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Species diversity in four contrasting sites in a peri-urban area in Indian dry tropics

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Abstract: Due to human activities peri-urban areas are witnessing rapid ecological alteration that make them highly dynamic. In the present study, plant species diversity and aboveground biomass (AGB) were investigated at four contrasting peri-urban sites, namely, brick kiln, grazing land, Kali river bank, and agricultural land in Indian dry tropics. The species occurrences at each site were recorded at monthly intervals for two years. Species IVI and AGB were estimated for each site seasonally. A total of 122 plant species, predominantly annuals, belonging to 34 angiospermic families were recorded from these sites. Total species count at each site was highest in rainy season and lowest in summer, whereas the reverse trend was observed for β diversity. Amongst the sites, grazingland and Kali river bank showed greater diversity than brick kiln and agricultural land. β diversity was highest at Kali river bank and much lower at agricultural land and brick kiln sites. The herbaceous vegetation showed a mosaic pattern which was more pronounced in dry months than in wet months. Species dominance altered with sites and seasons with increasing tendency of exotic species like *Parthenium hysterophorus.* Soils of study sites were heterogeneous with lower moisture, organic carbon and C:N ratio at brick kiln compared to other sites. The AGB at these sites (228 to 738 g m^{-2}) showed wide spatial and temporal variations. In conclusion, the drier months after rains, soil organic C and disturbance regimes greatly influence the species composition and diversity in these peri-urban habitats in Indian dry tropics.

Resumen: A consecuencia de las actividades humanas las áreas periurbanas están atestiguando una alteración ecológica rápida, lo que las hace muy dinámicas. En el presente estudio se investigó la diversidad de especies vegetales y la biomasa aérea en cuatro sitios periurbanos contrastantes del trópico seco de la India: ladrilleras, terrenos de pastoreo, ribera del río Kali y terrenos agrícolas. La presencia de las especies en cada sitio fue registrada a intervalos mensuales durante dos años. Fueron estimados el IVI y la biomasa aérea de las especies para cada sitio y por estación. En todos los sitios se registró un total de 122 especies de plantas, predominantemente anuales, pertenecientes a 34 familias de angiospermas. El conteo total de especies en cada sitio tuvo su máximo en la temporada lluviosa y su mínimo durante el verano, mientras que la diversidad β mostró la tendencia opuesta. Entre sitios, los terrenos de pastoreo y la ribera del río Kali mostraron una mayor diversidad que las ladrilleras y los terrenos agrícolas. La diversidad β alcanzó su valor máximo en la ribera del río Kali y fue mucho más baja en los terrenos agrícolas y las ladrilleras. La vegetación herbácea mostró un patrón en mosaico, el cual fue mucho más pronunciado en los meses secos que en los húmedos. La dominancia de especies varió con los sitios y las estaciones, mostrando una tendencia creciente de especies exóticas como *Parthenium hysterophorus.* Los suelos del área de estudio fueron heterogéneos con un menor contenido de humedad, carbono orgánico y cociente C:N en las ladrilleras que en los otros sitios. La biomasa aérea en estos sitios (228 a 738 g m^{-2}) mostró amplias variaciones espaciales y temporales. En conclusión, el C orgánico del suelo y los regímenes de disturbio influyen fuertemente sobre la composición de especies y la diversidad en estos hábitats periurbanos del trópico seco de la India.

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Resumo: Devido às actividades humanas nas áreas péri-urbanas estamos a testemunhar uma rápida alteração ecológica que as tornam altamente dinâmicas. No presente estudo, a diversidade das espécies vegetais e da biomassa aérea (AGB) foram investigadas em quatro locais péri-urbanos contrastantes, nomeadamente num forno de tijolos, numa pastagem, nos bancos do rio Kali e no campo de cultivo nos trópicos secos na Índia. A ocorrência das espécies foi registada em intervalos mensais durante dois anos. Espécies IVI e AGB foram estimadas sazonalmente para cada local. Nestes locais registaram-se no seu conjunto122 espécies de plantas, predominantemente anuais, e pertencendo a 34 famílias angiospérmicas. Em cada local, a contagem mais elevada de espécies verificou-se na estação seca e a mais baixa no verão enquanto a tendência inversa foi observada para a diversidade β. Entre os locais, a pastagem e os bancos do rio Kali mostraram maior diversidade α and β do que o campo de cultivo ou a do forno de tijolos. A vegetação herbácea mostrou um padrão do tipo mosaico que foi mais pronunciado nos meses secos do que nos húmidos. A dominância específica, alterada com as estações ecológicas e estações evidenciou uma tendência de espécies exóticas como *Parthenium hysterophorus*. Os solos dos locais estudados eram heterogéneos apresentado os do forno de tijolos um teor mais baixo em água, carbono orgânico e razão C:N quando em comparação com as outras estações. O AGB nestes locais (228 to 738 g m^{-2}) mostrou uma variação espacial e temporal larga. Em conclusão, o C orgânico no solo, e os regimes de distúrbio, influenciaram fortemente a composição das espécies e a diversidade destes habitats péri-urbanos nos trópicos secos indianos.

