Tropical Ecology **55**(2): 177-193, 2014 ISSN 0564-3295

www.tropecol.com

Environmental correlates of vegetation distribution in tropical Juri forest, Bangladesh

S. K. SARKER*, S. RASHID, M. SHARMIN, M. M. HAQUE, S. S. SONET & M. NUR-UN-NABI

Department of Forestry and Environmental Science, Shahjalal University of Science & Technology, Sylhet-3114, Bangladesh

Abstract: In this paper, we provide a primary assessment on the relationships between vegetation and environmental factors for the ecologically unexplored tropical Juri forest, Bangladesh, using numerical methods. Vegetation and environmental data (13 variables) were collected from 120 sample plots. We classified and verified vegetation communities using Two-Way Cluster Analysis (TWCA) and Multi-response Permutation Procedures (MRPP), respectively. We also estimated species alpha diversity and compositional similarity between the communities. In total, 146 vascular plant species belonging to 66 families of 122 genera were surveyed. Finally, Canonical Correspondence Analysis (CCA) with associated Monte Carlo permutation tests was performed to explore the patterns of variation in vegetation distribution explained by the environmental variables. We identified eight community types that significantly varied in species composition. Soil acidity, phosphorus, calcium, and organic matter content were identified as the most influential soil variables responsible for species compositional variation.

Resumen: En este artículo presentamos una primera evaluación de las relaciones entre la vegetación y los factores ambientalespor medio del uso de métodos numéricos, para el bosque Juri, Bangladesh, cuya ecología no ha sido explorada. Los datos de la vegetación y el ambiente (13 variables) fueron obtenidosen 120 parcelas de muestreo. Clasificamos y verificamos las comunidades de plantas usandoun Análisis de Clasificación de Dos Vías y Procedimientos de Permutación de Respuesta Múltiple, respectivamente. También estimamos la diversidad alfa de especies y la similitud en la composición entre las comunidades. En total, registramos 146 especies de plantas vascularespertenecientes a 66 familias y 122 géneros. Finalmente, se realizaron Análisis Canónicos de Correspondencia con sus respectivas pruebas de permutación de Monte Carlopara explorar los patrones de variación en la distribución de la vegetaciónexplicados por las variables ambientales. Identificamos ocho tipos de comunidades, las cualesvariaron significativamenteen su composición de especies. La acidez del suelo, el fósforo, el calcio y el contenido de materia orgánica fueron identificados como las variables edáficas con mayor influencia sobre la variación en la composición de especies.

Resumo: Neste artigo, apresentamos uma avaliação preliminar sobre as relações entre a vegetação e os fatores ambientais para a floresta tropical ecologicamente inexplorada de Juri, Bangladesh, usando métodos numéricos. Foram coletados dados de vegetação e ambientais (13 variáveis) de 120 parcelas. Classificámos e verificámos as comunidades de vegetação, utilizando uma análise clusterde duas entradas(TWCA) e procedimentos de permutação multi-resposta (MRPP), respectivamente. Também foram estimadas a diversidade alfa das espécies e semelhança de composição entre as comunidades. No total, 146 espécies de plantas vasculares, pertencentes a 66 famílias de 122 géneros foram inventariadas. Finalmente, procedeu-se a uma análise de correspondência canónica (CCA) associada a testes de permutação de Monte Carlo para explorar os padrões de variação na distribuição da vegetação explicada pelas variáveis

*Corresponding Author; e-mail: swapan-fes@sust.edu

ambientais. Foram identificados oito tipos de comunidade que variaram de forma significativa na composição de espécies. A acidez do solo, fósforo, cálcio e teor de matéria orgânica foram identificados como as variáveis mais influentes do solo responsáveis pela variação na composição de espécies.

Key words: Community classification, cluster analysis, indicator species, natural forest, species conservation.

Introduction

Disentangling the principal mechanisms responsible for structuring tropical plant communities has been a central research issue in community ecology (Condit *et al*. 2011; Davidar *et al*. 2005; Devi & Yadava 2006; Jabot & Chave 2011; Vellend 2010). It is now obvious that tropical forests exhibit exceptional biogeochemical variation (e.g., soil age, soil chemistry, rates of erosion, etc.) that allows for a suite of potential limiting nutrients that, in turn, have varied effects on vegetation structure and functions at both local and regional scales (Townsend *et al*. 2008). Several studies have documented the prominent role of environmental factors particularly soil physio-chemical factors in determining diversity and distribution of plants in tropical forests (Htun *et al*. 2011; Laurance *et al*. 2010; Pena-Claros *et al*. 2012; Toledo *et al*. 2012). Furthermore, since the advent of multivariate statistical techniques, quantification of ecological relationship between vegetation and environment has become one of the major research issues in the modern community ecology (Legendre & Legendre 1998).

Bangladesh is recognized as one of the most vulnerable countries in South-Asia to climate change (IPCC 2007). Moreover, drastic changes in the forest composition and structure driven by environmental and human perturbations have been reported (Sarker *et al*. 2011). In addition, large scale fragmentation of the primary forests has resulted in increased number of threatened species (IUCN 2004). Hence, Bangladesh forests are considered to be in great risk of losing plant diversity (Alam & Sarker 2011; MoEF 2009). Despite presence of such climatic and anthropogenic disturbances, the remaining primary forests of Bangladesh are grossly devoid of studies that explained vegetation-environment relationships in a quantitative manner (Sarker *et al.* 2013). In fact, most of the previous studies (e.g., Biswas & Misbahuzzaman 2008; IUCN 2004; Uddin & Hasan 2011) used semi-formal non numerical approach which is heavily criticized for reliance on non-statistical table work (Wesche & von Wehrden 2011). Moreover, such research approach provides little information on the relationships between species and environmental factors. As a result, forest management systems are lagging far behind in implementing effecting monitoring and conservation strategies including facilitation of communication between conservation and land management agencies, advancing basic understanding of vegetation patterns, and providing baseline information for planning and assessing the success of restoration activities (Sarker *et al*. 2011).

We conducted the present study at the largest natural forest of the north-eastern Bangladesh namely Juri natural forest. The forest is situated along the Bangladesh-India border and is a part of the Indo-Burma Biodiversity Hotspot (Myers *et al*. 2000). Despite having high conservation value, the Juri forest is one of the ecologically unexplored natural forests in the tropics. In this paper, we provide a preliminary assessment on the relationships between vegetation and environmental variables using multivariate statistical methods. The research hypothesis is that the distribution of plants in the forest is a function of a set of critical and measurable environmental variables. Therefore, the study has two objectives; firstly to numerically classify the plant communities and secondly, to investigate the distribution of the plant communities in relation to environmental variables. In addition, plant diversity patterns within the communities and compositional variability among the communities are also explored to assist plant conservation.

Materials and methods

Study site

The tropical Juri natural forest (Lathitila) (24° 32′ 56″ N to 24° 34′ 19″ N latitude and longitudes

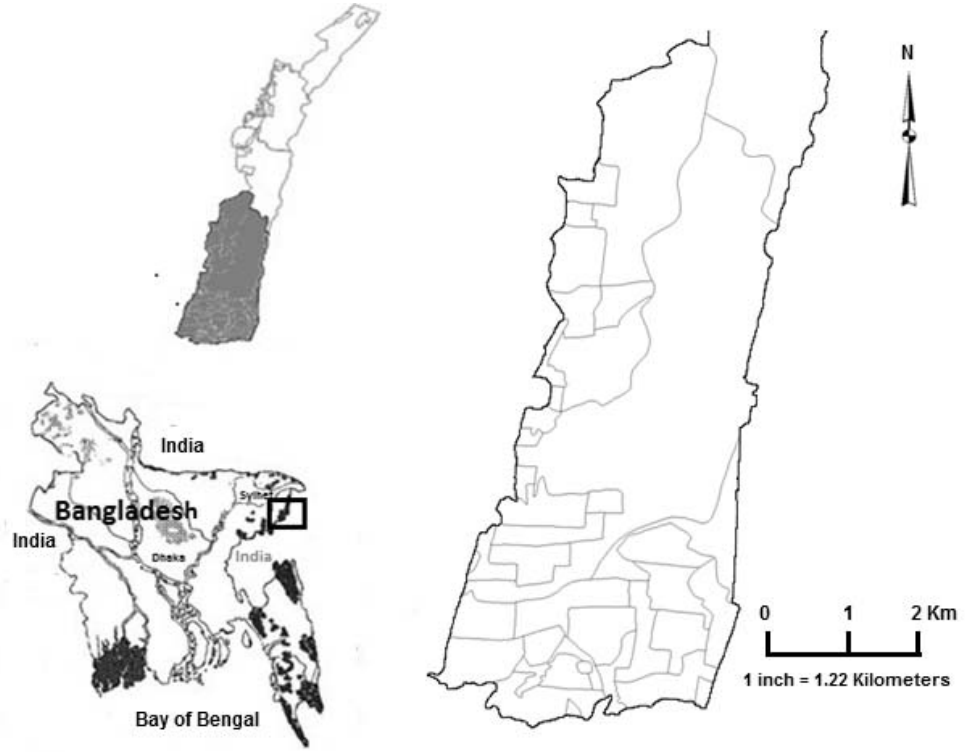

Fig. 1. Map of the study area.

