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Mid-domain effect: A hypothesis testing in the Gandhamardan natural forest of Bargarh and Balangir districts, Odisha, India

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ABSTRACT

Tree community is the structural and functional basis of forest ecosystems. Forest ecosystem on hills is influenced by elevation due to variation in temperature, aspect and topographic features. Can the understanding of tree species occurrence guided by altitude help in finding the distributional pattern in different elevational bands? Gandhamardan hills belong to Eastern Ghats in Bargarh and Balangir districts of Odisha, India (20°53'29.7''N, 82°49'57.8''E). One hundred quadrates of 20m×20m size were laid during the year 2008 to study tree community with trees ≥ 15cm GBH in the 100ha protected forest. Relative frequency, relative density and relative abundance of tree species were calculated and summed up to get importance value index (IVI). Abundance to Frequency (A/F) ratio of each species was determined to get distribution pattern as regular (<0.025), random (0.025-0.050) and contiguous (>0.050). Dominance-Diversity (D-D) curves were plotted taking species rank on abscissa axis and IVI value on ordinate axis for the determination of species correlationship. Spearman's rank correlation (ρ) of IVI to relative frequency, relative density and relative abundance were calculated using Spearman's Rank formula. A total of 49 species belonging to 42 genera and 29 families were recorded throughout ten elevational bands within 300m to 550m. Species occurring at only single altitude range are *Cochlospermum religiosum* (L.) Alston (425-450m), *Dalbergia latifolia* Roxb.(400-425m), *Diospyros montana* Roxb. (500-525m), *Ficus benghalensis* L.(500-525m), *Garuga pinnata* Roxb. (350-375m), *Morinda pubescens* Sm. in Rees (425-450m), *Wrightia arborea* (Dennst) Mabb. (400-425m) and *Ziziphus mauritiana* Lam. (450-475m). All these species show contiguous type of distribution. Five species viz. *Buchanania lanzan* Spreng., *Cleistanthus collinus* (Roxb.) Benth. Ex Planch., *Diospyros melanoxylon* Roxb., *Terminalia alata* Heyne ex Roth and *Haldinia cordifolia* (Roxb.) Ridsdak were found in all the studied altitude bands. Out of 272 occurrences of species across all altitude bands, 136 occurrences of species are contiguous distribution type while the rest 136 occurrences are of regular (48 numbers) and random (88 numbers) distribution type. Random and contiguous distribution increase from lower altitude to mid altitude and again decrease from mid to higher altitudes whereas the opposite trend is observed for regular distribution. In the mid altitude band (400-425m) highest thirty eight species are observed. The Spearman's rank correlation value (ρ) shows that IVI is highly correlated with RD (ρ =0.90 to 0.98) compared to that of RF (ρ =0.66 to 0.85) and RA (ρ =0.68 to 0.92). The theory of mid-domain effect with hard boundary concept for plant species distribution along altitude appears to be valid for Gandhamardan hill ecosystem.

Key words : Eastern Ghats; Gandhamardan hill; Tree species; Dominance-Diversity; Mid-domain effect

INTRODUCTION

A central question in community ecology is concerned about the control of alpha diversity, or the number of species that are able to coexist at small spatial scales (Wright, 2002). Study of plant species composition and diversity have been widely accomplished in order to perform conservation, effective management and logical exploitation of forests (Lovett *et al*. 2000; Andel, 2001; Chiarucci *et al*. 2001; Nebel *et al*.2001; Parthasarathy, 2001; Aubert *et al*. 2003 and Huang *et al*. 2003). Tropical forests are regarded as the most species rich terrestrial ecosystems. However, most of

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these forests are under immense anthropogenic disturbances and require careful management intervention to maintain overall biodiversity and sustainability (Kumar *et al*., 2006). Therefore, much emphasis has been laid down in the past 20 years on species distribution modeling, which is otherwise known as ecological niche modeling (Guisan and Thuiller, 2005).

Understanding species diversity and distribution patterns is important for helping managers evaluate the complexity and forest resources. Information with reference to species diversity and distribution pattern may help in evaluating the ecological significance of the study area. Species distribution models are based on presence, absence, or abundance data from museum vouchers or field surveys and environmental predictors to create probability models of species distribution within landscapes, regions and continents (Guisan and Thuiller, 2005). Quantifying species diversity on a regional scale is quite challenging because of difficulties in measuring species abundance and distribution (Koellner et al., 2004), and hence floristic inventories and studies of forest dynamics usually rely on sampling plots (Dallmeier and Comiskey, 1998).

Plant diversity inventories in tropical forests have mostly been concentrated on tree species than on the other life-forms, because tree species diversity is an important aspect of forest ecosystem diversity (Rennolls and Laumonier, 2000) and also fundamental to total tropical forest diversity (Huang *et al*., 2003). Trees form the major structural and functional basis of tropical forest ecosystems and can serve as robust indicators of changes and stressors at the landscape scale (Misra, 1968). They provide resources and habitat structure for almost all other species (Cannon, 1998). Competing explanations for patterns of tree diversity have alternately emphasized role of spatial or temporal variability in tree regeneration (Grubb, 1977; Pacala & Roughgarden, 1982; Huston, 1994; Kelly & Bowler, 2002). An understanding of the distribution of tree species and their assemblages must play an important role in elucidating the larger patterns of distribution of biodiversity (Reddy and Ugle, 2008).

Temporal variability is a fundamental property of any ecosystem and as such, it has been the subject of many studies during the last decades (Ruijven and Berendse, 2007). Topography data has also been an important component of species distribution models (Pearson *et al*., 2004; Eltih *et al*., 2006). The pattern of vegetation distribution on ground is always associated with particular topographic features (Mahajan and Kale, 2006). On the other hand, the regional variation in species richness is the subject of long standing debates in ecology and biogeography (Piank, 1966; Huston, 1994; Lomolion, 2001; Whittaker *et al*., 2001). The variation of species richness along elevation gradients has been documented for a variety of taxa and geographical areas (Terborgh, 1977; Stevens, 1992; Rahbek, 1995, 1997; Brown, 2001; Heaney, 2001; Md. nor, 2001; Bhattarai & Vetaas, 2003, 2005; Grytness, 2003; Bhattarai *et al*., 2004; Carpenter, 2005). Two general patterns have emerged: a monotonic decrease in species richness (e.g. Yoda, 1967; Mac Arthur, 1972; Stevens, 1992); or a hump-shaped relationship with a peak in species richness at intermediate elevations (e.g. Grytness & Vetaas, 2002).

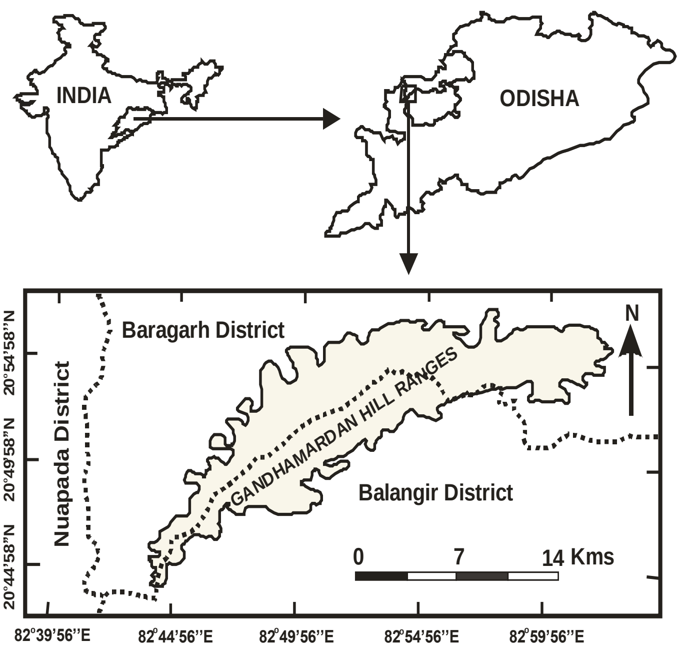
The forest of Gandhamardan hill ranges of Bargarh-Balangir districts of Odisha has attracted the attention of many botanists, ecologists and plant explorers because of its unique geography and plant diversity. A number of floristic works have been carried out by many plant explorers like Haines (1921-25), Mooney (1950), Panigrahi *et al.* (1964), Misra (1990,1998,2004), Misra and Das (1998), Saxena and Brahmam (1996) on Gandhamardan hill ranges which harbour many economically and medicinally important species. The present investigation attempts to examine the tree species occurrence in the protected natural forest of this hill range across altitudes because trees are more influenced by climate than herbaceous species (e.g. Bhattarai & Vetaas, 2003) and their elevation ranges are more accurately determined than that of smaller plants.

