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RESEARCH ARTICLE

Ecological investigation on vegetation structure and soil characteristics of *Prosopis juliflora* – invaded and non-invaded urban ecosystems in Indian dry tropics

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Abstract

Plant invasion in Indian tropics have caused alternation of vegetation structure and soil characteristics. Present study was carried out to assess vegetation structure and physico-chemical properties of soils of *Prosopis juliflora*-invaded and non-invaded sites in a rapidly urbanizing dry tropical region of India. Abuandance of plant species was estimated through 120 randomly quadrats (each 1mx1m) from both sites in three seasons (n= 20x3x2). A total of 36 randomly sampled surface soil (0-10 cm) from both sites in three seasons where analyzed for soil pH, moisture content, organic carbon and total nitrogen. Diversity of the vegetation was estimated using nine alpha diversity and one beta diversity indices and dominance was assessed by plotting abundance-diversity curves. Similarity of the vegetation was estimated by Sorrenson's modified index. A total of 98 plant species distributed over 35 families were recorded. Top dominant families included Poaceae, Malvaceae, Asteraceae and Fabaceae. Dominants changed with site and season. Seasonal diversity varied in the order rainy>winter>summer. Diversity of *P. juliflora*-invaded site was lower than that at non-invaded sites. The vegetation tended to be distinct in dry months compared to rainy season. The site-soils showed considerable alteration of characteristics. Higher organic and total N were recorded at invaded sites. Soil moisture significantly changed with change of season, although there was no inter-site difference in the same season. In conclusion, the study revealed a complex interplay of soil-site conditions, season, plant invasions and disturbance in shaping the structure of vegetation in dry tropical urbanizing landscapes of India.

Keywords: Dry tropics, Plant diversity, Plant invasion, *Prosopis juliflora*, Urban vegetation.

Introduction

Tropical ecosystems are generally considered as reservoirs of rich biodiversity (Brown 1996, Schimel 1995, Apguaua *et al*. 2015). The abundance of flora and fauna reflects the natural richness of biodiversity (Tarun Kumar Thakur 2018). However, human activities such as pollution, overgrazing, and land alterations have led to significant variations in floristic diversity within these ecosystems. This directly impacts their structure, composition, diversity, productivity, and ultimately modifies global ecology (FAO 1995, King *et al*. 1997, Sundarapandian and Karoor 2013).

The repercussions of alterations in community composition or the loss of biodiversity on ecosystem functioning (Chaturvedi *et al*. 2014) have garnered significant attention in ecological research, witnessing a surge in studies over the past decade (Schulze and Mooney 1993, Kinzi Pacala and Tilman 2002, Loreau Naeem and Inchausti 2002).

India stands as one of the 19 mega-diverse countries globally, owing to its rich diversity of habitats, flora, and fauna (Paradva *et al*. 2018). However, the massive developmental activities driven by the commercial interest of the humans, has led to rapid degradation of native ecosystems here, especially across urban areas. Meerut city is situated within the National Capital Region of Delhi, bounded by the Himalayan Rivers Ganga and Yamuna to its east and west, respectively. This region is witnessing accelerated developmental activities over the last 4-6 decades. The district supports a rich diversity of plants distributed

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across various forest and non-forest areas. Alien plants are reportedly expanding their areas of influence in the dry tropical urban habitats of Meerut in India (Yadav *et al*. 2022).

Plants constitute the fundamental components of any ecosystem, and a diverse plant population here, can influence the overall functionality of such ecosystems to different scales, especially of the urban ones. Plant diversity values that elucidate intricate relationships between individual plant species, serve also as a unique indicator of the utilization of environmental resources. Presently, invasive alien species in urban ecosystem have increasingly been reported to cause alteration of ecosystem structure and function (Agrawal and Narayan 2017, Gupta and Narayan 2010). Such invasive species extend behind its native distribution range (Shine *et al*. 2009) and are often reported to influence economy and ecology of the area of their dominance.

