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Pattern of Species Distribution along Environmental Variables in Two Different Forest Beat of Raghunandan Reserve Forest of Habiganj

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Abstract

The study has piloted to find the Pattern of species distribution along environmental variables and disturbance in Raghunandan Reserve Forest. Shaltila and Shahapur beat of Raghunandan Hill Reserve Forest are situated in Chunarughat sub-district of Habiganj district between 24°5'-24°10' N and 91°25'-91°30' E under the Sylhet Forest Division. The Environmental variable and vegetation data were collected from 30 sample plots from each forest beat by using arbitrary sampling without preconceived bias. 51 species were found from Shaltila and 34 species found in Shahapur forest beat. Thus the dataset continued with total 85 species in 60 samples. To determine the relationships between tree species distribution and environmental variables, Canonical Correspondence Analysis (CCA) ordination method were performed separately for two forest beat. In CCA ordination, tree species showed significant variation along environmental gradients in terms of soil organic matter and disturbances ($p<0.05$) in the case of Shaltila forest. Potassium has a significant relationship with axis 1 and axis 2 in this forest. But Shahapur forest showed no significant relationship between species and environmental variables. Phosphorus has a significantly negative relationship with axis 2 in this forest. Disturbance played as a critical role of this forest thus influencing the distribution of species. The study showed that the distributions of tree species are strongly influenced by disturbance and organic matter in Shaltila and Shahapur forest beat showed no significant relationship between species and environmental variables. Future research should be included more environmental variables with larger study area that identify the most important environmental forces which will drive by species distribution findings in this forest.

Key Words: species distribution, environmental variables, CCA, disturbance

Introduction

In ecological studies, the understanding of relationships between biotic and abiotic components of an ecosystem has been a major research focus. Realizing the interactions of different plants and their relationships with various soil variables could provide essential guidance in forest improvement and forest ecosystems (Tavili and Jafari 2009). Species diversity in forests is important in conservation management and is frequently used as an indicator of the stability of community systems (Pausas 1994). In community ecology, structural variability and high species diversity

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are central research themes (Sarker et al. 2013). Tropical forest vegetation is highly influenced by climate and soil. But realizing the individual tree species distribution respond to specific resources have been hindered by high diversity and consequent rarity (Condit et al. 2013). In fact, the relationships of community structure, composition and species diversity of forest with environmental factors have been considered as a central issue in ecological and environmental sciences (Zhang and Zhang 2011).

The variation in species diversity can be linked to several ecological gradients (Kessler 2001). The most ecologically important environmental factors which affecting species composition and distribution are topography and soil (Jafari et al. 2004). Tropical forest represents one of the most biologically diverse ecosystems in the world, which are experiencing high rates of deforestation. As a result, day by day the concentration of CO_2 in the atmosphere is increasing (Malhi and Grace 2000). So, it is necessary to identify the vegetation pattern and structure of the forest to determine the key environmental variables responsible for their distribution for future management or conservation purposes. In the tropical region, community ecological studies became impossible due to the scarcity of information on soil, topography, geography, and climate (Sollins 1998). Northeastern forests of Bangladesh cover an area of 40,000 ha. Only a small part of the area (118.46 ha) comprises of freshwater swamp forest (Choudhury 2003) and the rest are hill forests having a mixture of tropical evergreen and deciduous vegetation. Some north-eastern reserve forests namely Patharia Hill Reserves, Tarap Hill Reserves and Raghunandan Hill Reserves etc. represent the latitudinal gradient of the north-eastern hill system. The ecologists have been studied about the species composition and distribution pattern, community classification, soil and plant species correlation, comparison of natural fragmentation etc. in these reserve forests. They found good species and distribution pattern, plant species are aggregated and form significantly distinct groups in this forest. But natural fragmentation and deforestation are the main causes of species extinction. Raghunandan Hill Reserve is one of such hill reserves of Bangladesh. Which is widespread biologically diverse and ecologically least explored reserve (Muzaffer et al. 2011) and comprised of a number of natural fragments. An extensive bibliographic search showed that the study on the interaction between species and environmental variables has been poorly studied or in many cases absent in this forest. In such a situation, the present study has the opportunity to focus on the relationships of tree distribution and soil properties in this forest. The findings of the study will provide indispensable information on vegetation patterns of the forests as well as the distributional patterns of species in terms of environmental variables. This information will serve as a baseline for future ecological studies and will provide an essential guideline for ecosystem management of the forest.

