Plant communities in Shivapuri-Nagarjun National Park, Central Nepal

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This study analyzes the plant communities in the Shivapuri-Nagarjun National Park (SNNP), Nepal. Field survey was carried in the national park using quadrat sampling at four different sites selected based on elevation and aspects. Diversity indices, density, frequency, abundance and importance value index (IVI) were measured for tree species. A total of 31 tree species representing 29 genera and 18 families were reported from the SNNP. Four types of plant communities (*Schima-Pinus-Alnus* community, *Schima-Lindera* mixed community, *Schima-Castanopsis* mixed community, and *Quercus-Myrsine-Rhododendron* mixed community) characterized with elevation and aspects were identified by cluster analysis. The Panimuhan Site situated on the south-west aspect at lower elevation was rich in terms of number of tree species. The IVI value of *Castanopsis tribuloides* in the Sundarijal Site showed the highest density and IVI. The *Quercus* species occurring at the Bagdwar Site at higher elevation was found to be the dominant trees with higher diameter (DBH) values. *Schima wallichii* and *Rhododendron arboreum* showed their association with different species in both the eastern and western aspects. Tree canopy, litter cover and shrub cover showed significant effect on species composition whereas herb cover and rock cover showed no effect on species composition. This study is expected to contribute in understanding the present vegetation status and diversity of SNNP, which could be helpful in implementing sound management planning to boost conservation of ecosystems and biodiversity.

Keywords: Diversity index, Shivapuri-Nagarjun National Park, species composition, vegetation

Vegetation, as an indicator, plays a pivotal role in evaluating the health and stability of the ecological environment, and primarily reflects the way ecological systems respond to both climate change and human disturbances (Huo & Sun, 2021; Zhang & Ye, 2021). Vegetation provides a wide range of benefit to humankind, commonly known as ecosystem services (Reid *et al*., 2005). These include carbon storage regulating the global climate (Mitchard, 2018), an important role in water regulation and soil conservation (Zhang & Ye, 2021) and the support of rural livelihoods in communities with high dependencies on natural resources (Asprilla-Perea & Díaz-Puente, 2019).

National parks and other similarly managed reserves contribute to addressing climate change and fostering development (Dimobe *et al*., 2019). Additionally, protected areas are outstanding in terms of their richness and abundance of species and provision of multiple ecosystem services

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(Harrison *et al*., 2014; Baccini *et al*., 2017). These areas serve as crucial sinks with the capacity to absorb substantial amounts of carbon dioxide from the atmosphere (Dimobe *et al*., 2019). Globally, protected areas store an average of 115 Mg ha^{-1} of carbon in above-ground biomass, which is higher than the average global estimate (71.6 Mg ha^{-1}) (FAO, 2010; Pandey, 2012). Changes in the composition and structure of vegetation, instigated by both climatic and human-induced disturbances, can result in shifts in species diversity and associated carbon stocks (Dimobe *et al*., 2019).

Owing to its wide range of physiographic and climatic variations as well as unique ecological setting, Nepal, a mountainous country, is an important Himalayan region in terms of ecosystem, vegetation and biodiversity where 118 ecosystems and 75 vegetation types were reported (Dobremez, 1970; GON, 2014). On the basis of climate, vegetation & floristic composition, the country's forests are classified into 35 types (Stainton, 1972). Nepal's topographical and climatological variations taken together with other local factors account for the high species richness within the country. Despite small land surface (0.1 % of the world's total land area), Nepal represents over 3 % of the world's known flora, of which 284 are endemic ones (GON, 2014). Nepal's forest including other wood land occupies a total of 44.74 %. Out of the total forest area, 37.80 % lies in the Middle Mountains, 32.25 % in High Mountains & High Himal, 23.04 % in Churia Hills, and 6.90 % in Terai (DFRS, 2015). Similarly, protected areas cover 23.56 % of the country's total area encompassing 12 national parks, six conservation areas, 13 buffer zones areas, one wildlife reserve and one hunting reserve (DNPWC, 2019).

Among the national parks, the Shivpuri-Nagarjun National Park (SNNP) with an area of 159 sq. km, lies in the sub-tropical and lower temperate zone and presents sole repository of the middle mountain's flora, fauna and ecosystem. It is located towards the north-eastern part of the Kathmandu Valley within Bagmati Province of central Nepal. The SNNP is one of the major fresh water sources for the Kathmandu Valley. Apart from that, the area possesses historical, religious, cultural, touristic, environmental, and archeological significance. Therefore, understanding the present vegetation status and diversity of the area is essential for sound management planning, thereby conserving ecosystem and biodiversity. Previous studies in the SNNP reported vegetation structure in a particular region of the park. For example, a study on quantitative analyses of vegetation (trees and shrubs) was undertaken on the north-east (NE) and south-west (SW) slopes of the Nagarjun hill (Yadav & Sah, 1998). Sigdel (2008) studied the vegetation structure along altitudinal bands in the Shivapuri National Park. Other studies are focused mainly on specific species such as *Adiantum* (Singh & Siwakoti, 2012) and the phyllospheric bacterial populations of the woody vegetation within the park (Yadav *et al*., 2013). This study aims to characterize the plant communities in the SNNP focusing mainly on tree species, and produce baseline information for community structure, diversity, and ecology that would be helpful for developing sustainable forest management strategy and conserving natural resources.

