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Vegetation and Soil Dynamics : Insights from *Prosopis juliflora*- Intruded Areas in Hastinapur Wildlife Sanctuary

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ABSTRACT

Ecological study on plant diversity and soil characteristics of two contrasting sites (*Prosopis juliflora*-invaded and non-invaded) in Hastinapur Wildlife Sanctuary was undertaken to understand the structure of vegetation and soils and implication of exotic dominance in a dry tropical region of India. Seasonal floristic composition was recorded for one year through monthly visits. Phytosociological study of the two sites in each of three seasons was carried out by sampling a total of 120 quadrats (each 1mx1m, n= 20×3×2). Plant species density and abundance was estimated for both sites in each season. Seasonal surface soil (0–10 cm) samples were analyzed for soil pH, moisture content, organic C, and total N. Species occurrences and their relative abundance data were used to estimate alpha and beta diversity. A total of 76 plant species from 29 families were recorded (Malvaceae, Fabaceae and Asteraceae being top dominants). Maximum flora was recorded in rainy season at both sites, higher at non-invaded sites in all seasons. Beta diversity followed similar trend, higher in rainy season and at non-invaded than invaded sites, highest being 13.2 at non-invaded site in rainy season. Dominants changed with site and season. Vegetation patches were distinct in drier seasons compared to rainy months. Soil organic carbon, total nitrogen and C : N ratios were high at invaded sites compared to non-invaded sites except in summer season. While higher diversity and higher similarity amongst different sites in rainy season indicated a homogenization impact in Indian dry tropical regions, higher diversity at non-invaded site suggested implication of diversity-reducing impact of tree invader *Prosopis juliflora*.

Keywords Plant invasion, Dry tropics, Alpha and beta diversity, Invasive species.

INTRODUCTION

Tropical ecosystems are often perceived as dynamic and rich in biodiversity. However, due to extensive developmental activities in these regions, concerns about their fragility are mounting, especially in urban and peri-urban ecosystems (Gupta and Narayan 2011). These ecosystems are rapidly being transformed into anthropo-ecosystems which have been reported with altered structure of vegetation and soil in dry tropics (Gupta and Narayan 2006, 2010, Agrawal and Narayan 2017). According to the Forest Survey of India (2015), India's total forest cover constitutes

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21.34% of its geographical area. Very dense forests (VDF) account for 2.61%, moderately dense forests (MDF) for 9.59%, and open forests (OF) for 9.14% of the total forest cover. India harbors 11.4% of the world's flora (Arisdason and Lakshminarasimhan 2016). Dry and moist deciduous forests collectively comprise 91% of India's tropical forests, with Chhattisgarh and Madhya Pradesh experiencing high rates of land use and land cover changes due to increased population and demands for various resources (Thakur *et al.* 2014).The herbaceous community plays a vital role in forest ecosystems, contributing significantly to total floristic composition, diversity, and stand structure (Gentry and Dodson 1987, Gentry and Emmons 1987, Mayfeld and Daily 2005, Tchouto *et al.* 2006). The structure of forest and heb vegetation in Indian dry tropics has been increasingly reported to be adversely impacted by invasive alien flora e.g. Yadav *et al.* (2022), Gupta and Narayan (2010).

Invasive species, introduced intentionally or through natural dispersal mechanisms, pose a significant threat to global biodiversity, second only to land use changes (Miranda *et al.* 2011). Plant invasion is currently recognized as the second-largest threat to biodiversity, particularly in anthropogenic ecosystems in India's dry tropics (Agrawal and Narayan 2017). The proliferation of invasive alien tree species, such as *Prosopis juliflora*, has become a reality in Indian dry tropics, impacting ecosystems significantly (Chepkwony *et al*. 2021). Infact, human disturbance and extensive grazing have led to the formation of highly fragmented vegetation, critically affecting community structure (Shahid and Joshi 2016) whose composition is a crucial determinant of plant community structure, with the number of species influencing community stability. Knowledge of the existing species composition and diversity is considered essential not only for understanding a plant community structure but also for devising conservation strategies (Malik *et al.* 2014, Malik and Bhatt 2015, 2016).