MATERIAL AND METHODS

Study area

Gandhamardan Hill ranges lies between 20°42' to 21°00'N latitude and 82°41' to 83°05'E longitude in the North-West of Balangir and South-West of Bargarh district, Odisha, India (*Fig.1*). The hill ranges define an undulating mountain system in the elevation range of 300m to 1220m a.s.l. It extends over several km in north-east and south-west direction and receives annual rainfall ranging from 750 mm to 1600 mm having average rainfall of 1296.8 mm.

Figure-1. Map of the Gandhamardan hill range



Field sampling

The field survey was conducted during months of January to December, 2008. The size and number of quadrates were determined by species area curve method (Mishra, 1968). A total number of 100 sample quadrates of 20m×20m for tree species were laid down. In all the plots trees with ≥ 15cm GBH were recorded following the procedure of Marimon *et al.* (2002) and Mishra *et al.* (2005). Species were identified following the standard procedure given in the regional flora by Saxena and Brahmam (1996) as well as in national flora by Hooker (1872-97).

Data analysis

The data recorded were quantitatively analysed for frequency, density and abundance and the relative values of these three parameters were calculated and summed up for IVI (Curtis, 1959 and Mishra, 1968): IVI = Relative Frequency (RF) + Relative density(RD)+ Relative Abundance(RA)

A/F of each species was determined to get distribution pattern of various species following the scheme given by Curtis and Cotton (1956) as regular (<0.025), random (0.025-0.050) and contiguous (>0.050). Dominance diversity curves have been plotted taking species rank on abscissa axis and IVI value on ordinate axis for the determination of species correlationship (*Fig-2*). The species absent in a particular altitudinal band are mentioned in tables below the list of existing species. Spearman's rank correlation (*ρ)* of Importance Value Index to Relative Frequency, Relative density and Relative Abundance were calculated using Spearman's Rank formula as given below.

$$\rho = 1 - \frac{6\sum d^2}{n(n^2-1)}$$

Where, *ρ* = Spearman's rank correlation, d= Difference in the ranks and n=Number of species present in the altitude range.

RESULTS

Forty nine tree species are found in the study area. These species belong to 29 families and 42 genera. In 300-325m, 325-350m, 350-375m, 375-400m, 400-425m, 425-450m, 450-475m, 475-500m, 500-525m and 525-550m altitude ranges, 16, 13, 30, 33, 38, 35, 30, 29, 32 and 16 numbers of species are found, respectively (*Table-1 to 10* & *11; Fig-3)*.

The maximum numbers (38) of species are present in elevation band 400-425m in contrast to a minimum of 13 in the elevation band 325-350m. Species occurring at only single altitude band are *Cochlospermum religiosum* (L.) Alston (425-450m), *Dalbergia latifolia* Roxb. (400-425), *Diospyros montana* Roxb. (500-525m), *Ficus benghalensis* L. (500-525m), *Garuga pinnata* Roxb. (350-375m), *Morinda pubescens* Sm. in Rees (425-450m), and *Ziziphus mauritiana* Lam. (450-475m). Species occurring across all altitude ranges are *Buchanania lanzan* Spreng., *Cleistanthus collinus* (Roxb.) Benth. Ex Planch., *Diospyros melanoxylon* Roxb., *Haldinia cordifolia* (Roxb.) Ridsdak and *Terminalia alata* Heyne ex Roth. When IVI value of all species considered in the single altitude range, *Casearia elliptica* Willd., *Casearia graveolens* Dalz. In Hook.f., *Garuga pinnata* Roxb., *Strychnos nux-vomica* L., *Ziziphus mauritiana* Lam., *Nyctanthes arbor-tristis* L. and *Mitragyna parviflora* (Roxb.) Korth. rank first in the altitude bands 300-325m, 325-350m, 350-375m, 375-400m, 450-475m, 475-500m, 525-550m, respectively, as observed on the Dominance-Diversity curves (*Table -1,2,3,4,7,8* &*10; Fig-2.a,b,c,d,g,h* & *j*).

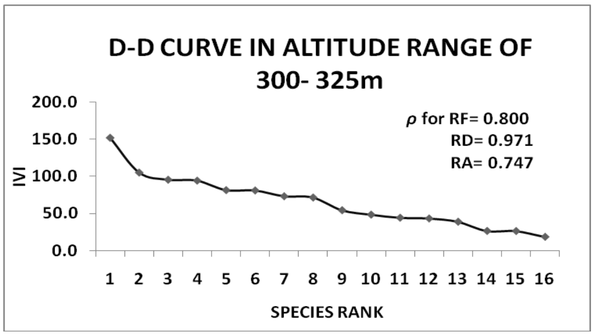
On the other hand, *Dalbergia latifolia* Roxb. & *Wrightia arborea* (Dennst) Mabb. (*Table-5* & *Fig-2.e*), *Cochlospermum religiosum* (L.)Alston & *Morinda pubescens* Sm. in Rees (*Table-6* & *Fig-2.f*) as well as *Diospyros montana* Roxb. & *Ficus benghalensis* L. (*Table-9* & *Fig-2.i)* jointly dominate in the altitude bands 400-425m, 425-450m and 525-550m, respectively. For these bands two species have the same IVI value. When the IVI values of above mentioned species are considered across all altitude ranges, they have highest value in the respective ranges except *Strychnos nux-vomica* L. and *Nyctanthes arbor-tristis* L. which have highest IVI value in the other altitude bands like 425-450m and 500-525m, respectively. This character implies dominated establishment of the species considered across species-single altitude range and species- multiple altitude ranges.

All plant species occurring in the single altitude range are contiguously distributed. Table - 11 and Figure- 3 & 4 shows that 48 regular, 88 random and 136 contiguous distributions are found out of 272 occurrences of species across all altitude ranges. Figure - 3 also shows that the curve attains a dome shape indicating the mid altitudinal increase in the species as well as families. The Spearman's rank correlation coefficient value (*ρ)* of IVI to RF, RD and RA of species (*Table-12* and *Fig-5*) were calculated. The *ρ* value for IVI and RD was highest (0.98) and lowest (0.90) for altitude bands 400-425m and 375-400m, respectively; for IVI and RF was highest (0.85) and lowest (0.66) for altitude bands 425-450m and 525-550m, respectively; for IVI and RA was highest (0.92) and lowest (0.68) for altitude bands 500-525m and 525-550m, respectively. High correlation of IVI with RF is observed for mid altitudinal range (*Fig-5*).

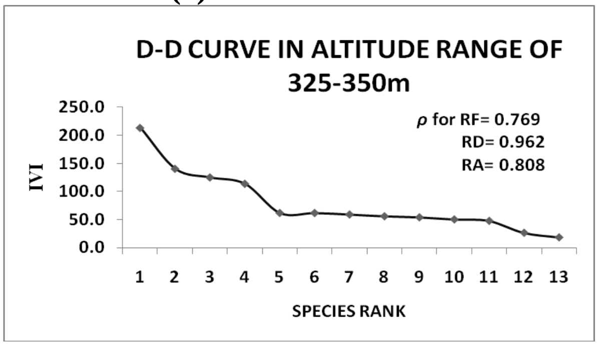
DISCUSSION

The forest of Gandhamardan hill ranges is Tropical Deciduous type (Champion and Seth, 1968). Its phytosociological study holds significance because of increasing biotic pressure and unaccounted exploitation of its natural resources which put immense pressure on the sustainability of this forest ecosystem, as well as to

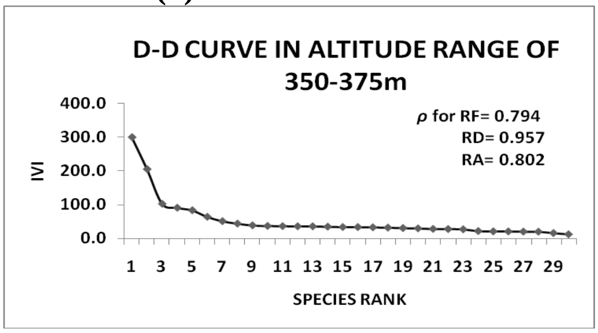
Figure - 2. (a to j) Dominance-Diversity curves for tree species occupying at different elevational bands



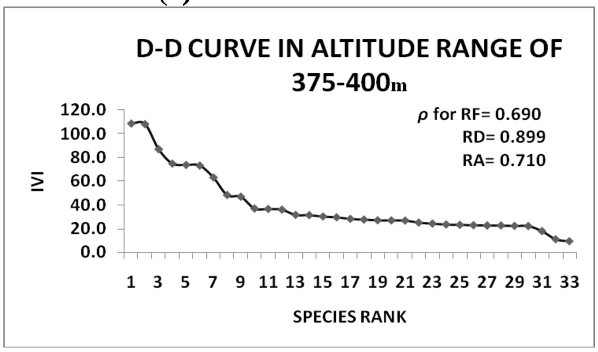
(a) 300-325m a.s.l.