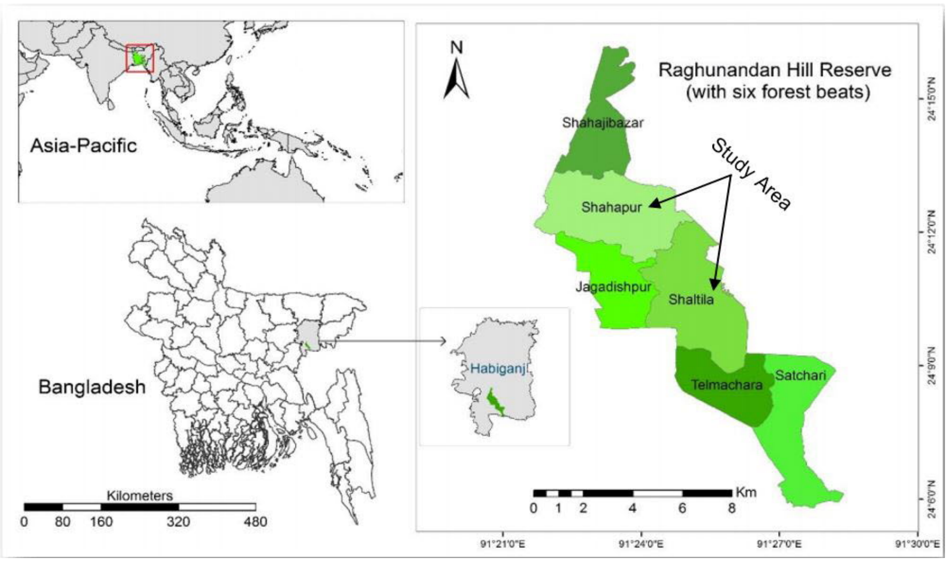

Fig. 1. The map of the study area.

Materials and Methods

Study site

The study site of Raghunandan Hills Reserve Forest is located between 24°5' - 24°10' N and 91°25' - 91°30' E under Sylhet forest division in Habiganj (Fig. 1). It is nearly 130 km northeast of Dhaka beside of Dhaka-Sylhet Highway. The total area of the forest is around 2,631 ha. It is an evergreen or semi-evergreen mixed natural forest. The vegetation is recognized as natural forest, mixed forest, plantation forest, bamboo patch, and grasslands.

Average annual rainfall in the area is 4,162 mm and January is the coldest month (minimum temperature around 9.6°C), while May and October are the hottest months (average maximum temperature around 34.8°C). The relative humidity is about 74% during December and over 90% during July-August (Mukul et al. 2006). The area of the forest is undulating with slopes and hillocks ranging from 10-50 m scattered in the forest and it is drained by a number of small, sand-bedded streams which are fully dry out at the end of the rainy season (Chemonics 2002).

Sampling design

The Sampling plots were selected randomly without preconceived bias as followed by McCune et al. (2002). Total 60 plots were selected from two forest beat of the Raghunandan hill reserve as 30 plots from each. The study was conducted from May 2014 to June 2014. The 20×20 m plot size was studied to conduct a quantitative field survey for tree species (Fig. 2). Within each plot name and number of all trees were recorded.

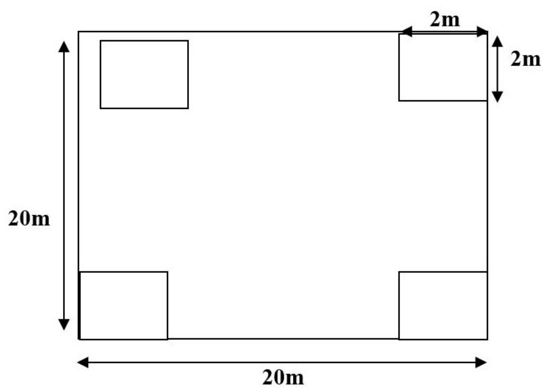

Fig. 2. Sampling Plot Design.

Vegetation data

All the tree species (dbh > 7.5 cm) found in the plots were counted and identified to their appropriate taxonomic identity. The Encyclopaedia of Flora and Fauna of Bangladesh by Asiatic Society of Bangladesh (2009) were used to determine the local and scientific names along with family (Ahmed et al. 2009). The knowledge from a local expert was also used where necessary to identify the species.

Environmental data

Elevation, Disturbance, Soil pH, moisture content (MC), organic matter (OM), soil nutrients as nitrogen (N), potassium (K), phosphorus (P) were considered as environmental variables which were measured. Four soil sample from each corner of the plot were picked up with the help of cylindrical soil borer and 10 cm of soil sample were extracted. These were pulled together and mixed thoroughly in the field and marked as one sample which used to measure environmental variables. Measurement of soil pH and moisture content was done by digital soil pH and moisture meter. For the measurement of N, P, K concentration and soil organic matter, soil samples were dried in open air in a circulated area rather than direct sunlight for a week. Then these soil samples were taken to SRDI (Soil Research Development Institute) to measure P, K, N, and OM. Disturbance data were measured through observation and per disturbance occurrence counted as one in number. Elevation data were measured by handheld digital GPS machine.