The historically important Hastinapur region of north-west Uttar Pradesh is situated within the upper Gangetic plain, covering a total area of 3364.3 hectares, with its 262.89 hectares designated as part of the Hastinapur Wildlife Sanctuary (Khan *et al.* 2013). Vegetation in the forests of the upper Gangetic plain predominantly consisted of tropical dry deciduous types, exhibiting xerophytic features due to arid climatic conditions. Major factors influencing vegetation structure here include human disturbances, extensive grazing, invasion by opportunistic alien species, and soil erosion. In 1953, during the colonization scheme of Hastinapur by the Uttar Pradesh government, Prof. V. Puri, who had previously studied the flora of Hastinapur (1961), recommended prioritizing intensive studies in the area due to the vulnerability of its lush vegetation due to human influences. The exotic *Prosopis juliflora* has intruded into this Sanctuary and has been growing in abundance, ostensibly impacting neighbouring vegetation and soils here.

This present study was conducted at two contrasting sites within the Hastinapur Wildlife Sanctuary (*Prosopis juliflora*-invaded and non-invaded) to understand changes in plant species diversity in relation to season, site and soil characteristics.

MATERIALS AND METHODS

Study area

The study area was located in Hastinapur (29°10' N lat, 78° 1' E long), western part of Uttar Pradesh. Two permanent study sites differing in habitat conditions were selected for the present investigation in Hastinapur Wildlife Sanctuary (HWLS). At each site, 2 km^2 of land, one *Prosopis juliflora*-invaded site (IH) and the other, non-invaded (NH) site was marked for this ecological study.

Plant sampling

An extensive field survey of floristic composition was carried out from July 2021 to June 2022 for listing the above ground flora in different seasons at both study sites. The recorded plant species were identified according to Sharma (1980), Gaur (1999) and Duthie (1960). At both study sites in each of three seasons 20 random quadrats (each of size 1m × 1m, a total of 240 quadrats) were laid for the phytosociological study of the above ground flora of the site. Every emergent tiller was considered as one individual for the density estimation of grasses. Relative abundance of each species (RA) was calculated according to MacArthur

(1960) and density and frequency of each species was calculated according to Phillips (1959).

Relative abundance

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats in which species occured}}$$

Whereas relative abundance

$$\text{Relative abundance (\%)} = \frac{\text{Abundance of species}}{\text{Sum of abundance of all species}} \times 100$$

Similarity coefficient

Similarity among the study sites within and across different seasons was estimated using the Modified Sorenson similarity coefficient (SC, Southwood 1978) according to the following formula :

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

Where, jN = Sum of lesser values of RA of species common in two communities, aN = Sum of RA of all species in community A, bN = Sum of RA of all species in community B.

Species diversity

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

α diversity of each study site across different seasons was estimated, using nine diversity indices (D_1 - D_9). The symbols used in computing D_1 to D_9 are: S = Total number of species, N = Total sum of abundance of all species, pi= Proportional RA of i^{th} species (ni/N), ni = RA of each species and N_{max}= RA of the most abundant species. Species diversity indices were calculated by using RA.

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 and 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 and 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)

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

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 and Parker 1970)

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

D_9, Simpson index (Simpson 1949)

$$D_9 = \sum pi^2$$

β diversity

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

Soil analysis

Six representative surface soil samples (0-10 cm) were collected from each study site in the months of October 2021(late rainy season), February 2022 (late winter season), and June 2022 (Summer season). The soil samples were air-dried and sieved (2 mm). The soil moisture content, pH, total organic carbon (Walkley and Black method) and total nitrogen (microkjeldahl's method) of each soil sample were estimated according to Piper (1944).

RESULTS

Species composition

A total of 76 plant species from 29 families (26 dicot and 3 monocot) were recorded during the study period. Considering all study sites together in a season, maximum flora was recorded in the rainy season (59), followed by winter (38) and summer (27) seasons. The herbaceous species belonging to Malvaceae (9), Asteraceae (7), Fabaceae (7), Solanaceae (7), Amaranthaceae (6), Poaceae (6), Lamiaceae (4) comprised more than 60% of the total flora. In terms of total number of plant species recorded during phytosociological study, the diversity at each site was in the order rainy > winter > summer (Table 1). The species count and the range of its variation in different seasons at a site varied with site and season showed much higher diversity at non-invaded site (NH) compared to invaded (IH) sites in rainy season. In contrast, winter and summer season harbored larger diversity at invaded sites. The plant species that generally occurred with prominence at every study site across all seasons included *Cynodon dactylon*, *Parthenium hysterophorus*, *Lantana camara* and *Senna occidentalis.*

Table 1. Top five dominants (in terms of their relative abundance) at *Prosopis julilfora* invaded and non- invaded sites in different seasons in an Indian dry tropical region.Codes: R (Rainy), W (Winter), S (Summer) seasons, prefixed with IH (Invaded Hastinapur), NH (Non-Invaded Hastinapur) study sites.

