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 m²), 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 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 biology1–4. 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 ranges5,6. 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 change6.

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 tesserarica, Ceropegia lucida and Bretschneidera sinensis8–11. Nath et al.12 analysed the vegetation and tree population structure in a few selected sites of NNP, while Deb and Sundriyal3,14 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 researchers18–25. 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 km² and lies between 27°23′–27°39′N lat. and 96°15′–96°58′E long. with altitude ranging from 200 to
4571 m amsl. The Park exhibits high diversity of flora and fauna, 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. NNPN exhibits tropical climate experiencing typical monsoon with prolonged rainy season. At lower altitudes, temperature varies from 5°C to 35°C, while it falls to 0°C or below at higher elevations. The annual precipitation ranges from a minimum of 1400 mm to a maximum of 5865–9511 mm. Below at higher elevations, the annual precipitation varies from 5°C to 35°C, while it falls to 0°C or below at higher elevations. The average relative humidity remains high (>60%) throughout the year, except during the dry season (November–April).

### Methodology

**Experimental sites and field work:** The present study was conducted in the western part of NNPN that serves as a gateway for visitors, forest personnel and residents of Gangtok, Lachung and Sela 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 was used to differentiate tree life stages into mature trees (C ≥ 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.

### Data analysis

The collected plant specimens were identified with help of the literature 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. In the present study, IVI of herbs was calculated by summing relative frequency and relative density following Rasingam and Parthasarathy. Various diversity indices, viz. dominance index, diversity index, evenness index, Margalef index and Fisher alpha 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. The statistical analysis was performed using MS Excel and SPSS.

### 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 | 483–612 |
| 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 |

**Note:** The table provides details of each study site in Namdapha National Park, Eastern Himalaya, India.
Table 2. Phytosociological attributes and diversity indices for different vegetation layers at six study sites

