (24.91)
	Terminalia myriocarpa Van Heurck & Müll. Arg. (33.28)	*Musa balbisiana* Colla (35.12)	*Elatostema platyphyllum* Wedd. (15.29)
	Duabanga grandiflora (DC.) Walp. (20.71)	*Musa velutina* H. Wendl. & Drude (32.27)	*Hedychium coccineum* Buch.-Ham. ex Sm. (13.70)
	Cleidion javanicum Blume (18.56)	*Calamus erectus* Roxb. (25.78)	*Rhynchotechum ellipticum* (Wall. ex D. Dietr.) A. DC. (12.79)
C4	*Dipterocarpus retusus* Blume (54.21)	*Bambusa tulda* Roxb. (74.30)	*Amischotolype mollissima* (Blume) Hassk. (20.01)
	Magnolia hodgsonii (Hook. f. & Thomson) H. Keng (35.46)	*Calamus erectus* Roxb. (48.83)	*Piper hymenophyllum* (Miq.) Wight (16.56)
	Kydia calycina Roxb. (26.21)	*Saurauia napaulensis* DC. (21.98)	*Begonia hatacoa* Buch.-Ham. ex D. Don (14.29)
	Bombax ceiba L. (19.78)	*Leea indica* (Burm. f.) Merr. (18.58)	*Psychotria denticulata* Wall.(9.54)

The average density per site recorded in the present study was 152.58 ± 10.04 ha^{-1} for trees, 1652.17 ± 317.61 ha^{-1} for shrubs and 92032.2 ± 3246.6 ha^{-1} for herbs (Table 2) which was in agreement with the density, range of trees and shrubs reported from other forests of Arunachal Pradesh by Rana and Gairola[21] and Das et al.[24], but herb density in the present study was much higher comparatively. Pearson's correlation analysis revealed that the tree density was negatively related with density of shrubs and herbs, while positively ($P > 0.05$) with the density of saplings and seedlings (Appendix 1). The tree density organized into different size classes represented reverse *J*-shaped distribution (Figure 2) because a higher stem density occurred in the lower size

classes (10–20, 21–30 cm) and it decreased in higher classes. Such distribution in natural forest stands indicates a stable population with good regeneration status[42–44]. Occurrence of 17.52% individuals in the core zone area and 14.97% in the buffer zone area in the highest diameter class (>80 cm) in the present study is indicative of old and climax forest that has maintained good regeneration status and reproductive success over the ages.

In the present study, *Dipterocarpus retusus* was identified as the dominant species in tree layers at all the four sites in the core zone area of NNP (Table 3), while the two sites in the buffer zone, viz. B1 and B2 were dominated by *Dysoxylum excelsum* and *Altingia excelsa* respectively. The shrub layer was dominated by *Bambusa*

Table 4. Comparison of diversity (H'), dominance (D) and evenness (E) indices in the present study with those of other studies from Arunachal Pradesh

Vegetation layers		*Dipterocarpus*-dominant tropical forest (Present study)	*Pinus merkusii*-dominant temperate forest[24]	*Albizia–Artocarpus – Terminalia* mixed subtropical forest[21]	*Rhododendron*-dominant temperate forest[22]
Tree	D	0.05–0.16	0.14–0.32	0.072–2.08	0.07–0.08
	H	2.38–3.1	1.82–2.27	02.89–4.17	2.59–2.80
	E	0.57–0.8	0.65–0.78	–	0.92–0.96
Shrubs	D	0.08–0.29	0.05–0.12	0.118–0.142	0.09–0.11
	H	1.75–2.81	2.14–3.03	2.99–3.27	2.13–2.46
	E	0.3–0.75	0.97–0.98	–	0.83–0.97
Herbs	D	0.06–0.13	0.07–0.11	0.077–0.133	0.06–0.10
	H	2.69–3.17	2.27–2.57	03.55–4.15	2.49–3.01
	E	0.42–0.67	0.94–0.95	–	0.92–0.95
Saplings	D	0.08–0.21	0.16–0.20		
	H	1.92–2.74	1.69–1.88		
	E	0.57–0.9	0.94–0.97		
Seedlings	D	0.09–0.26	0.33–0.53	No study made	
	H	1.67–2.6	0.91–1.25		
	E	0.5–0.79	0.63–0.78		

Appendix 1. Pearson's correlation between the phytosociological parameters of different vegetation layers