Species name	RIH	RNH	WIH	WNH	SIH	SNH
Abutilon hirtum (Lam.) Sweet	0.59	1.23	2.88	1.11		1.65
Achyranthes aspera L.	1.10	0.93	7.26	1.34		1.76
Ageratum conyzoides L.	13.01	5.49	14.26	6.05	8.18	5.48
Chenopodiastrum murale (L.) S. Fuents Uotila and Borsch		2.46	2.70	1.78		
Cynodon dactylon (L.) Pers.	9.81	4.86	13.50	8.66	8.06	5.95
Eclipta prostrata (L.) L.	2.01	2.18		1.67		4.24
Lantana camara L.	2.89	1.63	2.54	1.14	2.75	5.02
Lindernia crustacea (L.) F.Muell.		1.99	4.32	3.67		12.57
Murraya koenigii (L.) Spreng.	4.62	4.11	6.60	6.09	10.67	11.03
Oxalis corniculata L.	0.64	1.85	4.06	2.17		7.94
Oxalis debilis Kunth	2.41		2.54	5.68	12.81	3.97
Parthenium hysterophorus L.	5.97	5.89	7.45	10.35	6.16	7.94
Scoparia dulcis L.	0.89	1.53		5.29	11.38	3.18
Senna occidentalis (L.) Link.		2.74	7.57	2.13	4.27	11.91
Sida acuta Burm.f.	15.34	2.24	9.73	4.81	7.11	4.24
Stellaria media (L.) Vill.			5.66	9.35	6.40	3.97
Other species (no. in parenthesis)	40.72 (21)	60.87 (28)	8.93 (12)	28.71 (7)	22.21 (10)	9.15 (2)

Senna occidentalis (rainy), *Ageratum conyzoides* (winter) and *Murraya koenigii* (summer) were dominats at IH site and *Parthenium hysterophorus* (rainy and winter), *Senna occidentalis* at NH site. *Cynodon dactylon* was one in top three dominants at both sites during rainy and winter season.

Inter-site species composition comparison

In all three seasons the inter-site differences in terms of dominant species varied narrowly. Maximum intersite similarity (modified sorrensen index) between IH and NH sites was recorded in rainy season (0.63)

Table 2. Spatial and seasonal similarity of the site vegetation based on similarity coefficient applying Modified Sorenson Index (using species relative abundance). Codes: R (Rainy), W (Winter), S (Summer) seasons, prefixed with IH (Invaded Hastinapur), NH (Non-Invaded Hastinapur) study sites.

	RNH	WIH	WNH	SIH	SNH
RIH	0.63	0.41	0.39	0.22	0.38
RNH		0.42	0.44	0.27	0.34
WIH			0.60	0.48	0.37
WNH				0.32	0.36
SIH					0.62

followed by summer (0.62) and in winter (0.60) (Table 2). While comparing inter-season similarity, it was apparent that rainy season and summer season flora were distinct, as minimum inter-season similarity was recorded between RIH and SIH. Winter season flora showed 0.4 similarity coefficient (approx) similarity with summer and rainy season flora. Thus, invaded sites in summer season evidently had lowest similarity with non-invaded sites reflecting its distinctness.

Soil properties

The soils of the study sites were neutral to slightly basic (pH 7.4-7.8) (Table 3). In winter season, significant inter-site difference was recorded in electric conductivity, organic carbon, available nitrogen, total nitrogen and C:N ratio. Moisture content showed variation across different seasons but there was no significant intersite difference. However total nitrogen content in soil was significantly different in summer season as well. Data analysis was done by using student's t-test in SPSS 20.00 software.

Abundance diversity structure

Abundance-diversity curves for vegetation at different sites and seasons showed that generally 1-3 species in the vegetation at all sites exploited major share of resources (Fig. 1). This trend was more apparent in vegetation in winter and summer where a near geometrical pattern of resource share was note worthy. Here, *Oxalis corniculata* (winter), *Parthenium hysterophorus* (summer) and *Cannabis sativa* (rainy) at NH site seems to exploit major resources as, evident by its largest share of RA. *Parthenium hysterophorus* (winter), *Cannabis sativa* (summer) and *Cynodon dactylon* (rainy) at NP site, *Murraya koenigii* (summer), *Parthenium hysterophorus* (winter) and *Cynodon dactylon* (rainy) at IH site, *Datura stramonimum* (winter),*Cannabis sativa* (summer) and *Oplismenus hirtellus* (rainy) at IP site exploited major resources as, evident by the share of their RA.

