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Diversity of tree vegetation of Rajasthan, India

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Abstract: We assessed tree diversity of tropical dry deciduous forest in Rajasthan at five sites (Jalmahal, Ramgarh, Nahargarh, Jhalana and Digota). A total of 102 circular plots was laid and all tree species ≥10 cm girth at breast height were enumerated. Tree diversity totalled 69 species and the Digota site harboured the maximum number of families (19), genera (25) and species (36). Mimosaceae (7 genera and 15 species) was the most species-rich family at all the sites. Shannon diversity (2.44) and species heterogeneity (2.23) were highest for Ramgarh site while species richness and ß diversity were highest for Digota (3.62 & 5.55) site. *Cassia fistula*, *Butea monosperma* and *Ehretia laevis* were the only species exhibiting regular distribution while all others showed random or contagious distribution. The forest composition varied across the sites. The study provides an understanding of tree distribution at landscape level.

Resumen: Evaluamos la diversidad de árboles del bosque tropical seco caducifolio de Rayastán en cinco sitios (Jalmahal, Ramgarh, Nahargarh, Jhalana y Digota). Se colocaronen total 102 parcelas circulares y se enumeraron todas las especies de árboles ≥ 10 cm de perímetro a la altura del pecho. La diversidad de árboles alcanzóla cifra de 69 especies y el sitio Digota albergólosmayores números de familias (19), géneros (25) y especies (36). Mimosaceae (7 géneros y 15 especies) fue la familia más rica en especies en todos los sitios. La diversidad de Shannon (2.44) y la heterogeneidad de especies (2.23) tuvieron los valores mayores en el sitio Ramgarh, mientras que la riqueza de especies y la diversidad ß fueron más altos en Digota (3.62 y 5.55). *Cassia fistula, Butea monosperma* y *Ehretia laevis* fueron las únicas especies que presentaron una distribución regular, mientras que todos los demás mostraron una distribución aleatoria o contagiosa. La composición del bosque varió entre los sitios. El estudio brinda una comprensión de la distribución de los árboles a nivel de paisaje.

Resumo: A diversidade de árvores da floresta decídua tropical em Rajasthan,foi avaliada em cinco locais (Jalmahal, Ramgarh, Nahargarh, Jhalana e Digota). Foram marcadas 102 parcelas circulares onde todas as espécies de árvores ≥ 10 cm circunferência à altura do peito foram enumeradas. A diversidade de árvores totalizou 69 espécies e no sítio Digota abrigava o número máximo de famílias (19), gêneros (25) e espécies (36). As Mimocaceae (7 géneros e 15 espécies) foi a família mais rica em espécies em todos os sítios. A diversidade de Shannon (2,44) e a heterogeneidade de espécies (2,23) foram maiores para o local Ramgarh, enquanto a riqueza de espécies e a diversidade ß foram maiores para sítio Digota (3,62 e 5,55). A *Cassia fistula, Butea monosperma* e *Ehretia laevis* foram as únicas espécies que apresentaram uma distribuição regular, enquanto que todas as outras apresentaram uma distribuição aleatória ou contagiosa. A composição da floresta variou através dos sítios. O estudo fornece uma compreensão da distribuição arbóreaao nível da paisagem.

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Key words: Distribution, diversity index, dominance curve, dry deciduous forest, Importance Value Index, Rajasthan, Whitford's Index.

The Aravalli hills form the skyline of north-west India i.e. Gujarat, Rajasthan, Haryana states and Delhi union territory stretching in the south-west and north-west direction

. These hills mainly represent tropical dry deciduous forest which is one of the world's most threatened ecosystems (Gentry 1992) and is being gradually converted to scrub and savanna (Sagar & Singh 2005). The rapid conversion of tropical forests for agriculture, timber production and other uses has generated vast, human-dominated landscapes with poten-tially dire consequences for tropical biodiversity (Gibson *et al*. 2011; Sahoo & Davidar 2013). The depletion of the resource base of the dry tropical forest is causing concern (Bhuiyan *et al*. 2009; Rathore 2002) and conservation of these forests will always depend on a sound understanding of forest ecosystem (Sussman & Rakotozafy 1994).