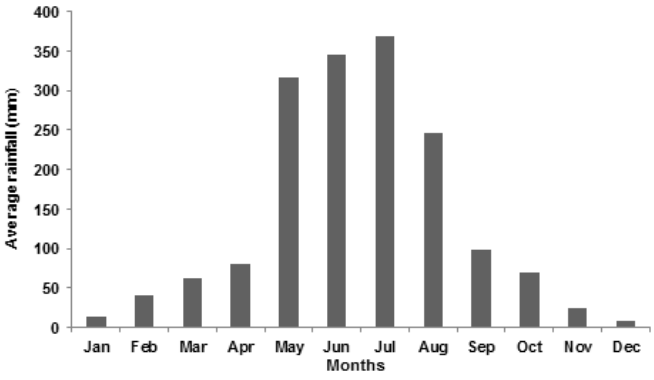

Fig. 2. Average monthly rainfall in the study area (Source: Bangladesh Meteorological Department 2012).

92° 12′ 01″ E to 92° 13′ 53″ E longitudes, 2280 ha) is one of the remnant natural forests in the north-eastern Bangladesh (Fig. 1) (Islam *et al.* 2008). The forest is generally classified as tropical semi-evergreen forest and lies under the jurisdiction of Sylhet Forest Division. The forest is within the monsoon climate zone. The maximum annual average temperature is 33.2 °C and the minimum 13.6 °C and total rainfall is 3334 mm. Average monthly rainfall substantially varies across the year (Fig. 2). Relative humidity remains high (75 - 90 %) most of the year, with the highest during the months of May to October. Humidity dips below 80 % from November to April (Bangladesh Meteorological Department 2012). The topography of the area varies from medium to steep slopes and hillocks of different elevations (10 - 100 m above mean sea level) with undulating valleys, ridges, and water streams. Lowlands occupy a reasonable portion of the area and are inundated by flood water during monsoon. Several channels with many tributaries criss-cross the forest (IUCN 2004). The hilly areas are composed of upper tertiary rocks. Sediments are generally well weathered and limestone is also found on the high elevated site, sometimes cemented with secondary ironstones (Islam *et al.* 2008). The soil varies from clay loam on level ground to sandy loam on hill slopes, and show low pH. Accumulation of humus on the top soil is very small due to the rapid decomposition of debris under moist warm tropical condition (Hassan 1994; IUCN 2004).

Vegetation survey

The field work was conducted during August 2011 to February 2012. We collected vegetation

data from 120 sample plots taken at random and the sample size was determined using species-area curves (McCune & Grace 2002). Tree (diameter at breast height (dbh) > 7.5 cm) data were collected from the main sample plots (20 m x 20 m). Shrub and herb data were collected from 4 sub plots of size 2 m x 2 m and 1 m x 1 m, respectively established at each corner of the main plot. All the plants were identified to species level where possible with the help of knowledgeable local inhabitants and forest officials acting as field assistants. A representative voucher was collected from the unidentified species for laboratory identification. All the voucher specimens were deposited in the Forest Ecology Laboratory, Shahjalal University of Science and Technology, Sylhet, Bangladesh. The source of nomenclature for the surveyed species follows Ahmed *et al.* (2008).

Environmental data

We measured elevation and 12 soil variables (i.e. total nitrogen (N), available phosphorus (P), potassium (K), zinc (Zn), soil acidity (pH), organic matter (OM), calcium (Ca), magnesium (Mg), copper (Cu), iron (Fe), manganese (Mn), soil moisture content (MC)) during the dry period (September 2011 to February 2012) to interpret main vegetation gradients ecologically. Measurements were performed in every sample plot. Five soil samples of 10 cm in depth from each plot were extracted using a cylindrical soil core sampler of 5 cm in diameter, thoroughly mixed in the field and one quarter taken to the laboratory for chemical analysis. The soil pH and moisture content were measured by a digital soil pH and moisture meter. Total nitrogen was determined following the Kjeldahl method (Bremner & Mulvaney 1982): oxidation of soil organic matter by H_2SO_4 and Se reagent mixture (catalyst), conversion to ammonium, distillation, and titration with HCl. Total organic matter content was measured in following the Springer-Klee method (Springer & Klee 1954): hot oxidation with $K_2Cr_2O_7$ and titration of oxidant excess with $(NH_4)_2 \cdot Fe(SO_4)_2.6H_2O$. Available soil phosphorus was measured by the molybdo-vanadate method and a 721-spectro-photometer (A & E Technology Import & Export Co., Ltd. China). K, Cu, Fe, Ca, Mg, Mn, and Zn were estimated using an Atomic Absorption Spectrophotometer (A Analyst™ 400 spectrometer, PerkinElmer, USA). Elevation data were collected by using a hand-held Global Positioning System (GPS).

Plant community classification and validation

Two-Way Hierarchical Polythetic Cluster Analysis (Peck 2010) was performed to define the groups of sample plots with similar species composition i.e. community types. Here, flexible beta (Lance & Williams 1967), and Bray-Curtis coefficient (Sørensen distance) (Faith *et al.* 1987) were used as group linkage method and distance measure, respectively. A value of β = -0.25 was chosen for group linkage method because this particular value shows less propensity to chain than other linkage methods (McCune & Grace 2002). Wishart's objective function was used to scale the resulting dendrogram that measures loss of information at each step of cluster formation (McCune & Mefford 1999). All the species abundance data were standardized using 'relativization by maximum' option of the PC-ORD 5 software before starting the analysis. Here, each cell was divided by the maximum observation in the row in which that cell occurred. We then used the Indicator Species Analysis (ISA) of Dufrêne & Legendre (1997) to detect indicator species of each plant community type and also to name the community types by the species having the highest significant Indicator Value (IV). ISA is a randomization technique that calculates IV for each species by multiplying relative frequency (proportion of sample units that contain the species in each group) by relative abundance (proportional abundance of species in each group) and expressing the outcomes (IV) as a percentage which range from 0 to 100. A zero value of ISA means that no indicator species was found within the community, a value of 100 means that species is always present. Monte-Carlo permutation test with 999 permutations was performed for assessing statistical significance of the indicator values. In each community, the species having the highest significant IV value was chosen for naming the community. After that we used Multi-response Permutation Procedure (MRPP) to check the validity of the cluster analysis results. MRPP is a multivariate non-parametric technique for testing group differences (i.e. species composition). MRPP calculates the mean within group distance to the observed pattern and then uses permutation procedures to decide whether this distance is significantly greater than expected by chance (Chavez & Macdonald 2010). It provides a test statistics 'T' and chance-corrected within group agreement 'A' reflecting respectively the separation among groups with significance and within

group similarity. MRPP was based on Sørensen (Bray-Curtis) distance measure and all community groups were weighted with n_i/N, where, n_i is the number of items in group i and N is the total number of items (McCune & Grace 2002).

Diversity analysis

In the identified communities, mean alpha diversity (Whittaker 1972) was calculated using the species richness, Shannon diversity (H′), and Simpson diversity (D′) and Evenness (E) indices (Magurran & Mcgill 2011). All the calculations were done using Biodiversity R package (Kindt & Coe 2005) in R software version 2.10.1 (R Development Core Team 2010). Morisita-Horn index based on two way probabilistic approach (Chao *et al.* 2008) was used to determine the compositional similarity between the communities. Despite being more sensitive to common species, this abundance based index gives the most satisfactory result to deal with bias (Chao *et al.* 2008). A bootstrap approach was taken by using the software SPADE (Chao & Shen 2010) to calculate the 95 % confidence interval based on 200 simulations to measure compositional similarity.

Numerical analysis

Canonical Correspondence Analysis (CCA) was used to analyze the relationship between distribution of plants and environmental variables. CCA is a direct gradient analysis technique that relates community variation (composition and abundance) to environmental variation, enabling the significant relationship between environmental variables and community distribution to be determined (Legendre & Legendre 1998). CCA assumes that meaningful environmental variables have been identified and measured. CCA axes were evaluated statistically with a Monte Carlo permutation test ($P = 0.05$). Because the inclusion of a moderately to strongly inter-correlated group of variables in the ordination may yield unreliable results (ter Braak 1986); the variables employed were tested first for correlation using the Pearson correlation coefficient. Only one variable was used from group of inter-correlated variables. For example, as Zn was highly correlated with Mn (r = 0.73), Mg (r = 0.63), Cu (r = 0.69) and Fe (r = 0.62), only Zn was retained in the analysis. In this way, only seven variables (P, Zn, pH, OM, Ca, MC and elevation) were retained in CCA (see Table 1). We also discarded all the singleton species (in total 62) from the species dataset prior to CCA. We also performed one way ANOVA to seek if environmental variables significantly ($P \leq 0.05$) vary among the communities. A post hoc pair wise Tukey HSD mean separation test along with Homogeneity of variance test was also performed. Our dataset contained 120 sample plots, 84 plant species and 7 environmental variables. Environmental variables were standardized to unit variance. In the ordination diagram, species names are abbreviated using six letters from the scientific name of each tree by combining the three initial letters for the genus and specific species. For example, "Ter che" is an abbreviation for *Terminalia chebula*. Full species names are given in the Appendix Table 1. In this study, Cluster analysis, ISA, MRPP, and CCA were performed using PC- ORD for Windows program, Version 5.0 (McCune & Mefford 1999).