	Tden	Tbas	Tdom	Tdiv	Saden	Sabas	Sadiv	Seden	Sebas	Sediv	Shden	Shbas	Shdiv	Hden
Tbas	0.65	1.00												
Tdom	−0.61	0.15	1											
Tdiv	0.45	−0.36	−0.94	1										
Saden	0.46	0.57	0.02	0.05	1									
Sabas	0.44	0.40	−0.13	0.24	0.97	1								
Sadiv	0.54	−0.06	−0.90	0.74	−0.19	−0.08	1							
Seden	0.24	0.00	−0.33	0.33	0.33	0.35	−0.01	1						
Sebas	−0.60	−0.45	0.16	−0.07	0.02	0.08	−0.28	0.53	1					
Sediv	0.50	0.28	−0.61	0.34	−0.09	−0.06	0.86	−0.06	−0.19	1				
Shden	−0.57	0.04	0.83	−0.67	0.36	0.28	−0.93	0.10	0.51	−0.73	1			
Shbas	−0.69	−0.19	0.79	−0.58	0.19	0.14	−0.94	0.12	0.55	−0.85	0.96	1		
Shdiv	0.54	−0.07	−0.84	0.74	−0.15	−0.03	0.95	−0.23	−0.46	0.75	−0.92	−0.92	1	
Hden	−0.20	−0.73	−0.57	0.73	−0.08	0.13	0.45	0.26	0.52	0.17	−0.23	−0.12	0.41	1
Hdiv	−0.54	−0.26	0.53	−0.42	−0.45	−0.46	−0.28	−0.91	−0.32	−0.30	0.14	0.21	−0.06	−0.21

Tden, Tree stem density; Tbas, Tree basal area; Tdom, Tree dominance index; Tdiv, Tree diversity index; Saden, Sapling density; Sabas, Sapling basal area; Sadiv, Sapling diversity index; Seden, Seedling density; Sebas, Seedling basal area; Sediv, Diversity index; Shden, Shrub density; Shbas, Shrub basal area; Shdiv, Shrub diversity index; Hden, Herb density, Hdiv, Herb diversity index.

tulda at all the sites in the core zone and in site B2 in the buffer zone, while shrub layer in site B1 was dominated by *Boehmeria macrophylla*. In the core zone *Carex baccans*, *Elatostema platyphyllum*, *Elatostema platyphyllum* and *Amischotolype mollissima* were recorded as the dominant herbs at sites C1, C2, C3 and C4 respectively, while in the buffer zone one site was dominated by *Elatostema sessile* and the other (B1) by *Amischotolype mollissima*.

The *d–d* curves clealy delimit the vegetational layers along different gradients and also show their dominance due to various ecological factors. Figure 3 shows the *d–d* curves for trees, shrubs and herbs respectively versus log normal values at different sites. The different diversity indices recorded from NNP were compared with those reported from other Eastern Himalayan forests (Table 4)[21,22,24]. The sites in the buffer zone area represented slightly higher values of SR, diversity, evenness, Margalef index and Fisher alpha index in comparison to the core zone area in the present study, while inverse results were obtained for dominance index. The tree dominance index showed significant negative correlation with the diversity index ($r = 0.94$, $P < 0.05$). Similar relation between dominance and diversity index was reported in some other Himalayan forests[45–48].

The existing natural population of trees at all the six forest stands exhibited 'good' regeneration status (i.e. density of seedlings > saplings > trees) in general during the study period, which varied at species level (i.e. same taxon showed different status at different sites). In

Table 5. Regeneration status of tree species in the Namdapha National Park, Arunachal Pradesh during 2017

