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Environmental Factors Affecting the Abundance and Presence of Tree Species in a Tropical Lowland Limestone and Non-limestone Forest in Ben En National Park, Vietnam

Thinh Van Nguyen[1,2,*], Ralph Mitlöhner[1], Nguyen Van Bich[2] and Tran Van Do[2]
[1]*Department of Tropical Silviculture and Forest Ecology, Faculty of Forest Sciences and Forest Ecology, University of Göttingen, Germany*
[2]*Silvicultural Research Institute (SRI), Vietnamese Academy of Forest Sciences (VAFS), Duc Thang, Bac Tu Liem District, Ha Noi, Vietnam*

Abstract

The effect of environmental variables on the presence and abundance of tree species in a tropical lowland undisturbed limestone and non-limestone forest in Ben En National Park, Vietnam was investigated. The relationships between 13 environmental variables and 29 tree species with a DBH $\geq$10 cm, as well as between six 6 physical variables with 26 species of seedling and sapling communities were assessed by canonical correspondence analysis (CCA). Data concerning all tree species $\geq$10 cm DBH were collected from eighteen 400 m^2 sample plots, while the abundance of regeneration (all individuals $\leq$5 cm DBH) was counted in fifty 2x20 m strip-plots. The significance of species-environments correlations were tested by distribution-free Monte Carlo tests. The CCA of the 29 examined tree species and 13 environmental variables indicated that the presence and abundance of the tree species were closely related to topographic factors. We may confirm that soil properties including pH, soil moisture content, and soil textures, were the most crucial factor in tree species composition and their distribution. Several species including *Pometia pinnata*, *Amesiodendron chinense*, *Gironniera cuspidate*, *Cinnamomum mairei*, and *Caryodaphnopsis tonkinensis* were not controlled by soil properties and topographic variables. The CCA also indicated that the abundance of regeneration tree species at all sites had positive and significant correlations with soil depth, while the occurrence of several other tree species (such as *Koilodepas longifolium* and *Aglaia dasyclada*) was positively correlated with a higher slope and rocky outcrop.

Key Words: Undisturbed limestone and non-limestone forest, environmental factors, canonical correspondence analysis, vegetation-environment relationship

Introduction

The relationship analysis between tree species composition and environmental variables is considered a crucial issue in the ecological and environmental sciences (Guisan and Zimmermann 2000; Zhang et al. 2012), as the interplay between forests and environmental variables is integral to any study of the former (Zhang and Zhang 2011). Floristic composition and its relationship to environmental factors have become recent topic investigation: numerous studies have shown that the distribution of vegetation types and floristic patterns are most associated with environ-

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Corresponding author: Thinh Van Nguyen

Department of Forest Inventory & Planning, Silvicultural Research Institute (SRI), Vietnamese Academy of Forest Sciences (VAFS), Duc Thang, Bac Tu Liem District, Ha Noi, Vietnam
Tel: 49 (0) 551 39 12101, Fax: 49 (0) 551 39 4019, E-mail: nguyenthinhfsiv@gmail.com and vnguyen@gwdg.de

mental factors, including local variables/topographic factors (elevation, slope aspect, slope degree), soil factors (a soil's physical and chemical properties) (Huang 2002; Eilu 2004; Jones et al. 2006; Jabeen and Ahmad 2009; Tavili et al. 2009; Zhang et al. 2012), and factors related to human impact (Enright et al. 2005; Hoang et al. 2011). Among these environmental variables, soil type and topographic variables are the most significant factors affecting species diversity and the woody vegetation of a locality (Hejcmanova-Nezerková and Hejcman 2006; Zhang et al. 2012). In general, the distribution of vegetation patterns is mainly controlled by soil factors consisting of organic carbon, total nitrogen, and clay, as well as topographic factors such as elevation (Arekhi et al. 2010). The importance of physicochemical soil properties and soil nutrients are key factors influencing tree species richness (Eilu 2004), plant growth, and vegetation development (Zhang and Zhang 2011).

Silt/clay content, organic matter, and the total nitrogen are primarily related to vegetation distribution (He et al. 2007; Zhang and Zhang 2011); however, it could be argued that soil moisture is the most important environmental variable affecting the distribution of native species among habitats (Lan et al. 2011) and is as such a crucial factor in the valley forest (Pinto et al. 2005). By affecting moisture availability, soil moisture plays a key role in determining the distribution of plant species and roots (Arekhi et al. 2010). Factors including C/N ratio, soil pH, and the content of exchangeable calcium (among others) influence plant diversity, vegetation structure, and the effects of vegetation processes (Chiarucci et al. 2001; Pärtel et al. 2004).

In addition to the abovementioned factors, the majority of the significant evidence for topographic variables controlling the distribution patterns of tree species was found in environmental-tree species studies (Lan et al. 2011). Elevation is one of the most essential factors relating to the distribution of vegetation patterns and confirms the importance of topographic features in controlling the diversity of a tree community on both a small scale (via plots) (Lan et al. 2011) and a regional scale (Chiarucci et al. 2001; Sharma et al. 2009; Zhang and Zhang 2011; Zhang et al. 2012). Other topographic factors like slope and aspect are also significant to the spatial variation of plant communities (Zhang and Zhang 2011). Slope and outcropping rocks were the two main factors associated with the presence of a species (Chiarucci et al. 2001), while climatic factors were central in controlling the distribution and species richness patterns of various tree species (Sharma et al. 2009). The main goals of this study are to answer the following questions: (1) What are the most important factors affecting tree abundance and the distribution of tree species in undisturbed limestone and non-limestone forests in Ben En National Park? And (2) How do physical factors influence the abundance and presence of regeneration in the park?

Materials and Methods

Study sites

This study was conducted in Ben En National Park, Vietnam, over total park area is 16,600 ha at 20～500 m above sea level. Forests in the park are defined as a tropical lowland evergreen forest (Hoang et al. 2008). Variance in soil depth and outcrop cover varies site to site due to topography and soils are derived from a limestone substrate with a pH ranging from 4.5 to 6.7. The most abundant soil in the park is ferralitic, while a small area surrounding Lake Muc has alluvial soils; macgalit is found in the limestone hill areas.