Results

Vegetation community classification

The vegetation survey identified 146 vascular plant species belonging to 66 families of 122 genera. Of these, 17 species have been declared as national red listed vascular plants (Bangladesh National Herbarium 2001) (see Appendix Table 1). However, except for a few (e.g. *Cyperus cyperoides, Euryale ferox,* and *Floscopa scandens*) threatened status of majority of the surveyed species has not yet been investigated on a global scale.

Two-Way Cluster Analysis identified the presence of eight vegetation community types (A. *Acacia catechu*, B. *Elaeocarpus floribundus*, C. *Illex godajam,* D. *Artocarpus lacucha,* E. *Terminalia chebula,* F. *Kydia calycina*, G. *Laportia crenulata,* H. *Euryale ferox*) (Fig. 3). Summary of the vegetation communities with mean values of the environmental variables are presented in Table 2. Indicator Species Analysis determined the presence of 25 significant indicator species in the identified communities (Table 3). Results of overall MRPP and pairwise comparisons confirmed the results of cluster analysis by showing significant differences in species composition among the community types (overall $T = -17.09$, $P < 0.00$, chance-corrected within-group agreement $A = 0.13$).

Diversity and compositional variation

Compositional similarity (between communities) and alpha (within community) diversity patterns are shown respectively in Tables 4 and 5.

Table 1. Pearson Correlation (r) between the environmental variables.

	N	P	K	Zn	pH	OM	Ca	Mg	Cu	Fe	Mn	MC
P	0.09											
K	0.20	-0.12										
Zn	0.20	-0.16	0.28**									
pH	0.011	0.02	-0.00	0.01								
OM	0.95**	0.06	0.24	0.26*	0.05							
Ca	0.20	-0.13	0.02	0.20	0.00	0.25						
Mg	0.23	-0.23	0.20	0.63**	-0.33	0.31*	0.84**					
Cu	0.21	-0.14	0.06	0.69**	-0.08	0.27*	0.95**	0.85**				
Fe	0.14	0.03	-0.06	0.62**	0.87**	0.21	0.35**	0.24	0.26*			
Mn	0.32*	-0.05	-0.00	0.73**	0.13	0.40*	0.74**	0.60**	0.69*	0.46**		
MC	-0.01	0.03	0.28*	-0.03	0.11	.01	0.10	0.17	0.06	0.07	0.14	
Ele	0.37**	0.18	0.21	0.41	0.11	0.38*	0.09	0.04	0.06	0.16	0.36**	-0.10

Note: * $P \leq 0.05$, ** $P \leq 0.01$.

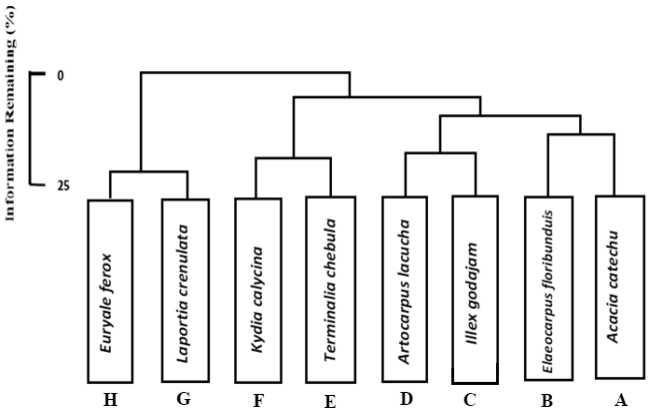

Fig. 3. Dendrogram of the results of Two-way hierarchical cluster analysis, grouping 120 vegetation sample plots into 8 community types, named for the species with the highest indicator value. The dendrogram is scaled by Wishart's (1969) objective function, expressed as the percentage of information remaining at each level of grouping (McCune & Grace 2002). Percentage of chaining for species and sample plot are 2.81 and 4.05 respectively.

The highest pair wise compositional similarity was recorded between *A. catechu* (A) and *K. calycina* (F) community types (0.55) while lowest similarity was observed between *T. chebula* (E) and *E. ferox* (H) community types (0.09). However, we observed considerable average similarity (0.30) across the communities. Highest mean species richness, Shannon and Simpson values were calculated for *I. godajam* (C) community while the *K. calycina* community showed the lowest alpha diversity.

Environmental correlates of vegetation distribution

The first three axes of CCA explained 25.5 % of the cumulative variance in species data (Table 6). The Monte Carlo analysis showed the CCA eigenvalues to be extremely robust ($P = 0.02$ for all axes), but the species-environment correlation to be less robust, particularly for axis 2 and axis 3 (axis 1, $P = 0.04$; axis 2, $P = 0.04$; axis 3, $P = 0.25$). Observed values of the correlation co-efficient (r) between the environmental variables and the axes scores suggest that no single environmental factor, rather a combination of factors, is responsible for the variability within the species data. For instance, the first CCA axis (eigenvalue = 0.351, variance explained = 10.1 %) primarily represented a gradient of high-to-low soil acidity ($r = 0.76$) and low-to-high organic matter content ($r = -0.35$), and the second CCA axis (eigenvalue = 0.332, variance explained = 9.2 %) primarily represented a gradient of soil with low-to-high concentration of P ($r = 0.80$) and Ca ($r = -0.63$) in soil (Table 7 and Fig. 4). ANOVA results also corroborated with the CCA outcomes showing that pH ($P < 0.03$; $F = 2.344$), P ($P < 0.04$, $F = 2.14$), Ca ($P < 0.03$, $F = 1.95$) significantly varied among the communities. Post hoc pair wise Tukey HSD mean separation tests revealed that Community C and D differed highly in pH, D and E varied significantly in Ca and available soil P ($P < 0.05$). The results of the Homogeneity of variance test ($P < 0.05$) also confirmed this.

CCA biplot (Fig. 5) indicates that *Talinum paniculatum, A. catechu, Indigofera linnaei* and *Clerodendrum viscosum* are strongly associated with

Table 2. Summary of the vegetation communities with mean values of the environmental variables.

Community types	A *Acacia catechu*	B *Elaeocarpus floribundus*	C *Illex godajam*	D *Artocarpus lacucha*	E *Terminalia chebula*	F *Kydia calycina*	G *Laportia crenulata*	H *Euryale ferox*
Sample nos.	20	18	15	12	16	15	12	12
Habitat	Upland (Mid-top hill)	Upland (Mid hill)	Upland (Strongly acidic mid hill)	Valleys	Ridges	Elevated flat land	Upland (Drier top hill)	Low lands
Species no.	47	39	32	29	15	22	17	21
Family no.	32	30	26	21	12	19	15	17
Genus no.	42	36	29	28	13	21	17	17
Mean values and standard deviation (±) of the measured environmental variables								
N (%)	0.11 ± 0.05	0.06 ± 0.04	0.06 ± 0.03	0.07 ± 0.03	0.06 ± 0.03	0.07 ± 0.02	0.07 ± 0.03	0.08 ±0.01
P(mg kg^{-1})	2.61 ± 1.21	2.30 ± 1.44	2.78 ± 0.30	1.78 ± 0.46	3.13 ± 1.29	2.69 ± 1.49	2.60 ± 1.55	2.43 ± 1.38
K(Cmol kg^{-1})	0.27 ± 0.06	0.17 ± 0.11	0.23 ± 0.07	0.18 ± 0.11	0.10 ± 0.05	0.12 ± 0.09	0.21 ± 0.11	0.19 ± 0.14
Zn(mg kg^{-1})	0.82 ± 0.27	0.74 ± 0.41	0.63 ± 0.24	0.55 ± 0.34	0.36 ± 0.22	0.50 ± 0.32	0.98 ± 0.70	0.37 ± 0.20
pH	4.26 ± 0.42	4.52 ± 0.28	4.11 ± 0.19	4.63 ± 0.55	4.53 ± 0.31	4.41 ± 0.32	4.58 ± 0.40	4.5 ± 0.19
OM (%)	1.89 ± 0.84	1.04 ± 0.62	1.03 ± 0.58	1.22 ± 0.51	0.88 ± 0.26	1.10 ± 0.32	1.15 ± 0.53	0.99 ± 0.44
Ca (Cmol kg^{-1})	4.23 ± 1.59	3.81 ± 1.76	4.32 ± 0.83	4.34 ± 3.17	2.01 ± 1.16	3.53 ± 3.44	4.22 ± 2.66	3.20 ± 0.98
Mg (Cmol kg^{-1})	1.05 ± 0.35	0.82 ± 0.55	1.05 ± 0.37	1.06 ± 0.73	0.18 ± 0.17	0.51 ± 0.65	1.07 ± 0.72	0.61 ± 0.33
Cu (mg kg^{-1})	1.37 ± 1.30	1.42 ± 1.34	0.57 ± 0.23	1.37 ± 0.70	0.51 ± 0.15	0.99 ± 1.18	2.39 ± 2.02	0.59 ± 0.27
Fe (mg kg^{-1})	57.37 ± 21.80	47.82 ± 29.68	45.35 ± 18.19	39.98 ± 11.81	43.92 ± 35.54	43.47 ± 18.24	66.11 ± 42.12	32.77 ± 12.56
Mn (mg kg^{-1})	21.20 ± 9.33	14.54 ± 13.05	22.89 ± 5.35	12.51 ± 8.02	10.13 ± 12.69	8.32 ± 10.25	22.83 ± 16.95	7.8 ± 8.69
MC (%)	54.15 ± 17.28	49.4 ± 13.02	52 ± 12.74	52.29 ± 13.43	48.75 ± 16.00	53.88 ± 8.48	39 ± 26.29	79 ± 6.52
Elevation(m)	59.38 ± 33.39	42.2 ± 21.52	43.83 ± 11.33	32.29 ± 24.51	23.25 ± 4.99	26.25 ± 7.05	52.25 ± 38.99	20.6 ± 10.16