Key words: α and β diversity, brick kiln, dominance-diversity, grazingland, peri-urban vegetation, semi-arid region.

Introduction

Peri-urban areas are highly dynamic and important both ecologically as well as economically. The ecosystem alteration caused by human activities is most apparent in and around urbanizing landscapes (Alberti *et al.* 2003), that accounts for 2% of earth's surface (Grimm *et al.* 2000). As a result of rapid expansion of urban areas, due to increasing human settlements, the species composition of vegetation of peri-urban areas is getting changed. Conversion of peri-urban area into urban area leads to decrease in plant species diversity due to elimination of several important native species, whereas the same conversion may increase the abundance of exotic species. Invasive species have been considered as the second largest threat to biodiversity globally after habitat destruction (Gurevitch & Padilla 2004). Land-use changes, the resultant of increasing human population, has been recognized as one of the major drivers of future changes in biodiversity (Sala *et al.* 2000). Modification of the natural habitats due to growing human population, transportation etc. resulting into accelerated biological invasion has been occurring the world over (Mc Kinney 2002; Rapoport 1991; Schei 1996; Turner *et al.* 2004). The urban and semi-urban environment is highly heterogeneous for plant survival and establishment (Pysek *et al.* 2004). The city floristics is different from semi-natural, natural and man-made habitats outside cities (Kowarik 1995). The spatial organization in cities is usually unique that undergoes change with time resulting into distinctive pattern of species behavior, population dynamics and the formation of communities, each of which is specific to the urban environment (Sukopp 2002).

India has about 285 million urban population. The cities of the northern Gangetic plain area, including Delhi, which is one of the most densely populated regions in the world, have negatively impacted their surrounding areas and are, in turn, being buffeted by the changes in their livelihood. These cities have set a new standard of economic affluence and quality of life (Asgher 2004).

Ghaziabad, NOIDA and Bulandshahr in the western region of Uttar Pradesh and the neighboring districts of Haryana, that comprise the potential emerging satellite cities of Delhi, have witnessed a range of planned and unplanned developmental and human settlement pressure on account of constant interaction and a sharing and trade of resources and burdens with its neighboring area. Bulandshahr assumes a strategic ecological significance here in the light of its location as a relatively less polluted urban center with rural conglomerates, developing under National Capital Region Plan. A mushroom growth of milk industrial units feeding the states of Haryana, Delhi, Rajasthan, Himachal etc., cattle rearing centers, brick kiln industries, interspersed agricultural fields (varying in size) and the Kali river (the river, ill famed for carrying the polluted industrial, municipal and domestic wastes), passing through the main city, have generated a variety of habitats. Various habitats in these regions, characterized by persistent disturbance, are likely to fall prey to invasion by non-native species (Sharma *et al.* 2005). There exists little authentic quantitative ecological information pertaining to vegetational aspects in relation to the environmental conditions in this region. This study was carried out in four contrasting sites in Bulandshahr to document the changes in plant species diversity in relation to seasons, sites and soil characteristics. Herbaceous biomass for these sites was also estimated.

Study area

The study area, Bulandshahr (28º24´ N lat. and 77º51´ E long.), western part of Uttar Pradesh, is located in the upper Doab of the Ganges and Jamuna rivers at an altitude of ca. 180 m above msl. Four study sites viz. (1) Brick kiln (BK), (2) Grazing land (GL), (3) Kali river bank (KRB), and (4) Agricultural land (AL) were selected within 1 km area around the city. BK site was located around an abandoned brick kiln. This site witnessed active brick baking operations for 12 years between 1988 and 2000 at a large commercial scale and was abandoned in 2001. Here, soil surface was generally covered by ash, and pieces of over burnt and half burnt bricks. The GL site was located near a dairy milk industry. The cows, goats, buffaloes, horses etc. frequently grazed around. The third site (KRB) was located along the banks of river Kali in the city. Kali river, a tributary of Ganga, originates from the plains of Uttar Pradesh in Muzaffarnagar district and after a long journey through the districts of Muzaffarnagar, Meerut, Bulandshahr and Aligarh finally merges with Ganga near Mahdurpur village at Kannauj in Farukhabad district. It receives untreated and partially treated industrial effluents and domestic sewage through heavily silted drains. The fourth study site was the agricultural land (AL) located close to BK and GL sites. This site was earlier occupied by a mango-guava orchard. With the establishment of a brick kiln industry in the vicinity and thereafter depleted fruit production in succeeding years, this area witnessed shift to cereal and vegetable cultivation during the last 14 years. During the study period, wheat (the staple food of the region) was cultivated in winter season, but no crop was cultivated in summer and rainy seasons. At each site, 1-2 ha land was selected for study.

The climate of the study area is semi-arid having three seasons, rainy (July-October), winter (November-February) and summer (March-June). The monthly mean minimum temperature ranged from 7.3ºC (January) to 29.7ºC (June), and the mean maximum from 16.9ºC (January) to 39.6ºC (June) (data collected at Bulandshahr research station of Sardar Vallabh Bhai Patel University of Agriculture & Technology). Annual mean rainfall (2001-2004, based on data available at Bulandshahr district head quarter) was 513 mm.