Quantitative floristic inventories of forest ecosystems provide necessary context for under-standing, planning and interpreting long-term ecological research (Phillips *et al*. 2003; Baithalu *et al*. 2013). The information resulting from forest inventories not only provides data on the floristic composition and abundance of individual species, but also on detailed structural attributes of the vegetation (Palomino & Alvarez 2009). Rajasthan is the largest state in India, occupying an area of about 3,42,239 km², or about 11 % of total area of India. The forest covers only about 37,638 km² i.e. 11 % and this includes roughly 7 % of the depleted and denuded forests (Forest Survey of India 2009). The aim of this paper is to generate quantitative information on tree species richness of tropical dry deciduous forest in Aravalli hill ranges at different sites.

The present study was conducted in Jaipur and Alwar districts. Five sites were selected i.e. forest near Jalmahal (26° 57′ 41.45″ N & 75° 51′ 03.25″ E), Nahargarh sanctuary (26° 56′ 21.80″ N & 75° 48′ 51.70″ E), Jhalana Dungri forest (26° 51′ 12.31″ N & 75° 50′ 00.76″ E), Jamwa Ramgarh sanctuary (27° 01′ 06.97″ N & 75° 00′ 48.12″ E) and Digota forest range (27° 08′ 38.67″ N & 76° 14′ 54.28″ E Alwar district). These sites have a dry climate except for the south-west monsoon season. The average annual rainfall in the area is 556.4 mm and temperature ranges from 48 °C to 8.3 °C within the year. The altitude of study area ranges from 240 m to 500 m asl.

Phytosociological analysis of tree and shrub species at each sampling site was carried out by laying a total of 102 circular plots (20 plots each in Nahargarh, Jhalana and Jalmahal while 21 plots each in Dikota and Ramgarh sites) each of 10 m radius in March 2006 and September 2009. The girth at breast height (GBH) of all trees was measured (Misra 1968) and later classified into various size categories (15 - 40 cm, 41 - 80 cm, 81 - 120 cm & >120 cm). Basal area was used as a dominance measure. Importance Value Index (IVI) of each species was also calculated (Cottam & Curtis 1956). The ratio of abundance to frequency (A/F) for different species was determined for eliciting the distribution pattern. This ratio indicates regular (< 0.025), random (0.025 - 0.05) and contagious (> 0.05) distribution patterns (Whitford 1949).

Coefficient of similarity among sites was calculated using the modified Sørensen's coefficient (Southwood 1978) by taking density into account.

Sørensen's Coefficient (S_S) = 2jN / aN + bN

where, jN = Sum of lesser values of density in two sites; aN = Sum of density of all species in site a; bN = Sum of density of all species in site b.

Similarity Index of different sites was also calculated by taking into account only the number of species (Janson & Vegelius 1981).

Similarity Index (SI) = 2j/(a+b), where, j = the number of species found at both sites, a = the number of species found in site a and b = the number of species found in site b. A value of 1 suggests complete similarity while 0 indicates complete dissimilarity.

Thus two different similarity indices were used to compare the sites by considering species density and composition.

Vegetation parameters such as Shannon diversity (H') (Shannon & Weaver 1963), species richness (D) (Margalef 1958), and concentration of dominance (Cd) (Simpson 1949), were calculated for each site.

$H' = -\sum pi \ln pi$, where, pi = ni/N, ni = individuals of species 'i', N = total number of individuals of all species and $D = S/\sqrt{N}$, where, S = total number of species, N = number of individuals of all species.

Species heterogeneity is defined as the reciprocal

Table 1. Density and diversity indices of plants at five sites of tropical dry deciduous forests of Rajasthan.

Variables	Values				
	Jalmahal	Ramgarh	Nahargarh	Jhalana	Digota
Number of families	10	16	10	10	20
Number of genera	13	24	15	17	26
Number of species	14	26	20	18	36
Tree density (stems ha^{-1})	917.2	1716.7	1093.9	1013.3	1367.9
Basal area (m^2 ha^{-1})	3.00	32.73	14.18	4.73	26.32
Shannon-Weiner index	1.89	2.44	2.43	1.92	2.11
Simpson's index	0.16	0.10	0.11	0.17	0.16
Margelef's species richness	1.95	3.38	3.49	2.42	3.62
Evenness index	0.78	0.86	0.92	0.73	0.65
Species heterogeneity	1.77	2.23	2.15	1.75	1.81
ß diversity	3.23	4.14	3.5	2.85	5.55

Table 2. Similarity (Sørensen's coefficients) in species composition (SI)/density (S_S) in five sites of tropical dry deciduous forest of Rajasthan.