	Major Species	Unique Species
A	*Ficus roxburghii, Duabanga grandiflora, K. calycina, A. catechu, Castanopsis tribuloides, Lippia alba, Vernonia patula.*	*Glochidion sphaerogynum, Anthocephalus chinensis , A. lebbeck, Protium serratum, Nymphoides indicum, H. auricularia.*
B	*F. roxburghii, G. lanceolarium, Palaquium polyanthum, E. floribundus, C. tribuloides.*	*Cynometra polyandra, Chisochetom paniculatus, Aerva sanguinolenta.*
C	*Lophopetatum wightianum, I. godajam, Vernonia patula, Hygrophila schulli, Cocciniea cordifolia.*	*Thysanolaena maxima, Talinum paniculatum, Molineria recurvata, Blepharis repens, Eranthus ravannae.*
D	*Alstonia scholaris, Bouea oppositifolia, Albizia lebbeck, Zizyphus oenoplea.*	NA
E	*Syzygium cumuni, K. calycina, M. pruriens, Ampelopteris prolifera.*	*T. chebula*
F	*Lophopetatum wightianum, F. roxburghii, K. calycina, C. tribuloides*	*C. mannii*
G	*Bombax insigne, C. tribuloides, L. crenulata.*	NA
H	*C. tribuloides, Eurya acuminate, Euryale ferox.*	NA

Table 3. Indicator species with indicator values.

Species	Community Types	Indicator Value	*P* Value
Acacia catechu	A	39.6	0.0092
Elaeocarpus floribundus	B	28.1	0.0402
Illex godajam	C	58.9	0.0018
Cocciniea cordifolia	C	43.8	0.0080
Lophopetatum wightianum	C	38.7	0.0190
Thysanolaena maxima	C	33.3	0.0238
Talinumpani culatum	C	33.3	0.0256
Molineria recurvata	C	33.3	0.0244
Blepharis repens	C	33.3	0.0234
Eranthus ravannae	C	33.3	0.0238
Orisonko	C	27.1	0.0494
Crataeva nervosa	D	38.7	0.0106
Artocarpus lacucha	D	38.4	0.0136
Vernonia patula	D	28.6	0.0450
Terminalia chebula	E	50.0	0.0090
Adina sessilfolia	E	43.3	0.0066
Ampelopteris prolifera	E	40.3	0.0140
Mucuna pruriens	E	34.0	0.0204
Terminalia belerica	E	31.2	0.0352
Kydia calycina	F	36.4	0.0072
Laportia crenulata	G	85.9	0.0002
Bombax insigne	G	62.3	0.0008
Euryale ferox	H	52.8	0.0014
Euryaa cuminata	H	43.6	0.0056
Castanopsis tribuloides	H	40.5	0.0042

low soil pH (extremely acidic soil) and, to varying degrees, high organic matter content in soil (i.e. the first axis) while *Streblus asper, Bischofia javanica, Xanthium indicum* and *E. floribundus* have opposite associations. *Mallotus roxburghianus*, *F. roxburghii* are associated with high soil P while *Colocasia mannii* and *Ficus hirta* are associated with high soil Ca. Several species, including widespread species such as *V. patula, B. oppositifolia, S. praecox* and *Corchorus aestuans,* are placed at the center of the biplot implying relatively neutral relationships with soil physio-chemical properties and elevation.

Discussion

Tropical Juri forest is comprised of eight plant community types that vary significantly in species composition (see Table 2 & Fig. 3). The upland communities namely *A. catechu* (A)*, E. floribundus* (B) and *I. godajam* (C) are comparatively species rich than the valley (*A. lacucha* (D)), ridge (*T. chebula* (E)), flatland (*K. calycina* (F)) and moist lowland (*E. ferox* (H)) communities. However, *L. crenulata* community type (G) that dominates the drier top hill sites is relatively species poor than the other upland communities. Alpha diversity is highest in the mid-hill community type C where

Table 4. Pair wise (C_{22}) and simultaneous (C_{28}) comparison of communities by Morisita-Horn index (Bootstrap SE in parentheses is based on 200 replications).

Estimator C22		Estimate	95 % Confidence Interval	
Community Types			Minimum	Maximum
A	B	0.51(0.07)	0.36	0.65
	C	0.38(0.06)	0.25	0.51
	D	0.30(0.06)	0.18	0.42
	E	0.33(0.07)	0.17	0.48
	F	0.55(0.06)	0.42	0.68
	G	0.20(0.06)	0.09	0.32
	H	0.30(0.06)	0.16	0.43
B	C	0.24(0.06)	0.13	0.36
	D	0.34(0.07)	0.20	0.48
	E	0.22(0.05)	0.11	0.33
	F	0.34(0.07)	0.20	0.48
	G	0.28(0.06)	0.15	0.42
	H	0.31(0.07)	0.16	0.46
C	D	0.39(0.09)	0.21	0.56
	E	0.14(0.05)	0.03	0.25
	F	0.40(0.08)	0.23	0.56
	G	0.14(0.05)	0.03	0.25
	H	0.24(0.06)	0.11	0.37
D	E	0.10(0.04)	0.01	0.19
	F	0.42(0.08)	0.25	0.59
	G	0.10(0.04)	0.02	0.18
	H	0.29(0.08)	0.13	0.45
E	F	0.48(0.11)	0.25	0.70
	G	0.16(0.06)	0.03	0.29
	H	0.09(0.05)	0.00**	0.20**
F	G	0.27(0.08)	0.11	0.43
	H	0.48(0.09)	0.30	0.67
G	H	0.38(0.10)	0.18	0.59
Estimator C_{28}		0.30(0.02)	0.25	0.34

C_{22}: A similarity measure of comparing 2 communities based on shared information between any two communities. C_{28}: A similarity measure of comparing 8 communities based on shared information between any two communities. **If the lower bound is less than 0, it is replaced by 0; if the upper bound is greater than 1, it is replaced by 1.