Materials and methods

Plant sampling

Floristic composition of the study sites was recorded at monthly intervals from January 2003 to December 2004. The plant species were identified according to Gaur (1999) and Sharma (1980). The phytosociological data were obtained during the three seasons from a total of 245 randomly laid quadrats (each 25 cm × 25 cm), across the four selected sites. Every emergent tiller was considered as one individual for density estimation of grasses. Diameter of 1-3 representative individuals of every species in each quadrat was measured using a screw gauge. For plants with rosette habit, the circumference of the shoot, usually a group of leaves at the ground level, was measured. In case of species with relatively higher density (>20 individuals) in a quadrat (e.g. *Cynodon dactylon, Cyperus rotundus, Dactyloctenium aegypticum*) basal diameter of 10-15 representative individuals of each species per site was measured. Basal cover was used as a dominance measure. Importance Value Index (IVI) of each species was calculated according to Curtis & McIntosh (1951) and relative importance value index (RIVI) as IVI/3 according to Risser & Rice (1971).

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 RIVI in two communities; aN = sum of RIVI of all species in community A; bN = sum of RIVI of all species in community B.

Species diversity

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

α & β 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 importance attribute of all species, pi = proportional importance of i^{th} species (ni/N), ni = importance attribute of each species and N_{max} = importance attribute of the most important species. Species diversity indices were calculated by using RIVI.

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)

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

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 & Parker 1970)

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

D_9, Simpson index (Simpson 1949)

$$D_9 = \Sigma pi^2$$

Diversity estimates by different diversity indices were subjected to Pearson-product moment correlation analysis (two tailed significance) by using SPSS 10.0 to examine the interrelationships among them.

β diversity

α and 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).

Plant biomass

Aboveground biomass (AGB) was estimated through ground level harvesting in 170 quadrats (each 400 cm^2) laid randomly across the four selected study sites in three seasons. The aboveground tissues were considered to be within the quadrat if they were connected to a tiller that was rooted in the quadrat. In the laboratory, plant samples were washed, dried at 60-80°C for 36-48 hours and weighed.

Soil analysis

Four representative surface soil samples (0-10 cm) were collected from each study site during

June 03, October 03 and February 04. 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) of each soil sample were estimated according to Piper (1944).

Results

Species composition

A total of 122 plant species from 34 families (31 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 (84), followed by winter (68) and summer (49) seasons. The herbaceous species belonging to Poaceae (25), Asteraceae (11), Leguminosae (10), Malvaceae (8), Cyperaceae (7) and Amaranthaceae (7) comprised more than 55% of the total flora. Of this, the grasses belonging to Poaceae and Cyperaceae alone accounted for more than 25% of the total species. In terms of total number of plant species recorded during survey visits (the simplest α diversity measure), the diversity order at each site was rainy > winter > summer (Table 1). The species count and the range of its variation in different seasons at a site

Table 1. Seasonal changes in relative importance value index (RIVI) of top five dominants at four contrasting peri-urban habitats in Indian dry tropics. RIVI values of these species if found at other sites (irrespective of their ranks) are also shown.

