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Recongregation of tree species of katerniaghat wildlife sanctuary, Uttar Pradesh, India

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Abstract

The study highlights the association pattern of tree species in Katerniaghat Wildlife Sanctuary (KWS) a tropical moist deciduous forest of Terai region of Uttar Pradesh, India. In the present study the ecological exploration has been done to dig out the current statuse of the forest types in the sanctuary area. The cluster and PCA analyses grouped the forests of KWS into three major forest types: sal forest, miscellaneous forest and teak plantation. The different forest type exhibit differences in tree dominance and diversity: sal forest is dominated by *Shorea robusta,* miscellaneous forest by *Mallotus philippensis* and teak plantation by *Tectona grandis*. The tree species richness has been found 48.07 species ha^{-1} in teak plantation, 52.63 in miscellaneous forest and 55.35 in sal forest. The tree density has been found 769.23 stem ha^{-1} in teak plantation, 742.86 in sal forest and 671.05 in miscellaneous forest. The basal cover was observed 1260.75 m^2 h^{-1} in miscellaneous forest, 3533.61 in sal forest and 4933.97 in teak plantation. The diversity indexes (Shannon & Fisher-alpha) have been found maximum (2.666 & 12.390) in miscellaneous forest, moderate (2.152 & 8.677) in sal forest and low (1.134 & 6.482) in teak plantation. The species heterogeneity has been found maximum (0.862) in miscellaneous forest, moderate (0.785) in sal forest and minimum (0.399) in teak plantation. The tree species richness and the basal area have also been found more in comparison with the previous reports from the area.

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Introduction

India has been considered as one of the 17 mega-diversity centers of the word with a wide range of phytogeographical variations. It consisits of about 64 million hectares forest covers out of which 86% is tropical forest comprising 54% dry deciduous, 37% moist deciduous and 9% wet evergreen & semi-evergreen (Kaul and Sharma, 1971). As a characteristic feature, the tropical forest shows a huge variation in tree species diversity place to place (Pitman et al., 2002). Among the different phytodiverse regions found in the country, the Terai region is one of them existing from Uttarakhand to W. Bengal. It is the transition zone between two eco-climatic zones, the Gangatic plain towards south and Bhabhar towards north, along with the sub-Himalayan tracts (Tripathi and Singh, 2009). The region has lost majority of its natural forest due to deforestration chiefly for agriculture and lack of sustainable forest management in last many centuries (Bajpai et al., 2012). Now the natural forests of the region have been restricted to the wildlife protected areas only. Katerniaghat Wildlife Sanctuary (KWS) is also one of the protected areas in this region in Bahraich district of Uttar Pradesh. In earlier the forest has been classified into two major forest types, (i) Sal Forest and (ii) Miscellaneous Forest (Champion and Seth, 1968). Tripathi and Singh, (2009) have also grouped the forest into (i) Natural Forest and (ii) Plantation Forest. Hence, to know the current status of the forest types in the sanctuary area the present study has been carried out.

In this recongregation study only tree species have been considered because the trees are more vulnerable and at the same time the forest ecosystems have always been defined by its tree species diversity (Hubbell and Foster, 1992; Cannon et al., 1998; Rennolls and Laumonier, 2000). Such type of quantitative assessment of the forest tree species provides important information related with the species diversity, distribution, composition as well as forest management for conservation and sustanaible utilization (Gentry, 1990; Hartshorn, 1990; Phillips et al., 2003; Reddy et al., 2008).

The study area has been sporadically explored in past by various workers (Panigrahi et al., 1969; Saini, 2005; Chauhan et al., 2008; Tripathi et al., 2009; Maliya and Dutt, 2010; Kumar et al., 2011; Maliya, 2012). The preliminary studies on distributional pattern of the tree species of the study area applying ecological parameters including less number of species than expected numbers was carried out by Tripathi and Singh, (2009) and they use only the dominant tree species for the congregation of forest, however, in the present study the data dealing with the large number of species from more areas have been generated to assess their distributional and association pattern. Cluster and PCA analyses have been done on the basis of IVI of the species for the re congregation of forest types in the sanctuary area. Tree density classes have been also made to categorise the tree species within the dominant to very rare class.

The main objectives of the study were (a) analysis of the community structure for species richness, evenness, density and dominance and (b) stratification of the forest tree species into different forest types. The result from such type of studies can be used in future for the assessment of the changes in the environment of the area and their impact on phytodiversity.

Materials and methods

Study area

The study area Katerniaghat Wildlife Sanctuary (KWS) is situated in Bahraich dstrict of Uttar Pradesh in India (Fig. 1). It lies along Indo-Nepal international boarder and is situated between 27° 41' - 27° 56' N and 81° 48' - 81° 56' E covering an area of 440 km² with 116 to 165 m elevation. The sanctuary comes under the tropical moist deciduous forest of the Himalayan Terai-Bhabar region (Champion and Seth, 1968; Rodgers and Panwar, 1988). The forest of the sanctuary area has been classified into two major forest types (i) The Sal forest and (ii) The

miscellaneous forest (Champion and Seth, 1968). Pedologicaly the study area is made up of the alluvial soil of the Kaudiyala and Saryu rivers and its tributaries flowing adjoining to it. Geologicaly the sanctuary area has been divided into high and low land areas.

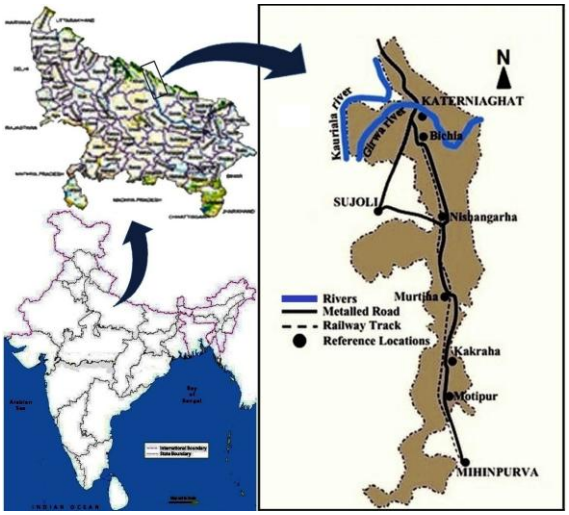

Fig. 1. Location map of study site (Katerniaghat Wildlife Sanctury).