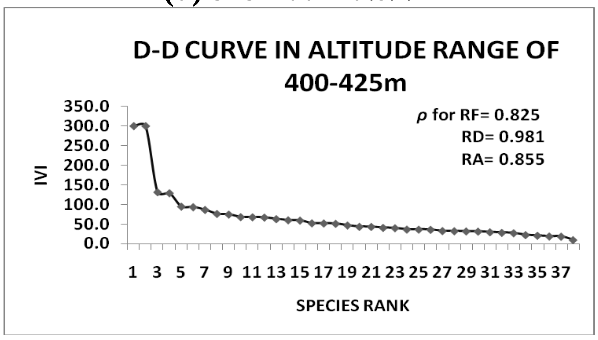
(b) 325-350m a.s.l.



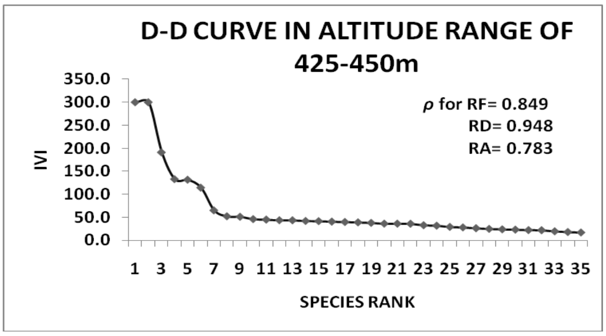
(c) 350-375m a.s.l.



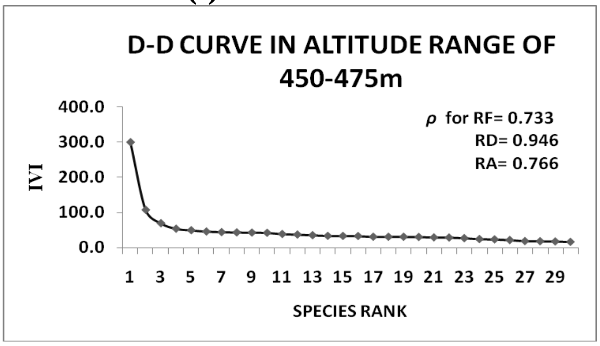
(d) 375-400m a.s.l.



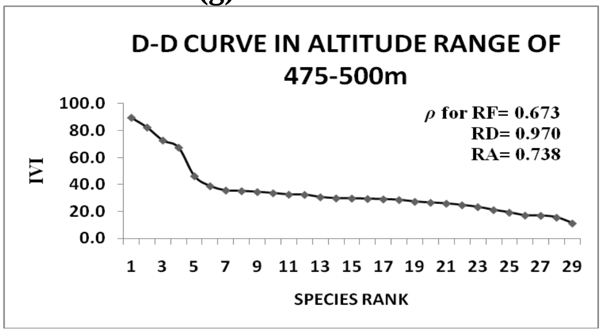
(e) 400-425m a.s.l.



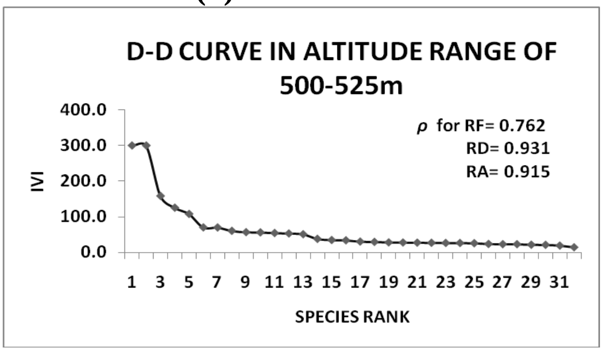
(f) 425-450m a.s.l.



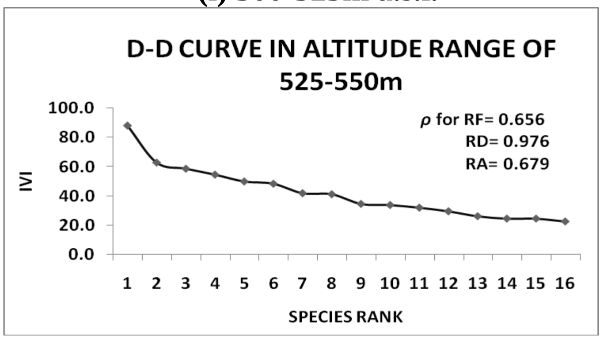
(g) 450-475m a.s.l.



(h) 475-500m a.s.l.



(i) 500-525m a.s.l.



(j) 525-550m a.s.l.

Table - 1. Species rank and distribution pattern of tree species in the altitude range of 300-325m

SPECIES RANK	TREE SPECIES(300-325m)	IVI	A/F	DISTRIBUTION
1	*Casearia elliptica* Willd.	151.7	0.02	Re
2	*Acacia lenticularis*Buch.ham. Ex Benth. In Hook.	105.0	0.01	Re
3	*Dillenia aurea* Sm.	95.3	0.03	Ra
4	*Madhuca indica* Gmel.	94.1	0.02	Re
5	*Desmodium oojeinensis* (Roxb.)Ohashi	81.4	0.02	Re
6	*Shorea robusta* Gaertn.f.	80.9	0.04	Ra
7	*Eriolaena hookeriana* Wt. &Arn.	73.2	0.01	Re
8	*Buchanania lanzan* Spreng.	71.4	0.05	Ra
9	*Ziziphus xylopyrus* (Retz.)Willd.	54.4	0.02	Re
10	*Semecarpus anacardium* L.f.	48.4	0.01	Re
11	*Diospyros melanoxylon* Roxb.	44.3	0.05	Ra
12	*Pterocarpus marsupium* Roxb.	43.3	0.01	Re
13	*Haldinia cordifolia* (Roxb.)Ridsdak	38.9	0.10	C
14	*Anogeissus latifolia* (Roxb.ex DC.) wall. Ex Guill. & Perr	26.6	0.02	Re
15	*Terminalia alata* Heyne ex Roth	26.4	0.01	Re
16	*Cleistanthus collinus* (Roxb.)Benth. Ex Planch.	18.6	0.02	Re
	Aegle marmelos (L.) Corr.			
	Bombax ceiba L.			
	Boswellia serrata Roxb.ex Coleb.			
	Bridellia retusa (L.)Spreng.			
	Careya arborea Roxb.			
	Casearia graveolens Dalz. In Hook.f.			
	Cassia fistula L.			
	Chloroxylon swietiana DC.			
	Cochlospermum religiosum (L.)Alston			
	Dalbergia latifolia Roxb.			
	Dalbergia paniculata Roxb.			
	Diospyros montana Roxb.			
	Erythrina variegata L.			
	Ficus benghalensis L.			
	Gardenia latifolia Aiton.			
	Garuga pinnata Roxb.			
	Gmelina arborea Roxb.	Species absent in the elevational band		
	Lagerstroemia parviflora Roxb.			
	Lannea coromandelica (Houtt.) Merr.			
	Mitragyna parviflora (Roxb.)Korth.			
	Morinda pubescens Sm.in Rees			
	Nyctanthes arbor-tristis L.			
	Phyllanthus emblica L.			
	Schleichera oleosa (Lour.)Oken			
	Schrebera swietenioides Roxb.			
	Stereospermum chelonoides (L.f.) DC.			
	Sterculia urens Roxb. Ex DC.			
	Strychnos nux-vomica L.			
	Terminalia belirica (Gaertn.) Roxb.			
	Terminalia chebula Retz.			
	Wrightia arborea (Dennst) Mabb.			
	Wrightia tinctoria (Roxb.) R.Br.			
	Ziziphus mauritiana Lam.			

