Biological Sciences

Comparison of floristic composition in four sites of a tropical lowland forest on the North-Central Coast of Vietnam

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Natural regeneration, floristic composition, forest structure, and diversity of all tree species with a DBH ≥ 10 cm were investigated in four sites of a tropical lowland limestone and non-limestone forest in Ben En National Park, Vietnam. Four one-ha plots (twenty-five 20 m x 20 m plots each) were established in disturbed/undisturbed tropical lowland limestone (DLF/ULF) and non-limestone forests (DNLF/UNLF). All trees with ≥ 10 cm DBH along with poles ≥ 5 cm DBH and under 10 cm DBH were measured in a total of one hundred 20 m x 20 m sample plots, while twenty-five 2 m x 20 m strip-plots were established to sample the regeneration of tree species. A total of 2265 stems representing 177 species and 43 families were recorded in all sites. Tree abundance was highest (626 stems ha^{-1}) in the DNLF and lowest in the UNLF and ULF sites. The greatest species richness was found in the UNLF (114 species ha^{-1}), the lowest (63) in the DLF. Species richness in the two non-limestone forest sites (150 species) was higher than that of the two limestone forest sites (85). There were no significant differences in the species richness of seedlings among the four forest types; however, the observed differences in the species richness of regeneration among the four forest sites showed a lower observed species number in the two disturbed forest sites than in their undisturbed counterparts. Most species had a low abundance of tree seedlings and saplings. *Journal of Nature and Science, 1(8):e144, 2015*

Tropical lowland limestone and non-limestone forests | disturbed and undisturbed forests | floristic composition and regeneration

1. Introduction

Forest structure is a key component in the analysis and management of forest ecosystems [18, 37], as well as in the growth and disturbance regimes of forests [18]. The term ‘‘forest structure’’ is complex to define and describe due to the vast array of contributing factors [7, 40, 58], but it is generally characterised by vertical stratification (e.g., the number of tree layers and understorey trees), horizontal structures (such as tree groups and spatial patterns), and tree species composition [22, 25, 36, 58, 60]. The vertical structure in the different developmental stages of the forest stand is one of the major aspects of forest structure [31, 37] and as such is frequently discussed in the context of ecosystem management [18]. Attributes comprised of stand height, the number of successive vegetation layers, and gap distribution are used to assess vertical structure [53]; the horizontal structure, on the other hand, includes the diameter distribution of tree species and the basal area per unit area [23, 42].

Structure and diversity are the main features necessary to describe a forest ecosystem [48]. Tree species diversity is a crucial aspect of forest ecosystem diversity [25, 51]; the main components of this diversity are species richness (alpha diversity) [30], relative abundance (species evenness), the presence of a particular species (species composition), and the interactions among species [49]. Tree species diversity in tropical forests varies greatly from site to site but is mainly the result of variation in biogeography, habitat, and disturbances [67]. The floristic composition plays a crucial role in assessing the health of the forests [46]**,** making knowledge of a forest’s horizontal and vertical structural diversity essential to both the effective management of a forest ecosystem [29] and the solid understanding of not only species regeneration [64] but also the history, function, and future of a forest ecosystem [58].

The natural regeneration of a species is a process dependent on various genetic and environmental factors [16] and is as such a crucial factor in determining forest structure for sustainable forest management [37]. A forest’s regeneration is essentially controlled by four groups of potentially limiting factors: disturbances, site resources, weed competition, and plants [20]. Natural forest regeneration and its response to changes in soil conditions provide a useful guide for managers in designing reasonable recovery plans [32]. Differences between local sites in factors such as soil condition may have a large influence on regeneration growth [34]. The intensity and quality of abiotic factors comprised of light, moisture, soil structure, and logging are critical for natural regeneration [61]; logging, for example, may have different effects on the establishment of seedlings and saplings among species [39]. On the one hand, logging activities reduce the abundance of mother trees [43], thus creating human disturbances that could negatively influence the regeneration of a species [43]; on the other hand, logging could create favorable conditions for the regeneration of other species [6].

One of the most common methods for evaluating diversity in tropical forests is based on a sampling methodology [30], an approach that provides an estimation of species richness and assumes that the diversity of other life forms correlates with tree species diversity [30]. The forest structure and tree species diversity of the non-limestone/limestone forests in this study are described and compared between the four forest types in question. Two key questions are addressed: (1) How does forest structure vary between tropical lowland non-limestone and limestone forests in Ben En National Park? and (2) What are the tree diversity and species richness of the natural regeneration in the park?