Climate

A typical tropical monsoonal climate with three distinct seasons i.e. summer (April to June), winter (November to February) and warm-rainy (July to September) prevails in the study area. March and October are considered as transition months between the seasons. The mean maximum temperature ranges from 22°C in January to 40°C in May and the mean minimum temperature ranges from 8°C in January to 27°C in June. The annual rainfall ranges from 36 to 142 cm in winter, 34 to 662 cm in summer and 1294 to 1689 cm in warm-rainy seasons (Fig. 2) (Bajpai et al., 2012).

Vegetation

The heterogeneous vegetation of the sanctuary area is tropical moist deciduous type and may be divided into upper stratum, lower stratum and ground vegetation. The upper stratum comprises trees like *Shorea robusta, Tectona grandis, Terminalia elliptica, Madhuca longifolia* var. *latifolia, Ficus benghalensis, Ficus racemosa, Bombax ceiba, Sterculia villosa, Lannea coromandelica* etc. which receives the full solar radiation. The lower stratum is represented by *Hymenodictyon orixense, Syzygium cumini, Ehretia laevis, Lagerstroemia parviflora, Diospyros exculpta, Mallotus philippensis, Mallotus nudiflorus, Ficus hispida, Streblus asper* etc. The ground vegetation chiefly consists of *Bergera koenigii, Glycosmis pentaphylla, Clerodendrum viscosum, Grewia hirsuta, Lantana camara* etc. where the minimal light is available.

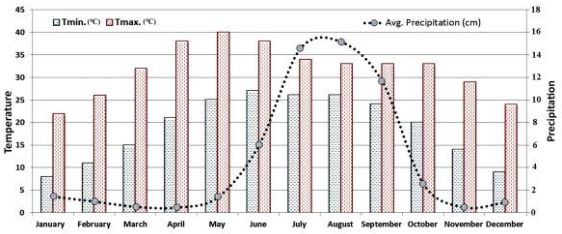

Fig. 2. Climatic variation in Katerniaghat Wildlife Sanctury

Field data collection and analysis

Random stratified sampling (Greig-Smith, 1983; Krebs, 1989) from 47 quadrates was done for the ecological data collection. Quadrates of 50 x 50 m were plotted to measure the frequency, density, abundance and species dominance (Curtis and McIntosh, 1950). Frequency, density, abundance & species dominance have been used to calculate the species Importance Value Index (IVI) and different diversity indexes (Simpson, 1949; Cootam and Curtis, 1956; Gauch, 1982; ter Braak and Prentice, 1988). Grouping of all random plots has been done by cluster analysis (Ludwig and Reynolds, 1988; Jongman et al., 1995; Rai et al., 2012) using IVI data, employing Bray-Curtis similarity measure and unweighted pair-group moving average (UPGMA) algorithm (Rai et al., 2012). PCA analysis has also been done to find out the differnt groups or communities of the forest area. Cluster and PCA analyses has been performed using multivar option in PAST version 2.12 (Hammer et al., 2001; Hall, 2005; Rai et al., 2012).

Results

Forest community structure

The cluster and PCA analyses have been conceded by using plot wise IVI data of all random plots to make the natural groups (Table 1). Cluster analysis formed three major clusters (I, II & II) and seven sub-clusters (A, B, C, D, E, F & G) employing Bray-Curtis similarity measure (Fig. 3). The cluster-I grouped the random plots having *Shorea robusta* as dominant species (Avg. IVI-122.2), *Mallotus philippensis* as 1st co-dominant species (Avg. IVI-54.3) and *Syzygium cumini* as 2nd co-dominant species (Avg. IVI-24.1); cluster-II consists of *Mallotus philippensis* as dominant species (Avg. IVI-98.2), *Mallotus nudiflorus* as 1st co-dominant species (Avg. IVI-39.6) and *Ficus hispida* as 2nd co-dominant species (Avg. IVI-23.0) and cluster-III comprises *Tectona grandis* as dominant species (Avg. IVI-231.5), *Mallotus philippensis* as 1st co-dominant species (Avg. IVI-21.0) and *Shorea robusta* as 2nd co-dominant species (Avg. IVI-7.1) (Table 2). On the basis of the major constituents, the cluster-I termed as the 'Sal Forest', cluster-II as the 'Miscellaneous Forest' and cluster-III as the 'Teak Plantation'. Almost similar results have been achieved in the PCA analysis except some variations (Fig. 4).

One plot (plot 14) has been found out-grouped in clustering and it has been placed between cluster-I (sal forests) and cluster-III (teak plantation) in PCA. It has *Shorea robusta* (IVI-125.6) as the dominant species with *Tectona grandis* (Avg. IVI-115.2) as 1st co-dominant species and *Mallotus philippensis* (Avg. IVI-24.9) as 2nd co-dominant species. The presence of *Shorea robusta* as well as *Tectona grandis* with more than 100 IVI is the reason of its placement between the clusters of sal forest and teak plantation in PCA plot.

Table 1. IVI of tree species in three forest types in Katerniaghat Wildlife Sanctury.