In Central America, South America, the Caribbean and Mexico, *Prosopis juliflora* (here after referred to as *P. juliflora*) is the indigenous plant flora (Pasiecznik *et al*. 2001). Introduced intentionally to Ethiopia in the late 1970s for the rehabilitation of degraded areas, *P. juliflora* has been identified as an invasive species (Abebe 2012, Haji and Mohammed 2013, Ayanu *et al*. 2015).This ecosystem boasts distinctive xerophytic vegetation that provides essential goods and services to the human population. However, recent threats by this species in dry habitats have been documented and attributed primarily to anthropogenic activities alongside the arid climate (Sallam *et al*. 2023).

Our hypothesis posits that harsh environmental conditions influence plant diversity and vegetation structure. Several studies have addressed wasteland aspects around Partapur Bypass in Meerut. However, there is lack of ecological study pertaining to plant communities here. The present ecological study focused on understanding the species diversity and vegetation structure in habitats under the influence of alien invader *P. juliflora*. The major objective of the present study was to assess the relationship between vegetation structure and soil of *Prosopis juliflora*-invaded and non-invaded sites in a dry tropical region of Meerut in India.

Materials and methods

Study Area

The study area was Partapur in the Meerut region (28° 55′ N lat. and 77° 39′ E long.) (UP). Two permanent study sites were selected, one invaded by *P. juliflora*-invaded (IP) and the other non-invaded (NP) for ecological investigation at Partapur Bypass in Meerut. This study area is a witnessed to excelarated development activities in vicinity in Meerut. This is mainly on account of heavy traffic menance. At each site, 1km^2 of area was marked for the study. Semi-arid climate is found here which is characterized by three distinct seasons: rainy (July-Oct), winter (Nov-Feb), and summer (March-June). The annual mean maximum temperature was 27.7°C.

Plant sampling

An extensive field study of floristic composition was done from July 2021 to June 2022 for listing the above ground flora in different seasons in the study area. The recorded plant species were identified according to Sharma (1980), Gaur (1999) and Duthie (1960). At both study sites, random quadrats were laid in three seasons (each of size 1m x 1m, n=20x3x2= 120) for phytosociological study. Each emergent tiller was counted as one unit for estimating the density of grasses. Relative abundance of each species (RA) was calculated according to Robert MacArthur (1960),density and frequency of each species was calculated according to Phillips (1959).

Relative abundance

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

Whereas Relative Abundance;

$$\text{Relative Abundance (\%)} = \frac{\text{Abundance of Species}}{\text{Sum of abundance of all species}} \text{X100}$$

Vegetation Similarity Estimation

Inter-site similarity in the vegetation at two sites in different seasons was assessed through the formula of Modified Sorenson similarity coefficient (SC, Southwood 1978), calculated with the following formula:

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

Where, jN = sum of lesser values of RA of species common to both communities; aN = sum of RA values of all species belonging to community A; bN = sum of RA values of all species belonging to community B.

Estimation of diversity of Species

The curve for understanding abundance diversity relations were generated by plotting values of abundance of species against their ranks according to Whittaker's method in 1975.

Nine alpha diversity indices (D1 - D9) were estimated for each site across different seasons. S = total number of species, N = sum of abundance attributes of all species, pi = proportional abundance of the ith species (ni/N), ni = abundance attribute of each species, and Nmax = abundance attribute of the most abundant species. RA data used for estimation of species diversity.

Species richness indices

D1 represents total number of species encountered in the sampled quadrats.

D2 refers to the Margalef index, as defined by Clifford and Stephenson in 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,

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

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

Beta diversity within a vegetation in the study site was calculated following Whittaker's method in (1972).

Soil characteristics

Six surface soil samples (0-10 cm) from each study site were collected in rainy (October 2021), winter (February 2022), and summer (June 2022) seasons. These air-dried and sieved (2 mm) soil samples where analyzed for soil pH, moisture, total organic carbon (determined using the Walkley & Black method), and total nitrogen (micro-Kjeldahl method) according to Piper 1944.