Table - 2. Species rank and distribution pattern of tree species in the altitude range of 325-350m

SPECIES RANK	TREE SPECIES (325-350m)	IVI	A/F	DISTRIBUTION
1	*Casearia graveolens* Dalz. In Hook.f.	212.9	0.01	Re
2	*Shorea robusta* Gaertn.f.	140.1	0.09	C
3	*Erythrina variegata* L.	124.7	0.01	Re
4	*Pterocarpus marsupium* Roxb.	113.4	0.05	Ra
5	*Terminalia alata* Heyne ex Roth	61.5	0.04	Ra
6	*Dalbergia paniculata* Roxb.	61.4	0.01	Re
7	*Haldinia cordifolia* (Roxb.)Ridsdak	58.7	0.02	Re
8	*Lagerstroemia parviflora* Roxb.	55.6	0.02	Re
9	*Stereospermum chelonoides* (L.f.) DC.	53.7	0.01	Re
10	*Gardenia latifolia* Aiton.	50.0	0.01	Re
11	*Cleistanthus collinus* (Roxb.)Benth. Ex Planch.	47.4	0.09	C
12	*Buchanania lanzan* Spreng.	26.2	0.01	Re
13	*Diospyros melanoxylon* Roxb.	18.0	0.01	Re
	Acacia lenticularis Buch.ham. Ex Benth. In Hook. *Aegle marmelos* (L.) Corr. *Anogeissus latifolia* (Roxb.ex DC.) wall. Ex Guill.& Perr *Bombax ceiba* L. *Boswellia serrata* Roxb.ex Coleb. *Bridellia retusa* (L.)Spreng. *Careya arborea* Roxb. *Casearia elliptica* Willd. *Cassia fistula* L. *Chloroxylon swietiana* DC. *Cochlospermum religiosum* (L.)Alston *Dalbergia latifolia* Roxb. *Desmodium oojeinensis* (Roxb.)Ohashi *Dillenia aurea* Sm. *Diospyros montana* Roxb. *Eriolaena hookeriana* Wt. &Arn. *Ficus benghalensis* L. *Garuga pinnata* Roxb. *Gmelina arborea* Roxb. *Lannea coromandelica* (Houtt.) Merr. *Madhuca indica* Gmel. *Mitragyna parviflora* (Roxb.)Korth. *Morinda pubescens* Sm.in Rees *Nyctanthes arbor-tristis* L. *Phyllanthus emblica* L. *Schleichera oleosa* (Lour.)Oken *Schrebera swietenioides* Roxb. *Semecarpus anacardium* L.f. *Sterculia urens* Roxb. Ex DC. *Strychnos nux-vomica* L. *Terminalia bellirica* (Gaertn.) Roxb. *Terminalia chebula* Retz. *Wrightia arborea* (Dennst) Mabb. *Wrightia tinctoria* (Roxb.) R.Br. *Ziziphus mauritiana* Lam. *Ziziphus xylopyrus* (Retz.)Willd.	Species absent in the elevational band		

Table - 3. Species rank and distribution pattern of tree species in the altitude range of 350-375m

SPECIES RANK	TREE SPECIES (350-375m)	IVI	A/F	DISTRIBUTION
1	*Garuga pinnata* Roxb.	300.0	0.080	C
2	*Careya arborea* Roxb.	205.1	0.240	C
3	*Terminalia bellirica* (Gaertn.) Roxb.	102.2	0.080	C
4	*Bridellia retusa* (L.)Spreng.	90.5	0.026	Ra
5	*Terminalia chebula* Retz.	83.0	0.030	Re
6	*Cassia fistula* L.	63.5	0.240	C
7	*Bombax ceiba* L.	50.6	0.080	C
8	*Dillenia aurea* Sm.	43.4	0.026	Ra
9	*Eriolaena hookeriana* Wt. &Arn.	38.1	0.240	Ra
10	*Casearia elliptica* Willd.	36.5	0.160	C
11	*Aegle marmelos* (L.) Corr.	35.8	0.060	C
12	*Lagerstroemia parviflora* Roxb.	35.4	0.071	C
13	*Buchanania lanzan* Spreng.	35.3	0.033	Ra
14	*Terminalia alata* Heyne ex Roth	34.3	0.031	Ra
15	*Desmodium oojeinensis* (Roxb.)Ohashi	33.2	0.100	C
16	*Phyllanthus emblica* L.	33.1	0.240	C
17	*Shorea robusta* Gaertn.f.	32.4	0.140	C
18	*Mitragyna parviflora* (Roxb.)Korth.	31.4	0.080	C
19	*Erythrina variegata* L.	30.2	0.080	C
20	*Ziziphus xylopyrus* (Retz.)Willd.	29.1	0.013	Ra
21	*Chloroxylon swietiana* DC.	27.6	0.320	C
22	*Cleistanthus collinus* (Roxb.)Benth. Ex Planch.	27.3	0.054	C
23	*Haldinia cordifolia* (Roxb.)Ridsdak	26.5	0.240	Re
24	*Semecarpus anacardium* L.f.	21.3	0.160	C
25	*Acacia lenticularis* Buch.ham. Ex Benth. In Hook.	20.2	0.080	C
26	*Anogeissus latifolia* (Roxb.ex DC.) wall. Ex Guill. & Perr	20.2	0.016	Re
27	*Pterocarpus marsupium* Roxb.	19.6	0.060	C
28	*Stereospermum chelonoides* (L.f.) DC.	19.3	0.160	C
29	*Madhuca indica* Gmel.	15.3	0.080	C
30	*Diospyros melanoxylon* Roxb.	11.6	0.044	Ra
	Boswellia serrata Roxb.ex Coleb. *Casearia graveolens* Dalz. In Hook.f. *Cochlospermum religiosum* (L.)Alston *Dalbergia latifolia* Roxb. *Dalbergia paniculata* Roxb. *Diospyros montana* Roxb. *Ficus benghalensis* L. *Gardenia latifolia* Aiton. *Gmelina arborea* Roxb. *Lannea coromandelica* (Houtt.) Merr. *Morinda pubescens* Sm.in Rees *Nyctanthes arbor-tristis* L. *Schleichera oleosa* (Lour.)Oken *Schrebera swietenioides* Roxb. *Sterculia urens* Roxb. Ex DC. *Strychnos nux-vomica* L. *Wrightia arborea* (Dennst) Mabb. *Wrightia tinctoria* (Roxb.) R.Br. *Ziziphus mauritiana* Lam.	Species absent in the elevational band		

Table - 4. Species rank and distribution pattern of tree species in the altitude range of 375- 400m

SPECIES RANK	TREE SPECIES (375-400m)	IVI	A/F	DISTRIBUTION
1	*Strychnos nux-vomica* L.	108.9	0.130	C
2	*Cassia fistula* L.	108.4	0.159	C
3	*Casearia graveolens* Dalz. In Hook.f.	87.1	0.260	C
4	*Schleichera oleosa* (Lour.)Oken	74.9	0.130	C
5	*Sterculia urens* Roxb. Ex DC.	73.8	0.260	C
6	*Chloroxylon swietiana* DC.	73.3	0.390	C
7	*Boswellia serrata* Roxb.ex Coleb.	63.2	0.130	C
8	*Semecarpus anacardium* L.f.	48.3	0.054	C
9	*Terminalia chebula* Retz.	46.9	0.012	Re
10	*Shorea robusta* Gaertn.f.	36.9	0.028	Ra
11	*Madhuca indica* Gmel.	36.6	0.057	C
12	*Bridellia retusa* (L.)Spreng.	35.9	0.098	C
13	*Phyllanthus emblica* L.	31.5	0.163	C
14	*Dalbergia paniculata* Roxb.	31.3	0.390	C
15	*Casearia elliptica* Willd.	30.1	0.260	C
16	*Haldinia cordifolia* (Roxb.)Ridsdak	29.5	0.073	C
17	*Ziziphus xylopyrus* (Retz.)Willd.	28.2	0.006	Re
18	*Terminalia alata* Heyne ex Roth	27.5	0.021	Re
19	*Gardenia latifolia* Aiton.	26.9	0.130	C
20	*Acacia lenticularis* Buch.ham. Ex Benth. In Hook.	26.8	0.260	C
21	*Diospyros melanoxylon* Roxb.	26.7	0.033	Ra
22	*Erythrina variegata* L.	25.0	0.130	C
23	*Mitragyna parviflora* (Roxb.)Korth.	24.1	0.130	C
24	*Buchanania lanzan* Spreng.	23.4	0.026	Ra
25	*Pterocarpus marsupium* Roxb.	23.1	0.087	C
26	*Lagerstroemia parviflora* Roxb.	22.8	0.163	C
27	*Eriolaena hookeriana* Wt. &Arn.	22.5	0.260	Ra
28	*Schrebera swietenioides* Roxb.	22.5	0.130	C
29	*Aegle marmelos* (L.) Corr.	22.2	0.260	C
30	*Anogeissus latifolia* (Roxb.ex DC.) wall. Ex Guill. & Perr	22.1	0.026	Ra
31	*Cleistanthus collinus* (Roxb.)Benth. Ex Planch.	17.8	0.028	Ra
32	*Dillenia aurea* Sm.	10.9	0.130	C
33	*Stereospermum chelonoides* (L.f.) DC.	9.2	0.130	C
	Bombax ceiba L.	Species absent in the elevational band		
	Careya arborea Roxb.			
	Cochlospermum religiosum (L.)Alston			
	Dalbergia latifolia Roxb.			
	Desmodium oojeinensis (Roxb.)Ohashi			
	Diospyros montana Roxb.			
	Ficus benghalensis L.			
	Garuga pinnata Roxb.			
	Gmelina arborea Roxb.			
	Lannea coromandelica (Houtt.) Merr.			
	Morinda pubescens Sm.in Rees			
	Nyctanthes arbor-tristis L.			
	Terminalia bellirica (Gaertn.) Roxb.			
	Wrightia arborea (Dennst) Mabb.			
	Wrightia tinctoria (Roxb.) R.Br.			
	Ziziphus mauritiana Lam.			

