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RESEARCH ARTICLE

Assessing the influence of invasive plant species on herb diversity and soils in Indian dry tropics: Insights from *Parthenium hysterophorus* and *Prosopis juliflora* invasion dynamics

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Abstract

Present study in Hastinapur wildlife sanctuary in Indian dry tropics aimed to understand vegetation structure and soil characteristics in areas invaded by invasive tree *Prosopis juliflora* (PJ site) and invasive weed *Parthenium hysterophorus* (PH site). Plant density was estimated through 120 random quadrats (each 1m x 1m) across the two sites in three seasons. Diversity and similarity of the two sites in different seasons was estimated. Nine soil samples (0-10 cm) from each site in different seasons were analyzed for their pH, moisture content, total N, organic C, exchangeable Na, K and Ca. A total of 74 plant species distributed across 30 families were recorded. Largest families were Amaranthaceae, Fabaceae, Malvaceae, Poaceae, Asteraceae, Solanaceae, Lamiaceae, Euphorbiaceae, and Acanthaceae, together accounting for over 65% of total flora. Largest number of flora in both sites occurred in rainy season (60), followed by winter (52) and summer (50). Diversity indices ranked sites differently. Species richness and evenness showed greater diversity at PJ compared to PH site in all three seasons. Beta diversity range indicated least variation in rainy and it increased in summer and winter. Species common across sites and seasons included *Cynodon dactylon* and many alien weeds *Cannabis sativa, Parthenium hysterophorus, Lantana camara*, and *Ageratum conyzoides*. Dominants and their associates changed with season and site and this dominance increased in non-rainy months, as evinced by dominance-diversity curves. Higher inter-site similarity was noted during the rainy season followed by the winter and summer. Dissimilarity of vegetation patches was more prominent in summer and winter. No general trend in soil characteristics could be deciphered. In conclusion, the study revealed a complex interplay of seasonal dynamics and invasive species interactions on plant community structure and soils in Indian dry tropical ecosystems.

Keywords: Beta diversity, dry tropics, heterogeneity, plant invasion, vegetation mosaic.

Introduction

Invasive Alien Species are non-native organisms introduced outside their natural habitat, either intentionally or unintentionally, by human activities, posing significant threats to global biodiversity. When they breach natural dispersal barriers, their natural predators lose control over them, a phenomenon known as enemy release hypothesis. In the absence of natural checks, such invasive species can proliferate rapidly, often outcompeting native species in their habitats (Kumar *et al*. 2024). These alien plants are increasingly reported for their prevalence in urbanizing landscapes in India (Yadav *et al*. 2022).

The Hastinapur Wildlife Sanctuary (HWLS), stands as one of India's largest wildlife sanctuary, encompassing regions of Muzaffarnagar, Meerut, Ghaziabad, Bijnore, and Jyotiba Phule Nagar districts in Uttar Pradesh. The Hastinapur forest region predominantly consists of dry thorn forests. However, the population decline of the barasingha, a species found in the sanctuary, is likely attributed to habitat loss or alteration due to agricultural expansion or the introduction of tree

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plantations such as eucalyptus (Raj 2020). This sanctuary has presently witnessed invasion of many invasive weeds including *Prosopis juliflora*.

Environmental factors directly or indirectly influence vegetation composition and structure and species exhibiting significant environmental tolerance develop unique plant associations characterized by distinct floristic and structural attributes e.g. topography, soil, and climate (Ullah *et al.* 2022). Phytosociological study of vegetation involves analyzing plant community characteristics, classification, distribution and relationships. It aims to describe the diversity of species within plant communities. In fact, a vegetation composition is strongly influenced by local microclimate in weedy vegetation (Gupta and Narayan 2006). Diversity in herb layers can influence herb layer diversity by affecting resource availability and environmental variables important for herb layer plants. Rahman *et al.* (2023) reported relationships between herb and tree layer diversity across different forest types in various Himalayan regions, often with the dominance of few tree species. Two important aliens viz. *Prosopis juliflora* and *Parthenium hysterophorus* have been witnessed prominently in the Hastinapur sanctuary who ostensibly have impacted vegetation and soils of this region.