Stataistical analysis

For the statistical analysis Canonical Correspondence Analysis (CCA), Statistical and ordination software have been used through out the study (Table 1). In CCA, environmental variables were standardized to Z score and squared root transformation of species data were carried out. Monte Carlo

Table 1. Statistical and ordination software

Analysis	Software
Data Coding	Microsoft Excel
CCA	CANOCO for Windows 4.5
Correlation between species and environmental variables	SPSS Statistics 17.0

Table 2. Summary statistical table for CCA ordination of Shaltila forest

Axes	1	2	3	4	Total inertia
Eigenvalues	0.348	0.319	0.249	0.230	5.874
Species-environment correlations	0.962	0.871	0.904	0.882	
Cumulative percentage variance of species data	5.9	11.4	15.6	19.5	
Cumulative percentage variance of species-environment relation	23.3	44.6	61.3	76.7	
Sum of all eigenvalues					5.874
Sum of all canonical eigenvalues					1.496

Permutation test under reduced model was used to identify significant factor reliable for the species compositional variation (Ter Braak 1987). Automatic forward selection of environmental variables in relation with Monte Carlo permutation test by using 499 permutations was carried out by CANOCO to test the significance of the eigenvalues of all the canonical axes. In the ordination diagrams, species names were abbreviated using six letters from the scientific name of each plant by combining the three initial letters for the genus and species, for example, "artcha" was an abbreviation for *Artocarpus chaplasha*.

A number of statistical and ordination software's were used to generate results and diagram are listed below (Table 1).

Results

Vegetation status

In Shaltila forest, total 289 individuals' tree belongs to 51 species and 26 families were found in 30 plots. A maximum number of species (6) found belongs to Moraceae family followed by Myrtaceae (5) and Euphorbiaceae (5). *Artocarpus chaplasha* (39) showed the highest number of occurrence in the forest followed by *Bauhinia acuminata* (14) and *Tectona grandis* (12).

In Shahapur forest, total 216 individuals tree belongs to 34 species and 19 families were found in 30 plots. A maximum number of species (7) found belongs to Moraceae family followed by Euphorbiaceae (4), Caesalpiniaceae (3) and Meliaceae (3). *Artocarpus chaplasha* represents the highest number of individual (23) occurrence in the forest followed by *Bauhinia acuminata* (10) and *Jatropha curcas* (9).

Environmental correlates of vegetation distribution

Shaltila forest

Canonical correspondence analysis (CCA) is an ordination technique which shows non-linear relations between

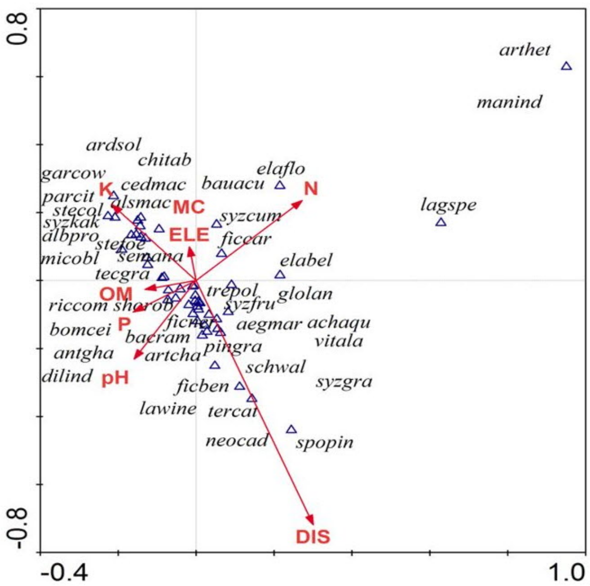

Fig. 3. Bi-plot representation of CCA ordination diagram comprises 51 species of 30 samples.

species and environmental variables and prefers the best weights for environmental variables. In CCA, all the environmental variables data are being used. The eigenvalues for the first four axes were 0.348, 0.319, 0.249, 0.230 and species-environmental correlations for these four axis were 96%, 87%, 90% and 88% respectively (Table 2). Gradual decrease of eigenvalues of first four axes indicated a well-structured dataset and it assured that the CCA analysis performed well in describing relationships between vegetation and environmental variables presented in the bi-plot (Fig. 3).

Cumulatively, the first four axes of CCA ordination clarified 19.5% of the variance in species data and 76.7% of the variance of species environmental relation. The higher value of species-environmental relation (94.1%) indicated that species data were strongly related to the measured environmental variables.

In CCA ordination, K was found a significantly positive correlation with axis 1 and in the case of axis 2, also K found to have highly significant correlation positively (Table 3). Automatic forward selection of environmental gradients by using CANOCO 4.5 (Table 4) demonstrated that Disturbance and Phosphorous (P) explained the most significant variance (27% and 19% respectively) while OM explained the least (15%). The forward selection of eight environmental variables in CCA ordination of 30 sample plots with 50 species results in two significant variables (Disturbance and OM with $p < 0.05$).