Materials and methods

Study sites

The study was conducted in the Shivpuri-Nagarjun National Park (SNNP) situated within the Bagmati Province of Nepal in 2020 (Figure 1). The national park is situated between 27°43' – 27°52' N latitudes and 85°13' – 85°30' E longitudes towards the north-eastern part of the Kathmandu Valley, and covers a total area of 159 sq km (SNNP, 2022). The elevation of the terrain ranges from 1350 m to 2795 m above the mean sea level (msl). Geographically the national park represents a transitional zone between subtropical and temperate regions. The mean annual rainfall of the SNNP is 2727 mm (SNNP, 2022). The rainy season start from June and ends by October whereas the dry season starts from November and ends by April. The temperature varies from 27.7° C to 0.30° C (SNNP, 2022). The vegetation of the area is characterized as subtropical and temperate. The subtropical zone is dominated by species such as *Schima wallichii*, *Castanopsis indica*, *C. tribuloides* and *Pinus roxburghii*. The mixed temperate forest at higher elevations

consists of *Quercus lanata*, *Q. semecarpifolia* and *Rhododendron arboreum* as dominant species (Sigdel, 2008).

Vegetation sampling and data collection

The study was conducted in 2020 during post-monsoon season. A total of 43 sample plots (quadrats), each of size 10×10m^2 were sampled at the south-eastern and south-western aspects and also at the top of the national park. Among those, 13 sample plots were within the Sundarijal Site (SS) located at an elevation between 1514–1634 m above the msl towards the eastern aspect while 9 plots were within the Panimuhan Site (PS) located between 1731–1869 m above the msl towards the south-western aspect. Similarly, 9 plots were sampled in the Okhreni Site (OS) located between 1883–1945m above the msl nearby the Okhreni Village within the national park. The remaining 12 sample plots were in the Bagdwar Site (BS) at the top of the national park (elevation between 2244–2795m above the msl). This site is dominated by *Quercus* species, and a sacred "Bagdwar Temple" exists within the site. Three to four plots were at a spacing of 100m along each of the three transects were established parallelly at a spacing of 150–200m in each site and there were 3–4 plots at a spacing of 100m in each transect. The locations of the sample plots are presented in Figure 1.

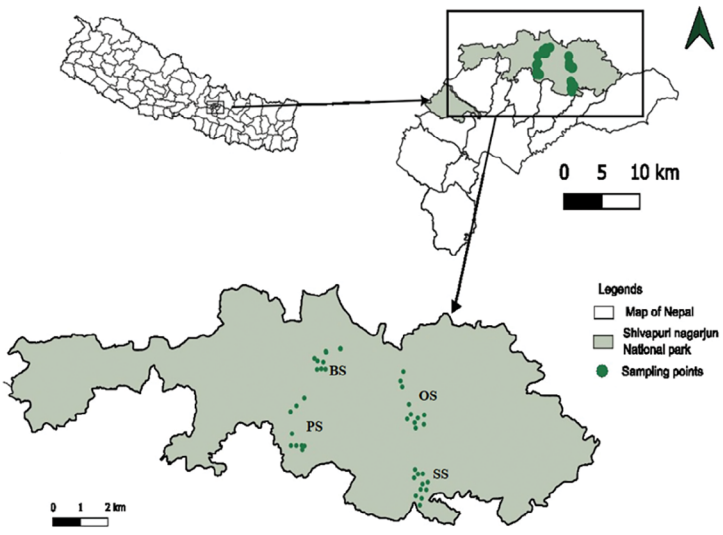

Figure 1: Map showing study area and sampling locations in the SNPP (BS = Bagdwar Site, OS = Okhreni Site, SS = Sundarijal Site, and PS = Panimuhan Site)

All the individual tree species in each plot were counted, and herbs, shrubs and climbers were also duly recorded. The density, frequency, total basal area, relative values of density, frequency, abundance, and DBH (diameter of breast height) of the tree species were calculated following Misra (1968), Muller-Dombois & Ellenberg (1974), and Zobel *et al*. (1987). Per hectare density and basal area were also calculated for all the tree species. Besides, the Importance Value Indices (IVIs) of the tree species were determined by summing up the values of relative of density (RD), relative frequency (RF), and relative dominance (RDo). The Shannon-Wiener Index, Simpson Index for species diversity and Pielou Evenness were computed following Shannon & Wiener (1963), Whittaker (1975) and Pielou (1975).

The tree canopy cover, shrubs, herbs, rocks and litter in each plot were estimated visually as a percentage cover. The plant species were identified by following Malla *et al.* (1986), Rajbhandari *et al*. (2021) and Shrestha *et al*. (2022). Voucher specimens were deposited at the Tribhuvan University Central Herbarium (TUCH), Kirtipur, Kathmandu, Nepal.

Statistical analysis

Multivariate analysis (ordination) was applied for knowing the effects of environmental variables (tree canopy, cover of shrubs, herb, litter, and rock) on species composition. All the species of herbs, shrubs and trees were included in the analysis. The gradient length in the data yielded through Detrended Correspondence Analysis (DCA) was 4.8; therefore, Canonical Correspondence Analysis (CCA) was used as a unimodal technique. The data were down-weighted so as to reduce the effect of rare species in the result. Besides, Permutational Multivariate Analysis of Variance (PERMANOVA) was used to test the significance of the relationships. Hierarchical Clustering Analysis (CA) based on Sørensen Similarity Index was applied to identify plant

communities. Average linkage clustering based on minimum average distance between groups was used, and a 'hierarchical cluster dendrogram' was generated. The analyses were performed using the R Software (version 3.5.1) (R Core Team, 2018).

