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Research Article

VEGETATION COMPOSITION, STRUCTURE AND DIVERSITY IN BARANDABHAR FOREST, CHITWAN, NEPAL

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ABSTRACT

The Barandabhar Forest, a vital corridor linking Chitwan National Park to the Mahabharat Range in central Nepal, supports diverse plant communities within a tropical ecosystem. However, increasing human migration and dependence on forest resources have contributed to vegetation decline. The present study explores the vegetation structure and diversity across four forest management regimes, viz., Buffer Zone Community Forest (BZCF), Community Forest (CF), Protected Forest (PF), and Buffer Zone Forest (BZ). This study assessed the structure, composition, and diversity of plant species across four forest management regimes using 256 concentric circular sampling plots (CCSPs) for trees (DBH ≥ 5 cm), shrubs, and herbs. A total of 90 plant species were recorded, comprising 30 trees, 26 shrubs, and 34 herbs, belonging to 37 families. Fabaceae represented the most species-rich family (16 species). Species richness in BZ, CF and PF was found to be significantly higher ($p < 0.05$) than the species richness of BZCF. Furthermore, the Community Forest (CF) exhibited the highest species richness, diversity, and maturity indices. Among trees, *Shorea robusta* showed the highest value for Importance Value Index (IVI), while *Clerodendrum infortunatum* dominated the shrub layer across all forest regimes. Dipterocarpaceae and Lamiaceae recorded the highest Family Importance Values (FIV) for trees and shrubs, respectively. The herb species *Imperata cylindrica* showed greatest prominence value among herbs across all regimes. These findings highlight variation in vegetation composition across management systems, emphasizing the importance of effective conservation strategies for maintaining forest biodiversity and ecological integrity.

Keywords: Biodiversity, Forest structure, Buffer zone, Species diversity, Family Importance Value

INTRODUCTION

Forests cover around 30.6% of the planet's total land area (FAO, 2018). They are indispensable to the world because they provide vital services for sustaining the natural ecosystem and human life, such as nutrient cycling, soil formation, climate and water cycle regulation, and cultural and scientific importance (MEA, 2005). Tropical forests are the most diverse biological communities on the Earth and they include many of the hotspots of global biodiversity in the world (Myer *et al*., 2000; Mittermeier *et al*., 2004; Baraloto *et al*., 2013; Naidu *et al*., 2016). In this context, the study of the diversity of plants in tropical forests is important for developing measures for their conservation.

Plant species growing collectively in an area with a clear relationship with each other form a “plant community” (Malik *et al*., 2014). Species of a plant community coexist because they share similar environmental requirements. The quantitative study of plant communities which aims to describe, explain, predict, and classify vegetation patterns is called phytosociology (Braun-Blanquet, 1932; Odum, 1971). Phytosociological analysis serves as a fundamental approach in ecological research, providing the foundation for understanding the structure and functioning of plant communities (Werger & Maarel, 1778). It facilitates the quantitative assessment of vegetation, offering insights into species relationships and environmental influences. Among the key parameters, species richness and diversity are vital indicators of community composition and ecological stability (Malik *et al*., 2014). Species richness is widely recognized as a simple yet effective measure of biodiversity (Peet, 1974), while species composition and diversity together define the structural organization of forest communities (Malik & Bhatt, 2015). Moreover, species richness and diversity often reflect the maturity and ecological conditions that shape the composition of vegetation (Schuster & Diekmann, 2005; Shaheen *et al*., 2011).

Increasing anthropogenic pressure has led to a global decline in forest cover, with losses estimated at 1–4% per year (Laurance, 1999). Nepal is no exception to this trend. To address ongoing forest degradation, the Government of Nepal has implemented various management strategies aimed at conservation and sustainable use. Based on these approaches, the country has adopted 11 distinct forest management regimes to conserve its forest resources (FRA/DFRS, 2014). Of these, Protected Forests and Buffer Zone Forests fall under state management, while Community Forests and Buffer Zone Community Forests operate under community management. The jurisdiction over these regimes lies either with the Province Forest Ministry or the Department of National Parks and Wildlife Conservation (DNPWC), depending on their administrative category.

The Barandabhar Forest is in the central lowland region of Nepal. This forest serves as an important ecological corridor linking the lowland forests with the Mahabharat physiographic region (Basnet *et al.* 2016). It exemplifies the management diversity, encompassing both government and community managed regimes within a single ecological landscape. The forest is managed under four distinct regimes. Among these, the Protected Forest (PF) and Community Forest (CF) fall under the jurisdiction of the Province Forest Ministry, whereas the Buffer Zone Forest (BZ) and Buffer Zone Community Forest (BZCF) are administered by the Department of National Parks and Wildlife Conservation (DNPWC) (FRA/DFRS, 2014). This mosaic of management systems provides an excellent opportunity to analyze how different conservation approaches influence vegetation composition and diversity. The aim of this study is to analyze vegetation structure and diversity across different forest management regimes, providing insights essential for evaluating the ecological outcomes of Nepal's forest management policies and for informing strategies to strengthen biodiversity conservation and promote forest sustainability.

MATERIALS AND METHODS

Study Area

This study was carried out in the Barandabhar Forest of Chitwan District, situated in the Central Terai region at latitude 27°36′21.60″ N and longitude 84°22′47.28″ E. A portion of the Barandabhar Forest forms part of the Chitwan National Park, which was the first national park of Nepal and established in 1973. The forest is characterized by a rich biodiversity in both flora and fauna, being home to numerous species of plants, mammals, birds, and reptiles. The Barandabhar Forest is jointly managed by Chitwan National Park and the Divisional Forest Office, Chitwan, under a participatory management framework as part of the park's buffer zone. Together, these sections cover a total area of approximately 42,302 ha (personal communication with concerned authorities).

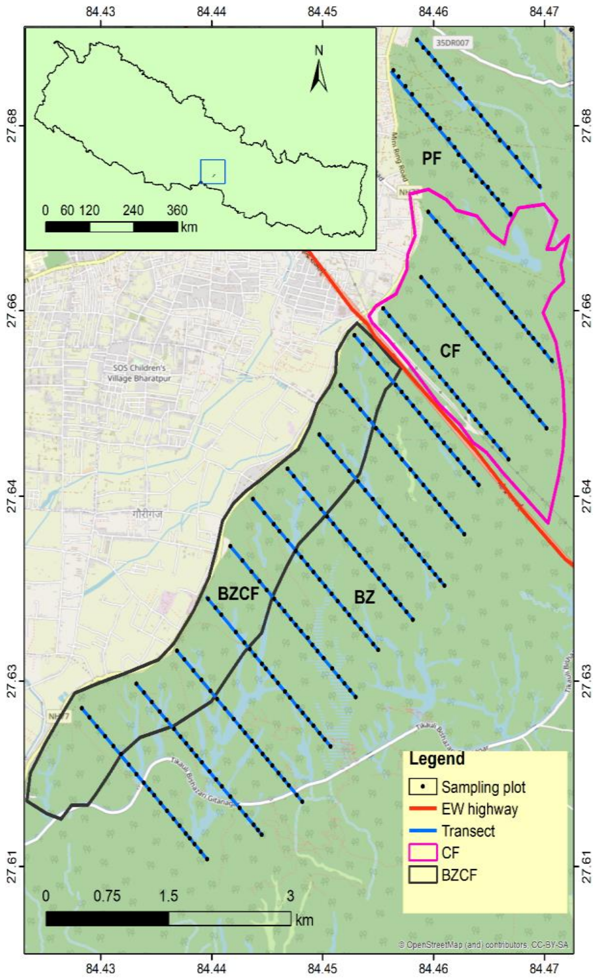

Figure 1. Location map of the Barandabhar forest study area showing the distribution of transects and sample plots

This study focused on four forest management regimes within the Barandabhar Forest: the Rambell Community Forest (CF) and the Bandevi–Barandabhar Buffer Zone Community Forest (BZCF), both managed by community user groups; the Protected Forest (PF), managed by the Province Forest Ministry; and the Buffer Zone Forest (BZ), administered by Chitwan National Park. The total areas of BZCF, CF, PF, and BZ are 254.25 ha, 197.11 ha, 6,922 ha, and 785.6 ha, respectively (Division Forest Office, Chitwan, 2023; CNP Office, 2015). The PF and CF are located to the north of the East–

West Highway, while the BZ and BZCF lie to its south (Fig. 1).