Parthenium hysterophorus, a noxious weed, has spread globally from its native environment over two centuries ago, thriving due to adaptive features like lack of natural enemies, broad adaptability, drought resilience, insensitivity to light conditions, rapid seed production, easy dispersal, and allelopathic traits, enabling it to flourish across diverse soil types and climatic conditions (Kumar and Aggarwal 2024). *Prosopis juliflora*, native to South America, the Caribbean, Mexico, and Central America, has been intentionally introduced to regions like Ethiopia for land reclamation purposes since the late 1970s (Pasiecznik *et al.* 2001, Abebe 2012, Haji and Mohammed 2013, Ayanu *et al.* 2015). *Prosopis julifora* invasion has negative impacts on native biodiversity, ecosystem structure and function (Hussain *et al.* 2021).

Parthenium hysterophorus and *Prosopis juliflora* both are listed in top 100 Invasive Alien Plant Species (Yadav *et al*. 2024).

This study, conducted in the Indian dry tropics, aimed to evaluate the impact of detrimental invaders, *Parthenium hysterophorus* and *Prosopis juliflora*, on the herb layer. We hypothesized that the abundance of these invaders significantly influenced herb layer biodiversity. To test this hypothesis, we conducted surveys across over 120 randomized sample plots, accounting for varying soil and habitat conditions

Materials and Methods

Study Area

The study area was Hastinapur (29°10′ N lat., 78° 1′ E long.) located in western part of Uttar Pradesh. Two permanent study sites with different habitat conditions, one dominated by *Parthenium hysterophorus* (PH) and the other by *Prosopis juliflora* (PJ), were selected for the present investigation at Hastinapur Wildlife Sanctuary (HWLS). An area of 1 km^2 was marked at each site for the present ecological study.

Plant sampling

An extensive field study of floristic composition was conducted from July 2021 to June 2022 to document the above-ground flora across both study sites during three different seasons. Plant species were identified following the taxonomic references of Sharma (1980), Gaur (1999) and Duthie (1960). At both the study sites, 20 random quadrats were laid in each of the three seasons for phytosociological study of the above-ground flora (each of size 1m x 1m, n=20x3x2). Density estimation of grasses was conducted by considering each emergent tiller as one individual. The density and frequency of each species were calculated following Phillips (1959).

Relative Density

$$Density = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats studied}}$$

$$\text{Relative Density (\%)} = \frac{\text{Density of a species}}{\text{Sum of densities of all species}} X100$$

Similarity coefficient

Similarity among the study sites within and across different seasons was estimated using the

Modified Sorenson similarity coefficient (Southwood 1978) according to the following formula:

$$SC = \frac{2jN}{aN + bN}$$

Where, jN = sum of lesser values of RD of species common in two communities; aN = sum of RD of all species in community A; bN = sum of RD of all species in community B.

Species diversity

Dominance-diversity curves were prepared by plotting species RD against the sequence of species (from highest to lowest RD) (Whittaker 1975).

A diversity of each study site across different seasons was estimated, using nine diversity indices (D1 - D9). The symbols used in computing D1 to D9 are: S = total number of species, N = total sum of RD of all species, pi= proportional dominant of i^{th} species (ni/N), ni = RD of each species and Nmax= RD of the most dominant species. Species diversity indices were calculated by using RD.

Species richness indices

D_1, Species count (Number of species/area in the present study the no. of species that occurred in quadrats sampled)

D_2, Margalef index (Clifford & Stephenson 1975)

$$D_2 = \frac{S - 1}{\ln N}$$

D_3, Menhinick index (Whittaker 1977)

$$D_3 = \frac{S}{\sqrt{N}}$$

Information statistic indices

D_4, Shannon-index (H') (Shannon & Weaver 1949)