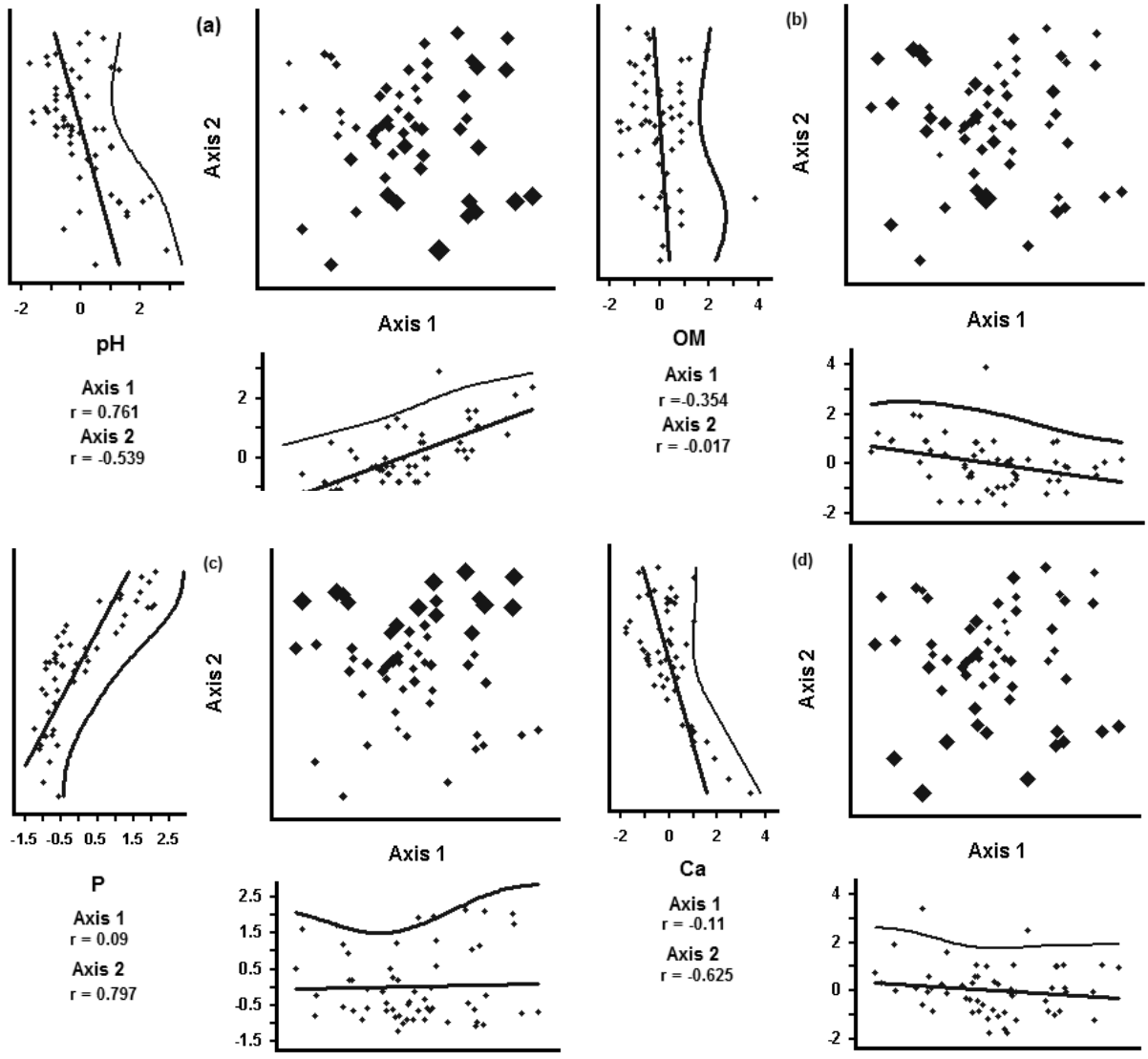

Fig. 4. Canonical correspondence analysis scatter diagram for (a) species and pH, (b) species and soil organic matter, (c) species and P, and (d) species and Ca at Juri, Bangladesh (CCA based on McCune & Mefford 1999). Axes scaled from the lowest to the highest score. Axis 1 shows strong correlation for the distribution of species predominantly along a pH gradient and then a gradient of organic matter. Both P and Ca are the variables that strongly regulate species distribution in the Axis 2. Each circle represents the value of particular environmental variable in a sample plot. The larger the circle the greater the value of the environmental variable.

soil is strongly acidic. Conversely, alpha diversity is lowest in the flatland community type F where soil is moderately acidic (see Table 5).

Although unraveling species composition and diversity patterns along environmental gradients has been common in community ecology, identification of the principle environmental gradient in the tropical forest ecosystems still remains a major research challenge (Jayakumar & Nair 2012). In fact, in tropical forests, natural vegetation often responds to several gradients simultaneously and different combinations of gradients produce divergent responses to the set of gradients (Davidar *et al.* 2007; Rydgren *et al.* 2003; Sarker *et al.* 2013). In this study, the CCA analysis indicates that species distribution patterns do not follow a single environmental gradient, rather a number of gradients account for species compositional variation. For instance, the first CCA axis is strongly correlated with soil organic matter content and pH; and the second axis with soil P and Ca (see Fig. 4).

It is well entrenched that soil nutrients

remarkably influence plant species distribution, composition, growth and development in the tropics (John *et al*. 2007; Santiago *et al.* 2012). Our results also indicate that soil organic matter, acidity, phosphorus, and calcium have strong influence on plant distribution at Juri. Soil organic matter plays important role for recycling cations, maintaining phosphorus availability, sequestering nitrogen and preventing soil erosion (Montagnini & Jordan 2005; Palm *et al*. 2007). Soil pH is important mainly because it varies directly with base-metal cation availability, especially below pH level 5.3 (Sollins 1998). In general, the soil is acidic in the study area. Presence of pre-weathered parent materials, amphoteric nature of aluminum, and the intense leaching of basic cations during the monsoons are the contributing factors for such acidity of the forest soils (Islam & Weil 2000). Results indicate that plants of two upland community types such as A and C prefer sites rich in soil organic matter with high acidity while plants of the community types B, D, E, G and H prefer lower acidic sites with moderate organic matter content. For instance, *Acacia catechu,* a medium-sized deciduous strong light demanding thorny tree species is the indicator species of community A, where deposition of organic matter is high in the soil. *E. floribundus* which is an evergreen moderate sized tree with spreading crown prefers low acidic sites and is the indicator species of community B. *Terminalia belerica* and *T. chebula,* both medium to large light demanding deciduous tree species prefer hill ridges (community E) where organic matter content is low. *Mucuna pruriens* is a vigorous annual (sometimes biannual) twining herb and prefers well drained, medium to high fertility soils but can grow successfully on sandy soils and tolerate a very wide soil acidity range (pH < 5.0 – 8.0) (Ahmed *et al*. 2008). However, this is the indicator species of community E and grows in the low acidic hill ridges.

Availability of phosphorus in soil significantly influences photosynthesis rate, stomatal conductance and root growth in tropical plants (Wright *et al.* 2011) and soil calcium directly influences occurrence and growth of plants, and indirectly affects the availability of other nutrients in tropical forests (Pausas & Austin 2001). Phosphorus is the soil nutrient that frequently limits tree growth and productivity in Oxisols and Ultisols (Cleveland *et al.* 2002; Sollins 1998), the most common soil types in the tropics (van Wambeke 1992). Forest soils in Bangladesh are poor in phosphorus too (Brammer 1996). CCA biplot (Fig. 5) depicts that soil phosphorus influences the distribution of a considerable number of plant species. *Kydia calycina,* a moderate sized deciduous tree shows specific affinity to available soil phosphorus level. This species is the indicator species of community F which is distributed in the elevated flat lands comparatively rich in available soil phosphorus. The distribution of *Eurya acuminate,* the indicator species of community H is also strongly linked to the availability of soil phosphorus. Ca also regulates the distribution of several species. For example, *Artocarpus lacucha,* a mid-canopy tree is the indicator species of sites (Community D) rich in Ca content.

Elevation is another important factor often responsible for species compositional variation in the tropics (Root & Nelson 2011). In this study, although CCA analysis does not show strong influence of elevation on overall plant distribution, we observed higher species richness in the mid-hill communities. This implies that despite having short elevation gradient, hump-shaped relationships between elevation and species richness (a peak in species richness at intermediate elevations) (Rahbek 1995) are common in the Juri forest.

Table 5. Alpha diversity patterns within the communities.

Community Types		A	B	C	D	E	F	G	H
Richness	Mean	7.76	7.50	9.33	6.85	6.00	6.00	6.50	6.60
	S.E.	0.63	0.63	0.66	0.93	0.40	0.90	0.28	0.60
Shannon (H′)	Mean	1.91	1.90	2.03	1.74	1.66	1.60	1.77	1.75
	S.E.	0.08	0.08	0.11	0.11	0.06	0.16	0.05	0.10
Simpson (D′)	Mean	0.83	0.83	0.83	0.79	0.79	0.75	0.81	0.80
	S.E.	0.01	0.01	0.02	0.02	0.01	0.04	0.01	0.02
Evenness (E)	Mean	0.94	0.95	0.91	0.93	0.93	0.93	0.94	0.93
	S.E.	0.00	0.00	0.02	0.01	0.01	0.01	0.01	0.01

Note: S.E = Standard Error.

Table 6. Results of CCA Ordination.

CCA axes	1	2	3
Eigenvalues	0.351	0.332	0.245
Variance in species data			
% of variance explained	10.1	9.2	6.2
Cumulative % explained	10.1	19.1	25.5
Pearson correlation, species-environment*	0.889	0.861	0.830

Table 7. Canonical coefficients and intraset correlations of environmental variables with the first three axes of CCA.

	Canonical coefficients (Standardized)			Correlation coefficients (Intraset)		
Variables	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3
P	0.163	0.398	0.148	0.090	0.797	0.060
Zn	0.229	0.105	0.111	-0.087	-0.146	0.389
pH	0.624	-0.069	0.122	0.761	-0.539	0.143
OM	-0.155	0.033	0.490	-0.354	-0.017	0.733
Ca	-0.406	-0.351	-0.038	-0.110	-0.625	0.227
MC	-0.025	-0.019	-0.029	0.004	-0.022	-0.099
Elevation	-0.077	0.010	-0.372	-0.19	0.170	-0.193

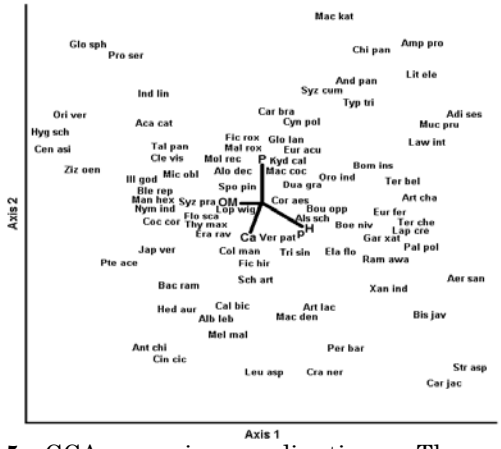

Fig. 5. CCA species ordination. The vectors represent environmental variables. The length of the vector is proportional to its importance and the angle between two vectors reflects the degree of correlation between variables. The angle between a vector and each axis is related to its correlation with the axis. Only the vectors showing correlation values (r) >0.20 with the axes were retained in the ordination space. For species abbreviations see Appendix.