Results

Species composition

During the study period, a total of 98 plant flora distributed over 35 families (32 dicots and 3 monocots) were identified (Table 1). Across both sites of study in a given season, the highest number of plant species was recorded in the rainy season (73), followed by winter (53) and summer (38).

Table 1: Relative abundance of top five dominants at *Prosopis juliflora*-invaded (IP) and non-invaded (NP) sites in different seasons in an Indian dry tropical region

	Rainy		*Winter*		*Summer*	
Species Name	*IP*	*NP*	*IP*	*NP*	*IP*	*NP*
Abutilon hirtum (Lam.) Sweet	7.89	9.31	7.5	8.23	-	1.65
Acalypha ciliata Forssk.	0.38	0.81	-	3.08	-	-
Ageratum conyzoides L.	5.56	5.49	8.65	6.05	-	-
Amaranthus spinosus L.	14.56	12.08	9.22	14.92	7.59	4.96
Boerhavia diffusa L.	0.80	-	-	1.00	8.26	6.01
Cannabis sativa L.	13.45	14.20	9.49	6.73	7.40	9.70
Cynodon dactylon (L.) Pers.	9.81	4.86	12.50	8.66	8.06	5.95
Echinochloa colonum (L.) Link	-	-	1.3	3.29	-	-
Gamochaeta pensylvanica (Willd.) Cabrera	0.80	0.68	6.18	4.33	-	-
Gomphrena serrata L.	1.76	2.33	-	3.29	-	2.17
Lantana camara L.	2.89	1.63	2.54	1.14	-	5.02
Oplismenus hirtellus (L.) P.Beauv.	0.41	0.98	-	-	-	-
Oxalis corniculata L.	0.64	1.85	4.06	12.34	9.85	7.94
Parthenium hysterophorus L.	5.97	5.89	7.45	10.35	6.16	13.04
Ricinus communis L.	-	0.91	2.1	4.3	1.3	2.4
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
Solanum nigrum L.	-	-	0.89	4.18	1.13	3.26
Stellaria media (L.) Vill.	0.48	1.64	5.66	9.35	-	-
Other species (no. in parenthesis)	33.71	33.07	14.89	8.66	34.6	22.81
	(30)	(31)	(17)	(18)	(15)	(10)

Poaceae (13), Malvaceae (12), Asteraceae (11), Fabaceae (7), Amaranthaceae (6), Lamiaceae (6), and Solanaceae (6) collectively accounted for over 60% of the total recorded flora. Notably, grass families from Poaceae and Cyperaceae together represented nearly 15% of the total recorded flora. The diversity of plant species at each site was observed in the ordered, rainy followed by winter and summer.Total number of species in different seasons at a site showed much higher diversity at NP site compared to IP site except in summer season. The common species occuring at all site and seasons included *Amaranthus spinosus*, *Cannabis sativa, Cynodon dactylon*, *Parthenium hysterophorus*, *Paspalum scrobiculatum,* and *Senna occidentalis*.

In the rainy season, *Cannabis sativa* and *Amaranthus spinosus* were dominant at both sites. *Amaranthus spinosus* was leading dominant at NP site in winter season and it also was third leading dominant at IP site, where top dominant was *Cynodon dactylon*. In summer season *Parthenium hysterophorus* and *Scoparia dulcis* dominated at NP and IP sites respectively.

Seasonal inter-site similarity comparison

The similarity of invaded and non-invaded sites in different seasons was recorded to be relatively greater in rainy season and lowered in drier summer and winter (Table 2). This is evident from range of similarity values of invaded site with other sites in different seasons (0.29-0.44).

Prefixed season codes: Rainy (R), Winter (W), Summer (S), prefixed with IP (Invaded Partapur), NP (Non-Invaded Partapur) study Sites.