The BZCF area is located within 500 meters of the nearest human settlements. The studied area lies in the south-eastern region of Bharatpur Metropolitan City and experiences a tropical climate. Seasonal temperatures range from a maximum of 36.1°C in summer to a minimum of 8.6°C in winter (DHM, 2024). Rainfall peaks at 620 mm in July and declines to about 5 mm in November (Fig. 2).

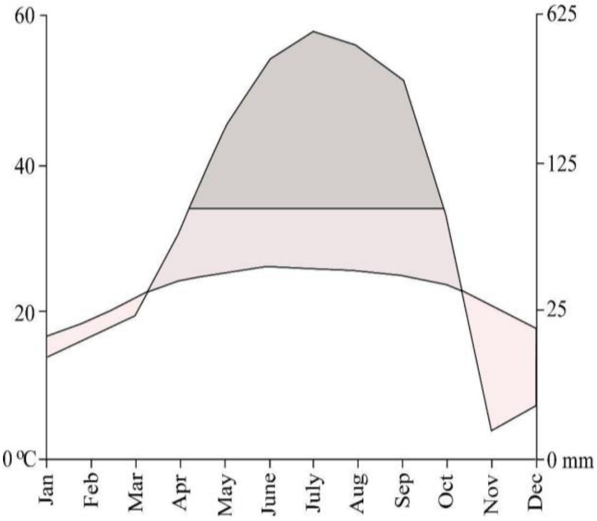

Figure 2. Rainfall and temperature of the study area (Rampur, Chitwan, Nepal, Lat: 27.65° N, Long: 84.35° E, alt: 189 m asl, Meteorological station index: 902, 1989 to 2024)

Sampling Design

The locations of all transects were determined using a Global Positioning System (GPS) to ensure spatial accuracy. Within each forest management regime, transect lines were first established at 500 m intervals. Then, sampling plots were systematically placed at 100 m intervals along each transect. A total of 15 transects and 256 plots were established across the study area. The distribution of sampling plots among the four forest regimes was as follows: 119 plots in the Buffer Zone Forest (BZ), 48 in the Buffer Zone Community Forest (BZCF), 56 in the Community Forest (CF), and 33 in the Protected Forest (PF).

Vegetation data were collected by using the Concentric Circular Sample Plot (CCSP) method (FRA/DFRS, 2014; Shrestha *et al.*, 2015; Shrestha *et al*., 2023), which enables efficient and size-based enumeration of trees within nested circular plots. Each CCSP comprised four concentric radii: r_1 = 20 m (1,256.6 m²) for trees with DBH ≥ 30 cm; r_2 = 15 m (706 m²) for trees with DBH ≥ 20 cm; r_3 = 8 m (201.1 m²) for trees with DBH ≥ 10 cm; and r_4 = 4 m (50.3 m²) for trees with DBH ≥ 5 cm. Within each main plot (1,256 m²), all trees with DBH ≥ 5 cm were measured and recorded. For each tree, DBH was measured at a height of 1.3 m above ground level using a diameter tape. Shrubs with a diameter at DBH < 5 cm were counted within a 5 m radius from the plot center (Subedi *et al.*, 2010). Herbs species were assessed within two circular subplots, each with a radius of 0.57 m, located 20 m north and south of the center of the main plot (Subedi *et al.*, 2010). The percentage cover of herbs species was then estimated within these two subplots.

Data Collection and Analysis

Data on trees were collected from different-sized trees following the guidelines of FRA/DFRS, (2014) from the respective concentric circular sample plots (CCSP). Shrubs were measured from a plot with 5 m radius from the center of CCSP. Data on herbs and herbs climbers were recorded from two circular sub plots, each of 0.57 m radius (Subedi *et al.*, 2010), constructed at North and South cardinal direction of CCSP at 20 m distance from the plot center. Shrubs were measured as counts and the herbs as percentage cover. Plant specimens which were not identified in the field were collected for herbarium preparation following standard procedures (Bridson & Forman, 1998; Press *et al*., 2000). Then, these specimens were identified at the Central Department of Botany, Tribhuvan University, Kathmandu. Shrestha *et al*. (2022) and Press *et al*. (2000) were followed for plant nomenclature.

Data collected from the different forest management regimes were analyzed to determine species distribution patterns. For each species, species richness was estimated following Dorji *et al.*, (2014). In addition, community diversity was assessed using the Shannon–Wiener Diversity Index (H′) and Pielou's Evenness Index (J). Shannon-Weiner diversity index is a measure of species diversity whereas Pielou's evenness index measures the degree of uniformity of species distribution within each forest regime. The respective formulae are as follows:

$$H' = -\sum_{i-1}^{s} (P_i)(\log P_i)$$

Where, H' is the Shannon-Weiner's diversity index, P_i is the proportion of individuals or abundance of i^th^ species. Abundance is given by the ratio of the number of individuals of a species to the total number of individuals belonging to all species.

The summation in the above formula is over all the recorded species. Similarly,

$$J = \frac{H\prime}{\log s}$$

Where, J' is the Pielou's evenness index; H' is the Shannon-Weiner diversity index, and 's' is the total number of species.

Next, the Maturity index (MI) was calculated for the studied forest area across all four management regimes, according to the formula given by Pichi-Sermolli (1948):

$$\mathrm{MI} = \frac{\Sigma \mathrm{f}}{\mathrm{n}}$$

Where, MI is the Maturity index of a particular regime; f is the frequency of individual species in the regime and n is the total number of species in the regime. The summation above is over all species recorded in a particular regime. MI is an important ecological measure of the state of succession of a forest (Bongers *et al.*, 1997). A larger MI indicates the presence of a more developed plant community in a study area (Shrestha *et al.*, 2015).

In addition, the families of all plant species were recorded. Then, the Family Importance Value (FIV) of species was calculated according to the formula of Mori *et al.* (1983):

FIV= Relative diversity + Relative density + Relative dominance

Where,

$$\text{Relative Density} = \frac{\text{Number of trees in a family}}{\text{Total number of trees}} \times 100$$

$$\text{Relative diversity} = \frac{\text{Number of species in a family}}{\text{Total number of species}} \times 100$$

$$\text{Relative Dominance} = \frac{\text{Basal area of family i}}{\text{Total Basal area}} \times 100$$

Prominence value of individual species of herbs was calculated by multiplying the percent coverage of each individual species with the square root of their respective frequencies, following (Sharma *et al.*, 2012).

$$PV = \%Cover \times \sqrt{Frequency}$$

The Sorensen's Similarity Index (SI) was calculated by following Sorensen (1948) to determine the degree of floristic similarity among the four forest management regimes. For a pair of regimes, A and B, the formula for SI is as follows:

$$SI = \frac{2C}{A+B} \times 100$$

where SI is the similarity index, A is the total number of species found in regime A, B is the total number of species found in regime B, and C is the total number of species that are common between regimes A and B.

To determine the dominant plant species, the Importance Value Index (IVI) of each tree and shrub species was calculated following Mandal and Joshi (2014). Finally, variation in species richness across forest regimes was assessed using the Kruskal-Walli's rank sum test. Any significant differences in species richness between regimes were checked by performing pairwise comparisons using Dunn's test available in the '*dunn.test*' package in R (Dinno, 2017).