Table 3. Intraset correlation coefficient between sample scores on first two axes and environmental gradients using canonical correspondence analysis of Shaltila forest

Variables	Correlation coefficients (Intraset)	
	Axis 1	Axis 2
pH	-0.027	0.253
N	-0.107	-0.036
P	-0.228	-0.326
K	.376*	.538**
OM	-0.092	-0.022
MC	0.187	0.287
Elevation	0.187	0.287
Disturbance	-0.14	-0.095

Fig. 3 shows the species distribution patterns when constrained by environmental factors. CCA ordination result revealed that in this study area pH was negatively correlated with N. The Disturbance found a negative association with elevation and K. *Artocarpus heterophyllus* and *Mangifera indica* had highest positive scores and *Paramignya citrifolia* and *Garcinia cowa* had a highest negative score in axis 1. Species with the highest positive score on axis 2 were *Ardisia solanaceae* and *Elaeocarpus floribundas* whereas species with highest negative score were *Spondias pinnata* and *Neolamarckia cadamba*. Some species have a highly positive correlation with pHs such as *Artocarpus chaplasha* and *Ficus nervosa*. But *Ficus caria* and *Syzygium cumini* were negatively correlated with pH gradient and positively distributed along N. In the case of disturbance, *Terminalia catappa*, *Ficus benghalensis*, and *Pinanga gracilis* shown a positive correlation. *Ricinus communis* and *Shorea robusta* were positively related with OM whereas *Stereospermum colaris*, *Chickrassia tabulari*, and *Cedrella macrocarpa* are positively related with K and MC.

Shahapur forest

The eigenvalues for the first four axes were 0.367, 0.181, 0.169, 0.156 and species-environmental correlations for these four axes were 91%, 83%, 73% and 75% respectively

Table 4. Marginal and conditional effect obtained from the summary of forwarding section of CANOCO software of Shaltila forest

Marginal effect		Conditional effect			
Variable	λ_1	Variable	λ_A	P	F
DIS	0.27	DIS	0.27	**0.044**	1.32
P	0.19	P	0.19	0.486	1
N	0.16	K	0.2	0.478	1
MC	0.16	MC	0.2	0.5	0.99
ELE	0.16	pH	0.17	0.756	0.84
K	0.15	N	0.19	0.618	0.91
OM	0.15	OM	0.28	**0.056**	1.4

Table 5. Summary statistical table for CCA ordination of Shahapur forest

Axes	1	2	3	4	Total inertia
Eigenvalues	0.367	0.181	0.169	0.156	4.900
Species-environment correlations	0.911	0.837	0.738	0.753	
Cumulative percentage variance of species data	7.5	11.2	14.6	17.8	
Cumulative percentage variance of species-environment relation	29.2	43.6	57.1	69.5	
Sum of all eigenvalues					4.900
Sum of all canonical eigenvalues					1.256

(Table 5). Here also we observe a gradual decrease of eigenvalues of first four axes indicating a well-structured dataset and it assured that the CCA analysis performed well in describing relationships between vegetation and environmental variables presented in the bi-plot (Fig. 4).

Cumulatively, the first four axes of CCA ordination clarified 17.8% of the variance in species data and 69.5% of the variance of species environmental relation (Table 5). The higher value of species-environmental relation indicated that species data were strongly related to the measured environmental variables.

In CCA ordination, MC was found strongly correlated (negatively) with axis 1 and P found significantly correlated (negatively) with axis 2 (Table 6). Automatic forward selection of environmental gradients by using CANOCO 4.5 (Table 7) demonstrated that Phosphorous (P) explained the most significant variance (20%) while pH explained the least (13%). The forward selection of eight environmental variables in CCA ordination of 30 sample plots with 34 species results has no significant variables.

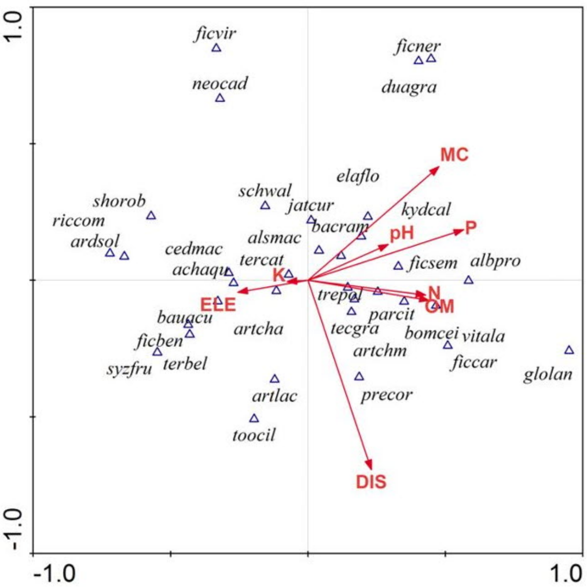

Fig. 4. Bi-plot representation of CCA ordination diagram comprises 34 species of 30 samples.