Results

Floristic composition

A total of 31 tree species from 29 genera and 18 families were reported from the study sites. The families Fagaceae and Rosaceae had 4 species each followed by Lauraceae, Theaceae and Myrsinaceae with 3 species each. Similarly, Betulaceae and Ericaceae were represented by 2 species each while the rest of the families by single species (Table 1). The Panimuhan Site (PS) was rich in terms of number of species (22 species) followed by the Sundarijal Site (SS) with 17 species, the Okhreni Site (OS) with 12 species and the least number of tree species (11 species) were reported from the Bagdwar Site (BS, Table 1).

Among the 22 species reported from the Panimuhan Site (PS), *Albizia julibrissin, Betula alnoides, Castanopsis indica, Eurya acuminata, Fraxinus floribunda, Prunus cerasoides, Pyrus pashia*, and *Saurauia napaulensis* were limited in this site (Table1). The tree *Ziziphus incurva* was confined in the Okhreni Site (OS) and *Cinnamomum tamala, Edgeworthia gardneri, Grevillea robusta* and *Lindera pulcherrima* were confined in Bagdwar Site (BS). The trees *Garuga pinnata, Heptapleurum rhododendrifolium* and *Woodfordia fruticosa* were found only in the Sundarijal Site (SS). Altogether, 6 species were found to be common in the Bagdwar and Panimuhan Sites. Similarly, 11 species were common in Okhreni and Sundarijal sites whereas 5 species were common in all the study sites (Table 1).

Table 1: Plants found in different sites of the SNNP

S. N.	Species name	Plant type	Family	Sites
1.	*Albizia julibrissin* var. mollis (Wall.) Benth.	Tree	Fabaceae	PS
2.	*Alnus nepalensis* D. Don	Tree	Betulaceae	SS, PS
3.	*Betula alnoides* Buch.-Ham. ex D. Don	Tree	Betulaceae	PS
4.	*Castanopsis tribuloides* (Sm.) A. DC.	Tree	Fagaceae	OS, SS, PS
5.	*C. indica* (Roxburgh ex Lindley)	Tree	Fagaceae	PS
6.	*Cinnamomum tamala* (Buch.-Ham.) T. Nees & Nees	Tree	Lauraceae	BS
7.	*Edgeworthia gardneri* Meisn.	Small Tree/Shrub	Thymelaeaceae	BS
8.	*Rhaphiolepis dubia* (Lindl.) B. B. Liu & J. Wen	Small Tree/Shrub	Rosaceae	OS, SS, PS
9.	*Eurya acuminata* DC.	Tree	Theaceae	PS
10.	*E. japonica* Thunb.	Tree	Theaceae	BS, OS, SS, PS
11.	*Fraxinus floribunda* Wall.	Tree	Oleaceae	PS
12.	*Garuga pinnata* Roxb.	Tree	Burseraceae	SS
13.	*Grevillea robusta* A. Cunn. ex R. Br.	Tree	Proteaceae	BS
14.	*Lindera nacusua* (D. Don) Merr.	Tree/Shrub	Lauraceae	OS, SS, PS
15.	*L. pulcherrima* (Nees) Hook. f.	Small Tree	Lauraceae	BS
16.	*Lyonia ovalifolia* (Wall.) Drude	Small Tree/Shrub	Ericaceae	BS, OS, SS, PS

S. N.	Species name	Plant type	Family	Sites
17.	*Morella esculenta* (Buch.-Ham. ex D. Don) I. M. Turner	Tree	Myricaceae	SS, PS
18.	*Myrsine capitellata* Wall.	Tree	Myrsinaceae	BS, OS, SS, PS
19.	*M. semiserrata* Wall.	Tree	Myrsinaceae	BS, OS, SS, PS
20.	*Pinus roxburghii* Sarg.	Tree	Pinaceae	OS, SS, PS
21.	*Prunus cerasoides* Buch. Ham. ex D. Don	Tree	Rosaceae	PS
22.	*P. nepalensis* Ser.	Tree	Rosaceae	PS
23.	*Pyrus pashia* Buch. Ham. ex D. Don	Tree	Rosaceae	OS, SS, PS
24.	*Quercus lamellosa* Sm.	Tree	Fagaceae	BS, PS
25.	*Q. semecarpifolia* Sm.	Tree	Fagaceae	BS, SS,
26.	*Rhododendron arboreum* Sm.	Tree	Ericaceae	BS, OS, SS, PS
27.	*Saurauia napaulensis* DC.	Tree	Actinidiaceae	PS
28.	*Heptapleurum rhododendrifolium* (Griff.) G. M. Plunkett & Lowry	Tree	Araliaceae	SS
29.	*Schima wallichii* (DC.) Korth.	Tree	Theaceae	OS, SS, PS
30.	*Woodfordia fruticosa* (L.) Kurz	Small Tree	Lythraceae	SS
31.	*Ziziphus incurva* Roxb.	Tree	Rhamnaceae	OS

Note: BS = Bagdwar Site; OS = Okhreni Site; PS = Panimuhan Site; and SS = Sundarijal Site.

Diversity and importance value indices of tree species

Based on the diversity indices, the Panimuhan Site was found to be more diverse than other sites. The order of the Simpson Diversity Index and Shanon-Weiner Index values were: PS>OS>BS>SS (Table 2). Similarly, the Pielou's Evenness also followed the same pattern as the diversity indices.