2. Materials and methods

2.1. Study sites

The study was conducted in Ben En National Park on the north-central coast of Vietnam. The total park area is approximately 16,600 ha over an elevation range of 20-500 m a.s.l. Forests in the park are defined as tropical lowland evergreen forests [24]. The region experiences four significant seasons: spring (February to April), summer (May to August), autumn (September to November), and winter (December to March). This region is a typical tropical monsoon climate with a rainy season from May to October and a dry season between November and March. The mean annual temperature of the area is 23.7°C and the mean annual precipitation is about 1,600 mm. More than 85% of the rainfall occurs during the rainy season.

Two one-ha plots in the two forest subtypes were established in the limestone forest areas. The location of the first site is at a disturbed tropical lowland limestone forest (denoted as DLF), with the second in an undisturbed tropical lowland limestone forest (ULF). The former is located at 105°26’ E and 19°36’ N, 142 m a.s.l., whereas the latter extends to 105°24’ E and 19°36’ N. The other two one-ha plots are located in a tropical lowland non-limestone forest: the first site is a disturbed non-limestone forest (DNLF) situated at 19°33’ N and 105°28’ E with an elevation of 60-150 m a.s.l., and the second (19°34’ N and 105°26’ E) is an undisturbed non-limestone forest (UNLF).

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2.2. Sampling procedure, data collection, and analysis

For each forest, a total of twenty-five 20 m × 20 m sample plots [2, 12, 54] were arranged in a systematic design with 50 m intervals between adjacent sampling plots (Figure 1). The total sampling area of the 25 sample plots was equivalent to one hectare. One transect 2 m x 20 m was placed in the middle of each 400 m^2 sample plot (Figure 2). Finally, twenty-five 2 m x 20 m strip-plots were established in each forest type, giving a total sampling area of 0.1 ha that accounted for 10% of the plot area.

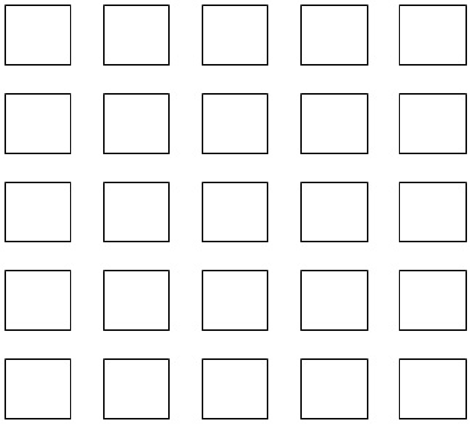

Figure 1. Layout of the sampling design with each 400 m² sample plot (20 × 20 m). The interval sample plot was 50 m.

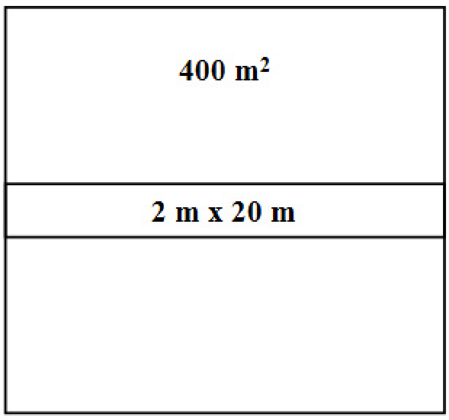

Figure 2. One transect of 2 m x 20 m was placed at the middle of each 400 m^2 sample plot.

At each transect 2 m x 20 m of the sample plot, tree height and DBH were used to identify the regeneration categories. The regeneration classifications of seedlings and saplings were modified based on studies of regeneration in natural forests [17, 37, 65]. Within tree species, individuals were separated into two categories: those below 130 cm in height were classified as seedlings [3] and; those ≥ 130 cm in height and below 5 cm DBH were saplings. The seedlings and saplings were sampled in 2 m x 20 m strips; various parameters, including total tree height and tree name, were recorded. The height pole meter was used to measure the total height of seedlings, saplings, and poles [17].

All trees with a DBH ≥ 10 cm [33, 55, 59] and poles with a DBH ≥ 5 cm and under 10 cm [65] were measured in a total of one hundred 20 m x 20 m sample plots. The botanical name of every living tree was identified in the field; the DBH was measured for the determination of tree basal area. Tree abundance per ha was calculated with the count of all tree individuals from 25 sample plots; the basal area of the trees was calculated by using the following equation: $BA = \pi r^2 = 3.142 \times (DBH/200)^2$, where BA = tree basal area (m^2) and r = radius (cm). The total basal area of one ha was calculated by the sum of the BA of all trees in the 25 subplots. The species richness was counted as the number of species occurring in all plots of each forest type [49].