Fig. 4 shows the species distribution patterns when constrained by environmental factors. CCA ordination result revealed that in this study area soil pH was negatively correlated with Elevation and K. *Glochidion lanceolarium* and *Albizia procera* had highest positive scores and *Ardisia solanaceae* and *Ricinus communis* had a highest negative score in axis 1. Species with the highest positive score on axis 2 were *Ficus virens* and *Ficus nervosa* whereas species with highest negative score were *Toona ciliata* and *Artocarpus lacucha*. Some species were highly positively correlated with MC such as *Kydia calycina*, *Baccaurea ramiflora*. *Bauhinia acumi-*

Table 6. Intraset correlation coefficient between sample scores on first two axes and environmental gradients using canonical correspondence analysis of Shahapur forest

Variables	Correlation coefficients (intraset)	
	Axis 1	Axis 2
pH	0.055	-0.139
N	0.09	-0.339
P	0.01	-.417*
K	0.005	0.125
OM	0.016	-0.352
MC	-0.169	-0.151
Elevation	0.018	-0.265
Disturbance	0.01	0.122

Table 7. Marginal and conditional effect obtained from the summary of forwarding selection of CANOCO software of Shahapur forest

Marginal effect		Conditional effect			
Variable	λ_1	Variable	λ_A	P	F
P	0.20	P	0.20	0.206	1.18
MC	0.20	MC	0.19	0.256	1.13
OM	0.19	DIS	0.18	0.386	1.07
N	0.19	K	0.18	0.346	1.11
DIS	0.16	N	0.15	0.648	0.89
K	0.13	OM	0.13	0.792	0.78
pH	0.13	pH	0.12	0.876	0.69

nate and *Artocarpus chaplasha* were positively correlated with elevation and negatively with MC and pH. *Paramignya citrifolia* and *Trewa polycarpa* showed positive correlation and *Achyranthes aquatica* and *Terminalia catappa* showed a negative correlation with the organic matter (OM).

Discussion

In a tropical forest, species richness, abundance, composition, structure, and growth are influenced by the diversity and quality of nutrients presents in soil (John et al. 2007; Jones et al. 2008). Several studies have documented that the natural forest of the northeastern part of Bangladesh also shows the high degree of variability in tree species composition which is strictly influenced by the variation of environmental gradients in different parts of the forest (IUCN 2004; Uddin et al. 2011).

The CCA ordinations were performed to identify the environmental correlates of vegetation distribution in Raghunandan Hill Reserve. In the case of Shaltila forest, the first four CCA axes explained 19.5% and 76.7% variance of the species data and species–environment relation, respectively (Table 2). These moderate values can be attributed to high noise levels typical of species–abundance data (Ter Braak 1987). The CCA ordination graph shows that abundance of certain species was related to the particular soil variables. The disturbance is the most important factor for compositional variation of the species followed by P, N, MC, Elevation, K and OM concentration. The abundance of *Artocarpus chaplasha* and *Ficus nervosa* occur in sites with a high concentration of pH. *Ficus caria* and *Syzygium cumini* were found in sites with higher soil N. However, it was revealed that nitrogen (N) did not have much impact on species distributions among these forest types, similar results found in (Condit et al. 2013). In addition, the abundance of *Ardisia Stereospermum colaris*, *Chickrassia tabulari*, and *Cedrella macrocarpa* are growing spuriously in the sites with a high concentration of K and MC in the soil. The results are supported by previous work on the tropical forest by John et al. (2007) as spatial distributions of tree species in three different forest areas are strongly associated with the distribution of environmental variables.

In the case of Shahapur forest, the first four CCA axes explained 17.8% and 69.5% variance of the species data and species–environment relation, respectively and these lower values can be attributed to high noise levels typical of species–abundance data. P is the most significant factor for compositional variation followed by MC, OM, N, Disturbance, K, and elevation. *Bauhinia acuminate* and *Artocarpus chaplasha* were positively distributed along elevation. In the case of OM, *Paramignya citrifolia* and *Trewa polycarpa* showed a positive correlation. *Kydia calycina*, *Baccaurea ramiflora* were highly positively correlated with MC. In terms of conditional effect, no environmental variables showed significant contribution in species variations.