Conservation applications

This study has several important implications for preparing and implementing conservation strategies and restoration techniques. It demonstrates that mid hill sites are relatively species rich than the valleys, ridges, hill tops and lowlands. Among the habitats, ridges and top hills are relatively infertile and species poor. Hence, hill tops and ridges require urgent restoration. In general, the results of this study imply that conservation strategies that take into account the variations in soil acidity, phosphorus, calcium, and organic matter content are required to conserve plant species in the study area. Most importantly, the comparisons we make among the habitats in terms of plant composition and diversity, and environmental conditions will help the Bangladesh Forest Department and other conservation agencies to assess the relative conservation value of different sites and choose suites of sites to maximize local and regional diversity.

Conclusions

We are not aware of any kind of research in the Juri forest that used numerical methods to classify plant communities and also to determine the environmental factors responsible for plant compositional variation. In this paper, we provide the first comprehensive investigation into environmental factors that significantly affect the distribution of plants in a priority conservation area of South Asia. Despite the low variance in the data explained, the accounted variables provide useful insight on plant distribution. Thus the research approach demonstrated here can help in conserving the last remaining natural patches of the forest by providing a basis for vegetation monitoring, mapping and assessing site qualities a priori.

Acknowledgements

We sincerely thank Eric Lamb and Jasmin Joshi for their constructive comments on an earlier version of the manuscript. The suggestions made by the four anonymous reviewers have remarkably improved the contents of the manuscript. This work was partially supported by Rufford Small Grant (ID: 11191-1), U.K.

References

Ahmed, Z. U., Z. N. T. Begam, M. A. Hassan, M. Khondker, S. M. H. Kabir, M. Ahmed, A. T. A. Ahmed, A. K. A. Rahman & E. U. Haque. 2008. *Encyclopedia of Flora and Fauna of Bangladesh.* Vol.1-8, Bangladesh profile, Asiatic society of Bangladesh.

Alam, M. & S. K. Sarker. 2011. Homestead agro-forestry in Bangladesh : dynamics of stand structure and biodiversity. *Journal of Sustainable Forestry* **30**: 584-599.

Bangladesh Meteorological Department. 2012. *Climate in Bangladesh*. Accessed on January, 2012. Available athttp://www.bmd.gov.bd/

Bangladesh National Herbarium. 2001. *Red Data Book of Vascular Plants of Bangladesh*.Bangladesh National Herbarium, Dhaka.

Biswas, S. R. & K. Misbahuzzaman. 2008. Tree species diversity and regeneration traits of the dominant species in a Dipterocarp forest in Bangladesh : implications for conservation. *International Journal of Biodiversity Science & Management* **4**:81-91.

Brammer, H. 1996. *The Geography of the Soils of Bangladesh*. University Press Limited, Dhaka, Bangladesh.

Bremner, J. M. & C. S. Mulvaney. 1982. Nitrogen-total. pp. 595-624. *In*: A. L. Page, R. H. Miller & D. R. Keeney (eds.) *Methods of Soil Analysis. Part 2, Chemical and Microbiological Properties*. 2nd edn. American Society of Agronomy, Madison, Wisconsin.

Chao, A. & T. J. Shen. 2010. *Program SPADE (Species Prediction and Diversity Estimation*). Program and Users Guide published at http://chao.stat.nthu.edu.tw. Accessed on 14 October 2011.

Chao, A., L. Jost, S. C. Chiang, Y. H. Jiang & R. Chazdon. 2008. A two-stage probabilistic approach to multiple-community similarity indices. *Biometrics* **64**:1178-1186

Chavez, V. & S. E. Macdonald. 2010. The influence of canopy patch mosaics on understory plant community composition in boreal mixed wood forest. *Forest Ecology and Management* **259**:1067-1075.

Cleveland, C. C., A. R. Townsend & S. K. Schmidt. 2002. Phosphorus limitation of microbial processes in moist tropical forests: evidence from short-term laboratory incubations and field studies. *Ecosystems* **5**: 680-691.

Condit, R., R. Pérez & N. Daguerre. 2011. *Trees of Panama and Costa Rica*. Princeton University Press, U.S.A.

Davidar, P., B. Rajagopal, D. Mohandass, J. P. Puyravaud, R. Condit, S. J. Wright & E. G. Leigh Jr. 2007. The effect of climatic gradients, topographic variation and species traits on the beta diversity of rain forest trees. *Global Ecology and Biogeography* **16**: 1-9.

Davidar, P., J. P. Puyravaud & E. G. Leigh Jr. 2005. Changes in rain forest tree diversity, dominance and rarity across a seasonality gradient in the Western Ghats, India. *Journal of Biogeography* **32**: 493-501.

Devi, L. S. & P. S. Yadava. 2006. Floristic diversity assessment and vegetation analysis of tropical semi-evergreen forest of Manipur, north east India. *Tropical Ecology* **47**: 89-98.

Dufrene, M. & P. Legendre. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs* **67**: 345-366.

Faith, D. P., P. R. Minchin & L. Belbin. 1987. Compositional dissimilarity as a robust measure of ecological distance. *Vegetatio* **69:** 57-68.

Hassan, M. M. 1994. Forest soils of Bangladesh. *Journal of Forest Science* **23**:1-11.

Htun, N. Z., N. Mizoue & S. Yoshida. 2011. Tree species composition and diversity at different levels of disturbance in Popa Mountain Park, Myanmar. *Biotropica* **43**: 597-603.

IPCC. 2007. Summary for Policymakers. pp. 7-22. *In*: M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, C. E. Hanson. (eds.) *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK,

Islam, K. R. & R. R. Weil. 2000. Land use effects on soil quality in a tropical forest ecosystem of Bangladesh. *Agriculture, Ecosystem & Environment* **79**: 9-16

Islam, M. A., M. M. Feeroz, S. B. Muzaffar, M. Kabir, S. Begum, K. Hasan, S. Mahmud & S. Chakma. 2008. Population status and conservation of *Hoolock gibbons* in Bangladesh. *Journal of Bombay Natural History Society* **105**:19-23.

IUCN. 2004. *Flora of Rema-Kalenga Wildlife Sanctuary*. IUCN Bangladesh Country Office, Dhaka.

Jabot, F. & J. Chave. 2011. Analyzing tropical forest tree species abundance distributions using a nonneutral model and through approximate bayesian inference. *The American Naturalist* **178**: E37-E47.

Jayakumar, R. & K. K. N. Nair. 2012. Beta diversity of angiosperms in the tropical forests of Nilgiri Biosphere Reserve, India. *Tropical Ecology* **53**: 125-136.

John, R., J. W. Dalling, K. E. Harms, J. B. Yavit, R. F. Stallard, M. Mirabello, S. P. Hubbell, R. Valencia, R. Navarrete, M. Vallejo & R. Foster. 2007. Soil nutrients influence on spatial distribution of tropical tree species. *Proceedings of the National Academy of Sciences of the United States of America* **104**: 864-869.

Kindt, R. & R. Coe. 2005. *Tree Diversity Analysis: A Manual and Software for Common Statistical Methods for Ecological and Biodiversity Studies*. World Agroforestry Centre (ICRAF), Nairobi.

Lance, G. N. & W. T. Williams. 1967. A general theory of classification sorting strategies in hierarchical systems. *Computer Journal* **9**: 373-380.

Laurance, S. G. W., W. F. Laurance, A. Andrade, P. M.

Fearnside, K. E. Harms, A. Vicentini & R. C. C. Luizao. 2010. Influence of soils and topography on Amazonian tree diversity: a landscape-scale study. *Journal of Vegetation Science* **21**: 96-106.

Legendre, P. & L. Legendre. 1998. *Numerical Ecology*. 2nd edn. Elsevier Science BV, Amsterdam.

Magurran, A. E. & B. J. Mcgill. 2011. *Biological Diversity: Frontiers in Measurement and Assessment*. Oxford University Press, New York.

Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. Da-Fonseca & J. Kent. 2000. Biodiversity hotspots for conservation priorities. *Nature* **403**: 853-858.

McCune, B. & J. B. Grace. 2002. *Analysis of Ecological Communities*. MJM Software Design, Gleneden Beach, Oregon.

McCune, B. & M. J. Mefford. 1999. *PC-ORD. Multivariate Analysis of Ecological Data*. MjM software design, Glenedon Beach, Oregon.

MoEF. 2009. *Bangladesh Climate Change Strategies and Action Plan 2009*. Ministry of Environment and Forests, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh.

Montagnini, F. & C. F. Jordan. 2005. *Tropical Forest Ecology : The Basis for Conservation and Management*. Springer, Netherlands.

Palm, C., P. Sanchez, S. Ahamed & A. Awiti. 2007. Soils: A contemporary perspective. *The Annual Review of Environment and Resources* **32**: 99-129.

Pausas, J. G. & M. P. Austin. 2001. Patterns of plant species richness in relation to different environments: An appraisal. *Journal of Vegetation Science* **12**: 153-166.

Peck, J. E. 2010. *Multivariate Analysis for Community Ecologists : Step-by-Step using PC-ORD*. MjM Software Design, Oregon, USA.

Pena-Claros, M., L. Poorter, A. Alarcon, G. Blate, U, Choque, T. S. Fredericksen, M. J. Justiniano, C. L . Leano, J. C. Licona, W. Pariona, F. E. Putz, L . Quevedo & M. Toledo. 2012. Soil effects on forest structure and diversity in a moist and a dry tropical forest. *Biotropica* **44**: 276-283.

R Development Core Team. 2010. *R : A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.