The Shannon-Wiener index, the most commonly used index in ecological studies [21], was used for identifying areas of high natural biological diversity [56].

$H' = -\sum_{i=1}^{k}[(\frac{n_i}{N}) x \ ln(\frac{n_i}{N})]$ (1)	where, n_i = the number of individuals or amount of each species (the i^{th} species), and N = the total number of individuals (or amount) for the site.

Simpson's diversity index was obtained via following the formula (2) [35].

$D = \frac{\sum_{i=1}^{k} n_i(n_i-1)}{[N(N-1)]}$ (2)	where, n_i = the number of individuals of the "i^{th}" species, k = the number of species occurring in the sample area, and N = the total number of sampled individuals.

Similarity indices measure similarity between communities based on species composition [13]. The Evenness index or Pielou (J') (distribution of abundance among species) was determined according to Pielou (1966).

$E = J' = \frac{H'}{H_{max}} = \frac{H'}{ln\ (S)}$ (3)	where, H= the Shannon-Weaver diversity index, H'_{max} = ln (S), and S = the total number of observed species in the community.

To be able to compare tree abundance, basal area, species numbers, and species diversity among the different forest types, pair-wise comparisons were made per plot area of 400 m^2. A two sample t-Test for independent samples (Levene's test) was applied to compare the mean values mentioned above. All statistical analyses were performed with Statistica, Version 10.

3. Results

3.1. Tree abundance, species richness, and tree diversity

A general description of the four forest types is given in Table 1. The tree abundance of the UNLF was lower than that of the DNLF, which had the highest abundance (626 stems ha^{-1}) of all trees ≥ 10 cm DBH among the four forest types. The ULF held the lowest tree abundance (521 stems ha^{-1}). Based on the data collected in a 400 m^2 sample plot, there was a significant difference between the number of trees counted in one hectare among the selected study sites ($p < 0.05$); comparisons between the DLF and DNLF sites, as well as between the ULF and UNLF ($p > 0.05$), were the exceptions.

177 woody species were encountered in the four sites; of these, 57 were common across all sites, 28 were only found in the limestone sites, and 92 were only identified in the non-limestone forests. The number of tree species was considerably higher in the non-limestone sites (149) than in the forests over limestone (85). Out of all the species recorded in the two limestone forest sites, nine were restricted to the DLF and 22 to the ULF. The percentage of common tree species between the two non-limestone forest sites (42%) was smaller than between the limestone sites (64%). The highest number of tree species was recorded in the UNLF (114 species), but the greatest number of families (39) was identified in the DNLF. No significant differences in species richness were found between the DLF and ULF sites ($p > 0.05$). The same pattern was observed between the DNLF and UNLF sites; however, in paired comparisons, the limestone and non-limestone forest sites differed significantly ($p < 0.05$) in species richness.

Table 1. The tree abundance, species richness, and basal area of all stems with a DBH ≥ 10 cm (adults) in the four forest types in Ben En National Park, Vietnam.

Variables	Forest types			
	DLF	**ULF**	**DNLF**	**UNLF**
Tree abundance [n/ha]	592	521	626	526
Basal area [m^2/ha]	28.6	46.2	29.5	52.2
Species richness [n/ha]	63	76	97	114
Family richness [n/ha]	29	27	39	35
Evenness index or Pielou (J') [%]	77.5	82.0	80.0	87.2
Shannon-Wiener index (H')	3.21	3.55	3.66	4.13
Simpson's diversity index (D)	0.07	0.04	0.06	0.02

Table 2. Species number and tree abundance of 43 families in the four different sites in Ben En National Park, Vietnam.