The role of anthropogenic disturbance has always been a controversial issue. Communities differ in response to disturbance depends on their age, species composition, regeneration status, and the basic site conditions, such as soil, aspect, the degree of slope, and moisture regime (Peet 1978; Denslow 1980). From the field inspection in Shahapur forest, disturbance plays a very important role in species distribution rather than soil variables. This forest is very easily accessible by people living around the forest. Illegal felling, fuel wood extraction, bamboo and cane extraction were observed during the data collection. This activity showed great influence on species composition. The CCA analysis did not identify any significant soil variables reliable for plant distribution in Shahapur. But in Shaltila forest, the CCA analyses identify two environmental variables-disturbances and OM has significant effects on plant distribution. However, this forest is not easily accessible by the people living adjacent to the forest. People are more dependent on tea garden rather than the forest. The forest remains intact at most of its parts.

Implications for management

In Bangladesh, forests are now under threat not only for the anthropogenic pressure but also for the climate change. So, proper management for the remaining forest vegetation has become forefront. The knowledge of species distribution along environmental variables is important for the forest managers which play vital role in decision making for the proper management of the forest. Distribution of the tree communities presented in this study can help to make the proper vegetation monitoring and to assess the site qualities for the species occurrence. It also provides a technique for ranking tree communities with respect to their importance in management planning and to develop the habitat maps and habitat suitability indices. In future, it will help to identify the change of land use pattern and the effect of climate change. However, further research is required to provide a meaningful integration ecosystem processes affecting the distribution and abundance of tree species in the natural forest of Raghunandan Hill Reserve.

Conclusion

In the study, distribution of tree species along environmental variables and disturbances in Shaltila and Shahapur forest has been examined. Soil variables considered in the study were soil pH, moisture content, N, P, K and organic matter (OM). Elevation and disturbance data were also considered to measure their contribution in tree distribution among these areas. Shaltila forest showed a significant relationship between species and environmental variables in terms of soil organic matter and disturbances. Potassium has a significant relationship with axis 1 and axis 2 in this forest. But Shahapur forest showed no significant relationship between species and soil variables. Phosphorus has a significantly negative relationship with axis 2 in this forest. Disturbance played as a critical role of this forest thus influencing the distribution of species. This study provides an insight into plant distribution with few measured environmental variables. For a better understanding of these forests, future research should be included more environmental variables with larger sample area that identify the most important environmental forces that drive species distribution in these forest of Raghunandan. This study puts emphasis on future forest composition and structure on the basis of environmental variables and disturbance factors and will be helpful for forest manager to choose efficient strategy to sustain the biodiversity management in these areas.

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Appendix 1. List of the Tree Species in Shaltila Forest Beat

Local name	Scientific name	Abbreviation	Family
Amla	*Spondias pinnata Kurz.*	spopin	Anacardiaceae
Awal	*Vitex alata*	vitala	Miliaceae
Badam	*Sterculia foetida L.*	stefoe	Sterculiaceae
Bel	*Aegle marmelos*	aegmar	Rutaceae
Belfoi	*Elaeocarpus floribundus*	elabel	Ealocarpaceae
Belembu	*Paramignya citrifolia Hk.f*	parcit	Rubiaceae
Bherenda	*Ricinus communis L.*	riccom	Euphorbiaceae
Bohera	*Terminalia belerica Roxb.*	terbel	Compretaceae
Bon Jam	*Ardisia solanaceae Roxb.*	ardsol	Myrtaceae
Bon jamir	*Acronychia pedunculata*	acrped	Rutaceae
Bonak	*Schima wallichii*	schwal	Theaceae
Bot	*Ficus benghalensis*	ficben	Moraceae
Bubi	*Baccaurea ramiflora Lour.*	bacram	Euphorbiaceae
Chalta	*Dillenia indica*	dilind	Dilleniaceae
Cham	*Artocarpus chama*	artchm	Annonaceae
Chapalish	*Artocarpus chaplasha*	artcha	Moraceae
Chhatim	*Alstonia macrophylla Wall.*	alsmac	Apocynaceae
Chickrassi	*Chickrassia tabularis Juss.*	chitab	Miliaceae
Dewa	*Artocarpus lacucha*	artlac	Moraceae
Dhakijam	*Syzygium Grande (watt.)Wall.*	syzgra	Myrtaceae
Dumur	*Ficus caria*	ficcar	Moraceae
Gunal	*Prema corymbosa Rttl.*	precor	Leguminosae
Gunuri	*Cedrella macrocarpa C.DC*	cedmac	Miliaceae
Hargaza	*Dillenia pentagyna Roxb.*	dilpen	Dilleniaceae
Jam	*Syzygium cumini Skiel*	syzcum	Myrtaceae
Jarul	*Lagerstroemia speciosa*	lagspe	Lythraceae
Joloj Apang	*Achyranthes aquatica L.*	achaqu	Amaranthaceae
Jolpai	*Elaeocarpus floribundus*	elaflo	Elaeocarpaceae
Kakjam	*Syzygium fruticosum DC.*	syzkak	Myrtaceae
Kakra	*Glochidion lanceolarium*	glolan	Rhizophoraceae
Kalojam	*Syzygium Fruticosum (Rosb.)DC*	syzfru	Myrtaceae
Kanchan	*Bauhinia acuminate L.*	bauacu	Caesalpinioceae
Kanthal	*Artocarpus heterophyllus*	arthet	Moraceae
Kath badam	*Terminalia catappa L.*	tercat	Combretaceae
Kaw	*Garcinia cowa Roxb.*	garcow	Guttiferae
Khudijam	*Antidesma ghaesembilla*	antgha	Euphorbiaceae
Kodom	*Neolamarckia cadamba Roxb.*	neocad	Caesalpiniaceae
Koroi	*Albizia procera Benth.*	albpro	Caesalpinioceae
Mango	*Mangifera indica*	manind	Anacardiaceae
Menda	*Lawsonia inermis L.*	lawine	Lythraceae
Pahari awal	*Stereospermum colaris*	stecol	Euphorbiaceae
Panidumur	*Ficus nervosa Heyne.*	ficner	Moraceae
Pichondi	*Grewia nervosa*	grener	Tiliaceae
Pinkadu	*Xylia dolabiformis Benth.*	xyldol	Leguminosae
Pitali	*Trewa polycarpa Benth*	trepol	Euphorbiaceae
Ramgua	*Pinanga gracilis*	pingra	Arecaceae
Sal	*Shorea robusta Roxb.*	shorob	Dipterocarpaceae
Shimul	*Bombax ceiba L.*	bomcei	Bombacaceae
Sundi	*Michelia oblonga*	micobl	Magniliaceae
Teak	*Tectona grandis L.F.*	tecgra	Verbenaceae
Vela	*Semecarpus anacardium L.*	semana	Anacardiaceae