Species name	Rainy season				Winter season				Summer season		
	AL	BK	KRB	GL	AL	BK	KRB	GL	BK	KRB	GL
Alternanthera polygonoides (Linn.) R. Br.	-	-	-	-	-	-	-	-	-	7.8	-
Alternanthera sessilis (L.) DC.	-	-	-	-	-	0.7	21.2	-	2.2	4.8	2.5
Anagallis arvensis L.	-	-	-	-	6.0	-	1.6	5.4	-	-	-
Argemone mexicana L.	-	-	-	0.9	-	-	2.2	5.9	-	5.1	-
Blumea lacera (Burm. F.) DC.	-	-	-	-	-	7.9	0.5	-	-	-	-
Boerhavia diffusa L.	-	0.4	-	-	-	-	-	-	5.3	1.1	-
Calotropis procera (Aiton) Dryander	-	0.9	2.8	-	-	1.3	1.2	1.5	2.7	5.2	1.5
Cannabis sativa L.	-	-	-	-	1.0	-	0.5	3.8	-	1.4	13.5
Cassia obtusifolia L.	3.3	1.4	7.1	5.5	-	-	-	-	-	-	1.7
Chenopodium album L.	-	-	-	-	5.3	-	0.6	-	-	-	-
Chenopodium murale L.	-	1.2	-	1.9	-	11.9	0.8	18.6	8.1	-	20.6
Croton bonplandianum Baillon	3.2	-	4.4	2.0	-	0.8	1.7	3.3	-	8.2	3.9
Cynodon dactylon (L.) Persoon	24.2	2.4	26.9	22.8	1.3	-	17.2	9.0	4.3	26.4	21.0
Cyperus rotundus L.	10.2	-	16.9	23.8	-	5.2	2.9	1.1	3.7	1.7	1.5
Dactyloctenium aegypticum (L.) P. Beauv.	9.8	22.1	-	5.5	-	-	-	-	3.6	-	-
Digitaria biformis Willd.	-	8.4	-	3.4	-	-	-	-	-	-	-
Eragrostis ciliaris (Linn.) R.Br.	5.9	5.2	2.9	-	-	-	-	-	-	-	-
Euphorbia hirta L.	-	14.3	-	-	-	0.9	-	-	3.3	-	-
Launaea asplenifolia (Willd.) Hook. F.	-	1.3	-	-	-	-	-	-	4.8	-	-
Malva sylvestris L.	-	-	-	-	-	-	4.1	5.2	-	-	-
Medicago sativa L.	-	-	-	-	2.9	13.5	1.6	0.7	-	-	-
Oxalis corniculata L.	-	-	-	-	1.1	-	0.9	8.7	-	-	-
Parthenium hysterophorus L.	2.0	1.0	4.1	4.9	4.4	1.6	7.4	5.4	4.0	22.1	16.6
Paspalidium flavidum (Retz.) A. Camus	8.2	10.3	-	-	-	-	-	-	-	-	-
Phalaris minor Retz.	-	-	-	-	8.8	-	-	-	-	-	-
Rumex dentatus L.	-	-	-	-	1.0	-	12.7	2.0	-	-	-
Saccharum munja Roxb.	-	11.1	2.6	-	-	35.5	-	-	30.9	-	-
Sida acuta Burm. F.	3.4	2.2	8.2	6.4	-	0.8	2.7	2.1	5.2	2.2	2.5
Stellaria media (L.) Villars	-	-	-	-	22.4	3.1	2.4	5.2	-	-	-
Triticum aestivum L.	-	-	-	-	32.1	-	-	-	-	-	-
Other species (no. in parenthesis)	30.0	17.8	24.1	22.8	13.7	16.8	17.8	22.3	22.0	14.0	14.8
	(11)	(13)	(12)	(15)	(10)	(9)	(16)	(15)	(9)	(12)	(8)
Total no. of species (monthly survey-based)	33	35	63	56	22	31	46	41	26	28	22

Codes: AL (Agricultural land), BK (Brick kiln), KRB (Kali river bank), GL (Grazing land) study sites.

showed much higher diversity at KRB and GL compared to AL and BK sites. The plant species that generally occurred at every study site across all seasons included *Achyranthes aspera, Chenopodium murale, Cynodon dactylon, Cyperus rotundus, Parthenium hysterophorus, Sida acuta* and *Sida rhombifolia*.

In the rainy season, grasses like *Cynodon dactylon* and *Cyperus rotundus* were the leading dominants at AL, KRB and GL sites, together accounting for 34-47% of total RIVI (Table 1). At BK site, in this season, *Dactyloctenium aegypticum*, *Euphorbia hirta* and *Saccharum munja* together accounted for over 47% of RIVI. *Sida acuta* was the third leading dominant at KRB (RIVI 8.2) and GL (6.4) in the rainy season. In winter season, the top leading dominant at all four study sites was distinctly different: *Saccharum munja* dominated at BK, *Alternanthera sessilis* at KRB, *Chenopodium murale* at GL and the cultivated crop of *Triticum aestivum* at AL. On the other hand, in summer season *Cynodon dactylon* dominated at both KRB and GL sites, with *Parthenium hysterophorus* as the second most dominant component at KRB, but third most dominant at GL after *Chenopodium murale* here. At BK in the summer season *Saccharum munja* alone was distinctly prominent accounting for 31% RIVI.

Inter-site species composition comparison

Similarity coefficient revealed that dominant species composition tended to exhibit distinctness with respect to site and season (Table 2). In the rainy season, the intersite differences in terms of dominant species varied narrowly. While BK vegetation, showed very low similarity (18-35%) with other three study sites, the GL and KRB site vegetation exhibited much higher similarity (67%). In summer too, high similarity (55%) was observed between GL and KRB. Winter vegetation across different study sites showed these sites as distinct and dissimilar (similarity < 50%).

Soil properties

The soils of the study sites were neutral to slightly basic (pH 6.9 - 7.9) (Table 3). BK soil characteristics, comparable to AL soil, showed lower moisture content, organic carbon and C:N ratio compared to GL and KRB soils.

Species diversity

Dominance-diversity curves for vegetation at different sites and seasons showed that generally one or two species in the vegetation at all sites exploited major share of resources (Fig. 1). This

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

	RBK	RKRB	RGL	WAL	WBK	WKRB	WGL	SBK	SKRB	SGL
RAL	0.35	0.55	0.57	0.03	0.09	0.27	0.17	0.21	0.34	0.34
RBK		0.18	0.21	0.02	0.19	0.08	0.09	0.32	0.09	0.12
RKRB			0.67	0.05	0.15	0.32	0.21	0.29	0.48	0.42
RGL				0.06	0.15	0.33	0.24	0.27	0.38	0.43
WAL					0.11	0.15	0.26	0.07	0.07	0.08
WBK						0.19	0.29	0.54	0.09	0.25
WKRB							0.42	0.21	0.43	0.38
WGL								0.22	0.32	0.48
SBK									0.21	0.31
SKRB										0.55

Codes: R (Rainy), W (Winter), S (Summer) seasons, prefixed with AL (Agricultural land), BK (Brick kiln), KRB (Kali river bank), and GL (Grazingland) study sites.