$D_4 = -\sum pi \ln pi$

D_5, Evenness (Pielou 1966)

$$D_5 = \frac{D_4}{\ln S}$$

D_6, Brillouin index (HB) (Brillouin 1962)

$$D_6 = \frac{\ln N! - \sum \ln ni!}{N}$$

D_7, Evenness (Brillouin 1962)

$$D_7 = \frac{HB}{HB_{max}}$$

Where,

$$HB_{max} = \frac{1}{N}\ln \frac{N!}{\{[N/S]!\}^{s-r}.\{([N/S]+1)!\}^{r}}$$

N/S = integer of N/S

r = N-S [N/S]

Dominance measures

D_8, Berger-Parker index (Berger & Parker 1970)

$$D_8 = \frac{N_{max}}{N}$$

D_9, Simpson index (Simpson 1949)

$D_9 = \sum pi^2$

β diversity

β diversity within a vegetation at a study site was calculated using the methodology proposed by Whittaker (1972). This involved dividing the total number of species present at the site by the average number of species per sample.

Soil analysis

Nine representative surface soil samples (0-10 cm) were collected from each study site in the months of October 2021 (rainy), February 2022 (winter), and June 2022 (summer). The soil samples were air-dried and sieved (2 mm). The soil moisture content, pH, total organic carbon (Walkley & Black method) and total nitrogen (microkjeldahl's method), flame photometric exchangeable cations Na, K and Ca were estimated according to Piper (1944).

Results

Species composition

A total of 74 plant species were recorded distributed across 30 families, comprising of 27 dicot and 3 monocot families. Seasonal variation in flora abundance was observed across both study sites, with the rainy season exhibiting the highest diversity (60 species), followed by winter (52 species) and summer (50 species). Among herbaceous species, those belonging to Amaranthaceae (9), Fabaceae (9), Malvaceae (6), Poaceae (6), Asteraceae (5), Solanaceae (5), Lamiaceae (4), Euphorbiaceae (3), and Acanthaceae (2) collectively accounted for more than 65% of the total flora.

Analysis of species counts at two sites in different seasons revealed a diversity order of rainy > winter > summer at each study site (Table 1). Notably, the diversity measures *viz*. species richness and evenness were significantly higher values at the PJ site compared to the PH site across all three seasons, highlighting relatively diversity at PJ site. The species common to both study sites across all seasons included *Ageratum conyzoides, Cannabis sativa*, *Cynodon dactylon*, *Parthenium hysterophorus* and *Lantana camara*.

In the rainy season, dominant species included *Parthenium hysterophorus, Cynodon dactylon,* and *Cannabis sativa* at both sites. Winter saw the dominance of *Cynodon dactylon* and *Stellaria media* at both sites, with *Parthenium hysterophorus* also exhibiting dominance at the PH site. Additionally, *Gamochaeta pensylvanica* was notably dominant at the PJ site during this season. Summer witnessed the continued dominance of *Cynodon dactylon*, with *Fumaria indica* and *Verbascum thapus* emerging as dominants at the PH site. *Cannabis sativa* and *Parthenium hysterophorus* remained dominant at the PJ site during this period.

Inter-site species composition comparison

The vegetation observed across the selected study sites revealed consistent similarities throughout all seasons, with the similarity coefficient remaining below 0.50 (Table 2). The highest inter-site similarity was noted during the rainy season (0.79), followed by the winter season (0.65), and the summer season (0.57).When examining intra-site inter-season similarities, the pattern followed the order of rainy-winter (ranging from 0.49 to 0.55), winter-summer (ranging from 0.42 to 0.47), and rainy-summer (ranging from 0.41 to 0.45). These findings underscore the persistent likeness between the study sites across various seasons, with the rainy season demonstrating the strongest coherence between sites.

Soil properties

Significant inter season difference was observed in moisture content but there was no significant inter-site difference. However, it's note worthy that the pH of the PH soil consistently represented higher values across all seasons compared to the PJ soil. Additionally, during the rainy season, the PJ soil displayed significantly higher levels of potassium (K) contents compared to the PH soil, as indicated in Table 3.