In the park, limestone forests occur infrequently, and have a total area of only approximately 400 ha. The main characteristics of the limestone topography are rocky tops with steep, 20～30^o slopes with shallow, partially uncovered soils and an outcrop and slope erosion. Because the limestone forest borders Nghe An Province, this area has suffered from illegal logging activities; likewise its proximity to the Ho Chi Minh Road makes the transportation of illegal logs easy. In undisturbed non-limestone forest areas, the physical properties of soils are good and large roots are observed reaching to depths of ≥1 m. The slope ranges from 5 to 20^o.

Sampling design and data collection

Sampling design

The sampling design was deployed in undisturbed lowland limestone (denoted as LF) and non-limestone forests (Non-LF) sites along with a strategy of systematic sampling. For each forest site, a total of twenty-five 20x20 m sample plots were arranged in a systematic design with 50 m intervals between adjacent sampling plots (Fig. 1). All

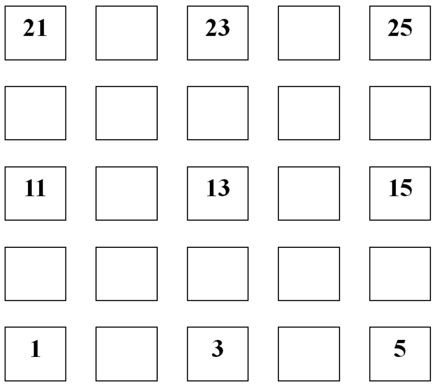

Fig. 1. Layout of the sampling design with each 400 m^2 sample plot (20x20 m). The interval sample plot was 50 m.

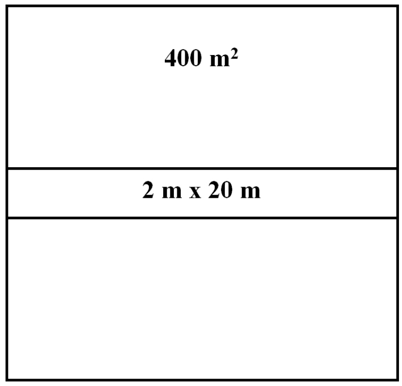

Fig. 2. One transect of 2x20 m was placed at the middle of each 400 m^2 sample plot.

sample plots were carried out in the strictly-protected zone. Sampling was conducted during the dry season from February to April 2012.

Vegetation data

All trees with a DBH $\geq$10 cm (Rana and Gairola 2009; Lu et al. 2010; Suratman et al. 2010) were collected and measured in a total of eighteen 20x20 m sample plots in the two undisturbed forest types (9 plots each, Fig. 1). The botanical name of every living tree was determined in the field and the DBH was measured to determine the tree basal area. At each 2x20 m transect (strip-plot), tree height and DBH were used to identify the regeneration. The abundance and names of tree species regeneration which is $\leq$5 cm DBH were sampled and recorded in 2x20 m strip-plots (Fig. 2).

Environmental and physical variables

In this study, the environmental variables measured in each of the nine sample plots per forest type consisted of three components: (1) Soil physical properties (including proportions of sand, silt, and clay), soil moisture content, and pH-$_{KCl}$; (2) Soil chemical properties, consisting of the total nitrogen, total potassium, total phosphorus, Cation-Exchange Capacity (CEC$=K^{+}+Ca^{2+}+Mg^{2+}$ $H+Al$), carbon to nitrogen C/N ratio, and the proportion of soil organic carbon; and (3) Topographical variables (slope and soil depth).

The slope was measured with a compass and looking down-slope (Zhang and Zhang 2007). Because of differences in the soil depth between the limestone and non-limestone forests, two different methods were applied in order to identify these forests' respective soil depths. At the limestone site, the soil depth was measured by a steel probe (Kelly et al. 1989) in two meter intervals at ten points in a transect/strip 2x20 m of each sample plot 20x20 m; the mean soil depth was calculated from the achieved values. At the non-limestone site, nine soil profiles were dug in nine sample plots to determine the soil depth; the mean soil depth value was calculated from these profiles.

The percentage of rock outcrops or percentage cover of surface stones was visually estimated at each sample plot in the undisturbed limestone forests and followed FAO's protocols (2006). The percentage of covered rock was calculated as the ratio of rock to the total area of a 100x100 cm grid with 25 sub- grids of 20x20 cm, taking the average of five points along the diagonal for each sample plot (Peng et al. 2012). The total coverage of ground vegetation (grass, herbs, and shrubs) was measured in each sample plot (Merkle 1951); it was calculated as the percentage of total area (Park et al. 2005; Kulla et al. 2009) and visually estimated (Zhang and Zhang 2011).

The topsoil layer is the most important source of nutrients for plants (Hejcmanova-Nezerková and Hejcman 2006). The soil's physical and chemical properties, which is to a depth of 20 cm, play an essential role in shaping vegetation (Tavili et al. 2009). In the case of the non-limestone forest site, soil samples were taken at the central point of the sample plot (Kiianmaa 2005; Nirmal et al. 2011) at depths of 0 to 20 cm (Tavili et al. 2009; Arekhi et al. 2010; Zhang and Zhang 2011) by using an auger 3 cm in diameter. In the limestone forest where the soil is shallow, soil samples were collected randomly in each sample plot at a depth of 0 to 20 cm (Jha and Singh 1990). A total of nine soil samples were collected from each forest type, leading to 18 soil samples in total.

The soil samples were air dried at room temperature and pooled to form one composite sample that was air-dried, thoroughly mixed, and then passively sieved through a 2 mm screen to remove rocks and large organic material. The percentage of moisture content was calculated as the difference between the pre- and post-drying weights divided by the pre-drying weight. The bouyoucos hydrometer method was used to determine the soil texture and calculate the percentage of sand, silt, and clay. Organic carbon was measured by the Walkley and Black method; pH_{KCl} was determined by using a pH meter (soil water ratio=1 : 5). The total nitrogen was estimated using the Kjeldahl method, and the total phosphorus was measured by wet digestion and the Bray II method. Wet digestion and the Atomic Absorption Spectroscopy method were applied in order to determine the total potassium content. The soil organic matter was measured by the $K_2Cr_2O_7$ method, and the Cation-Exchange Capacity ($CEC=K^+ + Ca^{2+} + Mg^{2+}$ $H + Al$) was determined via a $BaCl_2$ solution, followed by the Atomic Absorption Spectroscopy method. All physical and chemical properties of the soil were analyzed at the laboratory of the Vietnamese Academy of Forest Sciences.