Table - 5. Species rank and distribution pattern of tree species in the altitude range of 400-425m

SPECIES RANK	TREE SPECIES (400-425m)	IVI	A/F	DISTRIBUTION
1	*Dalbergia latifolia* Roxb.	300.0	0.090	C
2	*Wrightia arborea* (Dennst) Mabb.	300.0	0.180	Ra
3	*Gmelina arborea* Roxb.	131.4	0.068	C
4	*Boswellia serrata* Roxb.ex Coleb.	129.0	0.180	C
5	*Careya arborea* Roxb.	94.9	0.090	C
6	*Schleichera oleosa* (Lour.)Oken	93.4	0.090	C
7	*Sterculia urens* Roxb. Ex DC.	86.5	0.045	Ra
8	*Wrightia tinctoria* (Roxb.) R.Br.	76.3	0.090	C
9	*Bombax ceiba* L.	74.7	0.045	Ra
10	*Terminalia chebula* Retz.	68.1	0.033	Ra
11	*Schrebera swietenioides* Roxb.	67.8	0.023	Re
12	*Desmodium oojeinensis* (Roxb.)Ohashi	67.0	0.293	C
13	*Mitragyna parviflora* (Roxb.)Korth.	63.0	0.030	Ra
14	*Lannea coromandelica* (Houtt.) Merr.	60.1	0.540	C
15	*Madhuca indica* Gmel.	59.3	0.056	C
16	*Phyllanthus emblica* L.	52.3	0.015	Re
17	*Eriolaena hookeriana* Wt. &Arn.	52.0	0.070	C
18	*Bridellia retusa* (L.)Spreng.	51.1	0.040	Ra
19	*Gardenia latifolia* Aiton.	46.9	0.032	Ra
20	*Ziziphus xylopyrus* (Retz.)Willd.	43.4	0.050	C
21	*Chloroxylon swietiana* DC.	43.2	0.056	C
22	*Dalbergia paniculata* Roxb.	40.7	0.034	Ra
23	*Semecarpus anacardium* L.f.	39.9	0.045	Ra
24	*Diospyros melanoxylon* Roxb.	36.4	0.048	Ra
25	*Anogeissus latifolia* (Roxb.ex DC.) wall. Ex Guill. & Perr	36.3	0.033	Ra
26	*Aegle marmelos* (L.) Corr.	35.8	0.270	C
27	*Buchanania lanzan* Spreng.	32.6	0.038	Ra
28	*Stereospermum chelonoides* (L.f.)DC.	32.3	0.018	Re
29	*Terminalia alata* Heyne ex Roth	31.8	0.026	Ra
30	*Lagerstroemia parviflora* Roxb.	31.3	0.029	Ra
31	*Cleistanthus collinus* (Roxb.)Benth. Ex Planch.	29.6	0.059	C
32	*Cassia fistula* L.	28.2	0.090	C
33	*Haldinia cordifolia* (Roxb.)Ridsdak	27.2	0.022	Re
34	*Dillenia aurea* Sm.	22.3	0.068	C
35	*Casearia elliptica* Willd.	20.7	0.090	C
36	*Acacia lenticularis* Buch.ham. Ex Benth. In Hook.	18.9	0.090	C
37	*Pterocarpus marsupium* Roxb.	18.4	0.030	Ra
38	*Shorea robusta* Gaertn.f.	9.7	0.090	C
	Casearia graveolens Dalz. In Hook.f. *Cochlospermum religiosum* (L.)Alston *Diospyros montana* Roxb. *Erythrina variegata* L *Ficus benghalensis* L. *Garuga pinnata* Roxb. *Morinda pubescens* Sm.in Rees *Nyctanthes arbor-tristis* L. *Strychnos nux-vomica* L. *Terminalia bellirica* (Gaertn.) Roxb. *Ziziphus mauritiana* Lam.	Species absent in the elevational band		

Table - 6. Species rank and distribution pattern of tree species in the altitude range of 425-450m

SPECIES RANK	TREE SPECIES (425-450m)	IVI	A/F	DISTRIBUTION
1	*Cochlospermum religiosum* (L.)Alston	300.0	0.110	C
2	*Morinda pubescens* Sm.in Rees	300.0	0.110	C
3	*Strychnos nux-vomica* L.	191.1	0.220	C
4	*Wrightia tinctoria* (Roxb.) R.Br.	132.9	0.220	C
5	*Schleichera oleosa* (Lour.)Oken	131.7	0.055	C
6	*Gmelina arborea* Roxb.	114.4	0.083	C
7	*Schrebera swietenioides* Roxb.	65.0	0.061	C
8	*Nyctanthes arbor-tristis* L.	52.2	0.110	C
9	*Chloroxylon swietiana* DC.	51.1	0.070	C
10	*Phyllanthus emblica* L.	46.0	0.098	C
11	*Bridellia retusa* (L.)Spreng.	44.9	0.049	Ra
12	*Dalbergia paniculata* Roxb.	43.6	0.055	C
13	*Aegle marmelos* (L.) Corr.	43.5	0.034	Ra
14	*Anogeissus latifolia* (Roxb.ex DC.) wall. Ex Guill. & Perr	42.0	0.060	C
15	*Terminalia chebula* Retz.	41.6	0.037	Ra
16	*Acacia lenticularis* Buch.ham. Ex Benth. In Hook.	40.6	0.330	C
17	*Stereospermum chelonoides* (L.f.) DC.	39.8	0.110	C
18	*Diospyros melanoxylon* Roxb.	38.9	0.042	Ra
19	*Gardenia latifolia* Aiton.	37.9	0.035	Ra
20	*Madhuca indica* Gmel.	36.1	0.138	C
21	*Ziziphus xylopyrus* (Retz.)Willd.	36.1	0.037	Ra
22	*Eriolaena hookeriana* Wt. &Arn.	35.9	0.034	Ra
23	*Lannea coromandelica* (Houtt.) Merr.	32.7	0.049	Ra
24	*Lagerstroemia parviflora* Roxb.	31.7	0.031	Ra
25	*Dillenia aurea* Sm.	29.1	0.041	Ra
26	*Cleistanthus collinus* (Roxb.)Benth. Ex Planch.	28.0	0.043	Ra
27	*Mitragyna parviflora* (Roxb.)Korth.	26.3	0.110	C
28	*Cassia fistula* L.	24.8	0.110	C
29	*Terminalia alata* Heyne ex Roth	23.8	0.025	Ra
30	*Pterocarpus marsupium* Roxb.	23.2	0.330	C
31	*Semecarpus anacardium* L.f.	22.2	0.049	Ra
32	*Haldinia cordifolia* (Roxb.)Ridsdak	21.9	0.061	C
33	*Desmodium oojeinensis* (Roxb.)Ohashi	19.5	0.083	C
34	*Bombax ceiba* L.	18.0	0.110	C
35	*Buchanania lanzan* Spreng.	16.9	0.073	C
	Boswellia serrata Roxb.ex Coleb. *Careya arborea* Roxb. *Casearia elliptica* Willd. *Casearia graveolens* Dalz. In Hook.f. *Dalbergia latifolia* Roxb. *Diospyros montana* Roxb. *Erythrina variegata* L. *Ficus benghalensis* L. *Garuga pinnata* Roxb. *Shorea robusta* Gaertn.f. *Sterculia urens* Roxb. Ex DC. *Terminalia bellirica* (Gaertn.) Roxb. *Wrightia arborea* (Dennst) Mabb. *Ziziphus mauritiana* Lam.	Species absent in the elevational band		

Table - 7. Species rank and distribution pattern of tree species in the altitude range of 450-475m