Table 3. Ranges of soil characteristics at four different sites in Bulandshahr.

Parameters	AL	BK	KRB	GL
Summer moisture (%)	0.99 - 1.02	1.01 - 2.04	1.35 - 5.63	1.01 - 3.46
pH	7.8 - 7.9	7.3 - 7.7	7.0 - 7.9	6.9 - 7.3
Org C (%)	0.39 - 0.66	0.11 - 0.31	0.84 - 1.16	1.14 - 1.33
C:N ratio	18 - 21	8 - 10	28 - 31	17 - 18

Codes: AL (Agricultural land), BK (Brick kiln), KRB (Kali river bank), GL (Grazingland)

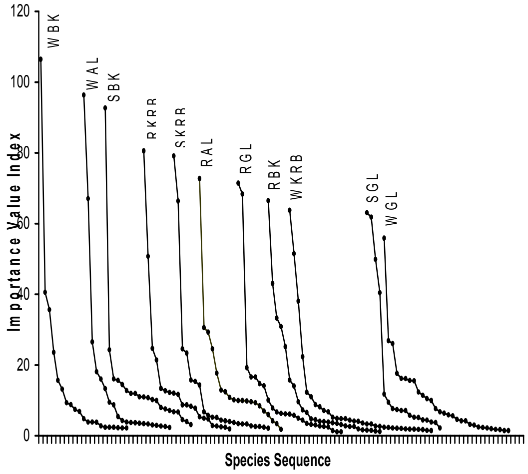

Fig. 1. Dominance-diversity curves of vegetation across different sites and seasons. The first letter of the code indicates season (R: rainy, W: winter, S: summer) and the next two/three letters indicate study sites (AL: Agricultural land, BK: Brick kiln, KRB: Kali river bank, GL: Grazingland).

trend was more apparent in vegetation at BK in winter and summer where a near geometrical pattern of resource share was noticed. Here, *Saccharum munja* seems to exploit major resources as, evident by its largest share of IVI. However, in rainy season, this resource share pattern of species at BK site tended to change due to the altered top dominant *Dactyloctenium aegypticum*. GL showed close resource share contest among grasses, e.g. *Cynodon* and *Cyperus* in summer and rainy seasons. However, in winter season dominance by *Chenopodium murale* at this site, tended to increase the geometric character of the dominance-diversity curve as shown by its initial segment. At KRB site, four species appear to be contesting well for the top position, which is better reflected in the winter season. However, *Alternanthera sessilis* showed pronounced dominance in winter and *Cynodon dactylon* in summer and rainy seasons here.

Table 4 summarizes the seasonal diversity levels, in terms of nine diversity indices at different sites using RIVI of species (i.e. N = 100). 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 the winter season at KRB. However, in terms of information statistic indices (Shannon, D_4 and Brillouin, D_6), the GL showed the maximum value in this season. Besides, this site also showed maximum range of diversity variation across seasons. In contrast, the AL site in winter season showed the lowest value. In terms of absolute value, for the same data, D_4 was always greater than D_6. Dominance measures (Berger-Parker, D_8 and Simpson, D_9) showed higher values for sites showing lower diversity e.g. BK and AL sites in winter in particular. The highest values of dominance concentration (D_9) in summer and rainy season were found at KRB and GL. In winter, however, AL and BK showed maximum dominance concentrations. Absolute value of D_8 was always greater than D_9. The evenness measure in this study D_7 (Brillouin-derived) is comparable to D_5 although its values are slightly higher. In the rainy season KRB and AL sites showed maximum evenness. In contrast, BK showed greater evenness in summer and GL in winter.

Table 4. Diversity estimates of the vegetation at various study sites in three seasons using different diversity indices.

Diversity indices	Rainy				Winter				Summer			Max/ Min
	AL	BK	KRB	GL	AL	BK	KRB	GL	BK	KRB	GL	
D_1 (Species count)	20.00	27.00	21.00	25.00	21.00	21.00	34.00	30.00	21.00	23.00	18.00	1.89
D_2 (Margalef)	4.13	5.65	4.34	5.21	4.34	4.34	7.17	6.30	4.34	4.78	3.69	1.94
D_3 (Menhinick)	2.00	2.70	2.10	2.50	2.10	2.10	3.40	3.00	2.10	2.30	1.80	1.89
D_4 (Shannon)	2.64	2.61	2.51	2.54	2.25	2.27	2.78	2.95	2.62	2.42	2.30	1.31
D_5 (Evenness, Pielou)	0.88	0.79	0.82	0.79	0.74	0.75	0.79	0.87	0.86	0.77	0.80	1.19
D_6 (Brillouin)	2.41	2.31	2.37	2.36	2.02	2.11	2.49	2.72	2.47	2.21	2.12	1.35
D_7 (Evenness, Brillouin)	0.91	0.81	0.87	0.83	0.76	0.78	0.82	0.92	0.91	0.80	0.83	1.21
D_8 (Berger Parker)	0.24	0.22	0.27	0.24	0.32	0.36	0.21	0.19	0.31	0.26	0.21	1.91
D_9 (Simpson)	0.09	0.10	0.12	0.12	0.17	0.17	0.10	0.06	0.12	0.13	0.13	2.58
β Diversity	1.98	3.68	6.12	4.78	2.36	5.16	11.21	6.66	5.53	9.86	6.43	5.66

Codes: AL (Agricultural land), BK (Brick kiln), KRB (Kali river bank), GL (Grazingland) study sites.