RESULTS

Species Richness

Across the whole forest, the study recorded a total of 90 plant species belonging to 81 genera and 37 families (Table 1). Among them, there were 34 species of herbs, 26 species of shrubs, and 30 species of trees. There were 12 families, 31 genera and 34 species among herbs; 13 families, 24 genera and 26 species among shrubs; and 19 families, 26 genera and 30 species among trees, respectively. Families that included the highest number of species were Fabaceae (16 species), Poaceae (9 species), Malvaceae (9 species), Asteraceae (8 species), and Lamiaceae (4 species). The total number of species recorded in the samples initially rose steeply and then increased more slowly, indicating that rare species, found only in the later sampled areas, were included in the total species count, as shown in the species accumulation curve. Notably, the protected forest (PF) exhibited the highest diversity (Fig. 3).

Table 1. Complete list of plant species, genera and families found in the study area.

S. No.	Scientific name	Family	Life-form	Shortform	Occurrence
1	1.*Semecarpus anacardium* L.f.	**1.Anacardiaceae**	Tree	Seme_anac	5
2	2.*Spondias pinnata* (L. f.) Kurz	Anacardiaceae	Tree	Spon_pinn	2
3	3.*Toxicodendron wallichii* (Hook. f.) Kuntze	Anacardiaceae	Tree	Toxi_wall	47
4	4.*Centella asiatica* (L.) Urb.	**2.Apiaceae**	Herb	Cent_asia	1

5	5.*Alstonia scholaris* (L.) R. Br.	**3.Apocynaceae**	Tree	Alst_scho	2
6	6.*Holarrhena pubescens* Wall. ex G.Don	Apocynaceae	Tree	Hola_pubi	12
7	7.*Phoenix acaulis* Roxb.	**4.Arecaceae**	Shrub	Phoe_aqua	144
8	8.*Asparagus racemosus* Willd.	**5.Asparagaceae**	Shrub	Aspa_race	2
9	9.*Ageratum conyzoides* (L.) L.	**6.Asteraceae**	Herb	Ager_cony	43
10	*Ageratum houstonianum* Mill.	Asteraceae	Herb	Ager_hous	4
11	10.*Bidens pilosa* L.	Asteraceae	Herb	Bide_pilo	1
12	11.*Blumea lacera* (Burm.f.) DC.	Asteraceae	Herb	Blum_lace	4
13	12.*Chromolaena odorata* (L.) R.M.King & H.Rob.	Asteraceae	Herb	Chro_odor	110
14	13.*Launaea aspleniifolia* (Willd.) Hook.f.	Asteraceae	Herb	Laun_aspl	5
15	14.*Mikania micrantha* Kunth	Asteraceae	Herb	Mika_micr	32
16	15.*Parthenium hysterophorus* L.	Asteraceae	Herb	Part_hyst	1
17	16.*Cordia dichotoma* G.Forst.	**7.Boraginaceae**	Tree	Cord_dich	1
18	17.*Terminalia bellirica* (Gaertn.) Roxb	**8.Combretaceae**	Tree	Term_bell	31
19	*Terminalia elliptica* Willd.	Combretaceae	Tree	Term_elli	119
20	18.*Commelina benghalensis* L.	**9.Commelinaceae**	Herb	Comm_beng	19
21	19.*Cornus oblonga* Wall.	**10.Cornaceae**	Shrub	Corn_obla	85
22	20.*Carex cruciata* Wahlenb.	**11.Cyperaceae**	Herb	Care_cruc	34
23	21.*Cyperus betafensis Cherm.*	Cyperaceae	Herb	Cype_beta	5
24	22.*Cyperus strongii* G.C.Tucker & Gandhi	Cyperaceae	Herb	Cype_stro	18
25	23.*Dillenia pentagyna* Roxb.	**12.Dilleniaceae**	Tree	Dill_pent	31
26	24.*Dioscorea bulbifera* L.	**13.Dioscoreaceae**	Herb	Dios_bulb	1
27	25.*Shorea robusta* Gaertn.	**14.Dipterocarpaceae**	Tree	Shor_robu	255
28	26.*Mallotus nudiflorus* (L.) Kulju & Welzen	**15.Euphorbiaceae**	Tree	Mall_nudi	5
29	27.*Albizia lebbeck* (L.) Benth.	**16.Fabaceae**	Tree	Albi_lebb	3
30	*Albizia procera* (Roxb.) Benth.	Fabaceae	Tree	Albi_proc	1
31	28.*Calopogonium mucunoides* Desv.	Fabaceae	Herb	Calo_macu	16
32	29.*Cassia fistula* L	Fabaceae	Tree	Cass_fist	2
33	30.*Centrosema molle* Benth.	Fabaceae	Herb	Cent_moll	6
34	31.*Dalbergia latifolia* Roxb.	Fabaceae	Tree	Dalb_lati	7
35	*Dalbergia sissoo* DC.	Fabaceae	Tree	Dalb_siso	6
36	32.*Flemingia macrophylla* (Willd.) Merr.	Fabaceae	Shrub	Flem_macr	77
37	*Flemingia strobilifera* (L.) W.T.Aiton	Fabaceae	Shrub	Flem_stro	120
38	33.*Grona triflora* (L.) H. Ohashi & K. Ohashi	Fabaceae	Herb	Gron_trif	1
39	34.*Indigofera atropurpurea* Hornem.	Fabaceae	Shrub	Indi_atro	14
40	35.*Medicago sativa* L.	Fabaceae	Shrub	Medi_sati	4
41	*36.Milletia extensa* (Benth.) ex Baker	Fabaceae	Shrub	Mill_exte	19
42	37.*Mimosa pudica* L.	Fabaceae	Herb	Mimo_pudi	1
43	*38.Senna tora* (L.) Roxb.	Fabaceae	Shrub	Senn_tora	1
44	39.*Tadehagi triquetrum* (L.) H.Ohashi	Fabaceae	Shrub	Tade_triq	12
45	40.*Curculigo capitulata* (Lour.) Kuntze	**17.Hypoxidaceae**	Herb	Curc_capi	20
46	41.*Clerodendrum infortunatum* L.	**18.Lamiaceae**	Shrub	Cler_info	172
47	42.*Colebrookea oppositifolia* Sm.	Lamiaceae	Shrub	Cole_oppo	2
48	43.*Premna barbata* Wall. ex Schauer	Lamiaceae	Shrub	Prem_barb	1