SPECIES RANK	TREE SPECIES (450-475m)	IVI	A/F	DISTRIBUTION
1	*Ziziphus mauritiana* Lam.	300.0	0.120	C
2	*Boswellia serrata* Roxb.ex Coleb.	107.8	0.060	C
3	*Sterculia urens* Roxb. Ex DC.	69.8	0.060	C
4	*Gmelina arborea* Roxb.	54.2	0.120	C
5	*Bridellia retusa* (L.)Spreng.	49.9	0.024	Re
6	*Lannea coromandelica* (Houtt.) Merr.	46.3	0.034	Ra
7	*Schrebera swietenioides* Roxb.	44.5	0.090	C
8	*Mitragyna parviflora* (Roxb.)Korth.	43.7	0.240	C
9	*Phyllanthus emblica* L.	43.3	0.060	C
10	*Eriolaena hookeriana* Wt. &Arn.	42.6	0.034	Ra
11	*Gardenia latifolia* Aiton.	39.2	0.043	Ra
12	*Cassia fistula* L.	37.6	0.060	C
13	*Ziziphus xylopyrus* (Retz.)Willd.	35.7	0.032	Ra
14	*Diospyros melanoxylon* Roxb.	33.9	0.041	Ra
15	*Dalbergia paniculata* Roxb.	33.7	0.029	Ra
16	*Cleistanthus collinus* (Roxb.)Benth. Ex Planch.	33.4	0.056	C
17	*Terminalia chebula* Retz.	31.4	0.060	C
18	*Anogeissus latifolia* (Roxb.ex DC.) wall. Ex Guill. & Perr	31.3	0.038	Ra
19	*Madhuca indica* Gmel.	31.3	0.067	C
20	*Lagerstroemia parviflora* Roxb.	30.8	0.019	Re
21	*Dillenia aurea* Sm.	29.6	0.080	C
22	*Aegle marmelos* (L.) Corr.	29.1	0.040	Ra
23	*Stereospermum chelonoides* (L.f.) DC.	27.4	0.045	Ra
24	*Haldinia cordifolia* (Roxb.)Ridsdak	24.8	0.023	Re
25	*Semecarpus anacardium* L.f.	24.0	0.038	Ra
26	*Chloroxylon swietiana* DC.	22.0	0.030	Ra
27	*Desmodium oojeinensis* (Roxb.)Ohashi	19.1	0.040	Ra
28	*Buchanania lanzan* Spreng.	18.7	0.060	C
29	*Casearia elliptica* Willd.	18.0	0.120	C
30	*Terminalia alata* Heyne ex Roth	16.9	0.034	Ra
	Acacia lenticularis Buch.ham. Ex Benth. In Hook. *Bombax ceiba* L. *Careya arborea* Roxb. *Casearia graveolens* Dalz. In Hook.f. *Cochlospermum religiosum* (L.)Alston *Dalbergia latifolia Roxb.* *Diospyros montana* Roxb. *Erythrina variegata* L *Ficus benghalensis* L. *Garuga pinnata* Roxb. *Morinda pubescens* Sm.in Rees *Nyctanthes arbor-tristis* L. *Pterocarpus marsupium* Roxb. *Schleichera oleosa* (Lour.)Oken *Shorea robusta* Gaertn.f. *Strychnos nux-vomica* L. *Terminalia bellirica* (Gaertn.) Roxb. *Wrightia arborea* (Dennst) Mabb. *Wrightia tinctoria* (Roxb.) R.Br.	Species absent in the elevational band		

Table - 8. Species rank and distribution pattern of tree species in the altitude range of 475-500m

SPECIES RANK	TREE SPECIES (475-500m)	IVI	A/F	DISTRIBUTION
1	*Nyctanthes arbor-tristis* L.	89.6	0.105	C
2	*Lannea coromandelica* (Houtt.) Merr.	82.3	0.063	C
3	*Terminalia bellirica* (Gaertn.) Roxb.	72.7	0.140	C
4	*Erythrina variegata* L.	67.4	0.093	C
5	*Bombax ceiba* L.	46.2	0.034	Ra
6	*Ziziphus xylopyrus* (Retz.)Willd.	38.8	0.037	C
7	*Diospyros melanoxylon* Roxb.	35.6	0.050	Ra
8	*Phyllanthus emblica* L.	35.2	0.210	C
9	*Acacia lenticularis* Buch.ham. Ex Benth. In Hook.	34.5	0.062	Ra
10	*Semecarpus anacardium* L.f.	33.6	0.079	C
11	*Lagerstroemia parviflora* Roxb.	32.6	0.022	Re
12	*Stereospermum chelonoides* (L.f.) DC.	32.4	0.05	Ra
13	*Schrebera swietenioides* Roxb.	30.6	0.07	C
14	*Cleistanthus collinus* (Roxb.)Benth. Ex Planch.	29.8	0.047	Ra
15	*Anogeissus latifolia* (Roxb.ex DC.) wall. Ex Guill. & Perr	29.7	0.024	Re
16	*Desmodium oojeinensis* (Roxb.)Ohashi	29.4	0.039	Ra
17	*Terminalia chebula* Retz.	29.1	0.076	Ra
18	*Buchanania lanzan* Spreng.	28.6	0.042	Ra
19	*Haldinia cordifolia* (Roxb.)Ridsdak	27.3	0.016	Re
20	*Gardenia latifolia* Aiton.	26.5	0.023	Re
21	*Aegle marmelos* (L.) Corr.	25.9	0.047	C
22	*Dillenia aurea* Sm.	24.7	0.034	Ra
23	*Mitragyna parviflora* (Roxb.)Korth.	23.3	0.140	C
24	*Dalbergia paniculata* Roxb.	21.1	0.105	C
25	*Terminalia alata* Heyne ex Roth	19.2	0.039	Ra
26	*Eriolaena hookeriana* Wt. &Arn.	17.1	0.076	C
27	*Casearia elliptica* Willd.	16.9	0.140	C
28	*Chloroxylon swietiana* DC.	15.6	0.047	Ra
29	*Pterocarpus marsupium* Roxb.	11.2	0.070	C
	Boswellia serrata Roxb.ex Coleb. *Bridellia retusa* (L.)Spreng. *Careya arborea* Roxb. *Casearia graveolens* Dalz. In Hook.f. *Cassia fistula* L. *Cochlospermum religiosum* (L.)Alston *Dalbergia latifolia* Roxb. *Diospyros montana* Roxb. *Ficus benghalensis* L. *Garuga pinnata* Roxb. *Gmelina arborea* Roxb. *Madhuca indica* Gmel. *Morinda pubescens* Sm.in Rees *Schleichera oleosa* (Lour.)Oken *Shorea robusta* Gaertn.f. *Sterculia urens* Roxb. Ex DC. *Strychnos nux-vomica* L. *Wrightia arborea* (Dennst) Mabb. *Wrightia tinctoria* (Roxb.) R.Br. *Ziziphus mauritiana* Lam.	Species absent in the elevational band		

Table-9. Species rank and distribution pattern of tree species in the altitude range of 500-525m

SPECIES RANK	TREE SPECIES (500-525m)	IVI	A/F	DISTRIBUTION
1	*Diospyros montana* Roxb.	300.0	0.060	C
2	*Ficus benghalensis* L.	300.0	0.060	C
3	*Nyctanthes arbor-tristis* L.	158.3	0.180	C
4	*Terminalia bellirica* (Gaertn.) Roxb.	125.1	0.060	C
5	*Aegle marmelos* (L.) Corr.	107.6	0.165	C
6	*Sterculia urens* Roxb. Ex DC.	69.8	0.060	C
7	*Schrebera swietenioides* Roxb.	69.5	0.045	Ra
8	*Lannea coromandelica* (Houtt.) Merr.	60.0	0.090	C
9	*Stereospermum chelonoides* (L.f.) DC.	56.4	0.360	C
10	*Bombax ceiba* L.	55.8	0.180	C
11	*Acacia lenticularis* Buch.ham. Ex Benth. In Hook.	54.1	0.180	C
12	*Erythrina variegata* L.	52.7	0.030	Ra
13	*Desmodium oojeinensis* (Roxb.)Ohashi	50.5	0.105	C
14	*Cassia fistula* L.	37.6	0.060	C
15	*Ziziphus xylopyrus* (Retz.)Willd.	34.3	0.040	Ra
16	*Dalbergia paniculata* Roxb.	33.5	0.045	Ra
17	*Diospyros melanoxylon* Roxb.	29.9	0.041	Ra
18	*Anogeissus latifolia* (Roxb.ex DC.) wall. Ex Guill. & Perr	29.0	0.023	Re
19	*Bridellia retusa* (L.)Spreng.	27.7	0.060	C
20	*Madhuca indica* Gmel.	27.4	0.030	Ra
21	*Cleistanthus collinus* (Roxb.)Benth. Ex Planch.	26.9	0.040	Ra
22	*Terminalia alata* Heyne ex Roth	26.6	0.047	Ra
23	*Casearia elliptica* Willd.	26.1	0.060	C
24	*Lagerstroemia parviflora* Roxb.	26.0	0.027	Ra
25	*Chloroxylon swietiana* DC.	25.4	0.180	C
26	*Pterocarpus marsupium* Roxb.	23.2	0.045	Ra
27	*Gardenia latifolia* Aiton.	22.6	0.030	Ra
28	*Haldinia cordifolia* (Roxb.)Ridsdak	22.6	0.045	Ra
29	*Dillenia aurea* Sm.	21.1	0.030	Ra
30	*Buchanania lanzan* Spreng.	20.7	0.033	Ra
31	*Eriolaena hookeriana* Wt. &Arn.	18.6	0.060	C
32	*Semecarpus anacardium* L.f.	13.9	0.060	C
	Boswellia serrata Roxb.ex Coleb. *Careya arborea* Roxb. *Casearia graveolens* Dalz. In Hook.f. *Cochlospermum religiosum* (L.)Alston *Dalbergia latifolia* Roxb. *Garuga pinnata* Roxb. *Gmelina arborea* Roxb. *Mitragyna parviflora* (Roxb.)Korth. *Morinda pubescens* Sm.in Rees *Phyllanthus emblica* L. *Schleichera oleosa* (Lour.)Oken *Shorea robusta* Gaertn.f. *Strychnos nux-vomica* L. *Terminalia chebula* Retz. *Wrightia arborea* (Dennst) Mabb. *Wrightia tinctoria* (Roxb.) R.Br. *Ziziphus mauritiana* Lam.	Species absent in the elevational band		