Table 2: Inter-site and season similarity of *Prosopis juliflora*-invaded (IP) and non-invaded (NP) sites in an Indian dry tropical region of Meerut (applying similarity coefficient formula of Modified Sorenson Index, using species relative abundance data)

	RNP	*WIP*	*WNP*	*SIP*	*SNP*
RIP	0.65	0.50	0.43	0.31	0.34
RNP		0.45	0.49	0.29	0.32
WIP			0.61	0.43	0.38
WNP				0.44	0.36
SIP					0.37

Soil properties

The pH of soils of the study sites in different seasons was neutral to slightly basic (pH 7.04-8.2) (Table 3). Soil pH at NP site in all seasons was higher compared to IP site soil, significantly higher in summer season. Moisture content of soils differed significantly with change of season, albeit inter-site difference in the same season was not significant. IP soil was comparatively rich in organic carbon and total nitrogen. C: N ratio in IP soil was high in rainy and winter season but lower in summer season..

Abundance diversity structure

One or two species at all sites generally exploited major share of resources, as evinced in abundance-diversity curves for vegetation at different sites and seasons, albeit about 4-5 species appear competing closely for resources as co- or sub-dominants (Figure 1). This trend was apparent in vegetation in all three seasons, where a steeply changing resource share pattern was exhibited. The harsh months of summer appear to have higher inclination towards log-normal share of resource share.

Species diversity

The analysis conducted in Table 4 provides a comprehensive overview of the seasonal diversity levels at different sites, utilizing nine diversity indices based on relative abundance values (N = 100). These indices ranked site diversity in various ways, showcasing the nuanced differences in ecological richness and structure across seasons and locations. Notably, the richness indices such as Menhinick's index, Margalef index and species count demonstrated higher values during the rainy season at the NP site, highlighting the influence of seasonal variation on species composition. On the other hand, information statistic measures of diversity like Brillouin and Shannon indices showed higher values at the IP site during the rainy season, indicating a greater complexity and diversity of species interactions. Furthermore, the IP site displayed the broadest range of diversity variation across different seasons, emphasizing its ecological dynamism and

Table 3: Soil characteristics of *P. juliflora*-invaded (IP) and non-invaded (NP) sites different seasons in Meerut regions of India. Different letters in a row (a,b,c,d) represent significant differences at $p \leq 0.05$, means with common letters are not significantly different according to Tukey's HSD test

	Rainy		*Winter*		*Summer*	
Parameters	*IP*	*NP*	*IP*	*NP*	*IP*	*NP*
pH	7.4± 0.07 ab	8.1 ± 0.18 ab	7.1± 0.24 a	7.8± 0.14 ab	7.0± 0.27 a	8.2± 0.45 b
Moisture content (%)	15.4 ± 0.94 c	14.8 ± 0.76 c	9.2 ± 0.45 b	9.9± 0.55 b	5.3± 0.34 a	5.5 ± 0.54 a
Organic C (%)	1.7 ± 0.22 cd	0.9 ± 0.11 ab	1.4± 0.26 bc	0.6 ± 0.07 a	2.2 ± 0.12 d	1.1 ± 0.13 abc
Total N	0.06 ± 0.008 abc	0.05± 0.004 ab	0.06± 0.003 bc	0.03 ± 0.003 a	0.09 ± 0.013 c	0.03 ± 0.002 a
C:N ratio	27.5± 4.55 a	18.0 ± 2.72 a	19.8 ± 3.24 a	17.8 ± 2.28 a	25.8 ± 2.95 a	29.8 ± 4.95 a