Data analysis

Tree species data and environmental analysis: The tree abundance, basal area, and number of species/families occurring at each forest type were determined. Tree abundance was calculated with a count of all trees with a DBH ≥10 cm from 25 sample plots of each forest type; the basal area was calculated by using the following equation: $BA=\pi r^2=3.142x(DBH/200)^2$, where BA=the tree basal area (m^2) and r=radius (cm). A two sample t-Test was used to test for significant differences in the physical and chemical properties between the soils at the Non-LF and LF sites. All statistical analyses were performed with Statistica, Version 10.

Species and environment matrices: Tree species and related environmental factors were analyzed using ordination techniques. First, the data were entered into a Microsoft Excel spreadsheet before being transferred to the computer program PC-ORD for Windows version 5.12; any species absent in the sample plots was entered with a value of '0'. A total of 18 sample plots from the two forest types were then analyzed, and two distinct data matrices consisting of the species matrix and the matrix of environment variables were set up as required by the multivariate analysis methods. The species matrix contained a count of the tree abundance per species/sample plot, where species with an abundance of less than 4 individuals were deleted (Pinto et al. 2005; Souza et al. 2007). The resulting samples from the species data matrix consisted of 29 species and 18 sample plots. A second sample from the environmental variables data matrix was also constructed for 13 environmental factors from the same sample plots; this matrix initially included all physical and chemical properties of the soil and assorted topographic variables.

The data on regeneration and physical variables collected in the LF and Non-LF types were constructed in fifty 2x20 m strip-plots (25 strip-plots each). Two input matrices were used in this analysis. The species matrix consisted of the tree abundance of regeneration and their species richness in each 2x20 m strip-plot in every 400 m^2 sample plot. This matrix contained the tree abundance per strip for those with ≥10 individuals in the total sample; as a result, the matrix had 26 species per 50 strip-plots. The physical matrix considered in the analysis were the assorted characteristics of the forest structure, including: the basal area and tree abundance of a 400 m^2 sample plot, the understorey vegetation cover (canopy coverage, percentage of herb and shrub cover), and the local topography (slope in degree, percentage of rock outcrops or percentage cover of surface stones, and soil depth). The matrix contained the values of six physical variables.

Species-environment relationship: To investigate the relationship between tree species variation and environmental variables, the CCA was employed. The statistical significance of the species-environment correlation was tested by the Monte Carlo test; a permutation test was used to reveal the effect of the obtained environmental variables on the composition of plant species (Hejcmanova-Nezerková and Hejcman 2006). Permutation tests were run with 499 permutations at a 0.05 significance level. To verify the correlations between species, environmental variables, the first three axes, and Spearman's rank correlation coefficients were utilized.

Results

Tree abundance, basal area, and species richness

The twenty-five sample plots at the LF site had a lower tree abundance than did the Non-LF site. A total of 146 species belonging to 39 families were encountered in fifty 400 m^2 plots. Of these species and families sampled, 76 species representing 27 families and 114 species from 35 families were respectively sampled in the LF and Non-LF sites (Table 1). 44 species (about 30%) were common to

Table 1. The number of individuals, species and families counted in fifty 400 m^2 sample plots of the LF and Non-LF sites (25 sample plots each) in Ben En National Park, Vietnam

Variables	Forest type	
	LF	Non-LF
The total tree abundance (n/ha)	521	526
Species number (n/ha)	76	114
Family number (n/ha)	27	35
Basal area (m^2/ha)	46.2	52.2

Table 2. The 29 most abundant tree species ≥10 cm DBH with an abundance ≥4 stems collected in eighteen 400 m^2 plots of the LF and Non-LF sites (9 plots each) in Ben En National Park, Vietnam. Species are ranked in order of descending abundance (Nt) found in the two forest types. The codes of the 29 most common species were used in the CCA as expressed in Fig. 3

Family	Species	Code	Forest type		Nt (n)
			LF (n/0.36 ha)	**Non-LF** (n/0.36 ha)	
Sapindaceae	*Pometia pinnata*	Pompin	10	13	23
Caesalpiniaceae	*Saraca dives*	Sardiv	19	0	19
Lauraceae	*Cinnamomum mairei*	Cinmai	10	7	17
Euphorbiaceae	*Koilodepas longifolium*	Koilon	16	0	16
Fagaceae	*Mellettia lasiopetala*	Mellas	5	10	15
Fagaceae	*Castanopsis annamensis*	Casann	12	1	13
Sapindaceae	*Mischocarpus oppositifolius*	Misopp	3	9	12
Ulmaceae	*Gironniera subaequalis*	Girsub	0	11	11
Lauraceae	*Actinodaphne obovata*	Actobo	11	0	11
Moraceae	*Streblus ilicifolius*	Strili	10	0	10
Sterculiaceae	*Pterospermum hetrophyllum*	Ptehet	9	0	9
Ulmaceae	*Gironniera cuspidata*	Gircus	0	9	9
Lauraceae	*Cinnamomum subavenium*	Cinsub	2	7	9
Lauraceae	*Cinnamomum parthenoxylon*	Cinpar	6	3	9
Caesalpiniaceae	*Erythrophleum fordii*	Eryfor	1	7	8
Lauraceae	*Caryodaphnopsis tonkinensis*	Carton	7	0	7
Meliaceae	*Dysoxylum cauliflorum*	Dyscau	5	2	7
Meliaceae	*Aglaia perviridis*	Aglper	5	1	6
Myrtaceae	*Syzygium chanlos*	Syzcha	1	5	6
Theaceae	*Schima superba*	Schsup	0	6	6
Ebenaceae	*Diospyros pilosula*	Diopil	5	0	5
Lauraceae	*Cryptocarya sp*	Crysp	5	0	5
Apocynaceae	*Wrightia laevis*	Wrilae	0	5	5
Verbenaceae	*Vitex trifolia*	Vittri	1	3	4
Meliaceae	*Aglaia dasyclada*	Agldas	0	4	4
Caesalpiniaceae	*Peltophorum tonkinensis*	Pelton	1	3	4
Lauraceae	*Cinnamomum tetragonum*	Cintet	0	4	4
Sapotaceae	*Sinosideroxylon racemosum*	Sinrac	1	3	4
Sapindaceae	*Amesiodendron chinense*	Amechi	2	2	4