Rahbek, C. 1995. The elevational gradient of species richness, a uniform pattern? *Ecography* **18**: 200-205.

Root, H. T. & P. R. Nelson. 2011. Does phylogenetic distance aid in detecting environmental gradients related to species composition? *Journal of Vegetation Science* **22**:1143-1148.

Rydgren, K., R. H.Økland & T. Økland 2003. Species response curves along environmental gradients. A case study from SE Norwegian swamp forests. *Journal of Vegetation Science* **14**: 869-880.

Santiago, L. S., S. J. Wright, K. E. Harms, J. B. Yavitt, C. Korine, M. N. Garcia, B. L. Turner. 2012. Tropical tree seedling growth responses to nitrogen, phosphorus and potassium addition. *Journal of Ecology* **100**: 309-316.

Sarker, S. K., J. C. Deb & M. A. Halim. 2011. A diagnosis of existing logging bans in Bangladesh. *International Forestry Review* **13**: 461-475.

Sarker, S. K., S. S. Sonet, M. M. Haque & M. Sharmin. 2013. Disentangling the role of soil in structuring tropical tree communities at Tarap Hill Reserve of Bangladesh. *Ecological Research* **28:** 553-565.

Sollins, P. 1998. Factors influencing species composition in tropical lowland rain forest: Does soil matter? *Ecology* **79**: 23-30.

Springers, U. & J. Klee. 1954. Prufung der Leistungsfahigkeit von einigen wichtigeren Verfahren zur Bestimmung des Kohlenstoffs mittels Chromschwefels ¨aure sowie Vorschlag einer neuen Schnellmethode. *Journal of Plant Nutrition and Soil Science* **64**: 1-26.

ter Braak, C. J. F. 1986. Canonical correspondence analysis: a new eigenvector method for multivariate direct gradient analysis. *Ecology* **67**: 1167-1179.

Toledo, M., M. Pena-Claros, F. Bongers, A. Alarcon, J. Balcazar, J. Chuvina, C. Leano, J. C. Licona & L. Poorter. 2012. Distribution patterns of tropical woody species in response to climatic and edaphic gradients. *Journal of Ecology* **100**: 253-263.

Townsend, A. R., G. P. Asner & C. C. Cleveland. 2008. The biogeochemical heterogeneity of tropical forests. *Trends in Ecology and Evolution* **23**:424-431.

Uddin, D. M. Z. & D. M. A. Hassan. 2011. *Plant Genetic Resources of Rema-Kalenga Wildlife Sanctuary*. Lambert Academic Publishing. USA.

van Wambeke, A. 1992. *Soils of the Tropics : Properties and Appraisal*. McGraw-Hill, New York.

Vellend, M. 2010. Conceptual synthesis in community ecology. *The Quarterly Review of Biology* **85**: 183-206.

Wesche, K. & H. von Wehrden. 2011. Surveying Southern Mongolia: application of multivariate classification methods in dry lands with low diversity and long floristic gradients. *Applied Vegetation Science* **14**: 561-570.

Whittaker, R. H. 1972. Evolution and measurement of species diversity. *Taxon* **21**: 213-251.

Wright, S. J., J. B. Yavitt, N. Wurzburger, B. L. Turner, E. V. J. Tanner, E. J. Sayer, L. S. Santiago, M. Kaspari, L. O. Hedin, K. E. Harms, M. N. Garcia & M. D. Corre. 2011. Potassium, phosphorus, or nitrogen limit root allocation, tree growth, or litter production in a lowland tropical forest. *Ecology* **92**: 1616-1625.

(Received on 09.08.2012 and accepted after revisions, on 31.12.2012)

Appendix Table 1. Surveyed plant species with representative community types.

Family	Genus	Scientific name	Code name	Representative community types
Acanthaceae	Andrographis	*Andrographis paniculata* (Burm. F.)[R] Wall. *Ex* Nees	And pan	D,E,F,G
	Blepharis	*Blepharis repens* (Vahl) Roth	Ble rep	C
	Hygrophila	*Hygrophila schulli* (Buch.-Ham.) M.R. & S. N. Almeida	Hyg sch	A,C
Amaranthaceae	Aerva	*Aerva sanguinolenta* (L.) Blume	Aer san	B
Anacardiaceae	Bouea	*Bouea oppositifolia* (Roxb.) Meissner	Mad ind	AD
	Holigarna	*Holigarna longifolia* Roxb. [R]	Hol lon	--
	Spondias	*Spondias pinnata* (L.f.) Kurz[R]	Spo pin	A,D,F
Annonaceae	Polyalthia	*Polyalthia simiatum* Hook. f. & Thom.	Pol sim	--
Apiaceae	Centella	*Centella asiatica* (L.) Urban	Cen asi	A,C
Apocynaceae	Alstonia	*Alstonia scholaris* (L.) R.Br. [R]	Als sch	D,F
	Tabernaemontana	*Tabernaemontana divaricata* (L.) R. Br. *ex* Roem. & Schult.	Tab div	--
Aquifoliaceae	Illex	*Illex godajam* Colebr. *ex* Hook.f.	Ill god	C,D
Araceae	Aglaonema	*Aglaonema hookerianum* Schott[R]	Agl hoo	--
	Alocasia	*Alocasia acuminata* Schott	Alo acu	--
		Alocasia cucullata (Lour.) G. Don	Alo cuc	--
		Alocasia decipiens Schott	Alo dec	A,B,D,F,G,H
		Alocasia fallax Schott	Alo fal	--
	Caladium	*Caladium bicolor* (Ait.) Vent.	Cal bic	A,D
	Colocasia	*Colocasia mannii* Hook. F.	Col man	F
		Colocasia oresbia A.Hay	Col ore	
	Typhonium	*Typhonium trilobatum* (L.) Schott	Typ tri	A,B,E,G
Aristolochiaceae	Aristolochia	*Aristolochia indica* L.	Ari ind	--
Asteraceae	Chromolaena	*Chromolaena odorata* (L.) King & Robinson	Chr odo	--
	Eclipta	*Eclipta alba* (L.) Hassk.	Ecl alb	--
	Galinsoga	*Galinsoga quadriradiata* Ruiz & Pav.	Gal qua	--
	Xanthium	*Xanthium indicum* Koen. Ex. Roxb.	Xan ind	B,D,G
Balsaminaceae	Impatiens	*Impatiens balsamina* L.	Imp bal	--
Bignoniaceae	Oroxylum	*Oroxylum indicum* (L.) Kurz[R]	Oro ind	F,H
Bixaceae	Bixa	*Bixa orellana* L.	Bix ore	--
Bombacaceae	Bombax	*Bombax ceiba* Burm. f.	Bom cei	--
Burseraceae	Protium	*Protium serratum* (Wall. *ex* Coelbr.) Engl.	Pro ser	A
Caesalpiniaceae	Malintoa	*Cynometra polyandra* Roxb.	Cyn pol	B
	Haematoxylon	*Intsia bijuga* (Colebr.) O. Kuntze var.bijuga Sanjappa	Int bij	--
Capparaceae	Crataeva	*Crataeva nervosa* L.	Cra ner	A,D
Celastraceae	Lophopetalum	*Lophopetalum wightianum* Arn.	Lop wig	A,B,C,D,F,H
Ceratophyllaceae	Ceratophyllum	*Ceratophyllum demersum* L.	Cer dem	--
Clusiaceae	Garcinia	*Garcinia cowa* Roxb. *ex* DC. [R]	Gar cow	--
		Garcinia xathocymus Hook.f. *ex* T. Anders.[R]	Gar xan	B,G,H
Combretaceae	Terminalia	*Terminalia belerica* (Gaertn.) Roxb. [R]	Ter bel	B,F
		Terminalia chebula Retz.	Ter che	F

Contd...

Appendix Table 1. Continued.