	SI/S_S				
Site	Jalmahal	Ramgarh	Nahargarh	Jhalana	Digota
Jalmahal	1.0/1.0	0.57/0.40	0.50/0.59	0.64/0.90	0.33/0.48
Ramgarh		1.0/1.0	0.39/0.75	0.45/0.47	0.43/0.89
Nahargarh			1.0/1.0	0.35/0.67	0.20/0.86
Jhalana				1.0/1.0	0.25/0.56
Digota					1.0/1.0

of Simpson's Index or under root of Concentration of Dominance (Cd) ($Cd = \sum pi^2$).

Beta diversity (ß - diversity) was computed following Whittaker (1972) as (ß) = Total number of species in all sites / average number of species. All values were log and arcsine transformed to achieve normality in the data.

A total of 23 families, 45 genera, 69 species and 3367 individuals of tree species were encountered in five sites of the tropical dry deciduous forest. Digota site had the maximum number of families (20) whereas sites Nahargarh, Jhalana and Jalmahal had ten families each (Table 1). The number of tree species recorded in the present study is lower than the number of species reported in other Indian tropical dry forests (Chowdhury *et al*. 2000; Khera *et al*. 2001) but higher than that reported by Nirmal Kumar *et al*. (2010). Among all families, Mimosaceae had the maximum number of species (Appendix Table 1).

In the surveyed sites, tree density and basal area were maximum at Ramgarh sanctuary and minimum at Jalmahal forest (Table 1). *Anogeissus pendula* (IVI = 172.99; 28.35 % of the total), *Boswellia serrata* (IVI = 45.65) and *Acacia senegal* (IVI = 42.63) emerged as the dominant species when data were pooled across five sites (Appendix Table 1). *Capparis decidua* (IVI = 0.75) and *Crataeva adansonii* (IVI = 0.73) were the least dominant species at all sites. Thus the tropical dry deciduous forest was dominated by few species only as also reported for the tropical forest in Udaipur (Nirmal Kumar *et al*. 2011) and Eastern Ghats (Kadavul & Parthasarathy 1999). Dominance-distribution curve for tree species at all sites showed that generally one or two species in the vegetation exploited major resources (Fig. 1). Distribution of plants in different age groups suggests a dominating intermediate age group at all sites (Fig. 2). No voluminous tree was found in Nahargarh and Jhalana sites (>120 cm GBH). Mature trees up to 155 cm GBH were found in Ramgarh and Digota only. A low tree density in lower girth class could be attributed to grazing intensity.

Sørensen's similarity coefficient (S_S & SI) values revealed a marked difference in the distribution of plant species among the sites (Table 2). Jalmahal forest showed maximum similarity with Jhalana forest (SI = 0.64) and the least with Digota forest (SI = 0.33). The low similarity with the Digota site could be attributed to the presence of exclusive species such as *Acacia catechu, Ano-*

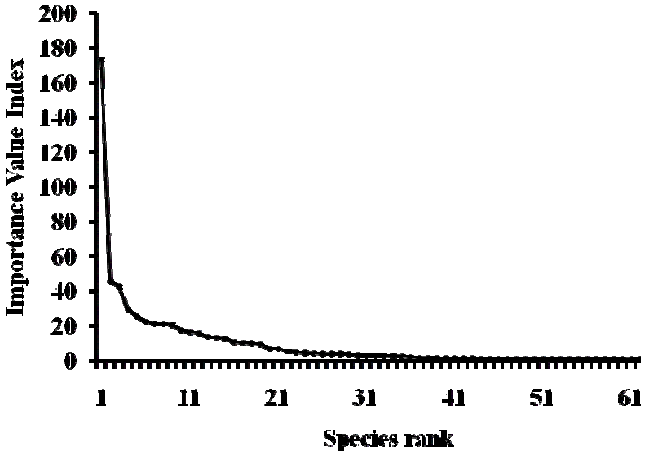

Fig. 1. Dominance-diversity curve for tropical dry deciduous forest of Rajasthan. Data from five sites were pooled.