Table 3. The mean values and standard deviations of topographical factors and soil variables collected in the LF and Non-LF sites in Ben En National Park, Vietnam. The codes of the 13 environmental factors were used in the CCA as expressed in Fig. 3

Environmental variables	Code	LF	Non-LF	p values
		Mean±SD	Mean±SD	
Slope (°)	SLO	19.7±4.94	7.0±3.08	0.00*
Soil depth (cm)	SD	10.7±5.76	96.1±15.7	0.00*
Soil moisture content (%)	SMC	8.35±0.84	4.98±0.53	0.00*
Sand (%)	SAND	29.18±7.90	19.84±9.25	0.03*
Silt (%)	SILT	27.69±3.59	34.46±3.47	0.00*
Clay (%)	CLAY	43.11±4.38	45.68±5.89	0.31 (ns)
pH-KCl	pH	5.28±0.21	3.78±0.15	0.00*
Soil organic carbon (%)	OC	2.13±0.50	1.92±0.13	0.24 (ns)
Total nitrogen (%)	TN	0.27±0.02	0.24±0.03	0.19 (ns)
Carbon to nitrogen ratio	CN	4.54±0.50	4.67±0.57	0.62 (ns)
Total phosphorous (%)	TP	0.30±0.06	0.18±0.05	0.00*
Total potassium (%)	TK	0.59±0.09	0.7±0.12	0.04*
CEC (me/100 g)	CEC	24.73±8.84	15.84±1.12	0.00*

ns, non-significant; *$p < 0.05$.

both the LF and Non-LF, but 32 were exclusive to the former and 70 to the latter (data not shown). In terms of the quantity of species, the most diverse family observed in both sites was Lauraceae with 16 (Non-LF) and 12 (LF) species. At the former site, Fagaceae, Meliaceae, and Moraceae ranked second with nine species, followed by Magnoliaceae (six species). The family with the largest number of species in the LF was Lauraceae with nine species; the next two families with the largest number of species were Caesalpiniaceae, Fagaceae, Meliaceae, and Sapindaceae represented by five species (data not shown). 29 most common species used in the CCA are given in Table 2. Altogether, 12 families were represented by one species and the remaining families were found to have two to three representative species each.

Features of topographic and soil variables

The mean values and standard deviation of the 13 environmental variables collected in the Non-LF and LF sites which can be broken down into topographic (2) and soil variables (11) is given in Table 3. The two forest types showed significant differences in eight of the 13 environmental factors, e.g., in the slope and soil depth (t-Test, $p < 0.05$), where the LF presented higher degrees of slope than did the Non-LF. The differences in soil properties between the two study sites were quite notable, suggesting that other environmental factors have a role in determining the soil nutrient availability. The soils of the Non-LF and LF were different in texture; there were significant statistical differences in sand and silt contents (t-Test, $p < 0.05$). The proportion of clay was higher in the Non-LF but the difference was statistically insignificant (t-Test, $p > 0.05$); differences in soil moisture content were, however, significant.

In regards to chemical properties, the soil pH values of both forest sites were low, indicating high acidity at the Non-LF and LF sites. The soil pH obtained in the latter site was significantly higher than that of the former (t-Test, $p < 0.05$). In paired comparisons, significant differences in the total phosphorous and CEC (t-Test, $p < 0.05$) were found between the two forest types; the similar result was found in total potassium (t-Test, $p < 0.05$). A total nitrogen value recorded in the soil of the Non-LF site was similar to that of the LF; there were thus no significant differences in this feature (t-Test, $p > 0.05$).

The relationship between the presence/abundance of tree species and environmental variables

The CCA's results using the tree abundance of the 29 most common tree species are presented in Table 4. According to this table, the CCA showed strong correlations between species frequency and the environmental variables. At a respective 0.575 and 0.336 accounting for 22.6% and 13.5% of variation in species composition, the eigenvalues for the first two axes were very high; they were thus good predictors of species distribution and abundance. The eigenvalue for the third axis was 0.208 and accounted for 8.2% of the variation in the species data set. It is clear, then, that the axis 1 value signaled the highest change in vegetation structure. The Monte-Carlo permutation test indicated a significant difference between the eigenvalues of the ordination axes ($p < 0.01$) and the species-environment correlations calculated for the first three axes of the CCA were high. The correlation between the first axis and the species-environment variables revealed by the Pearson and Kendall correlation was a respective 0.99 and 0.93. Similarly, the species-environment correlations of the second axis checked by the two aforementioned correlations were 0.95 and 0.79, respectively. A Monte-Carlo permutation test showed that the vegetation-environment relationships distinguished by all axes were highly significant ($p < 0.01$). These parameters suggest that the forest-environment relationship was well explained by the CCA.

Table 4. Eigenvalues and the amount of variance explained by the species/species-environment correlations of the first three CCA axes for the distribution and abundance of tree species in the LF and Non-LF sites in Ben En National Park, Vietnam

Results of CCA	Axis 1	Axis 2	Axis 3
Eigenvalue	0.575	0.344	0.208
Variance in species data:			
Percentage of variance explained	22.6	13.5	8.2
Cumulative percentage variance ex plained	22.6	36.2	44.3
Species-Environment Correlations by			
Pearson correlation	0.994	0.952	0.968
Kendall (Rank) correlation	0.935	0.791	0.882
p value of Monte Carlo test for *Eigenvalues*		0.002	
Species-Environment correlations		0.002	

The correlation matrix of the environmental variables collected in the 18 sample plots of the Non-LF and LF is listed in Table 5. A correlative analysis of the 13 environmental variables in the study sites demonstrated that slope was significantly and positively correlated with the SMC and soil pH, while soil depth negatively correlated with these factors. Soil texture significantly and positively related to the carbon to nitrogen ratio, total phosphorous, and total potassium. There was a significant positive correlation between the CEC and soil pH, soil organic carbon, and total nitrogen, but a negative correlation with soil depth.