Furthermore, the PH soil demonstrated richness in total nitrogen content across all seasons, with particularly significant levels noted during all seasons. These findings suggest significant variations in soil characteristics between

Table 1: Seasonal changes in relative density (RD) of top five dominants at two invasive weed infested sites. Site codes: PH (*Parthenium hysterophorus*) and PJ (*Prosopis juliflora*) in an Indian dry tropical region

	Rainy		*Winter*		*Summer*	
Botanical Name	*PH*	*PJ*	*PH*	*PJ*	*PH*	*PJ*
Ageratum conyzoides (L.) L.	5.22	4.74	4.74	3.46	5.88	4.15
Alternanthera sessilis (L.) R.Br. ex DC.	0.26	-	2.03	1.13	1.58	0.94
*Argemone mexicana*L.	-	-	1.65	3.46	-	0.37
Boerhavia diffusa L.	-	-	-	-	3.39	-
Calotropis procera (Aiton) Dryand.	0.3	0.32	0.75	-	2.15	2.83
Cannabis sativa L.	5.79	6.5	5.04	5.95	5.43	7.56
Chenopodiastrum murale (L.)S.FuentsUotila& Borsch	2.67	2.33	1.13	-	-	-
Commelina benghalensis L.	-	2.33	1.73	1.88	1.69	-
Cynodon dactylon (L.) Pers.	9.26	9.48	8.36	10.02	7.92	7.18
Desmostachya bipinnata (L.) Stapf	1.62	2.78	-	-	2.15	-
Dichanthium annulatum (Forssk.) Starf	1.14	0.77	-	1.8	1.69	-
Duranta rapens L.	2.94	2.74	1.58	-	-	-
Fumaria indica (Hausskn.) Pugsley	-	-	-	-	6.11	3.02
Gamochaeta pensylvanica (Willd.) Cabrera	-	-	4.59	11.98	1.47	-
Lantana camara L.	1.62	1.51	1.28	1.2	4.3	3.78
Murraya koenigii (L.) Spreng.	3.99	4.45	3.08	3.76	1.58	-
Parthenium hysterophorus L.	9.48	6.66	5.8	3.31	4.19	6.8
Paspalum scrobiculatum L.	-	0.65	3.76	2.11	-	1.13
Salvia plebeia R.Br.	-	-	-	-	-	5.1
Senna occidentalis (L.) Link.	2.5	2.57	2.33	-	-	-
Solanum villosum Mill	2.1	2.65	-	1.73	-	-
Solanum nigrum L.	2.1	2.41	-	-	-	1.51
Spergula arvensis L.	-	-	3.46	3.39	-	3.1
Stellaria media (L.) Vill.	-	-	11.9	10.39	-	-
Tephrosia purpurea (L.) Pers.	-	-	4.74	3.31	3.73	-
Verbascum thapsus L.	-	2.61	-	-	6.11	-
Withania somnifera (L.) Dunal	-	1.3	-	3.16	2.6	-
Other species (number in parenthesis)	49.01 (30)	43.2 (30)	32.05 (21)	27.96 (24)	38.03 (14)	52.53 (24)

Table 2: Spatial and seasonal similarity of the site vegetation based on similarity coefficient applying Modified Sorenson Index (using species relative density)

	RPJ	*WPH*	*WPJ*	*SPH*	*SPJ*
RPH	0.79	0.55	0.52	0.41	0.49
RPJ		0.56	0.49	0.43	0.42
WPH			0.65	0.47	0.45
WPJ				0.44	0.42
SPH					0.57

the weed-infested sites, with notable disparities in pH, potassium and nitrogen content, particularly evident during the rainy season.