Appendix 2. List of the Tree Species in Shahapur Forest Beat

Local name	Scientific name	Abbreviation	Family
Awal	*Vitex alata*	vitala	Miliaceae
Benembu	*Paramignya citrifolia Hk.f*	parcit	Rubiaceae
Bhrenda	*Ricinus communis L.*	riccom	Euphorbiaceae
Bohera	*Terminalia belerica Roxb.*	terbel	Compretaceae
Bon jam	*Ardisia solanaceae Roxb.*	ardsol	Myrtaceae
Bonak	*Schima wallichii*	schwal	Theaceae
Bot	*Ficus benghalensis*	ficben	Moraceae
Bubi	*Baccaurea ramiflora Lour.*	bacram	Euphorbiaceae
Cham	*Artocarpus chama*	artcha	Annonaceae
Chapalish	*Artocarpus chaplasha*	artcha	Moraceae
Chhatim	*Alstonia macrophylla Wall.*	alsmac	Apocynaceae
Dewa cham	*Artocarpus lacucha Buch.-Ham.*	artlac	Moraceae
Dumur	*Ficus caria L.*	ficcar	Moraceae
Gunal	*Prema corymbosa Rttl.*	precor	Leguminosae
Gunuri	*Cedrella macrocarpa C.DC*	cedmac	Miliaceae
Jaigga dumur	*Ficus semicordata Buch.-Ham*	ficsem	Moraceae
Joloj Apang	*Achyranthes aquatica L.*	achaqu	Amaranthaceae
Jolpai	*Elaeocarpus floribundus*	elaflo	Elaeocarpaceae
kakra	*Glochidion lanceolarium*	glolan	Rhizophoraceae
Kalojam	*Syzygium Fruticosum (Rosb.)DC*	syzfru	Myrtaceae
Kanchan	*Bauhinia acuminate L.*	bauacu	Caesalpinioceae
Kath badam	*Terminalia catappa L.*	tercat	Combretaceae
Kodom	*Neolamarckia cadamba Roxb.*	neocad	Caesalpiniaceae
Koroi	*Albizia procera*	albpro	Caesalpinioceae
Kuma	*Toona ciliata*	toocil	Meliaceae
Panidumur	*Ficus nervosa Heyne.*	ficner	Moraceae
Patabela	*Kydia calycina*	kydcal	Malvaceae
Pitali	*Trewa polycarpa Benth*	trepol	Euphorbiaceae
Ram dhala	*Duabanga grandiflora Roxb.*	duagra	Sonneratiaceae
Sada dumur	*Ficus virens Ait.*	ficvir	Moraceae
Sal	*Shorea robusta Roxb.*	shorob	Dipterocarpaceae
Shimul	*Bombax ceiba L.*	bomcei	Bombacaceae
Teak	*Tectona grandis L.F.*	tecgra	Verbenaceae
Verenga	*Jatropha curcas L.*	jatcur	Euphorbiaceae

Appendix 3. Environmental variables and disturbance matrix of 30 plots in Shahapur Forest