| Parameters                     | Study site | Statistics (N = 6) |
|--------------------------------|------------|-------------------|
|                                |            | Maximum | Minimum | Mean  | SE    |
| **Tree**                       |            |         |         |       |       |
| No. of plots (size 400 m²)     | 10 11 10   | 11      | 11      | 9.50  | 0.67  |
| No. of taxa                     | 21 28 20   | 28      | 16      | 20.83 | 1.62  |
| No. of individuals              | 63 80 47   | 80      | 47      | 57.83 | 5.22  |
| Total stem density (ha⁻¹)      | 157 181    | 181     | 117.5   | 152.58| 10.04 |
| Total basal area (m² ha⁻¹)     | 34.11 34.05| 34.05   | 22.73   | 38.05 | 7.98  |
| Dominance index                | 0.07 0.05  | 0.05    | 0.12    | 0.11  | 0.02  |
| Diversity index                | 2.80 3.10  | 3.10    | 2.38    | 2.65  | 0.11  |
| Evenness index                 | 0.57 0.78  | 0.80    | 0.72    | 0.72  | 0.03  |
| Margalef index                 | 4.83 6.16  | 6.16    | 2.00    | 4.83  | 0.90  |
| Fisher alpha                   | 11.03 15.31| 15.31   | 13.16   | 11.83 | 0.97  |
| Tree regeneration status       | Fair       | 38.71   | 29.01   | 29.01 | 1.03  |
|                                | Good       | 16.13   | 20.66   | 20.66 | 2.03  |
|                                | New (only seedling stage) | 9.68 3.23 | 27.62 | 27.62 | 3.03  |
|                                | Nil (without regeneration) | 29.03 7.41 | 38.71 | 38.71 | 4.03  |
|                                | Poor       | 6.45    | 10.23   | 10.23 | 4.03  |
| **Saplings**                   |            |         |         |       |       |
| No. of plots (size 25 m²)      | 40 44 40   | 44      | 28      | 38.00 | 2.68  |
| No. of taxa                     | 18 20      | 20      | 14      | 16.00 | 1.15  |
| No. of individuals              | 37 51 40   | 51      | 32      | 36.33 | 3.77  |
| Total stem density (ha⁻¹)      | 370 463.64 | 463.64  | 400     | 389.56| 38.91 |
| Total basal area (m² ha⁻¹)     | 0.58 0.78  | 0.78    | 0.62    | 0.61  | 0.07  |
| Dominance index                | 0.08 0.21  | 0.21    | 0.12    | 0.11  | 0.02  |
| Diversity index                | 2.69 2.74  | 2.74    | 1.92    | 2.48  | 0.13  |
| Evenness index                 | 0.82 0.78  | 0.82    | 0.57    | 0.77  | 0.05  |
| Margalef index                 | 4.71 4.83  | 4.83    | 2.96    | 4.22  | 0.30  |
| Fisher alpha                   | 13.83 12.12| 12.12   | 8.65    | 12.74 | 2.43  |
| **Seedlings**                  |            |         |         |       |       |
| No. of plots (size 1 m²)       | 40 44 40   | 44      | 28      | 38.00 | 2.68  |
| No. of taxa                     | 17 20      | 20      | 14      | 16.00 | 1.15  |
| No. of individuals              | 79 71 64   | 79      | 50      | 57.67 | 6.73  |
| Total stem density (ha⁻¹)      | 19,750 16,136| 16,136 | 16,000 | 16,726.51| |
| Total basal area (m² ha⁻¹)     | 0.58 0.78  | 0.78    | 0.62    | 0.61  | 0.07  |
| Dominance index                | 0.08 0.21  | 0.21    | 0.12    | 0.11  | 0.02  |
| Diversity index                | 2.69 2.74  | 2.74    | 1.92    | 2.48  | 0.13  |
| Evenness index                 | 0.82 0.78  | 0.82    | 0.57    | 0.77  | 0.05  |
| Margalef index                 | 4.71 4.83  | 4.83    | 2.96    | 4.22  | 0.30  |
| Fisher alpha                   | 13.83 12.12| 12.12   | 8.65    | 12.74 | 2.43  |
| **Shrubs**                     |            |         |         |       |       |
| No. of plots (size 25 m²)      | 40 44 40   | 44      | 28      | 38.00 | 2.68  |
| No. of taxa                     | 17 20      | 20      | 14      | 16.00 | 1.15  |
| No. of individuals              | 79 71 64   | 79      | 50      | 57.67 | 6.73  |
| Total stem density (ha⁻¹)      | 19,750 16,136| 16,136 | 16,000 | 16,726.51| |
| Total basal area (m² ha⁻¹)     | 0.58 0.78  | 0.78    | 0.62    | 0.61  | 0.07  |
| Dominance index                | 0.08 0.21  | 0.21    | 0.12    | 0.11  | 0.02  |
| Diversity index                | 2.69 2.74  | 2.74    | 1.92    | 2.48  | 0.13  |
| Evenness index                 | 0.82 0.78  | 0.82    | 0.57    | 0.77  | 0.05  |
| Margalef index                 | 4.71 4.83  | 4.83    | 2.96    | 4.22  | 0.30  |
| Fisher alpha                   | 13.83 12.12| 12.12   | 8.65    | 12.74 | 2.43  |
| **Herbs**                      |            |         |         |       |       |
| No. of plots (size 1 m²)       | 40 44 40   | 44      | 28      | 38.00 | 2.68  |
| No. of taxa                     | 22 22      | 22      | 19      | 23.83 | 1.58  |
| No. of individuals              | 135 110    | 110     | 138     | 152.83| 30.22 |
| Total stem density (ha⁻¹)      | 1350 1000  | 1000    | 3000    | 1652.17| 317.61 |
| Total basal area (m² ha⁻¹)     | 1.37 0.61  | 0.61    | 1.3     | 0.90  | 0.16  |
| Dominance index                | 0.09 0.26  | 0.26    | 0.14    | 0.15  | 0.03  |
| Diversity index                | 2.6 2.31   | 2.31    | 1.67    | 2.32  | 0.14  |
| Evenness index                 | 0.79 0.53  | 0.53    | 0.64    | 0.66  | 0.05  |
| Margalef index                 | 3.66 4.46  | 4.46    | 2.16    | 3.71  | 0.35  |
| Fisher alpha                   | 6.65 9.26  | 9.26    | 5.81    | 8.01  | 1.31  |

**Note:** The data for **Saplings** and **Seedlings** have been transposed to match the format of the other layers for consistency.
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 Kushwaha18 observed high SR for trees (cbh ≥ 15 cm) from Subansiri district, Arunachal Pradesh than that in the present study (trees, cbh ≥ 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) trees, (b) shrubs and (c) herbs.
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 Gairola23 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 Dirosyllum excelsum and Altingia excelsa respectively. The shrub layer was dominated by Bambusa

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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) |
|       | Messa ferrea L. (36.58) | Milissa roxburghiana Hook.f. & Thomson (59.22) | Chloranthus elatioi Link (18.19) |
|       | Cleidion javanicum Blume (31.16) | Strobiolanthes 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) | Sarpsona ternatum (Wall.) Hook.f. (33.18) | Selaginella monospora Spring (19.39) |
|       | Colona floribunda (Wall. ex Kurz) Craib (24.02) | Milissa 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) | Balsispermum 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 Loutr. (15.94) | Amischotolype mollissima (Blume) Hassk. (20.06) |
|       | Terminalia myriocarpa Van Heurck & Müll. Arg. (23.53) | Strobiolanthes secunda T. Anderson (14.22) | Begonia batacoid 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 balhistanica 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) | Rhynechotrichum 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 batacoid Buch.-Ham. ex D. Don (14.29) |
|       | Bombax ceiba L. (19.78) | Lea indica (Burm. f.) Merr. (18.58) | Psychotria denticulata Wall. (9.54) |
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 merkysti-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                                       | 0.89–4.17                                        | 2.59–2.80                                         |
|                   | E 0.57–0.8                                          | 0.65–0.78                                       | –                                                | 0.92–0.96                                         |
| Shrub             | 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                                         |
| Herb              | 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                                       | 0.55–4.15                                        | 2.49–3.01                                         |
|                   | E 0.42–0.67                                         | 0.94–0.95                                       | –                                                | 0.92–0.95                                         |
| Sapling           | 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                                       |                                                  |                                                   |
| Seedling          | D 0.09–0.26                                         | 0.33–0.53                                       |                                                  |                                                   |
|                   | 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  |
| 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 |