Table 2: Diversity indices and evenness at different sites

Index/Evenness	Sites			
	PS	OS	BS	SS
Simpson Index	0.90	0.89	0.79	0.73
Shannon-Weiner Index	2.50	2.36	1.86	1.79
Pielou's Evenness	0.50	0.47	0.36	0.32

Quercus semecarpifolia had the highest IVI value (103.55) in the Bagdwar Site, with 24.11 relative density and 15.58 relative frequency, but the relative density was high in *M. semiserrata* (34.75). *Q. semecarpifolia* was also present in the Sundarijal Site, but its IVI was <10. Comparing the values of the IVI among the species in the Bagdwar Site, *M. semiserrata, R. arboreum,* and *M. capitellata* were found to be the species having the IVI >25 (Table 3). *M. semiserrata* had the IVI value of 26.19 in the Okhreni Site while the values were >5 in the other two sites viz. Sundarijal and Panimuhan. *R. arboreum* had the IVI value of 25.05 in the Sundarijal Site following the Bagdwar Site whereas the values were less (>10) in the Panimuhan and Okhreni sites (Table 3). Similarly, *M. capitellata* was present in the other three sites besides the Bagdwar Site with the IVI values ranging from 12.42 to 35.20. Among the species having the least IVI in the Bagdwar Site,

G. robusta was not found in the other sites while *L. ovalifolia* had almost the similar IVI value in the Sundarijal Site, but the values were higher in the Panimuhan (14.51) and Okhreni (20.46) sites than in the Bagdwar Site (4.33, Table 3).

The tree species in the Okhreni Site had the IVI values ranging from 2.62 (*R. arboreum*) to 47.54 **(***L. nacusua*). *S. wallichii, P. pashia, P. roxburghii* had the IVI values of 44.61, 33.46, and 31.38, respectively. *Z. incurva* was the species having comparatively the least IVI (6.50) in the Okhreni Site. *L. nacusua* was also present in the Sundarijal and Panimuhan sites with low density and frequency as compared to those in the Okhreni Site. The density and frequency of *S. wallichii* were higher in the Panimuhan Site with the IVI value of 66.37 but lesser in the Sundarijal Site than in the Okhreni Site (Table 3). *P. pashia* and *P. roxburghii* were also reported in Sundarijal and Panimuhan sites. *P. pashia* had less than 5 relative density and relative frequency in both the Sundarijal and Panimuhan sites, but *P. roxburghii* had much higher IVI value of 15.59 in the Sundarijal Site and 27.12 in the Panimuhan Site (Table 3).

Among all the tree species, *C. tribuloides* was the dominant at the Sundarijal Site with the highest IVI value of 120.05 followed by Panimuhan site (40.09) and Okhreni site (16.21). *E. acuminata, G. pinata*, *W. fruticosa, P. pashia, A. nepalensis* and *M. semiserrata* were among the species having the least IVI (<5) at the Sundarijal Site (Table 3). Following *S. wallichii* and *C. tribuloides*, *A. nepalensis* had the IVI value of 29.63 at the Panimuhan Site. The tree species- *A. julibrissin, C. indica* and *S. napaulensis* were found only at the Panimuhan Site with the relative density, frequency, and dominance less than 2 and the IVI less than 3 (Table 3).

Table 3 : Relative Density (RD), Relative Frequency (RF), Relative Dominance (RDo), and Importance Value Index (IVI) of tree species in different sites of SNNP

S. N.	Name of species	Bagdwar Site (BS)				Okhreni Site (OS)				Sundarijal Site (SS)				Panimuhan Site (PS)			
		RD	RF	RDo	IVI	RD	RF	RDo	IVI	RD	RF	RDo	IVI	RD	RF	RDo	IVI
1.	*A. julibrissin*	-	-	-	-	-	-	-	-	-	-	-	-	0.39	1.67	0.40	2.46
2.	*A. nepalensis*	-	-	-	-	-	-	-	-	0.56	1.85	1.25	03.66	6.98	6.67	15.98	**29.63**
3.	*B. alnoides*	-	-	-	-	-	-	-	-	-	-	-	-	0.39	1.67	4.32	6.38
4.	*C. indica*	-	-	-	-	-	-	-	-	-	-	-	-	0.39	1.67	0.20	2.26
5.	*C. tamala*	1.42	10.39	0.12	11.93	-	-	-	-	-	-	-	-	-	-	-	-
6.	*C. tribuloides*	-	-	-	-	4.73	3.57	7.91	16.21	48.60	14.81	56.64	**120.05**	12.79	6.67	20.63	**40.09**
7.	*E. acuminata*	3.55	5.19	3.02	11.76	6.76	8.93	2.29	17.98	0.28	1.85	0.68	02.81	0.78	1.67	2.68	5.13
8.	*R. dubia*	-	-	-	-	6.08	8.93	3.26	18.27	4.19	5.56	4.15	13.90	1.55	3.33	0.19	5.07
9.	*E. gardneri*	0.71	3.90	0.03	4.64	-	-	-	-	-	-	-	-	-	-	-	-
10.	*E. japonica*	-	-	-	-	-	-	-	-	-	-	-	-	5.82	10.00	0.10	15.92
11.	*F. floribunda*	-	-	-	-	-	-	-	-	-	-	-	-	5.04	8.33	2.36	15.73
12.	*G. pinata*	-	-	-	-	-	-	-	-	0.28	1.85	0.60	02.73	-	-	-	-
13.	*G. robusta*	2.13	1.30	0.33	3.76	-	-	-	-	-	-	-	-	-	-	-	-
14.	*L. nacusua*	-	-	-	-	18.92	12.50	16.12	**47.54**	1.96	3.70	0.32	05.98	2.33	1.67	0.53	4.53
15.	*L. ovalifolia*	0.71	2.60	1.02	4.33	6.08	8.93	5.45	20.46	1.40	3.70	0.3	05.40	7.37	5.00	2.14	14.51
16.	*L. pulcherrima*	2.13	3.90	0.16	6.19	-	-	-	-	-	-	-	-	-	-	-	-
17.	*M. capitellata*	13.48	11.69	4.78	**29.95**	5.41	5.36	1.65	12.42	14.25	14.81	6.14	**35.20**	7.37	5.00	1.45	13.82
18.	*M. esculenta*	-	-	-	-	-	-	-	-	3.07	5.56	2.18	10.81	3.88	6.67	2.06	12.61
19.	*M. semiserrata*	34.75	14.29	5.04	**54.08**	6.08	12.50	7.61	**26.19**	1.68	1.85	1.15	04.68	1.16	3.33	0.20	4.69
20.	*P. cerasoides*	-	-	-	-	-	-	-	-	-	-	-	-	5.82	1.67	1.26	8.75
21.	*P. nepalensis*	-	-	-	-	-	-	-	-	-	-	-	-	1.55	1.67	0.87	4.09
22.	*P. pashia*	-	-	-	-	16.89	14.29	2.28	**33.46**	0.28	1.85	1.32	03.45	1.16	5.00	0.61	6.77
23.	*P. roxburghii*	-	-	-	-	0.68	1.79	28.91	**31.38**	3.35	5.56	6.68	15.59	3.10	5.00	19.02	**27.12**