Table - 10. Species rank and distribution pattern of tree species in the altitude range of 525-550m

SPECIES RANK	TREE SPECIES (525-550m)	IVI	A/F	DISTRIBUTION
1	*Mitragyna parviflora* (Roxb.)Korth.	88.2	0.020	Re
2	*Anogeissus latifolia* (Roxb.ex DC.) wall. Ex Guill. & Perr	62.9	0.070	C
3	*Phyllanthus emblica* L.	58.7	0.040	Ra
4	*Bombax ceiba* L.	54.6	0.020	Re
5	*Gardenia latifolia* Aiton.	50.0	0.010	Re
6	*Semecarpus anacardium* L.f.	48.4	0.010	Re
7	*Chloroxylon swietiana* DC.	41.9	0.040	Ra
8	*Cleistanthus collinus* (Roxb.)Benth. Ex Planch.	41.3	0.075	C
9	*Dalbergia paniculata* Roxb.	34.7	0.020	Re
10	*Lagerstroemia parviflora* Roxb.	33.9	0.040	Ra
11	*Terminalia alata* Heyne ex Roth	32.1	0.060	C
12	*Stereospermum chelonoides* (L.f.) DC.	29.6	0.020	Re
13	*Buchanania lanzan* Spreng.	26.2	0.010	Re
14	*Diospyros melanoxylon* Roxb.	24.6	0.020	Re
15	*Pterocarpus marsupium* Roxb.	24.6	0.020	Re
16	*Haldinia cordifolia* (Roxb.)Ridsdak	22.6	0.020	Re
	Acacia lenticularis Buch.ham. Ex Benth. In Hook. *Aegle marmelos* (L.) Corr. *Boswellia serrata* Roxb.ex Coleb. *Bridellia retusa* (L.)Spreng. *Careya arborea* Roxb. *Casearia elliptica* Willd. *Casearia graveolens* Dalz. In Hook.f. *Cassia fistula* L. *Cochlospermum religiosum* (L.)Alston *Dalbergia latifolia* Roxb. *Desmodium oojeinensis* (Roxb.)Ohashi *Dillenia aurea* Sm. *Diospyros montana* Roxb. *Eriolaena hookeriana* Wt. &Arn. *Erythrina variegata* L. *Ficus benghalensis* L. *Garuga pinnata* Roxb. *Gmelina arborea* Roxb. *Lannea coromandelica* (Houtt.) Merr. *Madhuca indica* Gmel. *Morinda pubescens* Sm.in Rees *Nyctanthes arbor-tristis* L. *Schleichera oleosa* (Lour.)Oken *Schrebera swietenioides* Roxb. *Shorea robusta* Gaertn.f. *Sterculia urens* Roxb. Ex DC. *Strychnos nux-vomica* L. *Terminalia bellirica* (Gaertn.) Roxb. *Terminalia chebula* Retz. *Wrightia arborea* (Dennst) Mabb. *Wrightia tinctoria* (Roxb.) R.Br. *Ziziphus mauritiana* Lam. *Ziziphus xylopyrus* (Retz.)Willd.	Species absent in the elevational band		

Table - 11. Distribution type and total families of tree species in different altitude ranges

Distribution types	Altitude range (meters)										Total
	300-325	325-350	350-375	375-400	400-425	425-450	450-475	475-500	500-525	525-550	
Regular species(Re)	11	9	3	3	4	0	3	4	1	10	48
Random species(Ra)	4	2	7	6	15	13	13	11	14	3	88
Contiguous species(C)	1	2	20	24	19	22	14	14	17	3	136
Total Species	16	13	30	33	38	35	30	29	32	16	272
Total families	13	11	20	23	26	24	19	17	20	11	184

Table - 12. Spearman's rank correlation (ρ) value of IVI to Relative Frequency, Relative Density and Relative Abundance across Altitude ranges

Altitude range (meters)	Spearman's rank correlation (*ρ*) value		
	RF	RD	RA
300-325	0.80	0.97	0.75
325-350	0.77	0.96	0.81
350-375	0.79	0.96	0.80
375-400	0.69	0.90	0.71
400-425	0.83	0.98	0.86
425-450	0.85	0.95	0.78
450-475	0.73	0.95	0.77
475-500	0.67	0.97	0.74
500-525	0.76	0.93	0.92
525-550	0.66	0.98	0.68
Range of *ρ* value	**0.66 -0.85**	**0.90-0.98**	**0.68-0.92**