Density diversity structure

The density diversity curves for the Indian dry tropical

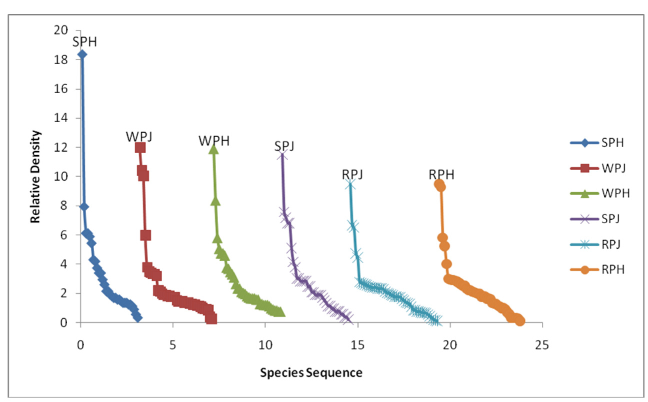

Figure 1: Density-diversity curve of vegetation across different sites and seasons. The first letter of the code indicates season (R: rainy, W: winter, S: summer) and the next two letters indicate study sites (PH: *Parthenium hysterophorus*, PJ: *Prosopis juliflora,* infested site)

Table 3: Soil characteristics (mean ± SE) of two invasive weed-infested sites in an Indian dry tropical region (n=9).Weed infested site codes: PH (*Parthenium hysterophorus*) and PJ (*Prosopis juliflora*). Means with common letters are not significantly different at p ≤ 0.05 according to Tukey's HSD

	RAINY		*WINTER*		*SUMMER*	
Parameters	*PH*	*PJ*	*PH*	*PJ*	*PH*	*PJ*
pH	7.4 ± 0.21 ab	7.0 ± 0.28 ab	7.6 ± 0.13 b	6.9 ± 0.21 a	7.7 ± 0.041 b	7.6 ± 0.080 ab
Mositure Content	14.9 ± 0.74 c	15.2 ± 0.53 c	9.9 ± 0.36 b	8.6 ± 0.43 b	4.6 ± 0.26 c	5.4 ± 0.108 c
Organic Carbon	0.9 ± 0.14 a	0.9 ± 0.18 ab	1.7 ± 0.30 b	1.0 ± 0.20 ab	1.06 ± 0.13 ab	1.1 ± 0.165 ab
Total Nitrogen	0.06 ± 0.003 bc	0.05 ± 0.006 ab	0.07 ± 0.001 c	0.07 ± 0.003 bc	0.04 ± 0.004 a	0.04 ± 0.002 a
C:N ratio	14.4 ± 2.21 a	20.4 ± 4.89 a	24.4 ± 4.33 a	15.3 ± 2.84 a	24.7 ± 3.32 a	24.3 ± 3.05 a
Exch. Na	0.06 ± 0.008 a	0.07 ± 0.009 a	0.64 ± 0.598 a	0.042 ± 0.003 a	0.05 ± 0.002 a	0.05 ± 0.002 a
Exch. K	0.08 ± 0.010 a	0.34 ± 0.046 c	0.28 ± 0.069 bc	0.157 ± 0.036 ab	0.18 ± 0.025 ab	0.14 ± 0.008 ab
Exch.Ca	0.35 ± 0.045 a	0.43 ± 0.045 a	0.46 ± 0.072 a	0.473 ± 0.060 a	0.57 ± 0.058 a	0.48 ± 0.072 a

Table 4: Diversity estimates of the vegetation at various study sites in three seasons using different diversity indices. Site codes: Weed infested site codes: PH (*Parthenium hysterophorus*) and PJ (*Prosopis juliflora*)

	Rainy		*Winter*		*Summer*		
Diversity indices	*PH*	*PJ*	*PH*	*PJ*	*PH*	*PJ*	*Max/Min*
D1 (Species Count)	45	48	37	41	31	37	1.55
D2 (Margalef Index)	9.55	10.21	7.82	8.69	6.51	7.82	1.57
D3 (Menhinick Index)	4.50	4.80	3.70	4.10	3.10	3.70	1.55
D4 (Shannon's Index)	3.50	3.58	3.34	3.32	3.07	3.27	1.17
D5 (Evenness Pielou)	0.92	0.93	0.93	0.89	0.89	0.91	1.04
D6 (Brillouin index)	3.16	3.20	3.04	2.99	2.82	2.97	1.14
D7 (Evenness (Brillouin)	0.95	0.97	0.90	0.89	0.91	0.88	1.10
D8 (Berger- Parker Index)	0.09	0.09	0.12	0.12	0.18	0.12	1.93
D9 (Simpson's Index)	0.04	0.04	0.05	0.05	0.07	0.05	1.88
Beta Diversity	1.98	1.96	2.79	3.09	3.51	6.99	3.56

region, as depicted in Figure 1, illustrate that across different seasons and at two distinct sites within the Hastinapur Wildlife Sanctuary, a limited number of species, typically ranging from 1 to 4, dominantly utilize the majority of available resources. This consistent pattern was observed across vegetation at both sites throughout all three seasons, presenting a near geometrical pattern of resource share.