The relationship between the distribution and abundance of the 29 most dominant tree species and environ-

Table 5. The correlation matrix calculated by the Spearman rank order between 13 environmental variables and the first three axes of the 18 sample plots collected in the LF and Non-LF sites in Ben En National Park, Vietnam. The full names of the 13 environmental variables and their units are listed in Table 3

Factor	Axis			Slope	SD	SMC	Sand	Silt	Clay	pH	OC	TN	CN	TP	TK	CEC
	1	2	3													
Slope	**0.89**	0.13	-0.02	1.00												
SD	**-0.70**	0.36	0.22	**-0.70**	1.00											
SMC	**0.85**	-0.02	-0.38	**0.78**	**-0.75**	1.00										
Sand	0.22	-0.25	0.31	0.28	-0.28	0.04	1.00									
Silt	**-0.54**	0.13	-0.25	**-0.60**	**0.60**	-0.37	**-0.87**	1.00								
Clay	-0.12	0.36	-0.32	-0.17	0.23	0.05	**-0.96**	**0.75**	1.00							
pH	**0.77**	0.14	-0.11	**0.78**	**-0.73**	**0.84**	0.28	**-0.59**	-0.18	1.00						
OC	0.09	-0.05	**-0.72**	0.02	-0.16	0.35	-0.38	0.27	0.36	0.29	1.00					
TN	0.21	-0.14	**-0.64**	0.15	-0.32	0.37	-0.04	-0.06	0.03	0.39	**0.92**	1.00				
CN	-0.02	0.32	-0.24	-0.17	0.17	0.19	**-0.84**	**0.68**	**0.85**	0.03	0.41	0.11	1.00			
TP	**0.71**	-0.13	-0.13	**0.71**	**-0.64**	**0.68**	**0.69**	**-0.78**	**-0.62**	**0.67**	-0.06	0.20	**-0.47**	1.00		
TK	-0.37	0.37	0.05	-0.43	0.44	-0.26	**-0.76**	**0.71**	**0.73**	-0.18	0.34	0.07	**0.82**	**-0.77**	1.00	
CEC	**0.65**	-0.05	**-0.64**	**0.59**	**-0.67**	**0.86**	0.11	-0.35	-0.05	**0.76**	**0.65**	**0.73**	0.08	**0.67**	-0.27	1.00

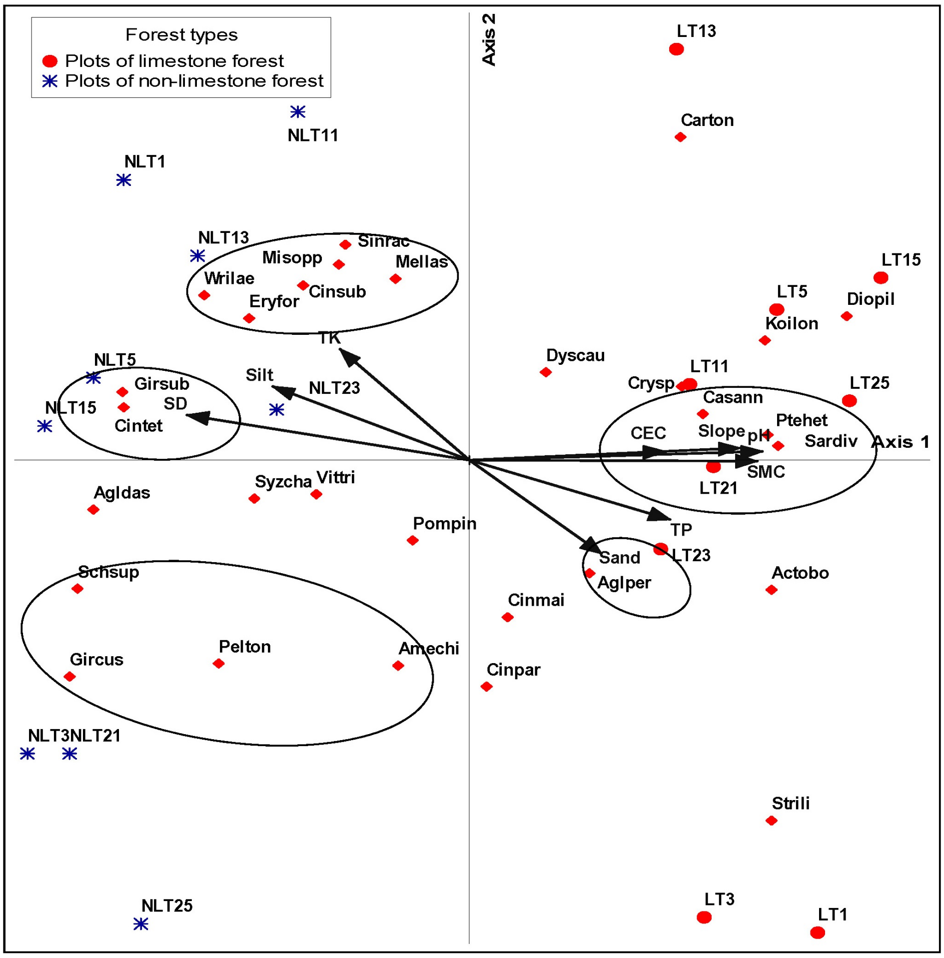

Fig. 3. A CCA ordination diagrams of the 29 most dominant tree species and 13 environmental variables of the first two ordination axes in Ben En National Park, Vietnam. Quantitative environmental variables are indicated by arrows, quadrilaterals stand for tree species, and sample plots are represented by red dots in the limestone forest, asterisks in the non-limestone forest. The codes referring to species and environmental factors were listed in Tables 2 and 3, respectively.

mental factors measured in 18 sample plots across the two forest types is presented in the CCA ordination diagrams (Fig. 3). It is clear that different species saw different distribution patterns within the sample plots. The CCA species ordination suggests that a number of species were restricted to the limestone forest site. Several species including *Saraca dives*, *Pterospermum hetrophyllum*, *Castanopsis annamensis*, and *Cryptocarya sp* were strongly associated with soil pH, soil moisture content, and slope which meant that they were more frequent in sample plots with high levels of these factors. The total potassium vector was strongly correlated with the occurrence of such species as *Wrightia laevis*, and *Erythrophleum fordii*, furthermore, *Cinnamomum tetragonum* and *Gironniera subaequalis* seemed to be influenced by the vector of soil depth. In contrast, six of the 29 species (*Pometia pinnata*, *Amesiodendron chinense*, *Gironniera cuspidate*, *Peltophorum tonkinensis*, *Cinnamomum mairei*, *Cinnamomum parthenoxylon*) were influenced by neither the soil properties nor the topographic variables.