Name of Species ↓ / IVI →	Miscellaneous Forest	Sal Forest	Teak Plantation
Acacia catechu	18.3	0	0
Aegle marmelos	0.0	0	3.8
Albizia lebbeck	0.9	0	0.0
Albizia procera	2.8	0.6	0.0
Alstonia scholaris	0.4	0.0	0.0
Barringtonia acutangula	1.8	0.0	0.0
Bauhinia purpurea	0.5	0.0	0.0
Bombax ceiba	11.0	0.0	0.0
Bridelia retusa	3.9	2.1	0.7
Buchanania cochinchinensis	0.0	0.7	0.9
Acacia concinna var. *rugata*	1.0	0.0	0.0
Cassia fistula	0.5	0.7	0.0
Cordia dichotoma	2.1	0.0	0.0
Dalbergia sissoo	4.4	0.0	0.0
Dillenia pentagyna	0.0	2.1	0.0
Diospyros exculpta	0.0	3.2	3.0
Ehretia laevis	11.7	3.4	2.3
Phyllanthus emblica	0.0	0.6	0.0
Eucalyptus tereticornis	0.0	0.0	0.7
Ficus bengalensis	0.0	0.0	1.5
Ficus hispida	23.0	0.0	1.3
Ficus palmata	0.5	0.0	0.6
Ficus racemosa	9.7	0.0	1.9
Ficus rumphii	0.0	1.3	0.0
Ficus squamosa	5.2	0.0	1.2
Grewia tiliifolia	5.3	0.0	0.0
Haldina cordifolia	4.7	0.5	0.0
Holoptelea integrifolia	0.4	0.0	1.3
Hymenodictyon orixense	1.1	1.2	0.0

Kydia calycina	0.9	1.9	0.7
Lagerstroemia parviflora	1.5	12.7	4.6
Lannea coromandelica	12.8	1.3	0.7
Leucaena leucocephala	0.0	1.3	0.0
Litsea glutinosa	0.6	0.6	0.9
Litsea monopetala	0.0	1.8	0.0
Madhuca longifolia var. *latifolia*	0.0	12.7	1.0
Mallotus nudiflorus	29.6	0.0	0.9
Mallotus philippensis	98.2	54.3	21.0
Miliusa velutina	3.0	10.0	1.6
Mitragyna parvifolia	3.4	0.0	3.9
Bergera koenigii	0.5	0.0	0.0
Desmodium oojeinense	0.0	4.7	0.0
Putranjiva roxburghii	3.0	0.6	0.0
Schleichera oleosa	1.5	4.3	4.4
Semecarpus anacardium	0.0	3.2	0.0
Shorea robusta	10.3	122.4	7.1
Sterculia villosa	0.5	0.0	0.0
Stereospermum chelonoides	0.0	1.2	0.0
Streblus asper	7.9	0.6	0.0
Syzygium cumini	12.9	24.0	2.7
Syzygium heyneanum	2.4	0.0	0.0
Tectona grandis	0.0	8.0	231.5
Terminalia elliptica	0.5	18.3	0
Toona ciliata	0.9	0	0
Ziziphus mauritiana	0.5	0	0
Total	**300.0**	**300.0**	**300.0**

Table 2. Dominant, 1st Co-dominant and 2nd Co-dominant trees species in three forest types with average, standard deviation and minimum – maximum IVI values.

Major Cluster		Avg. IVI	STDEV	Min. - Max.	Sub Cluster		Avg. IVI	STDEV	Min. - Max.
I	**Dominant Species**				A	**Dominant Species**			
	Shorea robusta	122.4	62.2	40.9 - 200.5		*Shorea robusta*	66.7	18.5	40.9 - 84.2
	1st Co-dominant Species					*Mallotus philippesis*	66.1	30.0	7.8 - 82.2
	Mallotus philippesis	54.3	27.8	7.8 - 82.2		**1st Co-dominant Species**			
	2nd Co-dominant Species					*Madhuca longifolia* var. *latifolia*	33.2	34.7	11.3 - 89.9
	Syzygium cumini	24.1	34.0	11.4 - 94.0		**2nd Co-dominant Species**			
						Lagerstroemia parviflora	27.5	20.8	18.8 - 55.1
					B	**Dominant Species**			
						Shorea robusta	169.0	42.9	94.6 - 218.6
						1st Co-dominant Species			
						Mallotus philippesis	40.9	25.4	10.2 - 74.2
						Syzygium cumini	40.7	37.4	16.7 - 94
						2nd Co-dominant Species			
						Terminalia elliptica	10.1	9.3	9.7 - 22.5
II	**Dominant Specie**				C	**Dominant Species**			
	Mallotus philippesis	98.2	53.2	14.4 - 180.3		*Mallotus philippesis*	128.1	33.5	73.8 - 180.3
						1st Co-dominant Species			

					Syzygium cumini	17.0	23.4	7.6 - 75.5
	1st Co-dominant Species				**2nd Co-dominant Species**			
					Lannea coromandelica	15.3	27.3	12 - 69.5
	Mallotus nudiflorus	29.6	49.9	8.4 - 176.2	*Shorea robusta*	15.0	27.5	12.8 - 83.1
	2nd Co-dominant Species				**D** **Dominant Species**			
					Mallotus nudiflorus	75.1	68.9	28.2 - 176.2
					1st Co-dominant Species			
	Ficus hispida	23.0	41.2	7.4 - 154.1	*Ficus hispida*	48.6	61.7	65.3 - 154
					2nd Co-dominant Species			
					Mallotus philippesis	33.6	12.8	14.4 - 47.7
III	**Dominant Species**				**E** **Dominant Species**			
					Tectona grandis	90.7	0.5	90.3 - 91.0
	Tectona grandis	231.5	72.3	90.3 - 300.0	**1st Co-dominant Species**			
					Mallotus philippesis	39.7	42.9	9.4 - 70.0
	1st Co-dominant Species				**2nd Co-dominant Species**			
					Mitragyna parvifolia	25.2	15.1	14.5 - 35.8
	Mallotus philippesis	21.0	24.3	7.2 - 70.0	**F** **Dominant Species**			
					Tectona grandis	282.5	19.0	252.8 - 300.0
	2nd Co-dominant Species				**1st Co-dominant Species**			
					Mallotus philippesis	2.8	5.1	7.2 - 12.6
	Shorea robusta	7.1	18.4	12.8 - 66.1	*Ficus bengalensis*	2.8	7.3	19.4
					2nd Co-dominant Species			
					Lagerstroemia parviflora	2.6	6.9	18.3
					G **Dominant Species**			
					Tectona grandis	212.7	21.0	183.3 - 232.8
					1st Co-dominant Species			
					Mallotus philippesis	43.4	5.4	36.1 - 47.6
					2nd Co-dominant Species			
					Shorea robusta	16.5	33.1	66.1000

Table 3. Inventory details of tree species in Katerniaghat Wildlife Sanctuary.