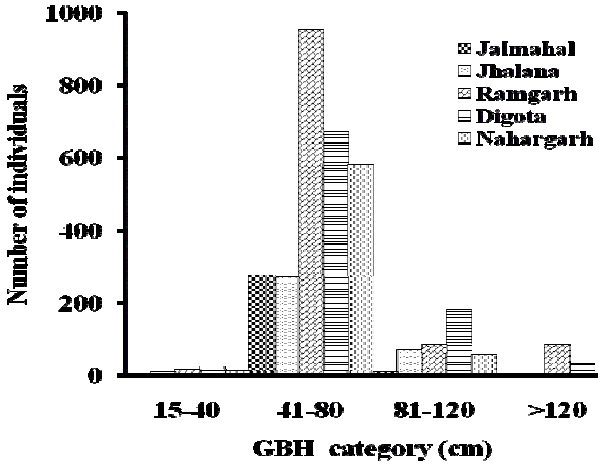

Fig. 2. Density-GBH distribution patterns in five sites of the tropical dry deciduous forest of Rajasthan.

geissus latifolia, Anogeissus sericea, Albizia procera, Bombax ceiba, etc. at this site of Alwar district. Ramgarh forest was denser in comparison with Jalmahal forest, whereas Digota and Ramgarh forests were also closer in the density of plant species (S_S = 0.89). Jhalana - Digota and Nahargarh - Digota forests were least similar in terms of species composition (SI = 0.25 & SI = 0.20, respectively, Table 2). *Tecomella undulata* was encountered only in Jhalana forest while *Rhus mysurensis* occurred only in Nahargarh sanctuary. Species such as *Anogeissus pendula, Butea monosperma, Dicrostachys cinerea* and *Boswellia serrata* occurred in all forests. The trend in tree diversity in five sites as per Shannon-Wiener diversity index was in the order of Ramgarh > Nahargarh > Digota > Jhalana > Jalmahal (Table 1). The highest diversity index was recorded in Ramgarh Sanctuary which is a protected area while Jalmahal and Jhalana forests are disturbed forests. The diversity range is higher than that reported by Nirmal Kumar *et al*. (2010) in tropical dry deciduous forest and lower than the value of 4.51 reported by Sahu *et al*. (2007) in Orissa.

The concentration of dominance was in the order Jhalana > Digota > Jalmahal > Nahargarh > Ramgarh. Concentration of dominance in the present study is within the reported range of 0.10 - 0.99 for tropical forests (Sahu *et al*. 2007), while the average value as reported by Knight (1975) is 0.06. Whittaker (1975) also reported high species diversity and low dominance in species-rich communities. The Margelef's species richness-ranged from 3.62 for Digota forest to 1.95 for Jalmahal forest. The maximum evenness was for Nahargarh (0.92) while the minimum for Digota forest. Species heterogeneity was higher in the Ramgarh forest (2.23) followed by Nahargarh (2.15) and Digota (1.81); the values are slightly lower than those reported by Nirmal Kumar *et al*. (2010) for Udaipur district whereas ß diversity ranged between 5.55 and 2.85 (Table 1) which is comparable to the earlier study of Nirmal Kumar *et al*. (2010). Greater ß diversity showed greater habitat specialisation in Digota and Ramgarh forests than Jalmahal and Jhalana forests.

Among the 69 species recorded, maximum number of species exhibited random and contagious distribution patterns. *Cassia fistula* (Whitford Index = 0.01), *Butea monosperma* (0.02), *Ehretia laevis* (0.02) showed regular distribution (Appendix Table 1). According to Odum (1971), the clumped distribution is common in nature and regular as well as the random distributions reflect the magnitude of biotic interference such as grazing and lopping in the natural forests. *Anogeissus pendula* (0.30), *Acacia senegal* (0.13), *Boswellia serrata* (0.07) showed contagious pattern while *Acacia catechu* (0.04), *Albizia odorattissima* (0.03) and *Diospyros melanoxylon* (0.03) were distributed in a random manner. The differences in the dispersion patterns among sites did occur which may reflect the response of species to disturbance as well as to changes in the habitat conditions (Sagar *et al*. 2003).