49	44.*Tectona grandis* L.f	Lamiaceae	Tree	Tect_gran	3
50	45.*Litsea monopetala* (Roxb.) Pers.	**19.Lauraceae**	Tree	Lits_mono	5
51	46.*Careya arborea* Roxb	**20.Lecythidaceae**	Tree	Care_arbo	53
52	47.*Lagerstroemia parviflora* Roxb.	**21.Lythraceae**	Tree	Lage_parv	64
53	48.*Woodfordia fruticosa* (L.) Kurz	Lythraceae	Shrub	Wood_frut	2
54	49.*Azanza lampas* (Cab.) Alef.	**22.Malvaceae**	Shrub	Azan_lamp	3
55	50.*Bombax ceiba* L.	Malvaceae	Tree	Bomb_ceib	4
56	51.*Grewia asiatica* L.	Malvaceae	Shrub	Grew_subi	39
57	*Grewia helicterifolia* Wall. ex G.Don	Malvaceae	Shrub	Grew_heli	2
58	52.*Helicteres isora* L.	Malvaceae	Shrub	Heli_isor	144
59	53.*Sida acuta* Burm.f.	Malvaceae	Shrub	Sida_acut	17
60	*Sida rhombifolia* L.	Malvaceae	Herb	Sida_rhom	1
61	54.*Triumfetta pilosa* Roth	Malvaceae	Herb	Triu_pilo	1
62	55.*Urena lobata* L.	Malvaceae	Herb	Uren_loba	2
63	56.*Melia azedarach* L.	**23.Meliaceae**	Tree	Meli_azed	1
64	57.*Ficus simplicissima* Lour.	**24.Moraceae**	Shrub	Ficu_simp	1
65	58.*Syzygium cumini* (L.) Skeels	**25.Myrtaceae**	Tree	Syzi_cumi	1
66	*Syzygium nervosum* A.Cunn. ex DC.	Myrtaceae	Tree	Syzi_nerv	155
67	59.*Oxalis latifolia* Kunth	**26.Oxalidaceae**	Herb	Oxal_lati	2
68	60.*Antidesma acidum* Retz.	**27.Phyllanthaceae**	Shrub	Anti_acid	15
69	61.*Cynodon dactylon* (L.) Pers.	**28.Poaceae**	Herb	Cyan_dact	26
70	62.*Dendrocalamus strictus* (Roxb.) Nees	Poaceae	Shrub	Dend_stri	1
71	63.*Desmostachya bipinnata* (L.) Stapf	Poaceae	Herb	Desm_bipi	1
72	64.*Digitaria ciliaris* (Retz.) Koeler	Poaceae	Herb	Digi_cili	2
73	*Digitaria insularis* (L.) Mez ex Ekman	Poaceae	Herb	Digi_insu	7
74	65.*Hemarthria compressa* (L.f.) R.Br.	Poaceae	Herb	Hema_comp	9
75	66.*Imperata cylindrica* (L.) Raeusch.	Poaceae	Herb	Impe_cyli	228
76	67.*Phragmites karka* (Retz.) Trin. ex Steud.	Poaceae	Herb	Phra_kark	1
77	68.*Themeda arundinacea* (Roxb.) A.Camus	Poaceae	Herb	Them_arun	6
78	69.*Persicaria maculosa* Gray	**29.Polygonaceae**	Herb	Pers_macu	1
79	70.*Persicaria pensylvanica* (L.) M. Gómez	Polygonaceae	Herb	Pers_macu	1
80	71.*Ardisia solanacea* (Poir.) Roxb.	**30.Primulaceae**	Tree	Ardi_sola	20
81	72.*Adina cordifolia* (Roxb.) Hook.f. & Benth.	**31.Rubiaceae**	Tree	Adin_cord	3
82	73.*Catunaregam spinosa* (Thunb.) Tirveng.	Rubiaceae	Tree	Catu_spin	4
83	74.*Tamilnadia uliginosa* (Retz.) Tirveng. & Sastre	Rubiaceae	Tree	Term_ulig	2
84	75.*Bergera koenigii* L.	**32.Rutaceae**	Shrub	Berg_koen	112
85	76.*Skimmia arborescens* T. Anderson ex Gamble	Rutaceae	Shrub	Skim_arbo	5
86	77.*Casearia graveolens* Dalzell	**33.Salicaceae**	Tree	Case_grav	109
87	78.*Madhuca longifolia* var. *latifolia* (Roxb.) A.Chev	**34.Sapotaceae**	Tree	Madh_lati	1
88	79.*Smilax ovalifolia* Roxb. ex D.Don	**35.Smilacaceae**	Shrub	Smil_oval	3
89	80.*Leea asiatica* (L.) Ridsdale	**36.Vitaceae**	Shrub	Leea_cris	18
90	81.*Curcuma aromatica* Salisb.	**37.Zingiberaceae**	Herb	Curc_arom	16

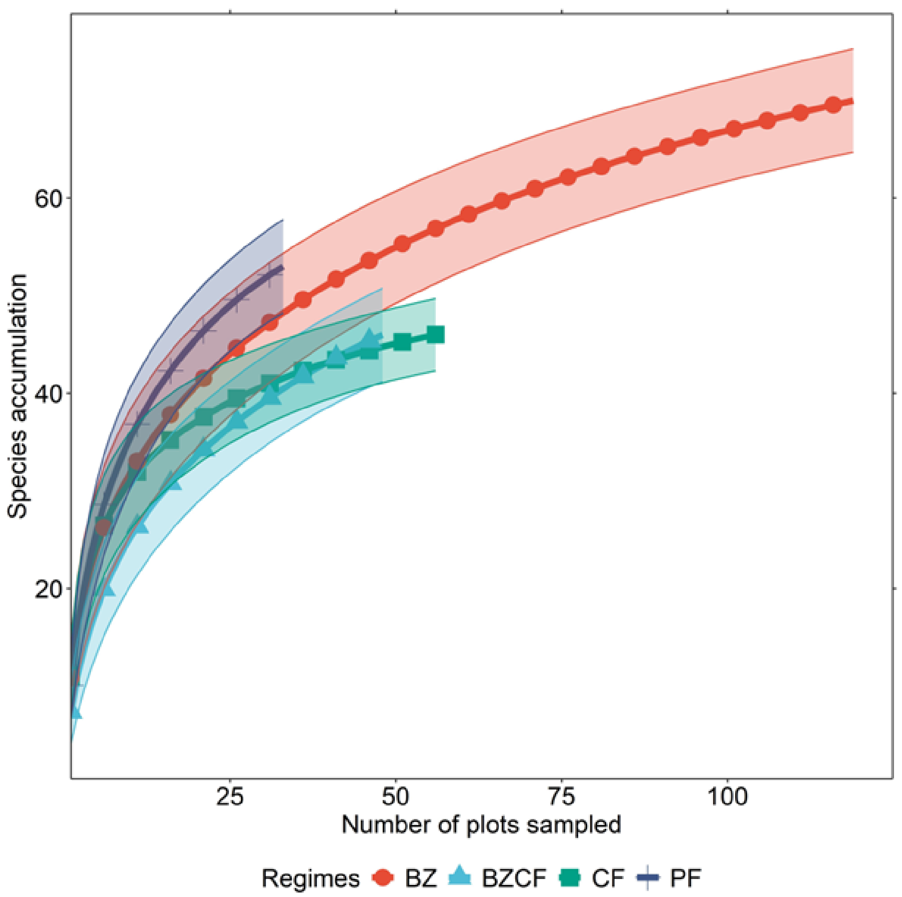

Figure 3. Species accumulation curves for all species in forest regimes

Average number of species (measured by species richness per hectare) in the studied area was found to be 76.38±1.54 per ha (range: 31.83-159.15/ha). Among the four management regimes**,** CF exhibited the highest average species richness (84.41 ± 2.94 per ha)**,** followed by BZ**,** PF, and BZCF. Species richness in BZ, CF and PF was found to be significantly higher ($p < 0.05$) than the species richness of BZCF (Table 2).

Table 2. Species richness compared across four forest regimes.

Statistics	**BZ (n=119)**	**BZCF (n=48)**	**CF (n=56)**	**PF (n=33)**
Min	40	32	32	48
Max	160	88	135	135
Mean±SE	81.6 ± 2.2^{a}	54.1 ± 2.1^{b}	84.4 ± 2.9^{ac}	76.4 ± 4.4^{ac}

Different superscript letters between regimes indicate significant differences at p < 0.05.

Plant Diversity, Evenness and Maturity Index of Tree Species by Regimes

Shannon Weiner's Diversity Index indicated that CF is the most diverse (1.51), and BZCF (0.59) is the least diverse forest regime (Table 3). As indicated by the evenness index, available tree species were distributed most evenly in CF (0.61), and the least evenly in BZCF (0.22). The maturity index (MI) was also found to be highest in CF (0.27), and the least in BZCF (0.14).

Table 3. Regime-wise plant diversity, evenness and maturity index of tree species (DBH ≥ 5 cm).

Regime type	Shannon Weiner's Diversity Index	Evenness	Maturity Index
BZ	1.27	0.41	0.16
BZCF	0.59	0.22	0.14
CF	1.51	0.61	0.27
PF	1.38	0.51	0.18

Similarities of Plant Species Across Regimes

There were a total of 90 species found in this study area. Among them, 23 species were found common in all four forest regimes, indicating a substantial overlap in species composition and suggesting a shared ecological base across management regimes (Fig. 4a). BZ contains the highest number of unique species (12), followed by PF (9), indicating that these two regimes harbor species not found in the other forests. From the study area, a total of 37 families of plant species were recorded. Among them, 14 families were shared across all four regimes, reflecting a core group of plant families common to the entire Barandabhar forest region. The presence of unique and partially shared families across regimes highlights the ecological importance of maintaining multiple management systems to sustain landscape-level biodiversity and habitat heterogeneity in the Barandabhar forest (Fig. 4b). The Sorensen similarity index of species was highest between CF and PF, with a value of 69.47% (i.e. 33 species were common between CF and PF), and it was least between BZCF and PF with 56.25% (27 common species) (Table 4). Likewise, among the families, the similarity index of families was highest between BZ and CF (85.19%) (23 families were common between BZ and CF) and was the lowest between BZCF and PF 65.31% (16 common families) (Table 5).