Variable	Forest Types		
	Miscellaneous Forest	**Sal Forest**	**Teak Plantation**
Dominant species	*Mallotus philippensis*	*Shorea robusta*	*Tectona grandis*
Number of species	40.0	31.0	25.0
Number of genera	33.0	29.0	20.0
Number of families	24.0	21.0	18.0
Site specific species	15.0	9.0	3.0

Species/genus ratio	1.21	1.07	1.25
Species richness (spp. ha^{-1})	52.63	55.35	48.07
Tree Density (stem ha^{-1})	671.05	742.86	769.23
Basal cover (m^2 ha^{-1})	22.97	65.90	89.07
Different indexes			
Dominance_D	0.138	0.215	0.601
Simpson_1-D	0.862	0.785	0.399
Fisher_alpha	12.390	8.677	6.482
Shannon_H	2.666	2.152	1.134
Equitability_J	0.723	0.627	0.352
Evenness_e^H/S	0.360	0.278	0.124

Table 4. Density classes of tree species in Katerniaghat Wildlife Sanctuary.

Density Classes	**Number of Species**				
	10- 500	**60- 20**	**21 - 50**	**51 - 100**	**> 100**
	Very rare	Rare	Common	Prominent	Dominant
Sal Forest	18	5	5	1	2
Miscellaneous Forest	19	14	4	2	1
Teak plantation	17	6	0	1	1

The paired group Bray-Curtis clustering placed the random plot 5 in the cluster-I while PCA analysis grouped it into cluster-II. All over species composition of the plot 5 and presence of *Terminalia elliptica* (Avg. IVI-87.3) as 1st co-dominant species is responsible for it's placement within cluster-I while the presence of 37 individuals of dominant species i.e. *Mallotus philippensis* with higher Avg. IVI-133.1 (as compare to cluster-I) and presence of only 5 individuals of 2nd co-dominant species i.e. *Shorea robusta* with lesser IVI-28.2 (as compare to *Shorea robusta* in cluster-I) make it closer to the sub-cluster-C of cluster-II which has the *Mallotus philippensis* with Avg. IVI-128.1 (very close to plot 5) as dominant species and *Shorea robusta* with Avg. IVI-15.0 as 2nd co-dominant species.

Sub-cluster-A of cluster-I has been drown closer to sub-cluster-C of cluster-II in the PCA plot, because sub-cluster-A grouped the random plots having *Shorea robusta* (Avg. IVI-66.7) as well as *Mallotus philippensis* (Avg. IVI-66.1) as dominant species which is closer to cluster-II where *Mallotus philippensis* is also a dominant species (Avg. IVI-98.2). Out of two sub-clusters C & D in cluster-II, sub-cluster-A of cluster-I shows its closeness with sub-cluster-C due to the presence of *Shorea robusta* in random plots of both the sub-clusters (as dominant species in sub-cluster-A with Avg. IVI-66.7 and as 2nd co-dominant species in sub-cluster-C with Avg. IVI-15.0). While sub-cluster-B of cluster-I has been drown away from the cluster-II, because it grouped the random plots having *Shorea robusta* as dominant species (with higher Avg. IVI-169.0) which is about four times higher than the 1st co-dominant species i.e. *Mallotus philippensis* & *Syzygium cumini* (Avg. IVI-40.9 & 40.7). Due to the presence of *Shorea robusta* with highest Avg. IVI in cluster-B, it can be named as "Sal Dominated Forest", while cluster-B can be named as "Sal Miscellaneous Forest" due to the mixed vegetation dominated by *Shorea robusta* (Avg. IVI-66.7) & *Mallotus philippensis* (Avg. IVI-66.1).

The cluster-II has been further grouped in two sub-clusters C & D. In the PCA plot both the sub-clusters can not be differentiated easily but in the cluster graph these both clusters can be easily differentiated. The major reason behind this regrouping of sub-clusters C and D is the species composition, which is

completely different. Sub-cluster-C has been represented by the *Mallotus philippensis* (Avg. IVI-128.1) as dominant species, *Syygium cumini* (Avg. IVI-17.0) as 1st co-dominant species and *Lannea coromandelica* (Avg. IVI-15.3) & *Shorea robusta* (Avg. IVI-15.0) as 2nd co-dominant species. Due to the presence of *Mallotus philippensis* with more than 100 IVI value (seven to eight times higher than its 1st & 2nd co-dominant species); cluster-C can be named as "*Mallotus* Miscellaneous Forest". Sub-cluster-D has been represented by *Mallotus nudiflorus* (Avg. IVI-75.1) as dominant species and *Ficus hispida* (Avg. IVI-48.6) as 1st co-dominant species. Both the species have been considered as the moisture adoring species, which grow luxuriantly in the low land areas. The presence of these low land species in this sub-cluster, it can be named as "Low Land Miscellaneous Forest".