At both study sites, *Cynodon dactylon* emerged as a key exploiter of resources, evident from its substantial share of relative density. Additionally, at the PH site, *Parthenium hysterophorus* demonstrated significant resource utilization during the rainy and winter seasons. Conversely, at the PJ site, *Gamochaeta pensylvanica* exhibited notable resource utilization during the winter season, while *Cannabis sativa* took precedence during the summer season. These observations highlight the dynamic utilization of resources by specific plant species across different seasons and sites within the Hastinapur Wildlife Sanctuary.

Species diversity

Table 4 provides a comprehensive summary of seasonal diversity levels across different sites, utilizing nine diversity indices based on the relative density of species (i.e., N = 100). Each index offers a unique perspective on site diversity, resulting in varied rankings across sites.

Richness indices, including species count (D1), Margalef index (D2), and Menhinick's index (D3), consistently showcased maximum values across all seasons at the PJ site. Conversely, information statistic indices such as Shannon index (D4) and Brillouin index (D6) demonstrated relatively higher values at PJ site during the rainy and summer seasons, albeit with a slight decrease observed in the winter season. Notably, the RPJ site exhibited the widest range of diversity variation across seasons, with D4 consistently surpassing D6.

Dominance concentration, as measured by the D9 index, peaked at the PH site during the summer season, remaining equal across other seasons. Moreover, the absolute value of D8 consistently exceeded D9 across all seasons.

In assessing the discriminant ability to discern subtle differences in diversity, the maximum: minimum ratio of diversity indices is crucial. In this study, the dominance measure Berger Parker (1.93) emerged as the highest, followed by Simpson (1.88), Margalef (1.57), and Menhinick index (1.55). Notably, the widely used Shannon index demonstrated a ratio of only 1.17, indicating comparatively lower discriminatory power.

These findings underscore the significant variations in diversity across seasons and sites within the study area, emphasizing the importance of employing multiple diversity indices to gain a comprehensive understanding of ecosystem dynamics.

β diversity

β diversity values ranged between 1.96 and 6.99 (Table 4). Notably, the lowest β diversity was observed at the PH site during the rainy season. Generally, β diversity at the PJ site tended to be higher compared to the PH site, except during the rainy season where the difference between the two sites was minimum. Moreover, β diversity exhibited a gradual increase during the summer season at both sites.

Discussion

Herb-layer productivity is considered to be an important part of ecosystem functioning (Molder *et al.* 2008). In the present study of herbaceous layer in the Hastinapur Wildlife Sanctuary revealed a highly dynamic nature of dry tropical ecosystem, comparable to that of peri-urban vegetation in Indian dry tropical region of Bulandshahr (Gupta and Narayan 2010). In fact, the structure of herb plant communities in Indian dry tropics is reportedly impacted by season and site conditions (Agrawal and Narayan 2017). This is evinced in this study too, evinced by larger number of flora recorded in the rainy season across both the PH and PJ study sites, followed by winter and summer seasons. Similar findings were observed by Gupta and Narayan (2006). Dominant families included Amaranthaceae, Fabaceae, Malvaceae, and Poaceae, which collectively comprised more than 65% of the total flora. While Fabaceae dominance indicated adaptive significance of leguminous plants to tropical conditions, the Poaceae reflected the grasses playing an important role in this herbaceous weedy vegetation (Yadav and Narayan 2023). The occurrence of certain ubiquitous species, such as *Cannabis sativa*, *Cynodon dactylon*, and *Parthenium hysterophorus*, underscores their ecological significance and adaptability across different environmental conditions in Indian dry tropics including subterranean vegetation (Yadav 2023).