Plot	pH	N	P	K	OM	MC	Elevation	Disturbance
1	5.2	0.1	0.08	1.35	2.08	38	33	4
2	4.9	0.09	0.12	1	1.815	40	29	2
3	4.9	0.03	0.07	3.99	0.536	46.5	35	6
4	4.8	0.06	0.1	2.63	1.21	46.5	31	2
5	4.9	0.03	0.12	4.47	0.535	43.3	29	4
6	4.9	0.12	0.25	2.51	2.48	43.3	37	1
7	4.8	0.06	0.21	2.23	1.27	33	35	0
8	4.8	0.1	0.18	2.14	2.09	30	32	2
9	4.7	0.1	0.17	2.41	2.1	46.5	43	4
10	5.1	0.05	0.14	2.157	0.95	33.3	62	1
11	5.4	0.05	0.19	1.79	0.96	33	75	4
12	4.8	0.09	0.2	3.91	1.815	42.7	35	7
13	5.1	0.03	0.12	2.17	0.672	40	44	3
14	5.4	0.03	0.17	2.4	0.538	30	53	2
15	5.3	0.1	0.24	3.13	2.08	73	38	6
16	5.3	0.12	0.19	3	2.47	80	29	0
17	5	0.16	0.15	3.86	3.37	70	25	4
18	5	0.12	0.14	2.97	2.42	50	21	5
19	4.6	0.1	0.34	2.67	2.01	40	32	2
20	4.8	0.15	0.19	4.54	3.02	43.3	47	1
21	4.9	0.15	0.2	2.35	3.05	33	49	3
22	5.4	0.05	0.2	2.66	1	45	37	2
23	5.2	0.1	0.19	2.35	2.01	46.5	44	0
24	4.9	0.1	0.12	2.62	2.01	35	53	5
25	5	0.16	0.27	2.6	3.36	40	41	3
26	4.5	0.19	0.15	3.69	3.83	70	26	4
27	4.7	0.1	0.2	2	2.01	42.7	47	0
28	4.5	0.12	0.12	3.15	2.42	33.3	52	4
29	4.5	0.19	0.19	3.16	3.83	30	18	6
30	4.4	0.14	0.22	6.45	2.89	52.5	22	5

N is nitrogen measured in percentage, P is Phosphorus measured in percentage, K^+ is potassium measured in mill equivalents per 100 g (mleq/100 g), OC is organic carbon measured in percentage, OM is organic matter measured in percentage, Moisture contents (MC) measured in percentage, Elevation is measured in meter (m), Disturbance is measured in number of occurrence.

Appendix 4. Environmental variables and disturbance matrix of 30 plots in Shaltila Forest

Plot	pH	N	P	K	OM	MC	Elevation	Disturbance
1	4.5	0.23	0.05	0.94	1.58	50	67	2
2	4.85	0.03	1.08	0.15	0.538	52	57	5
3	6.01	0.03	2.95	0.11	0.672	44.5	24	4
4	5.1	0.1	3.65	0.25	2.08	37	47	3
5	4.9	0.16	3.03	0.2	3.29	40	53	4
6	5.02	0.03	1.62	0.11	0.537	50.7	50	3
7	5.3	0.17	1.9	0.59	3.42	40	42	4
8	4.9	0.18	2	0.47	3.56	33	50	3
9	5.3	0.03	2.57	0.2	0.538	25	41	6
10	5.1	0.07	2.43	0.17	1.34	36.6	43	4
11	4.4	0.14	1.69	0.15	2.75	40	68	2
12	5.1	0.18	2.48	0.75	3.55	40	41	4
13	5	0.2	2.64	0.55	4.03	45	42	3
14	5	0.05	3.79	0.13	1.08	43.5	38	2
15	5.1	0.03	2.95	0.11	0.538	50	38	4
16	4.7	0.06	1.31	0.06	1.21	40	61	6
17	4.5	0.12	1.64	0.21	2.48	42	57	6
18	5	0.09	3.5	0.21	1.815	30	60	4
19	5.3	0.03	0.09	1.61	0.537	52	32	4
20	5.3	0.03	0.1	2.36	0.536	42.7	29	1
21	5	0.19	0.14	3.12	3.89	52	38	5
22	4.5	0.1	0.17	3.04	2.08	45	38	6
23	6.1	0.07	0.16	3.82	1.54	55	18	3
24	4.8	0.14	0.11	4.4	2.82	50	40	2
25	5.5	0.03	0.11	2.25	0.537	53	42	1
26	4.5	0.05	0.12	1.53	0.94	65	31	2
27	5	0.05	0.12	1.17	1	43.3	27	3
28	5.6	0.03	0.12	1.87	0.538	20	37	2
29	5.1	0.05	0.29	1.73	1	30	50	1
30	5	0.07	0.44	1.37	1.47	25	46	2