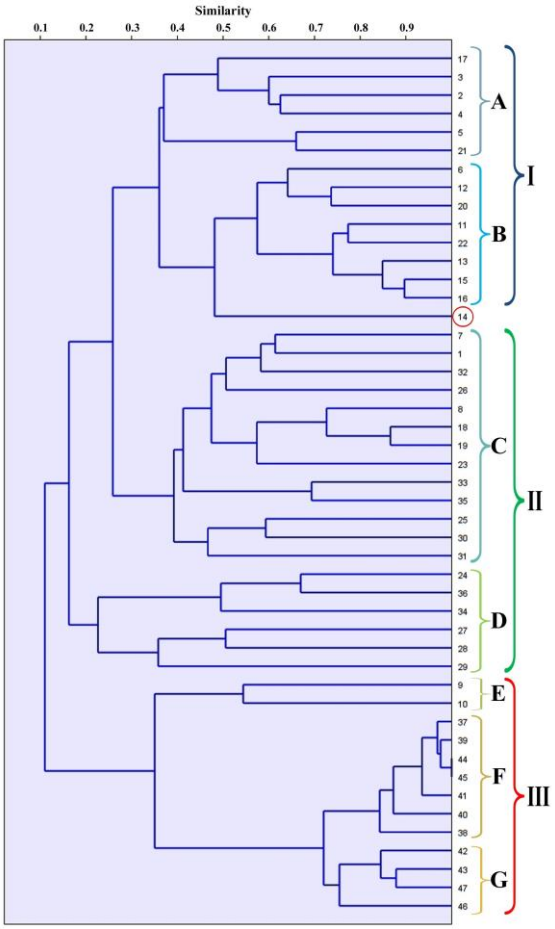

Fig. 3. Cluster showing the different forest types: I-Sal Forest (A- Sal Dominated Forest and B- Sal Miscellaneous Forest), II- Miscellaneous Forest (C-*Mallotus* Miscellaneous Forest and D- Low Land Miscellaneous Forest) and III-Teak Plantation (E-Teak Miscellaneous Forest, F- Pure Teak Plantation and G- Teak Sal Miscellaneous Forest) with one out group (Plot-14).

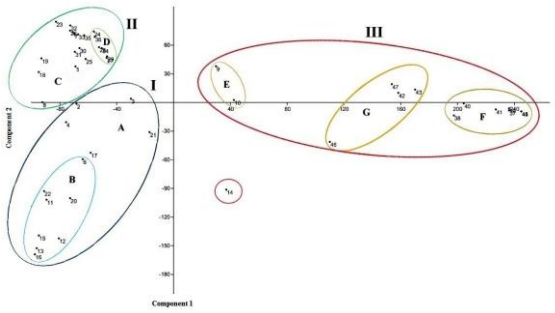

Fig. 4. PCA plot showing the different forest types: I-Sal Forest (A- Sal Dominated Forest and B- Sal Miscellaneous Forest), II- Miscellaneous Forest (C-*Mallotus* Miscellaneous Forest and D- Low Land Miscellaneous Forest) and III-Teak Plantation (E-Teak Miscellaneous Forest, F- Pure Teak Plantation and G- Teak Sal Miscellaneous Forest) with one out group (Plot-14).

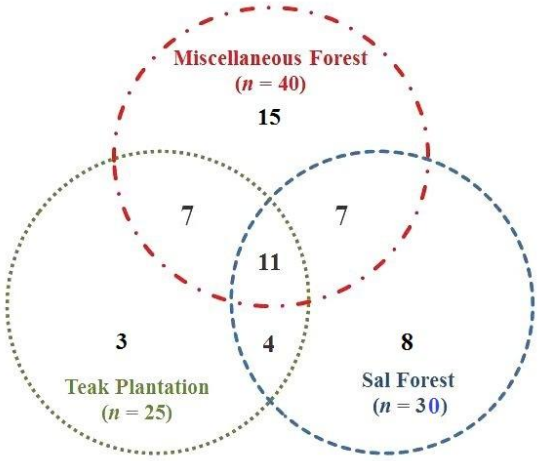

Fig. 5. Venn diagram showing species distribution in different forest types of Katerniaghat Wildlife Sanctury.

Within the cluster-III three sub-clusters E, F and G are easily visible in PCA plot as well as in cluster graph. The species composition in the sub-cluster-E moves towards the cluster-II, due to the presence of *Mallotus philippensis* (Avg. IVI-39.7) as 1st co-dominant species and *Mitragyna parvifolia* (Avg. IVI-25.2), *Aegle marmelos* (Avg. IVI-24.8),

Schleichera oleosa (Avg. IVI-23.9) & *Lagerstroemia parviflora* (Avg. IVI-20.6) as 2nd co-dominant species. The presence of these miscellaneous species with *Tectona grandis* (Avg. IVI-90.7) may be used to name this sub-cluster as "Teak Miscellaneous Forest". The sub-cluster-F has been ploted far away from sub-cluster-E. The random plots of this sub-cluster have been dominated by *Tectona grandis* with an Avg. IVI-282.5. The IVI of *Tectona grandis* is very high here, due to the monoculture of the species. Thus this sub-cluster may be named as "Pure Teak Plantation". The sub-cluster-G has been placed in between sub-cluster E & F. The random plots of this sub-cluster have been dominated by *Tectona grandis* (Avg. IVI-212.7) with *Mallotus phileppensis* (Avg. IVI-43.4) as 1st co-dominant species and *Shorea robusta* (Avg. IVI-16.5) as 2nd co-dominant species. The lower Avg. IVI value of *Tectona grandis* (as compare to sub-cluster-F) and presence of *Shorea robusta* as 2nd co-dominant species is responsible for its place in the PCA plot. Thus this sub-cluster may be named as "Teak Sal Miscellaneous Forest".

Tree species richness, dominance, density and heterogeneity

The number of species has been found maximum in miscellaneous forest (40 spp.) followed by sal forest (30 spp.) and teak plantation (25 spp.) (Table 3). The species/genus ratio (Ricklefs and Miller 2000) has been found maximum in teak plantation showing its recent diversification. In all the three forest types 11 tree species have been found commonly growing (Fig. 5). The miscellaneous forest shows maximum tree diversity by having 15 site specific species which are present here only (i.e. *Acacia catechu*, *Albizzia lebbek*, *Alstonia scholaris*, *Barringtonia acutangula*, *Bauhinia purpurea*, *Bombax ceiba*, *Acacia concinna* var. *rugata*, *Cordia dichotoma*, *Dalbergia sissoo*, *Grewia teliafolia*, *Bergera koenigii*, *Sterculia vilosa*, *Syzygium heyneanum*, *Toona ciliata* and *Zizyphus mauritiana*), while the sal forest and teak plantation have only 8 species (i.e. *Dillenia penatagyna*, *Phyllanthus emblica*, *Ficus rumphii*, *Leucaena lucosifela*, *Litsea monopetala*, *Desmodium oojeinense*, *Semecarpus anacardium* and *Stereospermum suaveolens*) and 3 species (i.e. *Aegle marmelos*, *Eucalyptus tereticornis* and *Ficus bengalensis*) as site specific respectively (Fig. 5).