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 (2.58), followed by Margalef (1.94) and Berger-Parker (1.91) (Table 4). The most widely used Shannon index showed a ratio of only 1.31.

The interrelationship among the diversity indices is shown in Table 5. All diversity indices were positively correlated to each other, except the dominance measures D_8 and D_9, that were negatively correlated to other indices. Species richness indices (D_1, D_2 and D_3) were significantly correlated to Shannon (D_4) and Brillouin's (D_6) indices ($r = 0.61$-0.74, $p < 0.01$). Evenness indices D_5 and D_7 showed poor and insignificant relation with species richness indices (D_1, D_2 and D_3), but were significantly related with D_9 and information statistic indices (D_4 and D_6).

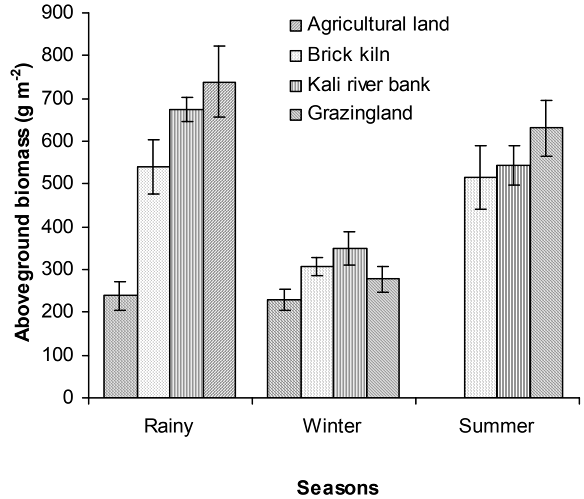

Fig. 2. Aboveground biomass (mean ± S.E.) in different seasons at four contrasting periurban study sites.

β diversity

α and β diversity ranged between 1.98 and 11.21 (Table 4). It was lowest at AL site. α and β diversity generally increased in winter and summer compared to that in rainy season for all study sites. α and β diversity at KRB site was maximum in all seasons compared to that at other study sites.

Herb aboveground biomass

Across all sites and seasons, the mean plant AGB ranged between 228 g m^{-2} and 738 g m^{-2} (Fig. 2). The AGB at all sites in different seasons was in the order: rainy > summer > winter. The GL and KRB vegetation exhibited much greater standing crop compared to BK or AL. Rainy season biomass increment over summer biomass was highest at KRB (about 24.2%), followed by GL (17.1%) and only about 4.6 % at BK. However, decline of winter biomass of a site from its rainy season biomass was maximum at GL (about 62%) followed by KRB (48%) and BK (42%). AL showed relatively less seasonal variation in AGB. While the inter-site standing crop difference in summer (max - min = 115 g m^{-2}) and winter (121 g m^{-2}) seasons was relatively narrow, it differed much in rainy season (500 g m^{-2}).

Stand structure and soil properties

In this study, the basal cover per individual declined with increasing stand density ($R^2 = 0.76$, $p < 0.01$) (Fig. 3a), indicating that large number of annuals dominate young stands with short life span. The relation between Berger-Parker index of diversity (a dominance measure) and soil organic carbon, although insignificant (may be owing to smaller value of n; $R^2 = 0.36$), suggests a plausible negative relation (Fig. 3b). Conversely, β diversity appears to be lower in impoverished soils and higher at relatively nutrient rich soils ($R^2 = 0.33$) (Fig. 3c).

Table 5. Correlation coefficients showing interrelationships among various diversity indices.

	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9
D_1	1.000**	1.000**	.738**	.045	.614*	.018	-.528	-.591
D_2		1.000**	.738**	.045	.614*	.018	-.528	-.591
D_3			.738**	.045	.614*	.018	-.528	-.591
D_4				.703*	.969**	.678*	-.655*	-.945**
D_5					.782**	.988**	-.436	-.783**
D_6						.789**	-.570	-.910**
D_7							-.391	-.745**
D_8								.808**

* Correlation is significant at the 0.05 level (2 tailed),** Correlation is significant at the 0.01 level (2 tailed).