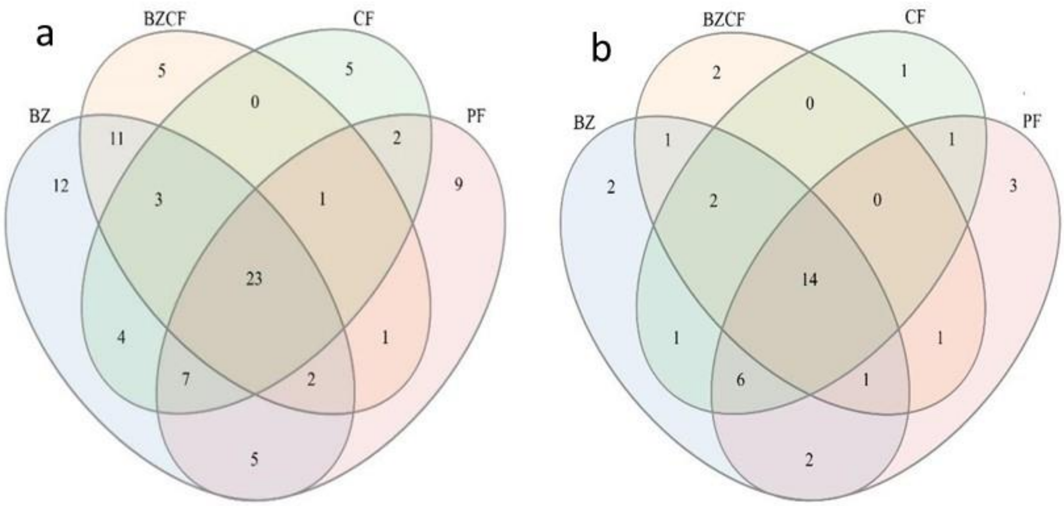

Figure 4. Venn diagram showing common: a. species, b. family in BZ, BZCF, CF and PF.

Table 4. Similarity index (%) of plant species across regimes.

Regime	BZ	BZCF	CF	PF
BZ	100	-	-	-
BZCF	69.03	100	-	-
CF	66.07	59.34	100	-
PF	63.25	56.25	69.47	100

Table 5. Similarity index (%) of family across regimes.

Regime	BZ	BZCF	CF	PF
BZ	100	-	-	-
BZCF	72.00	100	-	-
CF	85.19	69.57	100	-
PF	80.70	65.31	79.25	100

Important Species

The tree species with five highest IVI values in each regime are listed in Table 6. Among the top five species, in BZ regime, *Shorea robusta* showed the highest IVI values, whereas *Casearia graveolens* showed lower values. However, *Shorea robusta* and *Holarrhena pubescens, Shorea robusta* and *Toxicodendron wallichii*, *Shorea robusta* and *Dillenia pentagyna* showed highest and lowest IVI values in BZCF, CF and PF respectively. In case of shrubs (Table 7), among the top five highest shrub species *Clerodendrum infortunatum* emerged with the highest IVI values in all four regimes, while *Bergera koenigii*, *Flemingia macrophylla*, *Helicteres isora* and *Leea asiatica* showed lower values, at BZ, BZCF, CF and PF respectively.

Table 6. Five tree species with highest values of Importance Value Index (IVI) across the four forest regimes.

Species	IVI			
	BZ	BZCF	CF	PF
Shorea robusta	173.02	232.84	136.05	168.30
Syzygium nervosum	36.47	22.56	75.77	52.20
Terminalia elliptica	30.03		29.90	35.22
Lagerstroemia parviflora	14.31		18.82	11.05
Casearia graveolens	12.18			
Dalbergia sissoo		8.69		
Dillenia pentagyna				8.85
Holarrhena pubescens		7.20		
Terminalia bellirica		9.08		
Toxicodendron wallichii			9.44	

Table 7. Five shrub species with highest values of Importance Value Index (IVI) across the four forest regimes.

Species	*IVI values in forest regimes*			
	BZ	*BZCF*	*CF*	*PF*
Clerodendrum infortunatum	*126.77*	*211.92*	*60.78*	*89.85*
Phoenix acaulis Roxb.	*40.08*	*10.72*	*42.20*	
Flemingia strobilifera	*39.98*	*23.51*		
Helicteres isora	*33.12*	*24.18*	*32.83*	*40.95*
Bergera koenigii	*15.83*		*36.05*	*24.92*
Cornus oblonga			*33.15*	*31.20*
Leea asiatica				23.98
Flemingia macrophylla		8.27		

The dominance–diversity curves for all forest management regimes followed Preston’s (1948) log-normal distribution model, indicating that a few species had high IVI values, while most species were less dominant in both trees (DBH ≥ 5 cm) and shrub layers (Fig. 5a, b).

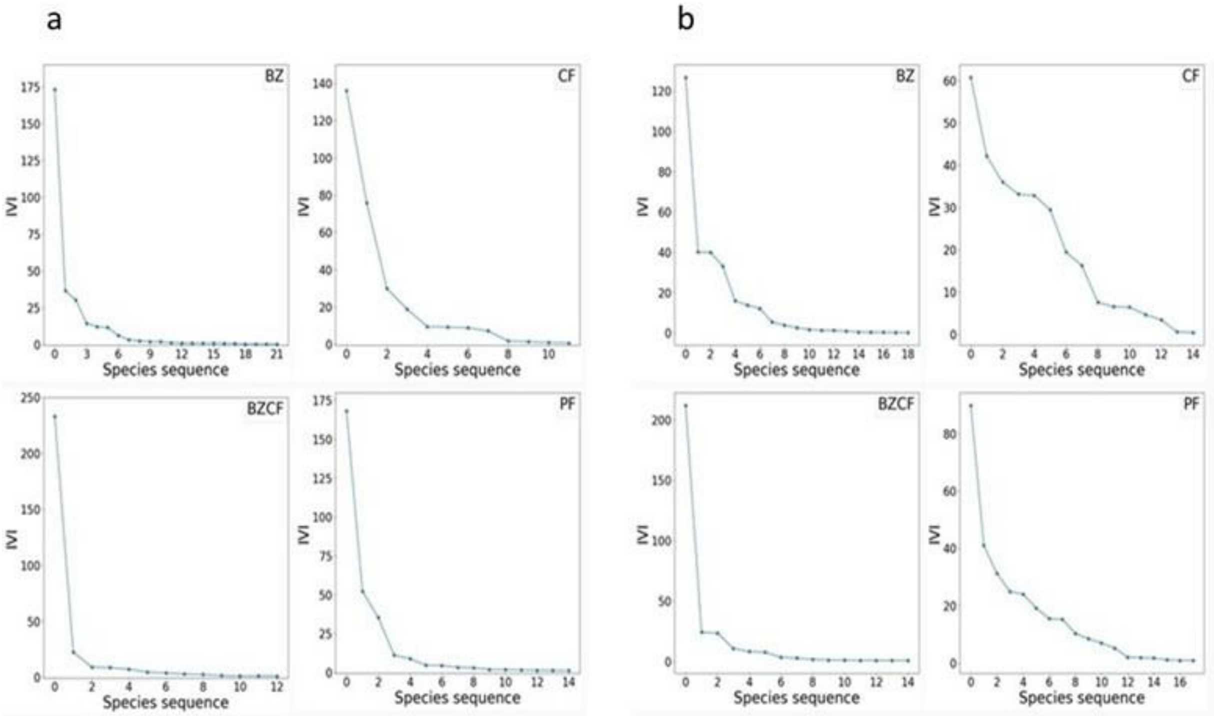

Figure 5. Dominance – Diversity curves (based on IVI): a. Tree species (DBH≥5 cm), b. Shrub species.