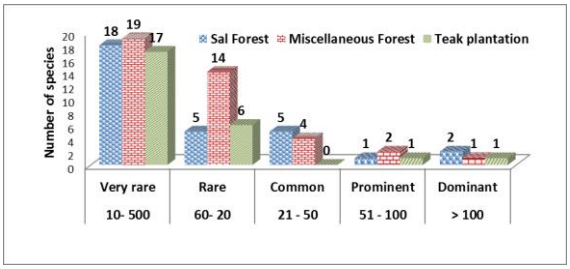

Fig. 6. Species dominance and rarity in Katerniaghat Wildlife Sanctury.

Although the maximum number of species has been reported from the miscellaneous forest but the maximum species richness (i.e. 55.35 species ha^{-1}) has been calculated in the sal forest followed by the miscellaneous forest (52.63). The teak plantation shows the minimum species richness (48.07) because of its monodominant nature. When we talk about the tree density (stem ha^{-1}), the maximum value has been found in teak plantation (769.23) due to sufficient distance provided between the trees. The miscellaneous forest having the highest number of species shows the minimum (671.05) tree density. The sal forest represents the moderate (742.86) tree density in the sanctuary area. As similar to the tree density, the maximum values of basal cover has been observed in the teak plantation (89.07 m^2 ha^{-1}) and the minimum in miscellaneous forest (22.97). The sal forest represents the moderate (65.90) basal cover.

The tree dominance has been computed maximum (0.601) for the teak plantation which clearly indicates its monoculture nature having only *Tectona grandis* as dominant tree species and it has been also supported by the lowest Simpson Index value (0.399). The minimum dominance has been computed for the miscellaneous forest (0.138) having the maximum number of dominant tree species i.e. highest heterogeneity (Simpson Index-0.862). The sal forest shows the moderate

heterogeneity of tree species having the dominance value 0.215 and Simpson Index 0.785.

The highest Shannon diversity index (2.666) as well as Fisher alpha diversity index (12.390) has been found in the miscellaneous forest, which indicates its highest species diversity in this forest type because the higher value of these two diversity indexes denote the higher species diversity. In the teak plantation the diversity indexes have been computed minimum in both Shannon diversity (1.134) and Fisher alpha diversity (6.482) which reveals its lowest tree diversity among the three forest types. In the sal forest, Shannon and Fisher alpha diversity indexes have been computed 2.152 and 8.677 respectively representing its moderate tree diversity in the sanctuary area.

The value of Equitability (0.723) and Evenness (0.360) has been computed maximum for the miscellaneous forest where the species are more evenly distributed in random quadrates while in the teak plantation the equitability and evenness have been found minimum 0.124 and 0.352 respectively. The sal forest represents the moderate value of the Equitability and Evenness (0.360 and 0.723 respectively).

Tree density classes

The five density classes have been made by using the tree density (stem ha^{-1}). Here it has been tried to list the number of dominant (> 100 stem ha^{-1}), prominent (51–100 stem ha^{-1}), common (21–50 stem ha^{-1}), rare (6–20 stem ha^{-1}) and very rare (1–5 stem ha^{-1}) tree species in different forest types of the forest in Katerniaghat Wildlife Sanctuary (Table 4). In sal forest 2, 1, 5, 5 and 18 tree species comes under dominant, prominent, common, rare and very rare density classes respectively while in the case of miscellaneous forest the number have been changed to 1, 2, 4, 14 and 19 respectively (Fig. 6). In the teak plantation single tree species has come in dominant and prominent classes, 6 in rare, 17 in very rare and no species has come in common class.

In sal forest *Shorea robusta* and *Mallotus philippensis* come under dominant density class, having 275.00 and 158.93 tree density respectively out of total tree density (742.86). *Syzygium cumini* with 53.57 tree density is the only prominant species according to density classes. *Terminalia elliptica* (33.93), *Lagerstromia parviflora* (32.14), *Madhuca longifolia* var. *latifolia* (32.14), *Miliusa velutina* (32.14) and *Tectona grandis* (25.00) come under common density class. *Desmodium oojeinense* (10.71), *Schleichera oleosa* (10.71), *Ehretia laevis* (8.93), *Diospyros exculpta* (7.14) and *Samecarpus anacardium* (7.14) belong to rare density class. *Abutilaon indicum* (5.36), *Bridelia retusa* (5.36), *Dillenia pentagyna* (5.36), *Litsea monopetala* (5.36), *Ficus rumphii* (3.57), *Hymenodictyon orixense* (3.57), *Lannea coromandelica* (3.57), *Leucaena lucosifelia* (3.57), *Stereospermum suaveolens* (3.57), *Albizzia prosera* (1.79), *Buchanania cochinchinensis* (1.79), *Casia fistula* (1.79), *Diospyros exculpta* (1.79), *Phyllanthus emblica* (1.79), *Haldina cardifolia* (1.79), *Litsea glutinosa* (1.79), *Putranjiva roxburbhii* (1.79) and *Streblus asper* (1.79) fall within very rare density class.