Tree taxon	Study site					
	B1	B2	C1	C2	C3	C4
Actinodaphne obovata (Nees) Blume	Fair	Nil	–	–	–	–
Aesculus assamica Griff.	New	Nil	–	Nil	–	Fair
Ailanthus excelsa Roxb.	Good	Nil	New	New	–	Poor
Alangium chinense (Lour.) Harms	Fair	–	Nil	–	–	–
Albizia procera (Roxb.) Benth.	–	Nil	–	New	–	–
Alnus nepalensis D.Don	–	–	–	–	Nil	–
Altingia excelsa Noronha	Nil	Fair	–	–	–	–
Aralia armata (Wall. ex G.Don) Seem.	Fair	Good	–	–	Fair	–
Balakata baccata (Roxb.) Esser	–	–	Poor	Poor	–	–
Bischofia javanica Blume	Fair	Nil	–	–	–	Nil
Bombax ceiba L.	–	–	–	–	–	Nil
Bridelia glauca Blume	–	Fair	–	New	Fair	Fair
Callicarpa arborea Roxb.	–	–	New	–	Good	–
Caryota urens L.	–	–	–	Nil	Fair	–
Castanopsis indica (Roxb. ex Lindl.) A.DC.	New	Good	–	–	–	–
Cinnamomum bejolghota (Buch.-Ham.) Sweet	Fair	Good	New	Poor	Fair	New
Cinnamomum glanduliferum (Wall.) Meisn.	Nil	–	–	–	Nil	New
Cleidion javanicum Blume	Fair	Good	–	Fair	Fair	Poor
Colona floribunda (Kurz) Craib	–	–	–	Fair	–	–
Crateva religiosa G.Forst.	–	Nil	–	–	–	–
Dipterocarpus retusus Blume	Good	Nil	Good	Good	Fair	Good
Duabanga grandiflora (DC.) Walp.	–	–	–	–	Fair	–
Dysoxylum excelsum Blume	Good	Good	Fair	Good	Good	Good
Elaeocarpus rugosus Roxb. ex G.Don	–	Fair	–	Fair	–	–
Engelhardtia spicata Lechen ex Blume	–	–	Nil	–	Nil	Nil
Erythrina arborescens Roxb.	–	–	–	–	–	Nil
Evodia fraxinifolia (Hook.) Benth.	–	–	–	–	Nil	–
Ficus altissima Blume	Fair	Nil	Good	New		Good
Ficus auriculata Lour.	–	–	–	–	New	–
Ficus nervosa B.Heyne ex Roth	–	–	Nil	–	–	–
Glochidion khasicum (Müll.Arg.) Hook.f.	Nil	Nil	–	–	–	Fair
Grewia eriocarpa Juss.	–	–	New	Fair	Nil	–
Gynocardia odorata R.Br.	–	Nil	–	–	–	–
Knema cinerea var. *glauca* (Blume) Y.H. Li	–	Fair	Nil	Good	Poor	Good
Kydia calycina Roxb.	Nil	–	–	–	New	Fair
Lasianthus lucidus Blume	Nil	Fair	–	Fair	–	–
Litsea monopetala (Roxb.) Pers.	–	Fair	Nil	–	–	–
Macaranga denticulata (Blume) Müll.Arg.	Fair	–	Good	Fair	New	New
Machilus gamblei King ex Hook. f.		–	Poor	Fair	Poor	Good
Magnolia hodgsonii (Hook.f. & Thomson) H.Keng	Good	Good	–	Fair	Nil	Good
Mallotus roxburghianus Müll.Arg.	–	–	Good	–	New	Fair
Mangifera sylvatica Roxb.	Nil	Fair	–	–	–	–
Melia azedarach L.	–	–	–	–	–	Nil
Mesua ferrea L.	Good	–	Poor	Poor	–	New
Ocotea lancifolia (Schott) Mez	Poor	Good	–	–	Nil	Fair
Olea dioica Roxb.	–	–	–	–	–	–
Oreocnide integrifolia (Gaudich.) Miq.	–	New	Poor	–	Good	–
Photinia integrifolia Lindl.	–	–	–	–	Poor	–
Puzunglo (localy identified)	–	Fair	–	–	–	–
Quercus lamellosa Sm.	Nil	–	–	Nil	–	–
Quercus semiserrata Roxb.	Fair	Nil	Fair	Good	–	Nil
Saprosma ternatum (Wall.) Hook.f.	Poor	–	–	–	–	–
Saurauia armata Kurz	Fair	Good	Fair	New	Good	Good
Schima wallichii Choisy	New	–	Nil	–	–	–
Shorea assamica Dyer	Fair	Fair	–	Poor	–	Fair
Styrax serrulatus Roxb.	–	–	–	Nil	Nil	–
Terminalia myriocarpa Van Heurck & Müll. Arg.	Fair	Nil	Good	Fair	Fair	Good
Toona ciliate M.Roem.	Nil	–	–	–	–	–
Turpinia pomifera (Roxb.) DC.	Nil	Poor	Nil	–	–	–
Uvaria dioeca Roxb.	–	–	–	–	Fair	–

species-level regeneration, majority of the species (29.01%) showed 'fair' regeneration status while 20.66% exhibited 'good' regeneration status and 10.23±5.03% species showed 'poor' regeneration status. About 12.48% of the species were only represented by seedlings ('new' regeneration) and 27.62% showed 'Nil' regeneration (Table 5). Inter- and intra-species competition, dense and virgin canopy cover (large and medium-sized trees) and abundant undergrowth of herbaceous layer could be reasons affecting the regeneration, particularly for species with 'poor' and 'Nil' regenerating status. However, the present contribution is part of ongoing work in the park. Further progress with increasing the number of monitoring plots may highlight the possible reasons for regeneration failure by some species.

Conclusion

The present study has provided data on tree, shrub and herbaceous communities in selected forest stands of NNP. Similar type of data from different parts of the Park can be generated which will be helpful in assessing the effect of climate change and other ecological impacts. The phytosociological attributes and ecological indices show that NNP has sustained a good floral diversity, with (good) overall regeneration status. The reasons for 'poor' and 'Nil' regenerating species need to be evaluated for their proper conservation.

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