Important Families

Family Importance Value Index (FIV) of tree species are presented in Table 8. Among species of trees, Dipterocarpaceae consistently exhibited the highest FIV across all forest regimes—150.76 in BZ, 188.31 in BZCF, 114.44 in CF, and 137.88 in PF. The next most dominant families varied among regimes, including Myrtaceae**,** Combretaceae**,** Fabaceae**,** Lythraceae**,** and Dilleniaceae**,** while families such as Apocynaceae and Anacardiaceae showed comparatively lower FIV values (Table 8).

Table 8. Family Importance Value Index (FIV) of five dominant families of tree species (DBH≥5 cm).

Families	**FIV values in forest regimes**			
	BZ	**BZCF**	**CF**	**PF**
Dipterocarpaceae	150.76	188.31	114.44	137.88
Myrtaceae	27.12	13.58	62.72	40.89
Combretaceae	22.45	17.04	34.49	33.91
Fabaceae	19.78	27.18		
Anacardiaceae	17.77			
Apocynaceae		11.55		15.07
Lythraceae			16.99	
Dilleniaceae			12.92	11.03

Among shrub species, the Lamiaceae family showed the highest FIV in most forest regimes, 120.52 in BZ, 188.43 in BZCF, and 86.20 in PF, indicating its dominance across these areas. In contrast, Malvaceae recorded the highest FIV (62.72) in CF, followed closely by Lamiaceae and Fabaceae. Other prominent families across regimes included Arecaceae, Rutaceae, and Cornaceae, though with comparatively lower FIV values. Overall, Lamiaceae emerged as the dominant shrub family in all forest regimes except CF (Table 9).

Table 9. Family Importance Value Index (FIV) of five major shrub families.

Families	FIV values in forest regimes			
	BZ	BZCF	CF	PF
Lamiaceae	120.52	188.43	59.35	86.20
Fabaceae	65.16	42.79	56.72	40.95
Malvaceae	41.10	31.22	62.72	61.26
Arecaceae	27.95	8.37	33.88	
Rutaceae	16.18	7.75	27.33	26.51
Cornaceae				25.87

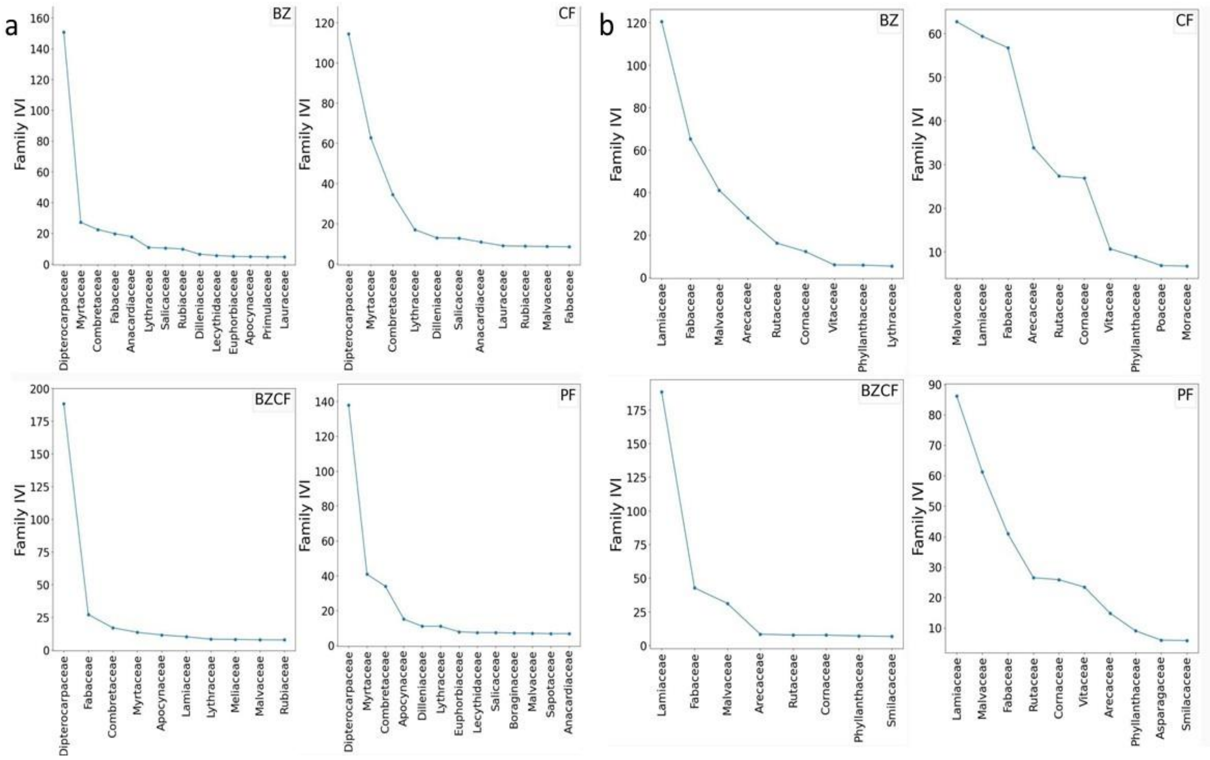

Figure 6. Family dominance curves in the study area: a. trees (≥5 cm DBH), b. shrubs.

The family-dominance curves for all forest management regimes exhibited a similar sharp and steep initial slope indicating higher dominance of a few tree and shrub families, and a decrease in slope after families 5-10 (Fig. 6a, b).

Prominent Herbs

Across all the forest regimes, the study recorded a total of 34 herbaceous species**.** In BZ**,** 26 species were identified, with *Imperata cylindrica* (PV = 22.34) being the most prominent herb species, followed by *Chromolaena odorata*, *Ageratum conyzoides*, *Mikania micrantha*, and *Carex cruciata* *(Table 10)*. The BZCF contained 18 species, where *Imperata cylindrica* (PV = 18.08) and *Chromolaena odorata* (PV = 15.09) were the most prominent. Similarly, CF supported 18 species, dominated by *Imperata cylindrica* (PV = 42.85), with *Chromolaena odorata*, *Carex cruciata*, *Ageratum conyzoides*, and *Curculigo capitulata* as co-occurring species. In PF, 17 species were recorded, with *Imperata cylindrica* (PV = 24.17) and *Chromolaena odorata* again being most dominant. Across all forest regimes, *Imperata cylindrica* and *Chromolaena odorata* consistently exhibited the highest prominence.

Table 10. Herb species with the five highest Prominence Values (PV).

Species	Prominence value (PV)			
	BZ	BZCF	CF	PF
Imperata cylindrica	22.34	18.08	42.85	24.17
hromolaena odorata	3.21	15.09	3.17	4.88
Ageratum conyzoides	0.72	0.29	0.68	
Mikania micrantha	0.58	0.76		
Carex cruciata	0.33		1.27	
Cynodon dactylon		0.60		
Curculigo capitulata			0.34	
Digitaria ciliaris				0.38
Commelina benghalensis				0.36
Triumfetta pilosa				0.13

DISCUSSION

A total of 90 plant species (including herbs, shrubs and trees) were found in the study area of Barandabhar forest. This is a smaller number than the result found by Dangol & Shivakoti (2001) in Tikauli Jungle, where they found a total of 119 species. A total of 34 herb species were found in this study area, which is comparable with the result found by Mandal & Joshi (2014). In their study, they found 27 species in Thano range and 49 species in Asharori range in Doon Valley, Western Himalaya, India. A total of 26 shrub species were found in this study area, which is comparable with the result found by Mandal & Joshi (2014). This is a smaller number of shrub species than that observed by Malik & Bhat (2015), with 44 tree species and 50 shrub species in the Kedarnath Wildlife Sanctuary in Western Himalayas of India. A total of 30 tree species were found in this study, which is a larger number than the result found by Mandal & Joshi (2015) where they found 15 species of trees in Asharori range in Doon Valley. The largest family in our study area was Fabaceae with 16 species. This is comparable with results found by Dangol & Shivakoti (2001) in Tikauli Jungle, and Pandey & Ghimire (2020) for forests managed by community in Kanchanpur District, Pathak & Baniya (2016) in Community Managed Tropical *Shorea* Forest in Nawalparasi, Nepal, Chaudhary *et al.*, (2014) in the forests of Katerniaghat Wildlife Sanctuary in Uttar Pradesh, India and also supported by results obtained by FRA/DFRS (2014). These discrepancies might be due to differences in the season of study, as well as intensity or area of study.