In miscellaneous forest only *Mallotus philippensis* comes under dominant density class with 230.26 tree density out of 671.05 total tree densities. *Ficus hispida* (59.21) and *Mallotus nudiflorus* (52.63) are the prominant tree species. *Acacia catechu* (39.47), *Ehretia laevis* (30.26), *Lannea coromandelica* (30.26) and *Syzygium cumini* (27.63) are common. *Streblus asper* (19.74), *Shorea robusta* (17.11), *Bombax ceiba* (15.79), *Ficus racemosa* (14.47), *Grewia teliafolia* (14.47), *Ficus saemocarpa* (11.84), *Haldina cardifolia* (11.84), *Bridelia retusa* (9.21), *Miliusa velutina* (9.21), *Putranjiva roxburbhii* (9.21), *Albizzia prosera* (7.89), *Dalbergia sissoo* (7.89), *Mitragyna parvifolia* (7.89) and *Barringtonia acutangula* (6.58) come under rare category. *Cordia dichotoma* (5.26), *Lagerstromia parviflora* (3.95), *Albizzia lebbek* (2.63), *Acacia*

concinna var. *rugata* (2.63), *Hymenodictyon orixense* (2.63), *Schleichera oleosa* (2.63), *Syzygium heyneanum* (2.63), *Abutilon indicum* (1.32), *Alstonia scholaris* (1.32), *Bauhinia purpurea* (1.32), *Cassia fistula* (1.32), *Ficus palmata* (1.32), *Holoptelea integrifolia* (1.32), *Litsea glutinosa* (1.32), *Bergera koenigii* (1.32), *Sterculia vilosa* (1.32), *Terminalia elliptica* (1.32), *Toona ciliate* (1.32) and *Zizyphus mauritiana* (1.32) belong to very rare group.

In teak plantation only *Tectona grandis* comes under dominant density class with 598.08 density out of 769.23 total tree density. *Mallotus philippensis* (59.62) is the only prominant tree species. *Lagerstromia parviflora* (13.46), *Shorea robusta* (13.46), *Aegle marmelos* (9.62), *Schleichera oleosa* (9.62), *Mitragyna parvifolia* (7.69) and *Syzygium cumini* (7.69) come under rare category. In this forest type, not a single species comes under common density class. *Diospyros exculpta* (5.77), *Ehretia laevis* (5.77), *Miliusa velutina* (5.77), *Ficus hispida* (3.85), *Ficus racemosa* (3.85), *Ficus saemocarpa* (3.85), *Abutilon indicum* (1.92), *Bridelia retusa* (1.92), *Buchanania cochinchinensis* (1.92), *Eucalyptus tereticornis* (1.92), *Ficus bengalensis* (1.92), *Ficus palmata* (1.92), *Holoptelea integrifolia* (1.92), *Lannea coromandelica* (1.92), *Litsea glutinosa* (1.92), *Madhuca longifolia* var. *latifolia* (1.92) and *Mallotus nudiflorus* (1.92) come under the very rare class.

Discussion

The results of PCA and Cluster analyses clearly formed three major forest types (sal forest, miscellaneous forest and teak plantation) on the basis of IVI value of the species in the random plotes. In teak plantation, 50 to 60 years before *Tectona grandis* was introduced by the forest department in the open land for timber production (Tripathi and Singh, 2009), however, gradually many tree species have been occupied the good position within this monodominant plantation (Table 2). The sal forest is the oldest natural forest of the Terai region dominated by *Shorea robusta*. However, the miscellaneous forest can be consider as the developing forest type since it consists of maximum site specific species and common species. The common species growing in this forest type after reaching here via immigration from nearby dissimilar habitats which have the higher ecological amplitude (Shimada and Wilson, 1985). This forest type is very important for the diversity point of view due to the presence of maximum site specific species with low ecological amplitude and less capable to survive outside their specific habitat.

In the Venn diagram (Fig. 5) some of the species have been found confined within a particular forest type. These species can be termed as habitat specific species (Varghese and Menon, 1999). These species have been considered valuable for the conservation point of view, because they have low ecological amplitude which may be responsible for its narrow distribution (Prasad et al., 2007) and have more risk to be vanished. On the other hands some of the species have been found commonly distributed throughout the forest in all kinds of habitats. The reason behind the existence of these companion species in all forest types may be the overlapping of nich requirements (Prasad et al., 2007).

To compare the species richness, tree density and basal cover of the three forest types per hectare scale has been taken (Table 3). The mean species richness has been found 52.02 species ha^{-1}, ranging from 48.07 in teak plantation to 55.35 in sal forest. These values of species richness have been found within the range of tropics i.e. 20-307 spp. ha^{-1} (Campbell et al., 1992; Valencia et al., 1994). These values of the species richness have been found lower in comparison with the humid tropical evergreen forest (61 species ha^{-1}) (Tripathi et al., 2004), but higher than the tropical rain forest (43 species ha^{-1}) (Strasberg, 1996) and tropical moist forest (45 species ha^{-1}) (Tripathi, 2001). The species richness in the study area has been found higher than the tropical dry forests of Mirzapur (9-14) (Singh and Singh, 1991), Similipal Biosphare Reserve (19-36)

(Mishra et al., 2008) and tropical dry evergreen forest of Tanil Nadu (19-35) (Venkateshwaran and Parthasarathy, 2003; Mani and Parthasarathy, 2005) but lower than tropical dry deciduous forest of Andhra Pradesh (69) (Reddy et al., 2008) and tropical wet evergreen forest of Kalakad (80-85) (Parthasarathy, 1999). More significantly, the mean species richness has been found greater than the earlier report from the area made by Tripathi and Singh, (2009) in which they have recorded only 44 tree species in 7.02 hectares.