The presence of exotic species *Prosopis juliflora* is notable at Jalmahal, Jhalana and Nahargarh sanctuary showing random distribution and it could be a potential threat to native species (Robinson 2003) in the future and thus warrants a check.

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Appendix Table 1. Phytosociological attributes (No. of individuals, Importance Value Index - IVI, and distribution pattern according to Whitford's Index - WI) of plant species in the studied five sites of tropical dry deciduous forest of Rajasthan.

(1 = Jalmahal, 2 = Ramgarh, 3 = Nahargarh, 4 = Jhalana, 5 = Digota, R = Random, C = Contagious, RG = Regular).

Rank	Species	Family	1	2	3	4	5	IVI	WI
			No. of individuals						
1	*Anogeissus pendula* Edgw.	Combretaceae	239	848	218	217	721	172.99	C
2	*Boswellia serrata* Roxb.	Burseraceae	3	113	0	1	40	45.65	C
3	*Acacia senegal* Willd.	Mimosaceae	4	2	240	58	0	42.63	C
4	*Butea monosperma* Lam.	Fabaceae	4	22	16	1	0	29.62	RG
5	*Dichrostachys cinerea* L.	Mimosaceae	7	7	3	10	12	25.63	C
6	*Sterculia urens* Roxb.	Sterculiaceae	0	10	0	0	2	22.35	C
7	*Prosopis juliflora* DC.	Mimosaceae	21	0	67	4	0	21.31	R
8	*Lannea coromandelica* Houtt.	Anacardiaceae	1	13	0	0	5	21.13	C
9	*Commiphora wightii* Arm.	Burseraceae	10	10	0	7	0	20.48	C
10	*Holoptelea integrifolia* Roxb.	Ulmaceae	3	0	0	20	6	17.57	R
11	*Acacia catechu* Willd.	Mimosaceae	0	0	0	0	42	16.40	R
12	*Acacia leucophloea* Willd.	Mimosaceae	0	12	8	0	3	15.87	C
13	*Lycium barbarum* L.	Solanaceae	0	78	0	0	0	13.61	C
14	*Prosopis cineraria* L.	Mimosaceae	0	1	16	0	0	13.22	C
15	*Acacia nilotica* L.	Mimosaceae	0	0	23	0	0	12.64	C
16	*Flacourtia indica* Burm.	Flacourtiaceae	0	0	16	0	0	10.74	C
17	*Diospyros melanoxylon* Roxb.	Ebenaceae	0	3	0	0	16	10.35	R
18	*Acacia tortilis* Forsk.	Mimosaceae	0	0	6	15	0	10.01	R
19	*Cassia fistula* L.	Caesalpiniaceae	1	6	0	0	5	9.40	RG
20	*Albizia procera* Benth.	Mimosaceae	0	0	0	0	7	6.77	C
21	*Ehretia laevis* Roxb.	Ehretiaceae	0	3	0	0	7	6.69	RG
22	*Cordia gharaf* Forsk.	Ehretiaceae	0	1	0	2	0	5.42	C
23	*Anthocephalus cadamba* Roxb.	Rubiaceae	0	0	0	0	8	4.70	R
24	*Anogeissus sericea* Brand.	Combretaceae	0	0	0	0	6	4.45	C
25	*Dalbergia sissoo* Roxb.	Fabaceae	0	0	36	0	0	4.35	R
26	*Rhus mysurensis* G. Don	Anacardiaceae	0	0	4	0	0	3.99	C
27	*Bauhinia racemosa* Lam.	Caesalpiniaceae	0	0	0	4	0	3.98	C
28	*Tecomella undulata* Sm.	Bignoniaceae	0	0	0	9	0	3.96	R
29	*Cordia dichotoma* Forst.	Ehretiaceae	0	0	0	0	4	3.85	C
30	*Anogeissus latifolia* Wall.	Combretaceae	0	0	0	0	2	3.06	C
31	*Moringa oleifera* Lam.	Moringaceae	0	0	0	1	2	3.02	C
32	*Maytenus emarginatus* Willd.	Celastraceae	0	0	0	0	2	2.90	R

Contd...