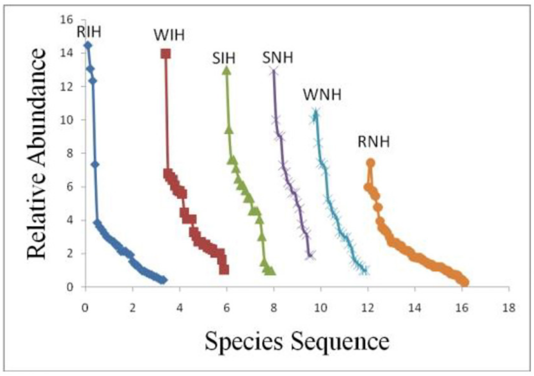

Fig. 1. Abundance-diversity curves of vegetation across different sites and seasons. The first letter of the code indicates season (R: rainy, W: winter, S: summer) and the next two letters indicate study sites (IH invaded Hastinapur).

Species diversity

Table 4 summarizes the seasonal diversity levels, in terms of nine α diversity indices at different sites using relative abundance of species (i.e. N = 100).

Table 3. Soil characteristics of *Prosopis juliflora*-invaded (IH) and non-invaded (NH) sites in different seasons in an Indian dry tropical region. *Represents significant differences at $p \leq 0.05$ by applying student's t-test. Season codes: R (Rainy), W (Winter), S (Summer) seasons, prefixed with IH (Invaded Hastinapur), NH (Non-Invaded Hastinapur) study sites.

Parameters	RIH	RNH	WIH	WNH	SIH	SNH
pH	7.57 ± 0.09	7.77 ± 0.20	7.44 ± 0.09	7.61 ± 0.23	7.70± 0.06	7.61 ± 0.04
Moisture	15.05± 0.84	13.95 ± 0.64	9.80± 0.38	9.33± 0.51	5.22 ± 0.33	5.32 ± 0.50
Org C	1.17 ± 0.21	0.77 ± 0.20	2.29 ± 0.09*	0.48 ± 0.04*	0.96 ± 0.16	1.45± 0.24
Total N	0.04 ±0.002	0.04 ± 0.001	0.05± 0.006*	0.02 ±0.005*	0.04±0.002*	0.06 ±0.004*
C:N ratio	27.4 ± 4.57	18.8± 4.37	46.2± 6.85*	18.7 ± 3.22*	21.9 ± 3.64	22.9± 3.11

Table 4. Diversity estimates of the vegetation at *Prosopis juliflora*-invaded (IH) and non-invaded (NH) sites in different seasons in an Indian dry tropical region in three seasons using different diversity indices. Season codes:R (Rainy), W (Winter), S (Summer) seasons.

Diversity indices	RIH	RNH	WIH	WNH	SIH	SNH	Max/Min
D_1 (Species count)	33	42	26	23	20	17	2.47
D_2 (Margalef index)	6.95	8.90	5.43	4.78	4.13	3.47	2.56
D_3 (Menhinick index)	3.30	4.20	2.60	2.30	2.00	1.70	2.47
D_4 (Shannon's index)	3.02	3.45	3.14	2.92	2.76	2.73	1.26
D_5 (Evenness pielou)	0.87	0.92	0.96	0.93	0.92	0.96	1.11
D_6 (Brillouin's index)	2.73	3.10	2.89	2.74	2.62	2.63	1.18
D_7 (Evenness brillouin's)	0.90	0.93	0.91	0.94	0.98	0.93	1.09
D_8 (Berger- parker index)	0.15	0.06	0.14	0.10	0.13	0.13	2.59
D_9 (Simpson's index)	0.07	0.04	0.05	0.06	0.07	0.07	1.71
β Diversity	10.60	13.15	6.29	7.96	2.72	4.24	4.83

Different indices ranked the site diversity differently. The values of richness indices viz., species count (D_1), Margalef index (D_2) and Menhinick's index (D_3) were found to be maximum in rainy season at NH site, in terms of information statistic indices (Shannon D_4 and Brillouin D_6), again NH site showed the maximum value in rainy season. Besides, this site also showed maximum range of diversity variation across seasons. Dominance measures (Berger-Parker, D_8 and Simpson D_9) showed higher values at IH site in all three seasons. Maximum Pielou's evenness was found at WIH site but Brillouin's evenness was maximum in summer season at IH site. In rainy season maximum evenness was observed at NH site.