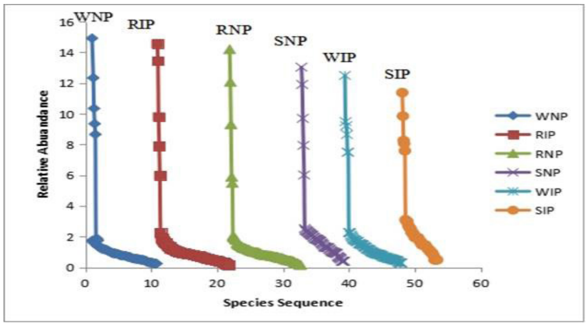

Figure 1: Abundance (dominance-diversity curves) for *P. juliflora*-invaded (IP) and non-invaded (NP) sites different seasons in Meerut regions of India. (Season codes: R: rainy, W: winter, S: summer)

resilience to seasonal shifts. Dominance measure Berger-Parker index (D8) was maximum at RIP site and WNP site whereas Simpson (D9) showed higher values at both site in summer season. Maximum Pielou's evenness was found at NP site in summer season but Brillouin's evenness was maximum in rainy season at IP site. The discriminant ability, evidently exhibited by differing maximum: minimum ratio to decipher subtle differences in diversity at a site, in the present study, the dominance measure Margalef index (2.09) was highest, followed by Menhinick index (2.04) and Simpson index (1.80) (Table 4). The commonly used the world over, the Shannon index in this study showed a ratio of only 1.4.

β diversity

The range of β diversity lay between 4.06 and 16.84 (Table 4). IP site had lower value compared to NP site in winter and summer, but it was much comparable in rainy season. β diversity was higher in rainy season compared to drier months of summer and winter.

Discussion

The investigated vegetation revealed highly dynamic floristic composition influenced by season, soil and site conditions, as evinced through comprehensive analysis of soil characteristics and structure of vegetation of two contrasting sites (*Prosopis juliflora*-invaded and non-invaded) and three season conditions in a dry tropical region of India. It reflected the intricate ecological dynamics discerned in the rapidly urbanizing ecosystems that being increasingly influenced by alien flora. Agrawal and Narayan (2017) in fact, suggested deterministic role of alien flora, especially the invasive ones for dry tropical peri-urban vegetation in the adjoining the national capital region (NCR) of Delhi.

Species diversity has been identified as a crucial component in promoting the sustainable development of *P. juliflora*, particularly when cultivated alongside native species, as suggested by (Wakie *et al*. 2014). This could be attributed to ecosystems with a variety of species being resilient in competing for resources with *P. juliflora* (Wakshum Shiferaw *et al*. 2023). However, in our study, the herbaceous species from prominent families such as Poaceae, Malvaceae, Asteraceae and Fabaceae constituted a substantial portion of the flora, indicating their importance in these habitats. The top four herbaceous angiospermic families in this study could be considered reflecting dry tropical similarity and adaptation to relatively harsher environmental conditions here. While predominance of leguminous members is commonly suggested in relatively impoverished soil conditions in Indian dry tropics (Gupta and Narayan 2006), the dominance of Asteraceae was indicative of weedy dominance in anthropic ecosystems (Khuroo *et al*. 2021, Gupta and Narayan 2006). Among the recorded flora, the grasses from the Poaceae and Cyperaceae families alone represented approximately 15% of the total species. This is possibly due growing prominence of grasses in disturbed ecosystems, where the grass flora, as annuals comparable to herbaceous annual weedy annuals of Asteraceae, could be considered ecological opportunists successfully surviving and

Table 4: Diversity estimates of vegetation of *P. juliflora*-invaded (IP) and non-invaded (NP) sites in different seasons in terms of various diversity measures.

	Rainy		*Winter*		*Summer*		
Indices of Diversity	*IP*	*NP*	*IP*	*NP*	*IP*	*NP*	*Max/Min*
D1 (Species Count)	45	47	31	36	25	23	2.04
D2 (Margalef Index)	9.55	9.99	6.51	7.60	5.21	4.78	2.09
D3 (Menhinick Index)	4.50	4.70	3.10	3.60	2.50	2.30	2.04
D4 (Shannon's Index)	3.66	3.65	3.29	3.41	3.13	3.02	1.21
D5 (Evenness Pielou)	0.96	0.95	0.96	0.95	0.97	0.96	1.02
D6 (Brillouin's index)	3.28	3.25	3.01	3.13	2.70	2.83	1.22
D7 (evenness Brillouin's)	0.99	0.98	0.98	0.92	0.95	0.97	1.07
D8 (Berger- Parker Index)	0.15	0.14	0.13	0.15	0.11	0.13	1.36
D9 (Simpson's Index)	0.03	0.03	0.04	0.04	0.05	0.05	1.80
β Diversity	16.81	16.84	8.89	11.74	4.06	5.44	4.15