Evenness index determines whether a forest is dominated by one or few species. If one species is dominant, the value of Evenness index will be zero whereas if all species are equally dominant, Evenness index will be one. (Shaheen *et al.*, 2011, Youkparigha & Patani 2019). The Evenness Index in this study was found to range between 0.41 in BZ, 0.22 in BZCF, 0.61 in CF, and 0.51 in PF. BZCF had shown minimal evenness index i.e., it was maximally uneven among the four regimes, according to Jost (2010). So, the study found that only few species were dominant across the regimes. Low competition should cause an increase in diversity, while high competition among species ultimately results in a loss in species evenness (Vandermeer, 1970). Evenness index ranged from 0.60-0.76 in studies of swamp forests by Youkparigha & Patani (2019) in Bayelsa State, Nigeria. The finding of Fashing & Gathua (2004) in East African rainforest found that evenness index ranged between 0.80 -0.84. Similarly, Naidu & Kumar (2016) found between 0.6 to 0.78 in tropical forests of Eastern Ghats of Andhra Pradesh, India. Hence, different studies which are available in literature are similar to our study despite some differences. The Evenness Index found by Rajeev *et al.*, (2019), with values from 0.40 to 0.58 in the community forest of Terai Region, Kanchanpur District, Nepal, was comparable with our studied area. The evenness Index ranged 0.6 to 0.78 found by Naidu & Kumar (2016) in the Eastern Ghat of Andhra Pradesh, India, was comparable with the result obtained in our study area. The reason behind this is Evenness Index varied markedly among the regimes, with BZCF showing the lowest evenness, indicating a highly uneven species distribution, while

CF had the highest evenness. This suggests that few species dominate all the forest management regimes, potentially due to varying levels of competition and disturbance across the regimes.

The Sorensen's Similarity Index, which is determined by presence-absence of common species among regimes, was high in the study regimes, that indicates the diversity across regimes is low. The similarity index between PF and CF was found to be the highest, followed by the similarity index between BZCF and BZ. This may be because these regimes in each pair comprise nearly contiguous forests in a similar physiographic region with a large overlap of species. It might be due to the pollination happening across short distances (Collevatti *et al.,* 2001, Felfili *et al.*, 2004). Environmental factors, which include both abiotic and biotic factors, such as precipitation, nutrient content of soil, and precipitation influence how plants are distributed in a forest area (Cronk & Fennessy, 2001). Moreover, these forest regimes would have almost similar management strategies due to nearness by space. A similar result was found in the Cerrado vegetation in the Central region of Brazil by Felfili *et al.,* (2004), where they found a high similarity index (0.5) between Sao Francisco and Pratinha forests, which are of same physiographic region. On the other hand, the Sorensen co-efficient (0.38) observed by Barua *et al.,* (2018) in between Nambor and Bornewria forest in Nambor Wildlife Sanctuary and Bornewria forest, Assam, India was lower than that of our studied area (0.7). Likewise, the Sorenson similarity index found by Malik and Bhatt (2015) 18.8% to 85.71% in Kedarnath Wildlife Sanctuary in Western Himalayas of India was comparable with our study area. The Sorenson similarity index found by Asinwa *et al.,* (2018) 0.42 to 0.96 in Ogun River Watershed, Southern Nigeria was comparable with this study area. The contiguous distribution of plant species in all four studied regimes, which has also been reported by Barua *et al.,* (2018), Kershaw (1973) and Greig-Smith (1957), might be another reason for high Similarity index found in studied area.

In the study area, values of Shannon Weiner's Diversity Index were found to be 0.59 in BZCF, 1.27 in BZ, 1.38 in PF, and 1.51 in CF. The Shannon Diversity Index found by Ayer *et al.*, (2024), 0.90 to 1.21 in Janata and Hazare community forest (CF) of Katari, Udayapur Distict of Nepal was comparable with our studied area. The Shannon diversity index found by Rajeev *et al*. (2019) with values of 1.12 to 1.61 in the community forests in Terai region of the Kanchanpur District in Nepal, were comparable with the results obtained in our study area. These values are larger than the value observed by Shaibu & Ogunsola (2018) in Dutsin-Ma government forests in Nigeria (0.54 to 0.68). However, our values are comparable to the results of Singh *et al.,* (2016) who found that Shannon Weiner's diversity index lies on 1.49 to 1.86 in Khokan Wildlife Sanctuary, Northwestern Himalaya, Himanchal Pradesh, India. Also, similar results for Shannon-Weiner diversity index were reported from community forest of Janata and Hazare Community Forest of Katari, Udaypur, Nepal (Ayer *et al*., 2024). Shuibu, (2014) and Pant & Sammant, (2012) obtained higher Shannon diversity index values of 2.93-2.59 and 0.7-2.66, respectively in the same forest. The values in the study area are smaller than the value found by Moshood & Olajuyigbe (2024) in Southwest Nigeria (Shannon diversity index=2.02). Likewise, Youkparigha & Patani (2019) found values of 2.334 -2.817 in freshwater swamp forest in Bayelsa State, Nigeria. Study of Sahu *et al*., (2016) found the value of 2.01 in dry tropical forests in Eastern Ghats, India. Biswas & Mukhopadhyay (2017) found values of 2.162 in Banka Forest Division, Banka, Bihar, and Naidu & Kumar (2016) found values of 3.76-3.96 in tropical forests of Eastern Ghats of Andhra Pradesh in India. This indicates the variation of Shannon Weiner's diversity index across different forest ecosystems.

The variation of Shannon Weiner index across ecosystems reflects the relationship between the diversity and rate of anthropogenic disturbances. For instance, studies of Loucks, (1970), Horn (1975) and Huston (1979) suggest that diversity is maximized when the disturbances are present at intermediate levels. This pattern occurs because in the absence of any disturbances, only the species with competitive dominance can survive whereas when the disturbances are high enough, only fugitive species that can withstand disturbances survive (Abugov, 1982; Sagar *et al.,* 2003). This is known as the intermediate level disturbance hypothesis (Grime, 1973; Connell, 1978; Huston, 1979). For maintenance of high biodiversity, there should be a competitive equilibrium of communities, which is rare and very difficult to find in nature. Complete exclusion of competition is possible only in laboratory (Gause, 1934; Crombie, 1947) where competition occurs in a uniform resource at the same time, but complete competitive exclusion does not or rarely occur in nature (Hutchinson, 1961; Miller, 1967).