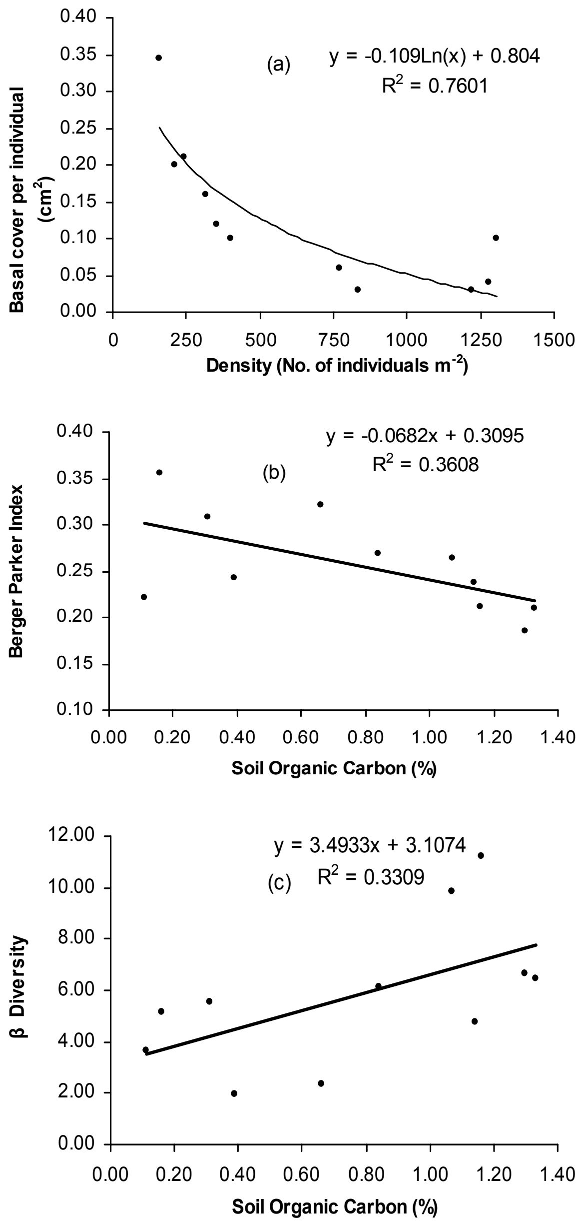

Fig. 3. Stand basal cover per individual and stand density relation (a), and soil organic carbon in relation to α diversity (Berger-Parker index) (b) and β diversity (c).

Discussion

The present ecological investigation across various natural/man-made habitat conditions in a developing peri-urban area of Bulandshahr revealed emergence of vegetation mosaic with a relatively higher plant diversity. The number of species recorded in the present study was higher than the 78 species reported by Sharma *et al.* (2001) for the comparable habitats in a semi-arid region, Sanganer, Jaipur. The predominance of Leguminosae has been suggested as an adaptive feature in the drier conditions (Givnish 1978). Predominance of legumes in the present study may be related to relatively low soil organic C content (0.11-1.33%). Predominance of annuals (as also found in the present study) on disturbed site soils have been reported in several studies (Foster & Stubb-endieck 1980; Tilman 1983). Annuals are suggested to act as opportunists having a short life span and high fecundity that enables them to rapidly colonize the open spaces generated as a result of disturbances. In the present study, species evenness tended to be higher in the rainy season, particularly at AL and KRB sites. During rainy season soil moisture favored occurrence of larger number of the herbaceous plant species and their population on account of semi-arid climate of this area (Sharma & Upadhyaya 2002). However, only a few species occurred throughout the study period (e.g. *Achyranthes aspera, Chenopodium murale, Cynodon dactylon, Parthenium hysterophorus* and *Sida acuta*), evidently due to the wide ecological amplitude of these species under the prevailing climatic conditions. Exotics like *Parthenium hysterophorus* have become naturalized in India, and have affected the distribution of native flora by completing 2-3 generations annually. Occurrence of this species at all sites with increased dominance at KRB and GL suggests that habitats modified due to persisting disturbance (e.g. grazing and anthropogenic pressure) create platform for the onset of biological invasion by such species (Schei 1996).

In the rainy season, the grasses were predominant at the disturbed sites such as GL and BK. As a result of mild grazing, most graminoids grow by increasing their tillers and persist for long time with annuals and finally maintain higher cumulative density of perennials and annuals in grassland (Srivastava & Singh 2005). The growing dominance of non-palatable species such as *Chenopodium murale, Sida acuta, Argemone mexicana* and others in the grazingland, is probably an indication of adaptation against herbivory and adverse climatic conditions. Bhandari *et al.* (1999) made similar suggestion for the alpine pasture of Garhwal Himalaya. The conversion of grassland into agroecosystem leads to sharp change in the standing flora and grassland species do not persist for long under continuously cultivated agroecosystems (Chancellor 1985). In this study the AL under wheat cultivation in winter showed altered standing flora when compared with neighboring GL in this season (similarity only 26%) (Table 2). The distinctness of various study sites observed here was more pronounced in winter season with lowest intersite similarity found in this season (Table 2). Characteristically different leading dominants at each site were recorded in this season e.g. *Alternanthera sessilis* along the sloppy bank of Kali river, forming a mat-like appearance here, is likely to help conserve soil and nutrients. This species has also been recognized for its ethnomedicinal importance for the tribals in Raigarh (Tirkey *et al*. 2004).