Analysis of inter-site species composition revealed distinct dissimilarity between the PH and PJ study sites across all seasons, with maximum inter-site similarity observed during the rainy season. Intra-site inter-season comparisons indicated varying degrees of similarity, with the rainy-winter transition showing the highest consistency followed by winter-summer and rainy-summer transitions. These findings suggested unique environmental factors shaping species composition dynamics at each site and highlight the importance of considering seasonal variations in ecological assessments. Obtained results were different from the results of Lillo *et al*. (2018) i.e. the average similarity of species among forest habitat types ranged from 23-37%, and the average dissimilarity among forest habitat types ranged from 63-77%.

Soil analysis indicated significant differences in soil pH, C:N ratio and exchangeable potassium (K) content between the PH and PJ sites, particularly during the rainy season. PH site soil exhibited higher pH values across all seasons compared to PJ soil, while K contents were notably higher in PJ soil during the rainy season. Additionally, PH soil demonstrated richness in total nitrogen content throughout the study period, indicating potential differences in nutrient availability and soil fertility dynamics between the two sites. Soil pH has been reported to have a significant positive relationship with the diversity index and species evenness (Ali *et al*. 2023). Maximum moisture content was observed in rainy season that was positively influencing diversity richness in that season at both sites, comparable to the findings of Yadav and Narayan (2023).

Density diversity curves depicted a consistent pattern across all study sites and seasons, with a limited number of species utilizing the majority of resources. Notably, *Cynodon dactylon* emerged as a significant resource exploiter across all seasons at both PH and PJ sites. However, distinct species such as *Parthenium hysterophorus* at PH and *Gamochaeta pensylvanica* at PJ site exhibited dominance in specific seasons, indicating niche specialization and resource partitioning within plant communities. Plant communities in the rainy season in particular, has been reported to have a relatively pronounced tendency to lognormal pattern of resource share in Indian dry tropics (Gupta and Narayan 2011).Extensive invasion by exotic flora in India e.g. *Parthenium hysterophorus* have considerable influence on community organization and productivity in the peri-urban ecosystems in Indian dry tropics, and such invasive alien flora have been reported to have potential to impact the plant species in the vicinity and ecological processes (Agrawal and Narayan 2017)

Seasonal diversity indices highlighted variations in species richness and diversity between the PH and PJ sites. PJ consistently exhibited higher diversity across all seasons, with maximum values recorded during the rainy season. Richness indices, including species count, Margalef index, and Menhinick's index, were consistently higher at PJ, indicating greater species richness and evenness compared to PH here. However, relatively much comparable values of information statistic indices of these two sites in the same seasons, particularly Shannon and Brillouin indices (that take into account both species count and equitability), suggested differential patterns of species distribution and community structure between the two sites across seasons. Diversity variation due to different fire regimes was reported by Jhariya and Singh (2021).Analysis of β diversity indices revealed spatial and temporal variability in species composition between the PH and PJ sites. Generally, PJ site exhibited higher α and β diversity compared to PH, except during the rainy season. The gradual increase in β diversity observed during the summer season at both sites suggested complex interactions of environmental factors and species turnover dynamics under ecosystems invaded by alien species. Beta diversity decreased with distance (Davidar *et al.* 2007). However, in ecological study at medium spatial scale, the Maximum: Minimum ratio being highest for β diversity, as recorded in the present study, compared to all alpha diversity indices, suggested its higher discriminant ability.

Conclusion

The comparative analysis of species composition, soil properties, density diversity structure, species diversity, and β diversity between the PH and PJ study sites provided valuable insights into the ecological dynamics of the Hastinapur Wildlife Sanctuary via the role of invasive alien flora. The observed variations underscore the influence of environmental factors, seasonal dynamics, and species interactions on plant community structure and composition. These findings emphasize the importance of integrating temporal and spatial scales in ecological assessments and conservation efforts. Further research focusing on the mechanisms driving observed patterns is essential for effective management and conservation of plant biodiversity in protected areas.

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