Variation in the abundance and distribution of regeneration as a result of physical factors

Among regeneration species, the 26 most common tree species from 15 families were examined in a canonical correspondence analysis; the list of species examined is given in Table 6. Many, such as *Gironniera cuspidate*, *Syzygium chanlos*, *Knema globularia*, and *Cinnamomum subavenium*, had a higher abundance in the Non-LF site; in contrast, *Diospyros pilosula*, *Streblus ilicifolius*, and *Koilodepas longifolium* were dominant in the LF site.

The physical variables explained most of the species abundance as shown by the CCA results (Table 7 and Fig. 4). The eigenvalues of the first, second, and third axes were 0.657, 0.072, and 0.061, respectively; the species-environ-

Table 6. The 26 most abundant tree species with an abundance ≥10 individuals, as collected in the LF and Non-LF sites (twenty-five 40 m^2 strip-plots each) in Ben En National Park, Vietnam. Species are ranked via descending abundance (Nt) found in both sites. The codes of the 26 most common species were used in the CCA (Fig. 2)

Species	Family	Code	**LF** (n/0.1 ha)	**Non-LF** (n/0.1 ha)	**Nt** (n)
Diospyros pilosula	Ebenaceae	Diopil	72	1	73
Pometia pinnata	Sapindaceae	Pompin	22	22	44
Streblus ilicifolius	Moraceae	Strili	28	0	28
Cinnamomum parthenoxylon	Lauraceae	Cinpar	3	23	26
Gironniera cuspidata	Ulmaceae	Gircus	0	24	24
Schima superba	Theaceae	Schsup	3	19	22
Syzygium chanlos	Myrtaceae	Syzcha	0	21	21
Gironniera subaequalis	Ulmaceae	Girsub	0	20	20
Cinnamomum mairei	Lauraceae	Cinmai	12	7	19
Aphanamixis grandifolia	Meliaceae	Aphgra	0	18	18
Knema globularia	Myristicaceae	Kneglo	0	18	18
Cinnamomum subavenium	Lauraceae	Cinsub	0	18	18
Aglaia dasyclada	Meliaceae	Agldas	0	16	16
Koilodepas longifolium	Euphorbiaceae	Koilon	16	0	16
Pterospermum hetrophyllum	Sterculiaceae	Ptehet	14	2	16
Syzygium zeylanicum	Myrtaceae	Syzzey	0	16	16
Erythrophleum fordii	Caesalpiniaceae	Eryfor	0	15	15
Wrightia laevis	Apocynaceae	Wrilae	2	11	13
Antidesma acidum	Euphorbiaceae	Antaci	0	12	12
Paranephelium spirei	Sapindaceae	Parspi	4	8	12
Mellettia lasiopetala	Fagaceae	Mellas	4	7	11
Canarium littorale	Burseraceae	Canlit	7	4	11
Dysoxylum cauliflorum	Meliaceae	Dyscau	6	4	10
Cinnamomum tetragonum	Lauraceae	Cintet	0	10	10
Actinodaphne obovata	Lauraceae	Actobo	6	4	10
Canarium parvum	Burseraceae	Canpar	2	8	10

Table 7. The eigenvalues, amount of variance explained by the species data, species-environment relation, and species-environment correlations of the first three CCA axes for the regeneration of regeneration species in the LF and Non-LF sites in Ben En National Park, Vietnam

Results of CCA	Axis 1	Axis 2	Axis 3
Eigenvalue	0.657	0.072	0.061
Variance in species data:			
Percentage of variance explained	18.4	2.0	1.7
Cumulative percentage variance explained	18.4	20.5	22.2
Species-Environment Correlations by			
Pearson correlation	0.959	0.603	0.566
p value of Monte Carlo test	0.002	0.002	0.002

ment correlations yielded by these axes were 0.959, 0.603, and 0.566, and their cumulative percentage variances were 18.4%, 20.5%, and 22.2%. These values, along with the results of the Monte Carlo test ($p < 0.01$), indicated a highly significant correlation between physical variables and the species abundance of seedlings and saplings.

Spearman's correlation (Table 8) indicates that the soil depth, slope, and rocky outcrop significantly correlated with the first axis ($p < 0.05$). The slope, tree abundance, and total herbaceous coverage also significantly correlated with the third axis, while only the ground vegetation coverage correlated with the second one ($p < 0.05$).

According to the CCA ordination diagram (Fig. 4), a significant relationship was revealed between the abundance and uneven distribution of regeneration and the physical variables measured in the Non-LF and LF sites. The effects of different physical factors varied among species, but most were clustered on the right (negative) side of Axis 1. The most distinct group was formed in plots with