Total species count at each site (Table 1) in different seasons showed a common trend of maximum flora in rainy season and minimum in summer, suggesting a general increase in species diversity with moisture availability in dry tropical habitats. However, independent and variable diversity response of these habitats is intelligible in terms of range of diversity variation across different seasons. The inconsistency in ordering of communities by different indices (Kempton 1979; Magurran 1988) is revealed in this study e.g. in winter GL was most diverse followed by KRB in terms of most popular Shannon (information statistic) index, but the order was reversed in terms of species count (richness index) (Table 4). This was due to both species richness and evenness taken into account in the information statistic indices, which assess species diversity more meaningfully (Peet 1974). But, in terms of discriminant ability for site diversities, the dominance measure Simpson index performed much better than Shannon index (May 1975; Routledge 1979). Since various indices are correlated, species number per unit area is often considered the simplest diversity measure. However, there exists little consensus on the best diversity measure (Roy *et al.* 2004). In this study, over all, GL and KRB sites showed greater species diversity compared to AL and BK sites. This appears likely due to better soil conditions at GL and KRB, and low soil nutrients besides long disturbance history at BK, and land-use change at AL. Reduction of plant diversity due to land-use change and environmental stress has been found in various ecosystems e.g. Wilsey & Potvin (2000). On the other hand, high species diversity in urban habitats has often been attributed to high heterogeneity of the urban environment which provides plants with habitats convenient for all kinds of strategies (Gilbert 1989).

Under stress community structure may change through decreasing diversity and increasing dominance (Odum 1985). This held true for BK site where edaphic and climatic stresses have operated for a long time and favored dominance of a stress tolerant perennial grass like *Saccharum munja*. Increased stress at this site can be inferred from its dominance-diversity structure corresponding to relatively higher geometrical pattern of resource share (increased dominance) markedly noticeable in winter and summer seasons compared to that in rainy season (Fig. 1). In contrast to *Saccharum munja* dominance in winter and summer, *Dactyloctenium aegypticum* assumed the highest importance in rainy season here. This species is suggested to be one of the very useful species in soil reclamation of the disturbed habitats (Sharma & Sunderraj 2005).

General increase in β diversity from the lowest in rainy to summer season, as observed in the present study, could be due to gradual reduction of microsite differences, to some extent, in rainy season as a result of environment homogenization impact in soils by plentiful soil moisture. Lososova *et al.* (2004) too reported that in summer weed communities tended to have higher β diversity. Harsh climatic conditions in summer are expected to generate larger variety of micro-site conditions differing in shade intensity, temperature, topographic features e.g. variable size of land depressions, elevation etc. Such local or microsite differences are usually not biological impact generating for higher life forms, e.g. trees, but herbs being sensitive indicators of environment are highly responsive to small scale environmental changes. The highest β diversity recorded at KRB across all seasons could be due to larger heterogeneity of habitat conditions generated by varying topography and dimensions of the river bank. This heterogeneity is further enhanced by rampant animal mobility, untreated urban solid wastes and drain discharges here.

The present study indicates that the increased nutrient status of soils facilitates higher species diversity (as reflected by lower species dominance, Fig. 3b), and enhanced β diversity suggests higher habitat heterogeneity due to increased soil resource (Fig. 3c). The range of micro-sites differing in micro environment increases with relatively enhanced nutrient condition of soil, thus allowing larger number of species with varying ecological amplitude to survive under such conditions.

Lososova *et al.* (2003) have shown the occurrence of temporal dynamics in weed communities on the scale of seasonal changes. This is evident from the present study on aboveground biomass variations in different seasons. The biomass build up strategy of plant assemblages at different sites under study in different seasons shows that the biomass production is conditioned by the environmental harshness e.g. temperature, moisture availability etc. (low site biomass and lower inter-site AGB difference in summer and winter compared to that in rainy season). However, under favorable conditions (e.g. rainy season) different sites exhibited biomass build up differently (Fig. 2). The vegetation mosaic in each territorial area could respond to the environment, but in an independent way, in each patch (Ramirez-Sanz *et al.* 2000). The vegetation at GL and KRB sites showed comparable biomass build up in different seasons that could be the result of floristic similarity between sites (Table 2) because of adaptational response of plants to the biotic/grazing pressure. The AGB range recorded in the present study sites (228 - 738 g m^{-2}) is comparable to the herbaceous biomass range 33-504 g m^{-2} for semi-arid grazingland of Madurai (Meenakshisunderavalli & Paliwal 1997), and 87-848 g m^{-2} for semi-arid habitats in Jaipur (Sharma *et al.* 2001).

The present study in peri-urban area in Indian dry tropics revealed occurrence of a vegetation mosaic more pronounced in dry months than in wet months, where species dominants altered with sites and seasons with increasing prominence of exotic species like *Parthenium hysterophorus*. Further, this study suggests that species diversity and compositional variations at these sites are much influenced by change of seasons, soil organic C and disturbance regimes.

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