The mean tree density has been found 727.71 stem ha^{-1}, ranging from 671.05 in miscellaneous forest to 769.23 in teak plantation. These values of tree density have been found within the range of tropics i.e. 276-935 stem ha^{-1} (Murali et al., 1996; Sundarapandian and Swamy, 1997; Ghate et al., 1998; Mani and Parthasarathy, 2005). The tree density in the sanctuary area has been found higher than the tropical evergreen forests of Western as well as Eastern Ghats where it ranges from 419-716 stem ha^{-1} (Singh et al., 1984; Ganesh et al., 1996; Ghate et al., 1998; Parthasarathy, 1999; Chittibabu and Parthasarathy, 2000) and tropical deciduous forests (150-627 stem ha^{-1}) (Jha and Singh, 1990; Singh and Singh, 1991; Varghese and Menon, 1998 ; Shrestha and Jha, 1997; Pandey and Shukla, 2003; Rautiainen, 1999). Tropical moist forest of Singapore (604 stem ha^{-1}) (Swan Jr, 1988) and tropical rain forest of Costa Rica (391-617 stem ha^{-1}) (Heaney and Proctor, 1990) also have the lower tree density than that of the sanctuary area. Some tropical deciduous forest of Eastern Ghats ranging from 735-810 stem ha^{-1} (Mishra et al., 2008; Reddy et al., 2008), tropical evergreen forest of Eastern Ghats and North-East India ranging from 750-935 stem ha^{-1} (Visalakshi, 1995; Mani and Parthasarathy, 2005; Supriya and Yadava, 2006) and tropical rain forest of Amazon and Malaysia ranging from 1054-1420 stem ha^{-1} (Campbell et al., 1986; Proctor et al., 1988) show the higher tree density than the sanctuary area.

The mean basal area of tree species in KWS has been found 59.31 m^2 ha^{-1}, ranging from 22.97 in miscellaneous forest to 89.07 in teak plantation. These values of basal area have been found within the range of tropics i.e. 7-104 m^2 ha^{-1} (Singh et al., 1984; Jha and Singh, 1990; Mishra et al., 2008). The basal area has been found higher than the tropical evergreen forests ranging from 11-82.76 m^2 ha^{-1} (Campbell et al., 1992; Visalakshi, 1995; Strasberg, 1996; Chittibabu and Parthasarathy, 2000; Mani and Parthasarathy, 2005; Supriya and Yadava, 2006) and tropical deciduous forest ranging from 7-61 m^2 ha^{-1} (Jha and Singh, 1990; Singh and Singh, 1991; Singh et al., 1995; Shrestha and Jha, 1997; Varghese and Menon, 1998 ; Singh et al., 2005; Tripathi and Singh, 2009) in India. The basal area of tropical rain forest of Malaysia i.e. 26-46 m^2 ha^{-1} (Proctor et al., 1988) also has the lower basal area than the sanctuary area. The basal cover of some evergreen forests of Western Ghat ranging from 29-103 m^2 ha^{-1} (Singh et al., 1984; Ganesh et al., 1996; Parthasarathy, 1999), Similipal Biosphere Reserve 48.7-10.9 m^2 ha^{-1} (Mishra et al., 2008) and the tropical rain forest of Amazonia 28 to 68 m^2 ha^{-1} (Campbell et al., 1986) have been found higher than the forest of sanctuary area. More significantly, the basal area of the adjacent forests ranging from 16-61 m^2 ha^{-1} (Shrestha and Jha, 1997; Singh et al., 2005; Tripathi and Singh, 2009) has been found lower than the basal cover of the study area.

In KWS the mean dominance (0.318) ranges from 0.138 in miscellaneous forest to 0.601 in teak plantation has been found much higher than the average dominance value (0.06) of tropical forests (Knight, 1975). However, it is within the range from the Indian tropics (0.21-0.92) repoted by Parthasarathy et al., (1992) and Visalakshi, (1995). Supriya and Yadava, (2006) have also reported the dominance value 0.23-0.97 from the tropical semievergreen forest of Manipur. The dominance range of KWS has been found very close to the dominance values of sal and teak forest (0.07-0.63)

of Madhya Pradesh, India (Prasad and Pandey, 1992).

The Shannon diversity index of the three forest types in KWS has been found 1.984 as a mean with a range from 1.134 in teak plantation to 2.666 in miscellaneous forest. The value of diversity index has been found within the range (0.83-4.10) of diversity index in Indian tropics (Singh et al., 1984; Parthasarathy et al., 1992; Visalakshi, 1995). Further, it has been found closer to the diversity indexes of tropical forest of Madhya Pradesh (0.32-3.76) (Prasad and Pandey, 1992) and Kodayar, Western Ghats (2.20-2.65) (Sundarapandian and Swamy, 2000). The higher value of diversity index has been reported from the tropical forest of Kalakad, Western Ghats (3.31-3.69) (Parthasarathy et al., 1992), Silent Valley, Kerala (3.52-4.15) (Singh et al., 1984) and tropical forest of Garo hills (2.47-4.27) (Ashish et al., 2006) in comparison to KWS. This diversity index is very low than the tropical forest of Panama (5.06-5.40) (Knight, 1975) which may due to high degree of disturbance and anthropogenic pressure such as grazing, burning, collection of woods and medicinal plants etc. (Foster 1990; Jayasingam and Vivekanantharaja, 1994).

Conclusion

The tree species richness and the basal area of the KWS have been found higher than previous report made by Tripathi and Singh, (2009). This increment in the value of species richness is a very good sign for the biodiversity expansion. The high species richness in the sal forest indicates that this forest stand is capable to achieve its natural conditions, if we reduce the biotic stress. The high species diversity and low basal cover in miscellaneous forest clearly indicate the growing nature of this forest types with maximum number of species having younger individuals. The teak plantation is the recently diversified forest which has been indicated by higher value of species genus ratio (Tripathi and Singh, 2009; Shukla, 2009; Reddy et al., 2007; Reddy et al., 2008; Parthasarathy, 2001; Mani and Parthasarathy, 2005). A very high IVI value (231.5) of *Tectona grandis* is responsible for the monodominant nature of the teak plantation. Champion and Seth, (1968) have classified the forest of the sanctuary area into two major types (i) Sal Forest and (ii) Miscellaneous Forest, however, Tripathi and Singh, (2009) have categorised them into (i) Natural Forest and (ii) Plantation Forest on the basis of the dominant species and species composition. In the present study three major forest types have been categorised (i) Sal forest, (ii) Miscellaneous forest and (iii) Teak Plantation on the basis of cluster and PCA analyses using IVI data of the random quadrates. The microclimatic condition may be the main cause of this diversification of forest types (Behera et al., 2012).

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