S. N.	Name of species	Bagdwar Site (BS)				Okhreni Site (OS)				Sundarijal Site (SS)				Panimuhan Site (PS)			
		RD	RF	RDo	IVI	RD	RF	RDo	IVI	RD	RF	RDo	IVI	RD	RF	RDo	IVI
24.	*Q. lamellosa*	4.26	3.90	5.74	13.90	-	-	-	-	-	-	-	-	0.78	1.67	0.79	3.24
25.	*Q. semecarpifolia*	24.11	15.58	63.85	**103.54**	-	-	-	-	2.23	7.41	0.31	09.95	-	-	-	-
26.	*R. arboreum*	12.77	7.79	15.04	**35.60**	0.68	1.79	0.15	2.62	7.54	11.11	6.40	**25.05**	2.71	5.00	0.46	8.17
27.	*H. rhododendrifolium*	-	-	-	-	-	-	-	-	4.47	7.41	0.62	12.50	-	-	-	-
28.	*S. napaulensis*	-	-	-	-	-	-	-	-	-	-	-	-	0.78	1.67	0.35	2.80
29.	*S. wallichii*	-	-	-	-	16.22	10.71	17.68	**44.61**	5.59	9.26	11.32	**26.17**	27.91	15	23.46	**66.37**
30.	*W. fruticosa*	-	-	-	-	-	-	-	-	0.28	1.85	0.11	02.24	-	-	-	-
31.	*Z. incurva*	-	-	-	-	1.35	1.79	3.36	6.50	-	-	-	-	-	-	-	-

DBH of trees

The Bagdwar Site possessed the highest number of trees (71) having DBH >50 cm while the Okhreni Site had the least number of such trees (50) (Figure 2). On the other hand, the Sundarijal Site consisted of the highest number of trees (148) with DBH 5–25cm while the Bagdwar Site had the lowest number of such trees (31).

Cluster dendrogram

A total of 4 plant communities were identified in the SNNP through cluster analysis. Cluster 'A' included all the sample plots from the Panimuhan Site except one (# 33) from the Sundarijal Site. Altogether, 22 species were found in this community having *S. wallichii, P. roxburghii, C. indica*, and *A. nepalensis* as the major ones; therefore, this cluster was categorized as '*Schima-Pinus-Alnus* community' (Figure 2). Similarly, Cluster 'B' consisted of the sample plots- 13–21 and 22–32 & 34 from the Okhreni Site, the later ones (plots- 22–32 & 34) mainly consisted of *S. wallichii, L. nacusua,* and *P. pashia*, and so it was categorized as '*Schima-Lindera* mixed community'. Likewise, Cluster 'C' included all the plots from the Sundarijal Site. The major tree species in this community were *S. wallichii, C. tribuloides, M. capitellata,* and *R. arboreum*, and therefore, it was thus categorized as '*Schima-Castanopsis* mixed community'. Cluster 'D' had distinctly two sub-clusters- one with the sample plots- 7–12 from the Bagdwar Site dominated by *Q. semecarpifolia*, *R. arborium*, and *M. semiserrata* and another with the sample plots- 1–6 also from the Bagdwar Site with the dominance of *Q. semecarpifolia*, *Myrsine* spp., *C. tamala* and *R. arborium,* and thus, this cluster was categorized as '*Quercus-Myrsine-Rhododendron* mixed community' (Figure 2).