Tden, Tree stem density; Tbas, Tree basal area; Tdom, Tree dominance index; Tdiv, Tree diversity index; Saden, Sapling density; Sabas, Sapling basal area; Sabas, Sapling density; Sebas, Sapling 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 bac-cans, 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 Ela-tostema sessile and the other (B1) by Amischotolype mol-lissima.

The d–d curves clearly 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)\textsuperscript{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\textsuperscript{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 |
| Alianthus excelsa Roxb.         | Good      | Nil    | New  | New  | –    | Poor |
| Alangium chinense (Lour.) Harms | Fair      | –      | Nil  | –    | –    | –    |
| Albizia procer (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.) Esse    | –         | Poor   | Poor | –    | –    | Nil  |
| Bischofia javanica Blume        | Fair      | Nil    | –    | –    | –    | Nil  |
| Bombax ceiba L.                | –         | –      | –    | –    | –    | Nil  |
| Bridelia glauca Blume           | –         | Fair   | New  | Fair | Fair |
| Callicarpa arboarea Roxb.       | –         | –      | New  | –    | Good | –    |
| Cardiota 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 |
| Colona floribunda (Kurz) Craib  | –         | –      | Fair | –    | –    | –    |
| Crateva religiosa G.Forst.      | –         | Nil    | –    | –    | –    | –    |
| Diplocarpus retusus Blume       | Good      | Nil    | Good | Good | Fair | Good |
| Dvabanga grandiflora (DC.) Walp. | –         | –      | –    | –    | Fair | –    |
| Dysoxylum excelsion Blume       | Good      | Good   | Fair | Good | Good | Good |
| Elaeocarpus rugosus Roxb. ex G.Don | –         | Fair   | –    | Fair | –    | –    |
| Engelharditia spicata Lechen ex Blume | –    | –      | Nil  | –    | Nil  | Nil  |
| Erythrina arborescens Roxb.     | –         | –      | –    | –    | –    | –    |
| 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  | –    | –    |
| Gymnocardia odorata R.Br.       | –         | Nil    | –    | –    | –    | –    |
| Knema cinerea var. glauca (Blume) Y.H. Li | –     | Fair   | Nil  | Good | Poor | Good |
| Kydia calyclina Roxb.           | Nil       | –      | –    | New  | Fair | –    |
| Lasianthus lucidus Blume        | Nil       | Fair   | –    | Fair | –    | –    |
| Litssea monoptera (Roxb.) Pers. | –         | Fair   | Nil  | –    | –    | –    |
| Macaranga denticulata (Blume) Müll.Arg. | Fair | Good | 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 sylvestica Roxb.      | Nil       | Fair   | –    | –    | –    | –    |
| Melia azedarach L.              | –         | Fair   | –    | –    | –    | –    |
| Mesua ferrea L.                 | Good      | –      | Poor | Poor | New  | –    |
| Ocotea lanceifolia (Schott) Mez | Poor      | Good   | –    | –    | Nil  | Fair |
| Olea dioica Roxb.               | –         | –      | –    | –    | –    | –    |
| Oreocnide integrigfolia (Gaudich.) Miq. | –        | New    | Poor | –    | Good | –    |
| Photinia integrigfolia Lindl.   | –         | –      | –    | Poor | –    | –    |
| Pocanglo (locally identified)   | –         | Fair   | –    | –    | –    | –    |
| Quercus lamellosa Sm.           | –         | –      | Nil  | –    | –    | –    |
| Quercus semiserrata Roxb.       | Fair      | Nil    | Fair | Good | –    | –    |
| Saprosma ternatum (Wall.) Hook.f. | Poor     | –      | –    | –    | –    | –    |
| Saurasia armata Kurz            | Fair      | Good   | –    | New  | Good | Good |
| Schima wallichii Choisy         | New       | –      | Nil  | –    | –    | –    |
| Shorea assamica Dyer            | Fair      | Fair   | –    | Poor | –    | Fair |
| Styrox serrulatus Roxb.         | –         | Nil    | –    | Nil  | –    | –    |
| Terminalia myriocarpa Van Heurec & Müll. Arg. | Fair | Nil   | Good | Fair | Fair | Good |
| Toona ciliate M.Roem.           | –         | –      | –    | –    | –    | –    |
| 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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