Comparing the maximum: Minimum ratio of a diversity index (used as discriminant ability to discern subtle differences in diversity) in the present study, the dominance measure by Simpson was highest (2.59), followed by Margalef index (2.56) and Menhinick index (2.47) (Table 4). The most widely used Shannon index showed a ratio of only 1.26.

β diversity

β diversity ranged between 2.72 and 13.15 (Table 4). It was lower at invaded site (IH) compared to non-invaded sites in all seasons. β diversity generally increased in rainy compared to winter and summer season for all study sites. β diversity at NH site was maximum in all seasons.

DISCUSSION

Spatio temporal dynamics of the investigated vegetation was evident at relatively smaller spatial scale from the findings of the present study, where a total of 76 plant species from 29 families were documented and herbaceous flora collectively comprised more than 60% of the total ones. Considering all study sites together across three seasons, the highest number of flora in the rainy season (59), followed by winter (38) and summer (27) seasons evinced seasonality dependent diversity structure in Indian dry tropics (Gupta and Narayan 2010). While increasing dominance of Fabaceae reflected a tropical characteristic (Gupta and Narayan 2006), the enhanced prominence of Asteraceae indicated influence of weedy flora here in HWLS (Khuroo *et al*. 2021). Growing dominance of exotic *Parthenium hysterophorus* in all seasons depicting its high ecological amplitude is also apparent from the phytosociological findings in this study.

The diversity order at each site viz. rainy > winter > summer indicated a predominant role of season on weeds-dominated vegetation in Indian dry tropics (Agrawal and Narayan 2017). However, with significantly higher diversity during the rainy season at non-invaded (NH) sites compared to *P. juliflora*-invaded (IH) sites, possibly indicated that in rainy season, when environment is commonly considered conducive for the successful growth of larger number of diverse plant propagules at all sites in dry tropics, it is due to the influence of exotic tree invader *P. juliflora*, the diversity decreased in its invaded sites. However, the opposite trend of higher diversity in its invaded-sites in the relatively harsher environmental conditions viz. winter and summer, successful growth and establishment of distinct species occurred that were different from the rainy flora. This is implicit from much lower inter-site similarity recorded in summer and winter compared to rainy season. In fact, β diversity, that reflected species turn-over rate, was always recorded to be lower at invaded sites compared to non-invaded sites in all seasons, supports the (Table 4). However, plant species such as *Cynodon dactylon*, *Parthenium hysterophorus*, *Lantana camara*, and *Senna occidentals* consistently present across all study sites and seasons could be attributed to their reportedly higher ecological amplitude various anthropo-ecosystems in Indian dry tropics.

Dominants changed with site and season e.g. in rainy season, *Senna occidentalis* dominated at the IH site, while *Parthenium hysterophorus* was prevalent at both IH and NH sites. In the winter season, *Ageratum conyzoides* was dominant at the IH site, whereas *Parthenium hysterophorus* continued to dominate at the NH site. Finally, during the summer season, *Murraya koenigii* was the dominant species at the IH site. Notably, *Cynodon dactylon* ranked among the top three dominant species at both IH and NH sites during both the rainy and winter seasons indicative of its wide ecological amplitude in disturbed ecosystems too. This changing dominant with site and season is also implicit from the nature of abundance-diversity curves.

Occurrence of vegetation mosaic is also implicit from the analysis of inter-site similarities in the present study. Highest similarity amongst the invaded and non-invaded sites during the rainy season, followed by summer and winter reflected the homogenization impact of rainy season under dry conditions. Vegetation patches tended to be more distinct under dry conditions, as evinced by minimum inter-season similarity observed between RIH and SIH. This corroborated the mosaic pattern being distinct in such vegetation. A comparable result was reported by Gupta and Narayan (2006, 2010) in the peri-urban vegetation in Indian dry tropics.

Significant differences in winter-soil characteristics e.g. soil organic carbon, total nitrogen, and C:N ratio revealed existence of heterogeneous soils observable at lower spatial scale. Additionally, available nitrogen and total nitrogen content showed significant differences during the summer season. However, despite variation in moisture content, it was not significant.

The study revealed the pronounced seasonal variations in plant diversity and soil heterogeneity across *Prosopis juliflora*–invaded and non-invaded sites in Hastinapur Sanctuary, with higher diversity level in rainy season and in non-invaded sites, emphasizing ecologically an invasive attribute. Overall, the findings highlight the complex dynamics of vegetation and soils in ecosystems in Indian dry tropics and stress the importance of seasonal considerations in biodiversity management strategies.

In conclusion, the structure of vegetation and soils of the HWLS is influenced by season, site and alien flora.

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