Effect of environmental parameters on tree species composition

The CCA results showed that the first (CCA1) and second (CCA2) axes accounted for 61% and 35% variations in the species composition (see Figure 3). The tree species like *Z. incurva, A. nepalensis* and *W. fruticosa* were closely associated with high tree canopy. Likewise, the shrub species such as *Diplomorpha canescens*, *Maesa chisia* and *R. arboreum* had close relationship with the tree canopy (Figure 3). Similarly, the tree species like *Lagerstroemia parviflora, L. pulcherrima* and shrubs *Rubus ellipticus,* and *Viburnum cylindricum* had optimum association towards the shrub cover, and they showed positive correlation. On the other hand, litter cover also had shown effect on species composition. The species *M. semiserrata, Drepanostachyum falcatum, Q. semicarpifolia, Daphne bholua, C. tamala,* and *Ilex dipyrena* have positive correlation with the litter cover while the species such as *M. esculenta* and *Sarcococca coriacea* were found to be negatively correlated with the same. The tree species such as *M. semiserrata, L. ovalifolia, M. esculenta,* and *S. coriacea* were allied with the rock cover. On the other hand, the species such as *Smilex zeylanica, P. parvifolius,* and *Ageratina adenophora* had their optimal abundance towards the herb cover (Figure 3). The PERMANOVA Test showed that the environmental variables (tree canopy, litter cover, and shrub cover) had significant effect on the species composition ($p<0.001$) whereas the herb cover and rock cover showed no effect on the same.

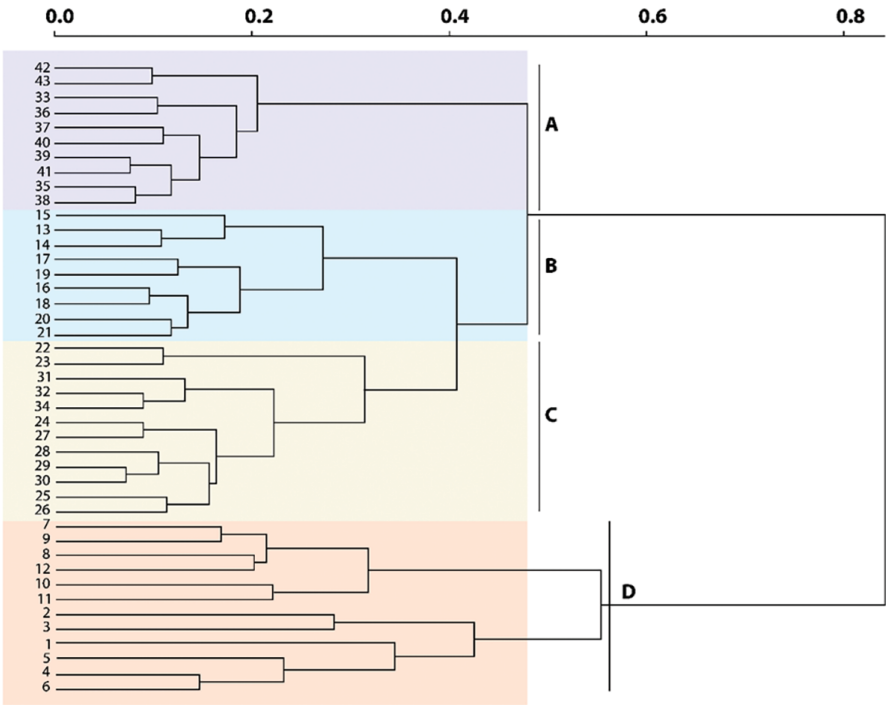

Figure 2: Hierarchical clustered dendrogram showing similarities among different sample plots within the watershed area of SNNP

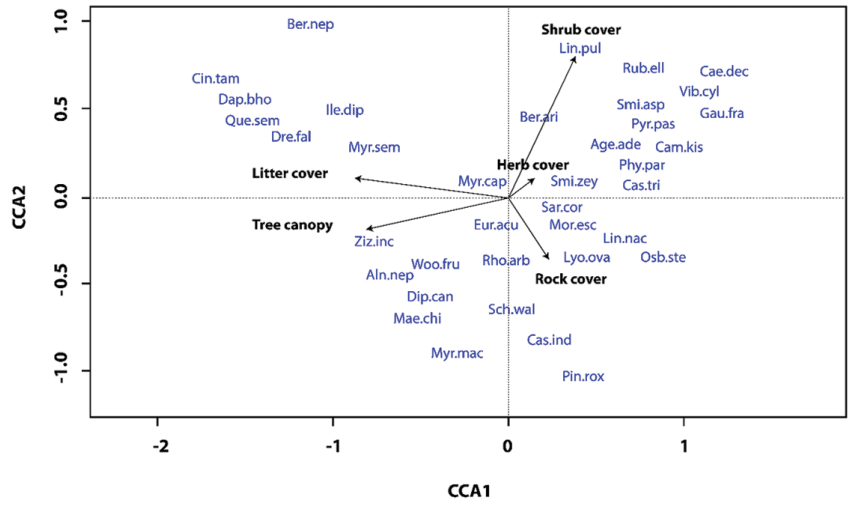

Figure 3: CCA biplot showing the effects of environmental parameters on species composition (complete list of the plant species is presented in Annex I)

Discussion

Comparing the richness of tree species among the four study sites in the SNNP, the Panimuhan Site was rich in terms of the number of species followed by the Sundarijal Site. These two sites are located at the entrance point of the national park. At the entrance point, there is an army check post and, therefore, the level of disturbance is low there compared to the other two sites. On the other hand, both the sites are located at more or less the same elevation (1514–1869 m). The Bagdwar and Okhreni sites had a lesser number of species (see Table 1). The Bagdwar Site lies at the top (2795 m) of the national park, and it has matured forest with almost closed canopy due to which the number of species at the understory of tree canopy is lower. Okhreni forest lies at 1945m above the msl within the buffer zone near the Okhreni, Chilauni and Mulpani villages; hence, the forest was used for grazing, collection of fodder and firewood. The low richness of species in this site was due to anthropogenic disturbances.