Magurran (2004) states that the value for Shannon diversity index usually ranges from 0 to 7; values from 0 to 2 indicate low diversity, values from 2 to 3 indicate moderate diversity, and values above 3 indicate high diversity. On the above scale, the research study area is found to have low diversity. Collection of fuelwood, grazing and trampling are examples of anthropogenic disturbances of typical low intensity (Malik & Bhatt, 2016), which may change the fitness of the habitat for several species (Pandey & Shukla, 1999). Nobel & Dirzo (1997) pointed out that high level of anthropogenic disturbances causes an immediate decline of species diversity. The low values of Shannon Diversity indices across the four regimes (0.59 to 1.51) show lowered diversity across all regimes, pointing to high levels of anthropogenic disturbance, particularly in BZCF. The lowest diversity in BZCF suggests that highest level of anthropogenic pressures is active in BZCF in comparison to other regimes, which reduce species evenness and diversity. In addition, the study shows that CF's diversity index is higher than BZ because there was intermediate level of disturbance in CF, whereas in BZ low level of disturbance is realized and thus competitive dominance led to lower diversity in BZ compared to CF which had intermediate disturbance. Therefore, the hypothesis of intermediate disturbances is practically supported in CF. Finally, the value of Shannon diversity index had greater fluctuations towards the periphery than towards the core of the forest i.e., BZ had high Diversity index (0.47) than BZCF (0.23), also observed by Pandey & Shukla (1999). There might be high level of anthropogenic disturbances towards the periphery of BZCF than core BZ. The extent of anthropogenic disturbances such as cattle grazing, logging and forest fires, can greatly influence forest diversity as well as species abundances besides the differences in management practices and forest types (Chapagain *et al.*, 2021), which may explain the variation in the Shannon Diversity index among the four studied forest regimes. In vegetation studies, there is a linear relationship between species richness and maturity rates and ecological factors (including elevation, aspects, and distances; Shaheen *et al.*, 2011; Schuster and Diekmann, 2005). Species richness and evenness were negatively correlated within plant community (Wilsey *et al.*, 2005).

The maturity index in the study area was found to be 0.16 in BZ, 0.14 in BZCF, 0.27 in CF and 0.18 in PF. Maturity index found in the studied regimes is comparable with result found by Sharma *et al.*, (2012) with values of 0.31, 0.37, 0.50, 0.21 and 0.21 for *Acacia catechu*, *Albizia julibrissin*, Savana, *Dalbergia* and *Trewia nudiflora* forests respectively in the Baghmara Buffer zone Community Forest of Chitwan Nepal (Sharma *et al.* 2012). Maturity index found in the studied regimes was very low in comparison to result found by Jadhav & Yadav (2004) in Maharastra, India, and Malik *et al.* (2014) with values of 15.41 for lower altitude forests to 20.66 for mid altitude forests in the Kedarnath Wild Sanctuary and its adjoining areas in Western Himalaya, India. The reason for very low maturity index values in this study area might be the presence of anthropogenic disturbance through activities such as looping, cattle grazing and collection of fuelwoods by dwelling people. The large presence of intense anthropogenic disturbances is known to continuously disturb the natural balance of forests preventing them from reaching a climax stage of community maturity (Saxena & Singh, 1984). The low Maturity index value of this study area shows that the studied forest is in the status of early succession. Moreover, the Maturity Index findings support the corresponding values of diversity indices, with CF showing the highest maturity due to lower historical disturbances, while other regimes experienced significant biotic disturbances. This aligns with the Important Value Index (IVI) results, where *Shorea robusta* dominated all regimes, reflecting a common response to anthropogenic pressures. The high IVI values and the dominance by a few tree species further highlight the disturbed nature of the studied forest.

The range of Important Value Index (IVI) values showed that all four Forest Regimes are dominated by few species. *Shorea rubusta* had highest IVI in all four regimes as by 173.02 in BZ, 232.84 in BZCF, 136.05 in CF and 168.30 in PF which are comparable with the value (178.49) obtained by Joshi et al. (2021) in Sal (*Shorea robusta*) forests managed by the community in Terai region of Nepal. Similarly, Mandal & Joshi, (2014) found value of 132 in Asarori forest, 114.66 in Selaqui - Jhajra forest and 176.00 in deciduous Thano forests located in the Doon Valley of Western Himalayas in India. The IVI showed that all four forest regimes are dominated by few species. The first seven species consist of about 94.6% in BZ, 96.4% in BZCF, 96.0% in CF, and 94.9% in PF of total IVI, which can be compared with the results of Mandal & Joshi (2014) in three dry and deciduous forests of Doon Valley: 96.07% in Thano Forest, 81% in Asarori forest and 78.51% in Slaqui - Jhajra Forest. Similar results were obtained by Murphy & Lugo, 1986 in the dry forest of Puerto Rico, Gonzalez & Zak (1996) in tropical dry forests in St. Lucia, West indies, Krishnamurthy *et al*. (2010) in the tropical dry and deciduous forests of Bhadra Wildlife Sanctuary in Karnataka, India, and Giri *et al*., (1999) in Bardiya National Park, Nepal with values of 55%, 67%, 62%, and 74.64% respectively.

The high percentages of IVI values in the studied forest regimes were covered by only few species because of high levels of anthropogenic disturbances such as logging, grazing etc., which was also revealed by the high IVI and Prominance Value of the shrub species *Clerodendrum infortunatum*, which is a shrub species favored by anthropogenic disturbances. This was also observed by Sapkota *et al*. (2009) in dry *Shorea robusta* forests of Nawalparashi district. The disturbance caused by treefalls, branchfalls and other anthropogenic activities has been known to enhance the growth of many disturbance – tolerant species in forest (Lieberman *et al*., 1985; Denslow, 1987).

Finally, the finding that *Shorea robusta* has the highest IVI among among tree species in the forest regimes can be compared with the result obtained by Biswas & Mukhopadhyay (2017) at Banka Forest Division, Banka, Bihar (Mandal & Joshi, 2014) where *Shorea robusta* had highest IVI 54.33 and 132.44 respectively among the all trees. The result of IVI in the studied forest regimes is comparable with the IVI obtained by (Joshi *et al.,* 2019) in community forest of Terai region, Nepal. Likewise, the result of IVI in all forest regimes is comparable with the IVI obtained by Awasthi *et al*., (2015) in Lumbini Collaborative Forest, Rupandehi, Nepal and Giri *et al*., (1999) in Bardiya National Park, Nepal. The largest value of IVI for *Shorea robusta* may be due to its strong adaptation to the prevailing environment of the Barandabhar forest area and its competitive efficiency in making use of available environmental resources (Shameem & Kangroo, 2011). In addition, the dominance of this species could be linked to its ecological significance and economic preference from the local communities (Sarkar & Devi, 2014; Dar *et al.*, 2017). The Prominence value of *Imperata cylindrica* was highest among herbs in all studied regimes. Similar results were found by Peet *et al*. (1999), Garrity *et al*. (1996), Astapati & Das (2012), Dangol & Shivakoti (2001). The higher prominence of *Imperata cylindrica* and *Chromolaena odorata* indicate the prevalence of disturbance-tolerant and invasive species adapted to open or degraded habitats. This pattern suggests that anthropogenic pressure and canopy disturbance have significantly influenced the herbaceous layer composition throughout the Barandabhar Forest.

CONCLUSIONS

This study examined the vegetation composition, structure, and diversity of the Barandabhar Forest, Chitwan, managed under four regimes: BZ, BZCF, CF, and PF. The study recorded a total of 90 plant species from 80 genera and 37 families. *Shorea robusta* and *Clerodendrum infortunatum* showed the highest IVI among tree and shrub species, while *Imperata cylindrica* dominated the herb layer. Among families, Dipterocarpaceae and Lamiaceae had the highest family importance values for trees and shrubs, respectively. Species richness, diversity, and maturity indices were highest in the Community Forest (CF) and lowest in the Buffer Zone Community Forest (BZCF)**,** indicating greater anthropogenic disturbance in BZCF. Overall, the Barandabhar Forest shows clear signs of human impact affecting species diversity and forest structure. Strengthening management efforts to minimize disturbance and maintain intermediate disturbance levels, as observed in CF, will be vital for sustaining and enhancing biodiversity and ecosystem resilience in the region.

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AUTHOR CONTRIBUTIONS

Conceptualization: VPG, BKS, RKPY; Investigation: VPG, BKS; Methodology: VPG, BKS, RKPY; Data curation: VPG, BKS; Data analysis: VPG, BKS, CBB, RKPY; Writing original-draft: VPG; Writing - reviewing and editing: BKS, CBB, RKPY.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

All relevant data are presented in the manuscript. Supporting information is available at a reasonable request from the corresponding author.

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