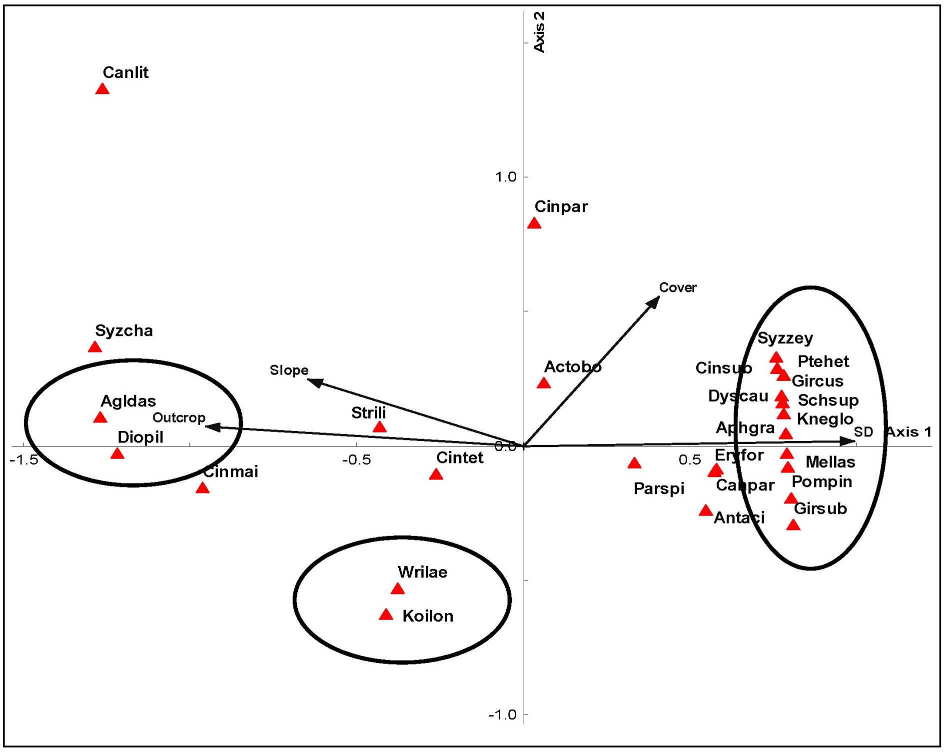

Fig. 4. Canonical correspondence analysis ordination diagrams in two dimensional attribute spaces of the 26 most dominant tree regenerations of seedlings/saplings and six physical variables in Ben En National Park, Vietnam. The codes referring to species and physical factors were listed in Tables 6 and 8, respectively.

Table 8. The correlation matrix calculated by the Spearman rank order between six physical variables and the first three axes of fifty strip-plots collected in the LF and Non-LF sites in Ben En National Park, Vietnam

	Axis			Slope (°)	Soil depth (SD, cm)	Outcrop (%)	BA (m^2/400 m^2)	Tree abundance (N/400 m^2)	Cover (%)
	1	2	3						
Slope (°)	**-0.61**	0.15	**0.49**	1.00					
Soil depth (SD, cm)	**0.77**	-0.05	-0.20	**-0.77**	1.00				
Outcrop (%)	**-0.75**	0.12	0.20	**0.77**	**-0.99**	1.00			
BA (m^2/400 m^2)	0.08	0.21	0.29	-0.14	0.24	-0.26	1.00		
Tree abundance (N/400 m^2)	-0.25	0.21	**-0.43**	-0.08	0.00	0.00	0.00	1.00	
Cover (%)	0.09	**0.58**	**-0.45**	**-0.47**	**0.50**	**-0.45**	0.21	0.04	1.00

higher soil depth, less rocky outcrop, and low slope, which means that the increase in soil depth appears to enhance the occurrence of these regeneration. In contrast, the occurrence of several tree species such as *Diospyros pilosula* and *Aglaia dasyclada* was positively correlated with higher slope and rocky outcrop. Unlike the abovementioned species, *Cinnamomum parthenoxylon* seemed to prefer plots with a relatively high amount of ground vegetation coverage; *Koilodepas longifolium* and *Wrightia laevis* were not influenced by any physical variables.

Discussion and Conclusion

Effects of topographic variables on the abundance and presence of tree species

Topography has numerous effects on the environment; for example, it influences vegetation and soil (Chahouki et al. 2012) and predicts tree species composition and tree abundance (Valencia et al. 2004). Other environmental factors such as aspect and slope affect plant community structure (Amezaga et al. 2004); indeed, one study indicated that slope had a significant effect on the composition and tree abundance of tree species (Mohtashamnia et al. 2011). In regards to both the distribution of species composition and the relationship between slope and tree abundance, the results of this study were well in keeping with those conclusions reached by other researchers. In two Israeli sites differing in the climatic and edaphic conditions of various woody life forms of eastern Mediterranean plant communities, species composition and richness differed significantly between north and south-facing slopes (Sternberg and Shoshany 2001). A study carried out in natural mixed forest stands in the Eastern Black Sea region of Turkey found that geomorphology features (e.g., elevation, slope, and aspect) strongly influenced tree species diversity and composition in the forests (Ozcelik et al. 2008). A similar finding also observed that terrain variables including altitude and slope affected the moisture regime and soil formation processes; consequently, there was a lower tree diversity to be found on steeper slopes and at higher elevation (Kebede et al. 2013).

Effects of soil properties on the abundance and presence of tree species

Soil is one of the most crucial components influencing vegetation (Chahouki et al. 2012) and as a result, changes in species composition among forests may be due to edaphic factors (Swamy et al. 2000); however changes in vegetation are mainly the result of soil properties in lowland forests (Arekhi et al. 2010). Ordination analyses for the LF and Non-LF sites revealed a close relationship between soil factors and tree species abundance/distribution. It is apparent that the distribution and abundance of tree species is determined by topography and soil properties (Clark et al. 1998). In the present study, the CCA's results demonstrated that of the environmental factors (i.e., the topographic and edaphic variables), the presence and abundance of tree species were most strongly correlated with several soil characteristics consisting of soil pH, soil moisture content, soil texture, total phosphorous, and total potassium. The results indicated that *Cinnamomum tetragonum* and *Gironniera subaequalis* were strongly influenced by soil depth which comes as no surprise as soil is an essential factor given its effect on the availability of moisture for plants (Chahouki et al. 2012).

Soil moisture content has many effects on the distribution of vegetation groups and plant species (Tavili et al. 2009). The CCA results expressing the magnitude of soil moisture in the present study have been confirmed by Lyon and Sagers (2003) who used multivariate analysis and ordinations to characterize the composition and distribution of woody vegetation within the Ozark National Scenic Riverways (ONSR), Missouri, USA. Soil moisture as a factor influencing the distribution of plant species has been reported by further studies conducted in a coastal desert plain of Southern Sinai, Egypt (El-Ghani and Amer 2003); similarly, it may be responsible for such evergreen species as *Xanthophyllum flavescens*, *Ixora brachiata*, and *Dimocarpus longan* in the low-elevation forests in the Western Ghats of Tamil Nadu, India (Swamy et al. 2000).