Subedi *et al*. (2020) also described that the species richness and the abundance decrease with elevation and the disturbances like cutting and grazing are also responsible for decreasing species richness. Santaniello *et al*. (2016) and Abella & Springer (2015) concluded that partial cutting is beneficial for the growth of plant species because it exposed understory vegetation toward sunlight, which makes growth more vigorously but larger scale has a negative impact on plant diversity. The results of our study are in favor of these studies.

The IVI along with the sum of RF, RD and RDo measure how dominant a species is in a given

forest area (Curtis & McIntosh, 1950). Based on the IVI, the four study sites within the SNNP (Bagdwar, Panimuhan, Okhreni and Sundarijal) were found to be dominated by different tree species. A dominant species has a significant influence over other organisms in the ecological community. Also, the species tend to have an impact on environmental situations, community diversification, and ecosystem features (Komatsu *et al*., 2019). The species *C. tribuloides* at the Sundarijal Site showed the highest density and IVI among the four sites (Table 3), which indicated that this species was the most dominant in this community (C), which is in line with the findings of Sigdel (2008). The lowest densities of *E. gardneri* and *L. ovalifolia* at the Bagdwar Site (Table 3) showed that these were the rare species in this community (D). The species- *Q. semecarpifolia* and *S. wallichii* at the Bagdwar and Panimuhan sites, respectively, showed the highest frequency indicating the uniformity of distribution of these species in those sites. The species- *G. robusta* at the Bagdwar Site showed the lowest frequency (1.3, Table 3), which indicated that this species was either irregularly distributed or rare in this community.

Presence of high number species indicate the characteristic of more diverse communities. If the species are uniformly distributed, then the diversity index value would be high (Henderson & Southwood, 2016). In our study, all the values were nearer to 1, which indicated that all these sites had moderate diversity (Table 2). The biodiversity indices slightly differed among the sites. The Panimuhan Site had the highest value of Shannon-Weiner Index, indicating high species richness, which might be due to the conservation of the species owing to the army check post nearby this site. On the other hand, the Bagdwar Site had a comparatively low Shannon-Weiner Index, indicating low species richness, which might be due to its location at higher elevation as compared to the other sites. Limbu *et al*. (2017) also reported that the number of species decreased with the increase in elevation. The observed value of evenness was moderate in this study, which might be due to the apartness of the study sites from one another or due to the differences in their micro-climates.

The tree species at the Bagdwar Site consisted of higher DBH (>50 cm) while those at the Sundarijal Site had comparatively lower (<25 cm) girth (Figure 2). The low DBH indicates the mid-level of succession (Bhatt & Khanal, 2010). Poudel *et al*. (2020), in the Panchase Area of western mid-hills of Nepal, described that higher DBH of trees were found in the forests which were far from anthropogenic disturbance whereas the forests which were easily accessible to humans and are subjected to regular disturbance possessed the trees with low DBH.

A total of 4 plant communities were identified in the SNNP through cluster analysis (Figure 2). The cluster 'A' from the Panimuhan Site (south-western aspect) was found to be rich in a number of species with the dominance of *S. wallichii*, *A. nepalensis*, and *P. roxburghii* which was categorized as *Schima-Pinus-Alnus* Community. The clusters- 'B' and 'C' formed a mixed composition of tree species like *S. wallichii*, *L. nacusua*, *P. pashia*, *C. tribuloides*, *M. capitellata*, and *R. arboreum* towards the Okhreni and Sundarijal sites (eastern aspect), showing the range of distribution of *S. wallichii* with association of different species towards the eastern and western aspects, and hence this cluster was categorized as '*Schima-Lindera* Mixed Community' (Figure 2). Similarly, the presence of *R. arboreum* at all the sites showed its association with varieties of tree species in all aspects. Cluster 'D' (*Quercus-Myrsine-Rhododendron* Mixed Community) had a peculiar community at the top of the SNNP with dominancy of *Q. semecarpifolia*, representing a transitional zone between subtropical and temperate regions (Figure 2). Higher abundance of species such as *P. roxburghii* at lower elevations, *R. arboreum* and *Q. lanata* at mid elevations, and *Q. semicarpifolia* at higher elevations were also reported by Sigdel (2008).

CCA biplot showed the association of species and environmental variables- tree canopy, shrub cover, herb cover, litter cover, and rock cover. The species like *Z. incurva*, *A. nepalensis*, *W. fruticosa*, *D. canescens*, and *M. chisia* were found associated with high tree canopy (Figure 3). *Z. incurva* and *A. nepalensis* were the trees forming canopy themselves, but the species such as *W.*

fruticose, *D. canescens*, and *M. chisia* were also found to be forming the canopy as they might be shade-tolerant species as well. The species such as *Persea pallida*, *Drepanostachyum falcatum*, *M. semiserrata*, and *Q. semecarpifolia* were correlated with litter cover (Figure 3), indicating the species capable of producing high amount of litter. In forest areas, species are subjected to a dense tree canopy that changes light quality & quantity (Holmgren *et al*. 1997) and water availability which are required to germinate and establish from beneath a thick litter layer (Sydes & Grime 1981). The CCA biplot also showed a group of plant species (mostly shrubs and herbs) towards a high cover of shrubs, herbs, and rock cover areas against high tree canopy (Figure 3). It shows that species such as *R. ellipticus*, *Berberis aristata*, *Smilex zeylanica*, *S. coriacea*, *Osbeckia stellata*, *L. pulcherrima* etc. do not prefer high amounts of litter and shade.