Figure – 3. Altitudinal variation in all species and family occurrence

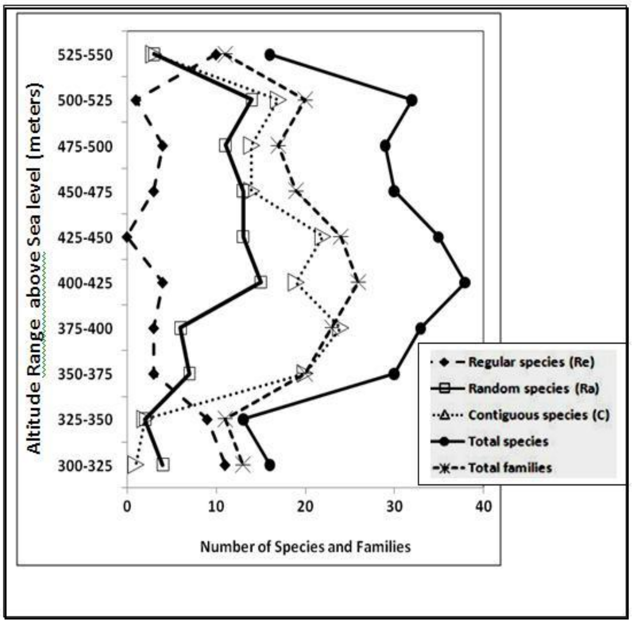


Figure - 4. Type and number of species distribution

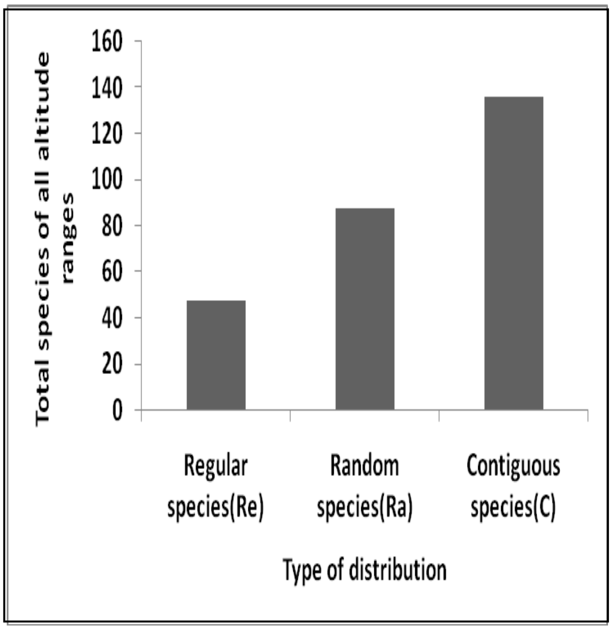
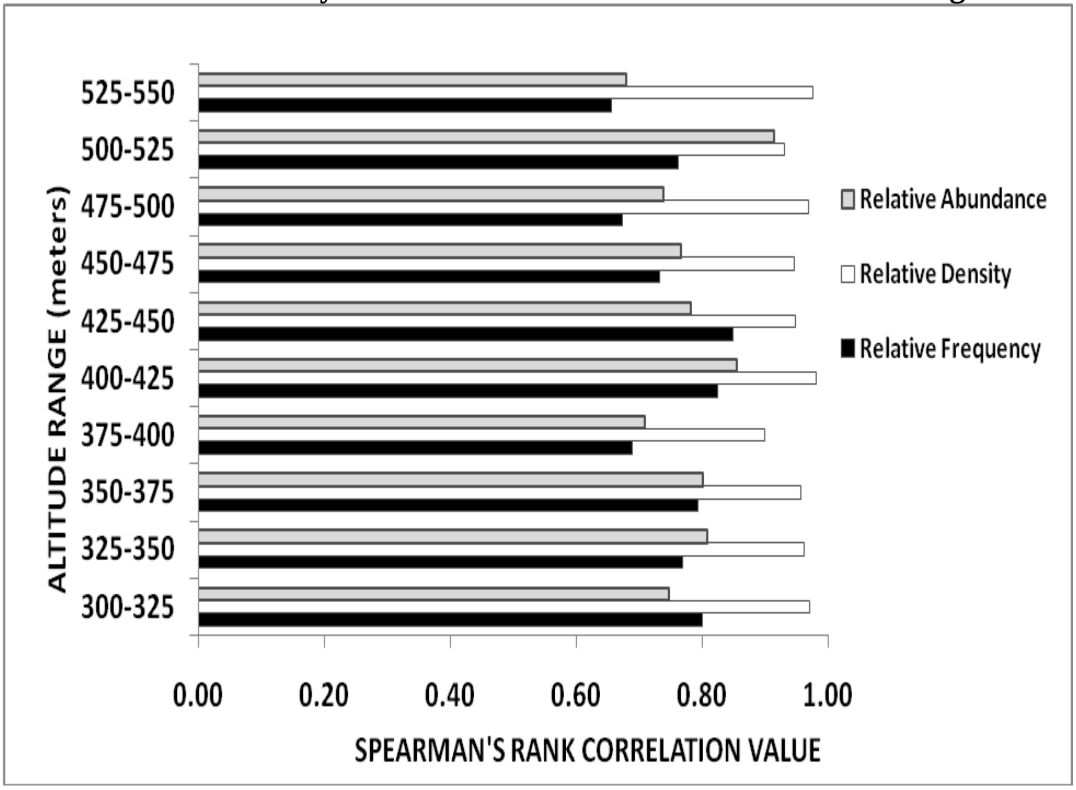


Figure-5. Spearman's Rank correlation value of IVI of tree species to Relative Frequency, Relative Density and Relative Abundance across Altitude ranges



understand the ecological control on species distribution.

One of the ecological features is the altitudinal variation in species occurrence and many hypotheses have been proposed to explain the variation in species richness along elevational gradients. The hypothesis that there is a positive correlation between elevation and the elevational range of species, called Rapoport's elevation rule (Stevens, 1992), has been derived from earlier work on latitudinal gradients by Rapoport (1975, 1982). This suggests that latitudinal ranges of species increase with increasing latitude (Rapoport, 1982; Stevens, 1989). Rapoport's elevation rule arises as a result of the ever-narrowing range of climatic conditions that species experience with decreasing elevation (Stevens, 1992). It suggests that species occurring at higher elevations must be able to withstand a broad range of climatic conditions and this leads to their wide elevational distribution. Species found at lower elevations are adapted to more specific temperature and rainfall conditions so they have narrow climatic tolerances and hence a smaller range, and therefore, large number of species occur in this lower elevations. Patterns consistent with Rapoport's rule have been documented for trees, mammals, amphibians, grasshoppers, and reptiles (Stevens, 1992 and references there in).

Colwell and Hurt (1994) proposed a new hypothesis called 'hard boundary' or 'mid-domain effect' to explain mid-elevational peaks in species richness. Explaining it, they suggested that mid-elevation peaks in species richness arise because of the increasing overlap of species ranges towards the centre of the domain, as the extent of the elevational ranges of species is bounded by the highest and lowest elevations. Also, the maximum richness at low-intermediate elevations could be partially explained by the mid-domain effect hypothesis (Colwell *et al.* 2004), which states that mid-elevation habitats have a higher diaspore input than areas close to the end points of the elevational gradient, where most of the diaspore input comes from one direction only (Grytness, 2003b). *Figure - 3 and Table - 11* suggest that the species distribution pattern of the study region is in accordance with the hard boundary hypothesis of Colwell and Hurt. Contrary to Rapoport's rule, the hard boundary hypothesis predicts that species ranges at higher elevations are narrow. This is supported by the present finding of decrease in number of species from mid altitude (400-425m) to high altitude (525-550m). Rahbek (1995) concluded that the mid-altitudinal hump-shaped pattern of species distribution is most common in both tropical and non-tropical biomes. The graph for the distribution of species and family (*Fig.3*) from lower to higher altitude ranges in Gandhamardan hills, being hump-shaped, the mid-domain effect hypothesis for species distribution is further supported on the line of Rahbek's observations.

Odum (1971) has emphasized that contiguous distribution is the commonest pattern in nature. Contiguous distribution has been reported by several workers viz. Greig-Smith (1957), Kershw (1973) and Singh and Yadav (1974). Kumar and Bhatt (2006) also reported contiguous distribution pattern in foot-hill forests of Garhwal Himalaya. In the Gandhamardan hill ranges, *Cochlospermum religiosum* (L.) Alston (425-450m), *Dalbergia latifolia* Roxb.(400-425m), *Diospyros montana* Roxb.(500-525m), *Ficus benghalensis* L.(500-525m), *Garuga pinnata* Roxb.(350-375m), *Morinda pubescens* Sm.in Rees(425-450m), *Wrightia arborea* (Dennst) Mabb.(400-425m) and *Ziziphus mauritiana* Lam.(450-475m) occur only in single altitude range and are found to be contiguously distributed. Thus, these species have narrow ecological niche and adaptation. In conformity with the Odum's finding, out of 272 occurrences of species across all altitude ranges, 136 occurrences of species are contiguous distribution type while the rest 136 occurrences are of regular and random distribution type. Regular distribution of species decreases from lower elevation to mid elevation and again increases from mid elevation to higher elevation. But on contrary, random and contiguous distribution increases from lower elevation to mid elevation and further it decreases from mid elevation to higher elevation (*Fig. 3*). This corroborates with the previous findings in support of mid-domain effect and the prevalent contiguous distribution can be attributed to the interaction of many factors that are acting together on the population. As such, clumping indicates inefficient mode of seed dispersal (Richards, 1996). While comparing dispersion patterns of trees in tropical to temperate climates of the world, Armesto *et al.* (1986) concluded that clumping is the characteristics of natural forests. The prevalent contiguous tree species distribution in the study region could also be a result of clumping.

The spatial distribution of a species is considered as its adaptability potential to the environment. Climatic factors and biotic interferences also influence the regeneration of different species in the forest vegetation. Good and Good (1972) have considered three major components which cause the successful regeneration of tree species. These components are the ability to initiate new seedlings, ability of seedlings and saplings to survive and ability of seedlings and saplings to grow. The IVI value and presence of five tree species i.e. *Buchanania lanzan* Spreng., *Cleistanthus collinus* (Roxb.) Benth. Ex Planch., *Diospyros melanoxylon* Roxb., *Terminalia alata* Heyne ex Roth and *Haldinia cordifolia* (Roxb.) Ridsdak in each altitude range show their high relative abundance, uniform distribution and wide climatic tolerance and adaptation compared to other tree species in the community. Hence these species are well adapted to the existing environmental conditions on Gandhamardan hills.

The Spearman's rank correlation value (*ρ)* shows that IVI is highly correlated with RD (***ρ*** =0.90 to 0.98) compared to that of RF (***ρ*** =0.66 to 0.85) and RA (***ρ*** =0.68 to 0.92) (*Table-12* and *Fig.5*). Hence, Importance Value Index of a tree species is more controlled by relative density than relative frequency and relative abundance.

CONCLUSION

Observed high correlation of IVI with RF for mid altitudinal range indicates that the probability of finding a species is maximum in the mid altitude range, and therefore, the theory of mid-domain effect with hard boundary concept appears to be valid for hill ecosystem.

Conflict of Interests

Authors declare that there is no conflict of interests regarding the publication of this paper.

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