establishing in open and disturbed dry tropical ecosystems. The plant families documented in the current study align closely with those reported by Aggarwal (2012) for peri-urban areas in Indian dry tropics. Demissie (2009) reported comparable results for Awash National Park in the dry tropics of Ethiopia.The dominants varied with the change of site and season. This varying dominance pattern is evidenced by *Senna occidentalis*, *Ageratum conyzoides* and *Murraya koenigii* dominating P. *juliflora*-invaded sites, while *Parthenium hysterophorus* and *Senna occidentalis* dominating at non-invaded sites. Season playing an important role in the organization of plant communities in Indian dry tropics has been reported by several workers e.g. Gupta and Narayan (2006, 2010). Gupta and Narayan (2017) opined that the species diversity and compositional variations in anthropo-ecosystems in Indian dry tropics was much influenced by season, site, soil and disturbance regimes.

Inter-season similarity analysis revealed distinct floras between seasons, with the rainy season exhibiting the highest similarity and winter showing limited similarity to summer and rainy seasons. The rainy season, in the present study, emerged as the period of highest diversity, emphasizing its ecological significance in Indian dry tropics. This season appears to have homogenization impact in such dry tropical ecosystems with larger variety of plant propagules finding equal opportunity to successfully emerge and survive under plentiful soil moisture conditions. Soil analyses provided insights into the ecological conditions of the study sites, with considerable differences observed in pH, soil organic carbon, nitrogen content, and levels of moisture content. Soil moisture content in dry tropical habitats is often suggested to play a significant role impacting plant community structure, especially in Indian dry tropics (Gupta and Narayan 2010). The harsher dry soil conditions appear to have screening impact on survival and establishment of the flora. Accordingly, the present study supports that the general mosaic vegetation in such dry tropical conditions becomes distinct in drier months of the season. Large-scale invasion by alien flora and their impactful influence on community structure, organization and productivity in the peri-urban ecosystems in Indian dry tropics (Agarwal and Narayan 2017), further complicated the vegetation organization patterns in anthropo-ecosystems in Indian dry tropics.

The estimated diversity indices of the vegetation of the two sites sites across different seasons demonstrated the complexity of plant communities, albeit non-invaded site generally showing higher diversity. A tendency to lower diversity at *P.juliflora*-invaded site compared to the non-invaded sites in different season, as evinced in this study, is possibly on account of the invasiveness of the exotic alien *Prosopis juliflora*. In fact, plant invasions have been globally recognized for their diversity-reducing impact. Abundance-diversity curves highlighted the resource exploitation patterns of dominant species, with certain species exerting a major influence across different sites and seasons. These plant communities under stress conditions often showed a steeply declining resource share among the top dominants. However, interestingly, in this study the harsher months of summer and winter indicated a greater tendency towards log-normal nature of resource-share, despite a steep decline of curve after mutual share among the major dominants (Figure 1). It could be due to complex ecological conditions in the studied vegetation where the environmental stress appears to have multiplied on account of plant invasions, dry seasons, relatively low soil resource, immense ecological stress generated by developmental activities in and around the area of Partapur Bypass with a high traffic load in the vicinity. The presence of ubiquitous species like *Cynodon dactylon*, *Parthenium hysterophorus*, *Lantana camar*a, and *Senna occidentalis* across all seasons highlighted their ecological amplitude across diverse stresses in the investigated urban environments.

Conclusion

Thus, in conclusion, the present ecological study revealed mosaic vegetation pattern, distinct in dry months, and intricate complex interplay of season, site-soil conditions and plant invasions in determination of vegetation structure in urbanizing areas in Indian dry tropics.

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