Conclusion

In the SNNP, four types of plant communities (*Schima-Pinus-Alnus* Community, *Schima-Lindera* Mixed Community, *Schima-Castanopsis* Mixed Community, and *Quercus-Myrsine-Rhododendron* Community) with 31 tree species representing 19 genera and 18 families were identified. The plant communities were characterized with elevation and aspects. Comparing the richness, the Panimuhan Site was rich in terms of number of tree species. The richness of species was lower at higher elevation (Bagdwar Site) and at the Okhreni Site near the Okhreni Village. The IVI value of *C. tribuloides* at the Sundarijal Site showed the highest density score and IVI among the four sites. The Panimuhan Site possessed the highest value of diversity indices while the Bagdwar Site had the lower values. On the other hand, the tree species at the Bagdwar Site had higher DBH (>50 cm) while those at the Sundarijal Site had lower DBH<25 cm. *E. acuminata, L. ovalifolia*, *M. capitellata*, *M. semiserrata*, and *R. arboreum* were found in all the four plant communities. Two species, *S. wallichii* and *R. arboreum* showed their association with different species in both the eastern and western aspects. The environmental variables like tree canopy, shrub cover, and litter cover were found to have significant effect on species composition whereas herb cover and rock cover showed no effect on tree species composition in the study sites.

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Author Contribution Statement

TMD: Data collection, analysis, draft writing. LBT: Conception and design, manuscript revision. RKPY: Conception and design, manuscript revision, supervision. CPP: Conception and design, result interpretation, manuscript revision, supervision.

Data Availability

The data used in this study are accessible upon request to the corresponding author.

Conflict of Interest

The authors declare no conflict of interest.

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Annex I: Plant species found in the SNNP with abbreviated name, local name and habit

S. N.	Name of plant species	Name abbreviation	Habit	Local name	S. N.	Name of plant species	Name abbreviation	Habit	Local name
1.	*Ageratina adenophora*	Age.ade	H	Kalo Banmara	26.	*Myrsine capitellata*	Myr.cap	S	Seti Kath
2.	*Albizia julibrissin*	Alb.jul	T	Seto Shiris	27.	*M. macrophylla*	Myr.mac	S	-
3.	*Alnus nepalensis*	Aln.nep	T	Uttis	28.	*M. semiserrata*	Myr.sem	T	Kali Kath
4.	*Berberis aristata*	Ber.ari	S	Chutro	29.	*Morella esculenta*	Mor.esc	T	Kaphal
5.	*B. napaulensis*	Ber.nap	S	Jamane Mandro	30.	*Maesa chisia*	Mae.chi	T	Bilaune
6.	*Betula alnoides*	Bet.aln	T	Lek Painyu	31.	*Osbeckia stellata*	Osb.ste	S	Rato Chulesi
7.	*Caesalpinia decapetala*	Cae.dec	C	Areli Kada	32.	*Phyllanthus parvifolius*	Phy.par	T	Khareto
8.	*Camellia kissi*	Cam.kis	S	Chiyaapaate	33.	*Pinus roxburghii*	Pin.rox	T	Rani Salla
9.	*Castanopsis indica*	Cas.ind	T	Dhale Katus	34.	*Prunus cerasoides*	Pru.cer	T	Painyu
10.	*C. tribuloides*	Cas.tri	T	Musure Katus	35.	*P. nepalensis*	Pru.nep	T	-
11.	*Cinnamomum tamala*	Cin.tam	T	Tejpat	36.	*Pyrus pashia*	Pyr.pas	T	Mayal
12.	*Daphne bholua*	Dap.bho	S	Lokta	37.	*Quercus lamellosa*	Que.lam	T	Falant
13.	*Diplomorpha canescens*	Dip.can	S	Phurke Paat	38.	*Q. semecarpifolia*	Que.sem	T	Kharsu
14.	*Drepanostachyum falcatum*	Dre.fal	S	Nigalo	39.	*Rhaphiolepis dubia*	Rha.dub	T	Jure Kafal
15.	*Edgeworthia gardneri*	Edg.gar	T	Argeli	40.	*Rhododendron arboreum*	Rho.arb	T	Gurans
16.	*Eurya acuminata*	Eur.acu	T	Saano Jhingane	41.	*Rubus ellipticus*	Rub.ell	S	Ainselu
17.	*E. japonica*	Eur.jap	T	Jhingane	42.	*Smilax zeylanica*	Smi.zey	C	Kukur Daaino
18.	*Garuga pinnata*	Gar.pin	T	Dabdabe	43.	*Sarcococca coriacea*	Sar.cor	S	Telpaaro
19.	*Gaultheria fragrantissima*	Gau.fra	S	Dhasingre	44.	*Saurauia napaulensis*	Sau.nap	T	Gogan
20.	*Grevillea robusta*	Gre.rob	T	Kaenyo	45.	*Schima wallichii*	Sch.wal	T	Chilaune
21.	*Heptapleurum rhododendrifolium*	Hep.rho	T	-	46.	*Smilax aspera*	Smi.asp	C	Kukur Daaino
22.	*Ilex dipyrena*	Ile.dip	S	Seto Khasru	47.	*Viburnum cylindricum*	Vib.cyl	S	Ghode Khari
23.	*Lindera pulcherrima*	Lin.pul	T	Phusre	48.	*Woodfordia fruticosa*	Woo.fru	T	Dhairo
24.	*L. nacusua*	Lin.nac	T	-	49.	*Ziziphus incurva*	Ziz.inc	T	Hade Bayar
25.	*Lyonia ovalifolia*	Lyo.ova	T	Angeri					

Note: C = Climber; H = Herb; S = Shrub; and T = Tree.