Appendix Table 1. Continued.

Rank	Species	Family	1	2	3	4	5	IVI	WI
			No. of individuals						
33	*Bauhinia purpurea* L.	Caesalpiniaceae	0	1	0	0	1	2.74	C
34	*Securinega leucopyrus* Willd.	Euphorbiaceae	0	0	0	0	3	2.71	C
35	*Bombax ceiba* L.	Bombacaceae	0	0	0	0	1	2.39	C
36	*Ficus mollis* Vahl	Moraceae	0	0	0	0	1	1.93	C
37	*Albizia odorattissima* Benth.	Mimosaceae	0	0	0	0	3	1.64	R
38	*Wrightia tinctoria* Roxb.	Apocynaceae	0	1	0	0	0	1.53	C
39	*Manilkara hexandra* Roxb.	Sapotaceae	1	2	0	0	1	1.44	R
40	*Grewia tenax* Forsk.	Tiliaceae	0	0	1	0	0	1.41	C
41	*Grewia flavescens* A.Juss.	Tiliaceae	1	0	1	0	0	1.38	R
42	*Erythrina indica* Lam.	Fabaceae	0	0	0	1	0	1.35	C
43	*Grewia oppositifolia* Roxb.	Tiliaceae	0	0	0	0	1	1.33	C
44	*Bridelia retusa* L.	Euphorbiaceae	0	0	1	1	0	1.29	C
45	*Tamarindus indica* L.	Caesalpiniaceae	0	0	0	0	1	1.28	C
46	*Terminalia chebula* Retz.	Combretaceae	0	0	1	0	0	1.28	C
47	*Diospyros cordifolia* Roxb.	Ebenaceae	0	1	0	0	0	1.20	C
48	*Terminalia arjuna* Roxb.	Combretaceae	0	1	0	0	0	1.19	C
49	*Ehretia aspera* Willd.	Ehretiaceae	0	0	0	0	1	1.18	R
50	*Mallotus philippensis* Lam.	Euphorbiaceae	0	1	0	0	1	1.18	C
51	*Dalbergia paniculata* Roxb.	Fabaceae	0	1	0	0	0	1.17	C
52	*Casearia elliptica* Willd.	Flacourtiaceae	0	0	0	0	1	1.15	C
53	*Acacia ferruginea* DC.	Mimosaceae	0	0	0	0	1	1.14	C
54	*Pongamia pinnata* L.	Fabaceae	0	0	1	0	0	1.14	C
55	*Mimosa hamata* Willd.	Mimosaceae	0	0	0	1	0	1.13	C
56	*Adina cordifolia* Willd.	Rubiaceae	0	0	0	0	2	1.12	C
57	*Ficus racemosa* L.	Moraceae	0	1	0	0	1	1.11	C
58	*Ficus palmata* King.	Moraceae	0	0	0	0	1	1.10	C
59	*Ficus virens* Ait.	Moraceae	0	0	1	1	0	1.00	C
60	*Grewia abutilifolia* Vent.	Tiliaceae	0	0	0	0	1	0.92	C
61	*Grewia tiliaefolia*, Vahl.	Tiliaceae	0	1	0	0	1	0.91	C
62	*Ricinus communis* L.	Euphorbiaceae	0	2	0	0	0	0.90	C
63	*Leucaena leucocephala* Lam.	Mimosaceae	0	0	1	0	0	0.88	C
64	*Acacia modesta* Wall.	Mimosaceae	1	0	0	0	0	0.87	C
65	*Carissa congesta* Wight	Apocynaceae	1	0	0	0	0	0.82	C
66	*Pithecellobium dulce* Roxb.	Mimosaceae	0	0	0	1	0	0.78	C
67	*Capparis sepiaria* L.	Capparaceae	0	1	0	0	0	0.76	C
68	*Capparis decidua* Edgew.	Capparaceae	0	0	0	0	1	0.75	C
69	*Crataeva adansonii* Jacobs	Capparaceae	0	0	1	0	0	0.73	C