Family	Genus	Scientific name	Code name	Representative community types
Commelinaceae	Floscopa	*Floscopa scandens* Lour.	Flo sca	B,C,H
Compositae	Vernonia	*Vernonia patula* (Dryand) Merr.	Ver pat	A,B,C,D,F,H
Cucurbitaceae	Cocciniea	*Cocciniea cordifolia* Cogn.	Coc cor	C,D,F
Cyperaceae	Carex	*Carex jackiana Boott*	Car jac	A,D
	Cyperus	*Cyperus cyperoides* (L.) O. Ktze.	Cyp cyp	--
	Schoenoplectus	*Schoenoplectus articulates* (L.) Palla	Sch art	B,C
Datiscaceae	Bombax	*Bombax insigne* Wall.[R]	Bom ins	A,B,G
Ehretiaceae	Ehretia	*Ehretia serrata* Roxb.	Ehr ser	--
Elaeognaceae	Elaeocarpus	*Elaeocarpus floribundus* Blume	Ela flo	A,D,H
Euphorbiaceae	Baccaurea	*Baccaurea ramiflora* lour.[R]	Bac ram	B,D
	Bischofia	*Bischofia javanica* Blume	Bis jav	A,D
	Phyllanthus	*Emblica officinalis* Gaertn.	Emb off	--
	Glochidion	*Glochidion lanceolarium* (Roxb.) Voigt	Glo lan	A,B,C,D,E,FH
		Glochidion sphaerogynum (Muell.-Arg) Kurz	Glo sph	A
	Jatropha	*Jatropha curcas* L.	Jat cur	--
	Macaranga	*Macaranga denticulata* (Blume) Muell.-Arg.[R]	Mac den	B,D
	Mallotus	*Mallotus albus* (Roxb.) Muell.-Arg.	Mal alb	--
		Mallotus roxburghianus Muell.-Arg.	Mal rox	B,C,F
	Stereospermum	*Stereospermum colais* (Bauch.-Ham. *ex* Dillw.) Mabberley	Ste col	--
Fabaceae	Crotalaria	*Crotalaria pallida* Ait.	Cro pal	--
	Desmodium	*Desmodium gyroides* (Roxb. *ex* Link) DC.	Des gyr	--
	Indigofera	*Indigofera linnaei* Ali	Ind lin	A,C
	Medicago	*Medicago sativa* L.	Med sat	--
	Mucuna	*Mucuna pruriens* (L.) DC.	Muc pru	B,E,F,G
	Pterocarpus	*Pterocarpus indicus* Willd.	Pte ind	--
	Vigna	*Vigna aconotifolia* (Jacq.) Marechal	Vig aco	--
Fagaceae	Arachis	*Arachis hypogaea* L.	Ara hyp	--
	Castanopsis	*Castanopsis tribuloides* (Smith) A.DC.	Cas tri	A,B,C,E,F,G,H
	Lithocarpus	*Lithocarpus elegans* var.elegans (Blume) Hatus. *ex* Soepad.	Lit ele	B,E
Graminae	Eranthus	*Eranthus ravannae* (L.) P. Beauv.	Era rav	C
Lamiaceae	Leucas	*Leucas aspera* (Willd) Link	Leu asp	A,B
Lauraceae	Cinnamomum	*Cinnamomum cicidodephne* Meiss.	Cin cic	A,B
	Cassytha	*Cinnamomum tamala* Ness & Eberm.	Cin tam	--
Leguminosae	Albizia	*Albizia procera* (Roxb.) Benth.	Alb pro	--
	Cassia	*Cassia fistula* L.[R]	Cas fis	--
Liliaceae	Asparagus	*Asparagus recemosus* Willd.	Asp rec	--
	Molineria	*Molineria recurvata* (Dryand.) Herbert	Mol rec	C
Loranthaceae	Macrosolen	*Macrosolen cochinchinensis* (Lour.) Van Tiegh	Mac coc	C,G,H
Lythraceae	Lagerstroemia	*Lagerstroemia indica* L.	Lag ind	--
		Lagerstroemia speciosa (L.) Pers.	Lag spe	--
	Lawsonia	*Lawsonia intermis* L.	Law int	A,F

Contd...

Appendix Table 1. Continued.

Family	Genus	Scientific name	Code name	Representative community types
Magnoliaceae	Michelia	*Michelia oblonga* Wall. *ex* Hook. f. & Thoms.	Mic obl	A,D
Malvaceae	Kydia	*Kydia calycina* L.	Kyd cal	A,B,C,E,F,G
Melastomaceae	Melastoma	*Melastoma malabathricum* L.	Mel mal	B,F
Meliaceae	Amoora	*Amoora wallichi* King	Amo wal	--
	Chisocheton	*Chisochetom paniculatus* Hiern	Chi pan	B
Menyanthaceae	Nymphoides	*Nymphoides indicum* (L.) O. Kuntze	Nym ind	A
Mimosaceae	Acacia	*Acacia catechu* (L.f) Willd.	Aca cat	A,C
	Albizia	*Albizia chinensis* (Osb.) Merr.	Alb chi	--
		Albizia lebbeck (L.) Benth. & Hook^{R}	Alb leb	A
Molluginaceae	Glinus	*Glinus lotoides* L.	Gli lot	
Moraceae	Artocarpus	*Artocarpus chama* Buch.-Ham. *ex* Wall	Art cha	A,B
		Artocarpus chaplasha Roxb.	Art cha	--
		Artocarpus lacucha Buch.Ham	Art lac	B,D
	Ficus	*Ficus hirta* Vahl	Fic hir	A,D
		Ficus roxburghii Wall. *ex*Miq.	Fic rox	A,B,C,FG
Musaceae	Musa	*Musa rosacea* Jacq^{R}	Mus ros	
Myrtaceae	Cleistocalyx	*Cleistocalyx operculatus* (Roxb.) Merr. & L. M. Perry var. Paniala (Roxb.) P. Chantaranothia & J.Parn.	Cle ope	--
	Psidium	*Psidium guajava* L.	Psi gua	--
	Syzygium	*Syzygium cumuni* (L.) Skeels	Syz cum	A,C,E,H
		Syzygium cymosum DC.	Syz cym	--
		Syzygium fruticosum DC.	Syz fru	--
		Syzygium praecox (Roxb.) Rathakr.& N. C. Nair	Syz pra	B,C,F,H
		Syzygium ramosissimum (Blume) Balakrishnan	Syz ram	--
Nymphaeceae	Euryale	*Euryale ferox* Salisb.	Eur fer	D,F,G,H
Orchidaceae	Arundina	*Arundina graminifolia* (D.Don) Hochr.	Aru gra	--
	Vanda	*Vanda tessellata* (Roxb.) Hook. f. *ex* G. Don	Van tes	--
Phytolaccaeae	Rivinia	*Rivinia humilis* L.	Riv hum	--
Poaceae	Leersia	*Leersia hexandra* Sw.	Lee hex	A,F
	Thysanolaena	*Thysanolaena maxima* (Roxb.) O. Kuntze	Thy max	C
Polygonaceae	Persicaria	*Persicaria barbata* (L.) Hara	Per bar	B,D
		Persicaria glabra (Willd.) Gomez de la Maza	Per gla	--
Portulacaceae	Talinum	*Talinum paniculatum* (Jacq.) Gaertn	Tal pan	C
Rhamnaceae	Ziziphus	*Zizyphus oenoplea* (L.) Mill.	Ziz oen	A,C
Rhizophoraceae	Carallia	*Carallia brachiata* (Lour.) Merr.	Car bra	B,C,G
Rubiaceae	Neonauclea	*Adina sessilfolia* (Roxb.)	Adi ses	A,F
	Neolamarckia	*Anthocephalus chinensis* (Lamk.) A. Rich. *ex*	Ant chi	A
	Hedyotis	*Hedyotis auricularia* L.	Hed aur	A

Contd...

Appendix Table 1. Continued.

Family	Genus	Scientific name	Code name	Representative community types
	Hymenodictyon	*Hymenodictyon orixensis* (Roxb.) Mabb.	Hym ori	--
	Ixora	*Ixora coccinea* L.	Ixo coc	--
	Tricalysia	*Tricalysia singularis* K. Schum.	Tri sin	A,B,D,F,G
Sapotaceae	Manilkara	*Manilkara hexandra* (Roxb.) Dubard	Man hex	--
	Palaquium	*Palaquium polyanthum* Engl.	Pal pol	A,B,D,F
Sonneratiaceae	Withania	*Duabanga grandiflora* (Roxb.) *ex* DC.) Walp.	Dua gra	A,D,E
Sterculiaceae	Pterospermum	*Pterospermum acerifolum* (L.) Willd.[R]	Pte ace	A,C
	Sterculia	*Sterculia villosa* Roxb. *ex* Smith[R]	Ste vil	--
Ternstroemicaceae	Eurya	*Eurya acuminata* DC.	Eur acu	B,D,H
Thelypteridaceae	Ampelopteris	*Ampelopteris prolifera* (Retz.)Kopel.	Amp pro	B,E
Tiliaceae	Corchorus	*Corchorus aestuans* L.	Cor aes	A,B,C,H
	Chisocheton	*Gurea peniculata* Roxb.	Gur pen	--
Urticaceae	Boehmeria	*Boehmeria nivea* (L.) Gaudich.	Boe niv	D,G,H
	Dendrocnide	*Dendrocnide sinuata* (Blume) Chew	Den sin	--
		Laportia crenulata (Roxb.) Wedd.	Lap cre	B,C,G
	Girardinia	*Girardinia heterophylla* (Vahl) Decaisne	Gir het	--
	Streblus	*Streblus asper* Lour.	Str asp	A,D
Verbenaceae	Clerodendrum	*Clerodendrum viscosum* Vent.	Cle vis	A,C
	Lippia	*Lippia alba* (Mill.) Briton et Wilson	Lip alb	A,B,C,H
	Prema	*Prema corymbosa* Rottl.	Pre cor	--
	Premna	*Premna obtusifolia* R. br. Vr. Pubescens Moldenke	Pre obt	--
	Vitex	*Vitex pinnata* L.	Vit pin	--
Zingiberaceae	Amomum	*Amomum dealbatum* (Roxb.)	Amo dea	--
…..	…..	Orisonko[V]	Ori ver	A,C
…..	…..	Ramai awal[V]	Ram awa	E,H
…..	…..	Macher kata[V]	Mac kat	A,B
…..	…..	Japa[V]	Jap ver	A,C,D,F,H
…..	…..	Guiya[V]	Gui ver	--

[R]indicates red listed vascular plants of Bangladesh (Bangladesh National Herbarium 2001), [V]Indicates used vernacular name, singleton species (62 species) are indicated by "--"under the representative community types.