The CCA results of the present study indicate that the tree abundance and distribution of *Saraca dives*, *Pterospermum hetrophyllum*, *Castanopsis annamensis*, and *Cryptocarya sp* were strongly associated with a higher soil pH, whereas *Pometia pinnata*, *Vitex trifolia*, and *Amesiodendron chinense's* abundance and presence were not associated with soil fertility. These findings also demonstrated the importance of pH in the top soil layers for plant species distribution, an observation was in keeping with the reports of several other authors who have discussed at length the variation in species composition and distribution as a result of soil pH. Tanner (1977), for example, noted that the limiting factor in the Mor Ridge forest, one of four montane rain forests of Jamaica, was the extremely low pH. A close relationship between plant species composition and soil chemistry (pH and organic carbon) was also explored in an inland arid desert of Egypt (Abd El-Ghani 1998); likewise, Zhang et al. (2005) suggested secondary botanical gradients relating to pH and soil moisture in the China's Tarim River, Southern Xinjiang,. Further studies implemented in the Tianshan Mountains, China confirmed that soil pH was one of the main factors determining the development and affecting the distribution of vegetation (Lou and Zhou 2001; Xu et al. 2006; Zhang et al. 2012).

Variation in the regeneration abundance and distribution of tree species related to physical variables

The natural regeneration of a species is a process dependent on various genetic and environmental factors (Felfili 1997) and is as such a crucial factor in determining forest structure for sustainable forest management (Montes et al. 2007). A forest's regeneration is essentially controlled by four groups of potentially limiting factors: disturbances, site resources, weed competition, and plants (Hardwick et al. 2000). It is clear that environmental conditions have a complex effect on the establishment and survival of seedlings has been clearly documented by Topoliantz and Ponge (2000) among others; a pattern of regeneration abundance, for example, seems to be related mainly to the climate (Silva et al. 2012) in connection with local factors spanning altitude, topography, soil and slope (Felfili 1997; Figueroa-Rangel and Olvera-Vargas 2000; Silva et al. 2012).

Other factors such as forest structure (basal area, stand abundance, and canopy), gap characteristics, and vegetation play a crucial role in structuring regeneration communities (Park et al. 2005). Most of the seedlings/saplings were related to forest types or the developmental stage, which consisted of the basal area and stand abundance of forests along with several environmental factors, e.g., soil moisture and light (Asanok et al. 2013). It is generally recognized that the species richness of seedlings is positively associated with species abundance (Denslow and Guzman G 2000); the species composition of regeneration communities in harvested areas appears determined by a complex assortment of environmental factors (Park et al. 2005). The ground flora, especially natural regeneration, may take advantage of any canopy openings (Madsen and Larsen 1997). The effects of the canopy density or the over-storey stand structure may have on the stand itself are among the most important factors for controlling both.

The CCA's results in this study indicated that the effect of the different physical factors varied among regeneration species. The results in Fig. 4 indicate that most species were clustered on the right side of Axis 1; the most distinct group was formed by those plots with higher soil depth, less rocky outcrop, and lower slope. This means that increasing the soil depth enhances the occurrence of these regeneration. In contrast, the occurrence of several tree species such as *Koilodepas longifolium* and *Aglaia dasyclada* was positively correlated with higher slope and rocky outcrop. Variations in slope were obvious and their effects on sapling abundance were apparent insofar as they affected the maintenance and germination of seeds in soils (Zhang and Zhang 2007). Unlike the species mentioned above, *Cinnamomum parthenoxylon* seemed to prefer plots with a relatively higher amount of ground vegetation coverage, this assumption is in accordance with a further study conducted on Crannach Hill, Aberdeenshire, Scotland where, Rao et al. (2003) found that taller saplings occurred in higher and denser understorey vegetation. However, Chapman and Chapman (1997) documented that when a dense shrub layer is established, it may inhibit seedling and sapling survival; it, therefore, appears that there was much lower recruitment into the sapling class in logged areas as opposed to unlogged ones.

The distribution and abundance of regeneration were affected by many factors and as such varied among species. Most of the regeneration were related to forest types which consisted of the basal area and stand abundance of forests along with several environmental factors, e.g., soil moisture and light (Asanok et al. 2013). It is generally recognized that the species richness of seedlings is positively associated with species abundance (Denslow and Guzman G 2000); the species composition of regeneration communities in harvested areas appears determined by a complex assortment of environmental factors (Park et al. 2005). The restricted distribution and range of the occurrence of species can be explained by the presence of steep ecological gradients including soil moisture, organic matter, exchangeable cations, soil pH, and temperature (Tesfaye et al. 2002). Differences in topography, slope, and altitudes among clusters contribute to differences in seedling species composition (Figueroa-Rangel and Olvera-Vargas 2000). In addition, the topographic gradient and ground water table level directly influence the pattern of a species' establishment in each forest (Marimon et al. 2010). Human disturbances could further influence seed dispersal mechanisms, fruiting, germination, and regeneration (Omeja 2004).

Conclusion

Our analysis based on a systematic design may have been constrained by lack of observations. 18 sample plots plus 18 soil sample collected in the two undisturbed forest types located in restrictly protected zone, while this may reflect current conditions, they does not facilitate detailed statistical analysis. We have realized that the main restriction of this study is constrained by pseudo-replication which is one of the most influential methodological issues in ecological research. From this point, investigations in this study will be a preliminary knowledge for exploring the spatial relationship between environmental variables and tree species distribution of an undisturbed tropical limestone/non-limestone forest. Further studies of other areas with similar characteristics in the National Park would be very welcome in order to draw more general conclusions. Other methods that may have been employed, such as line distance sampling, are believed to be more efficient and are recommended for a better understanding of tree species distribution/abundance and environmental factors in such areas.

The preliminary results of the ordination analysis revealed a close relationship between environmental factors and the abundance/presence of tree species in such an undisturbed limestone/non-limestone forest. The distribution of the tree species was closely related to edaphic and topographic factors; soil was the most crucial factor for forest composition, and these results emphasized the importance of the soil's physical and chemical properties in influencing tree species distribution. Significant differences between limestone and non-limestone forests were observed in terms of tree species composition, diversity, and dominance; it is believed that variation in soil characteristics between the two forest types influences the distribution of the forests' tree communities. *Saraca dives*, *Diospyros pilosula* and *Koilodepas longifolium* were the most dominant in the limestone forest, whereas *Gironniera subaequalis*, *Gironniera cuspidate*, *Erythrophleum fordii*, and *Wrightia laevis* dominated in the non-limestone forest. It appears that the distribution of tree species in the both sites was determined by soil pH, SMC, slope, and soil texture. Differences in tree species distribution observed over the gradients of a soil's physical/chemical properties, as well other environmental factors such as slope, should be taken into account when designing management strategies in the undisturbed limestone/non-limestone forest of the park.

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