Family	DLF		ULF		DNLF		UNLF		Total Abundance (n/ha)
	Abundance (n/ha)	Species (n/ha)	Abundance (n/ha)	Species (n/ha)	Abundance (n/ha)	Species (n/ha)	Abundance (n/ha)	Species (n/ha)	
Alangiaceae	-	-	-	-	10	1	2	1	12
Amaranthaceae	-	-	-	-	3	1	3	2	6
Anacardiaceae	13	4	7	4	5	1	5	4	30
Apocynaceae	12	2	7	2	47	2	16	2	82
Araliaceae	-	-	-	-	2	1	2	1	4
Bignoniaceae	2	1	1	1	2	2	5	2	10
Bombacaece	-	-	-	-	1	1	-	-	1
Burseraceae	5	2	-	-	24	3	16	4	45
Caesalpiniaceae	87	7	53	5	54	2	23	2	217
Clusiaceae	3	1	5	2	3	2	11	3	22
Dilleniaceae	3	1	2	1	-	-	2	2	7
Dipterocarpaceae	4	1	2	1	5	1	6	2	17
Ebenaceae	54	3	41	4	1	1	3	3	99
Elaeocarpaceae	1	1	-	-	1	1	2	1	4
Euphorbiaceae	103	3	52	5	27	6	7	4	189
Fabaceae	7	1	2	1	3	2	3	2	15
Fagaceae	48	3	59	5	28	6	56	9	191
Hypericaceae	4	1	3	1	2	1	-	-	9
Ixonanthaceae	-	-	-	-	1	1	-	-	1
Juglandaceae	1	1	-	-	2	2	-	-	3
Lamiaceae	-	-	-	-	1	1	-	-	1
Lauraceae	109	7	118	12	46	15	91	16	364
Lythraceae	-	-	-	-	5	2	3	1	8
Magnoliaceae	2	1	1	1	11	3	17	6	31
Meliaceae	17	6	35	5	12	5	30	9	94
Mimosaceae	-	-	-	-	-	-	1	1	1
Moraceae	30	1	26	3	43	6	19	9	118
Myristicaceae	1	1	3	2	5	2	7	2	16
Myrtaceae	6	2	8	2	13	4	25	4	52
Opiliaceae	1	1	2	2	-	-	3	1	6
Oxalidaceae	-	-	-	-	1	1	1	1	2
Rosaceae	-	-	-	-	1	1	2	1	3
Rubiaceae	-	-	2	2	1	1	-	-	3
Rutaceae	8	2	10	2	-	-	-	-	18
Sapindaceae	37	4	47	5	80	4	60	4	224
Sapotaceae	1	1	2	2	6	1	12	3	21
Simaroubaceae	-	-	-	-	1	1	-	-	1
Sterculiaceae	30	2	28	2	3	2	3	2	64
Symplocaceae	1	1	1	1	1	1	4	2	7
Theaceae	-	-	1	1	11	1	19	2	31
Tiliaceae	-	-	-	-	8	2	4	1	12
Ulmaceae	1	1	-	-	142	4	56	3	199
Verbenaceae	1	1	3	2	14	3	7	2	25
Total	**592**	**63**	**521**	**76**	**97**	**626**	**114**	**526**	**2265**

Statistically, significant differences in the Shannon-Weiner index and Simpson's diversity index were evidenced between the DLF and the two undisturbed forest types ($p < 0.05$); in contrast, there were no significant differences in these indices between the two limestone forest types and the DNLF ($p > 0.05$). It is clear that the species richness and Shannon-Wiener index observed in the ULF were lower than those of the DNLF. In contrast, the ULF had higher values in both the Evenness and Simpson's diversity indices than did the DNLF; these differences, however, were not statistically significant ($p > 0.05$). Among the four forest sites, the UNLF was the most complex in terms of species diversity, whereas the DLF was the simplest community in regards to species composition.

3.2. Tree species and family composition

Based on the number of individuals in each forest type, tree species were categorized as very rare (represented by a single individual), rare (from 2 to 10 stems), common (from 11 to 20 individuals), and dominant (greater than 20 stems) [38]. The "very rare" species varied but made up 30% - 40% of all the forest types. The lowest value of very rare species was recorded in the DLF and the highest in the ULF, while the two non-limestone forest types were each approximately 35%. The majority of species recorded in the DNLF were "rare" (53%), a number that was only 41% in the ULF. About 7% of the species found in the non-limestone forest sites were common, whereas this number was around 8% in the ULF and only 3% in the DLF. Nine species with more than 20 individuals were identified in the two limestone sites, whereas indicators of species richness demonstrated that only 4% and 5% of "dominant" species were found in the UNLF and DNLF sites, respectively.

Table 3. Tree abundance and species richness of poles in the four forest types in Ben En National Park, Vietnam.

Variables	Forest types			
	DLF	**ULF**	**DNLF**	**UNLF**
Tree abundance [n/ha]	143	110	172	31
Species richness [n/ha]	32	30	58	17
Family richness [n/ha]	20	13	28	11

Table 4. The 12 most abundant species of poles ranked in descending abundance collected in the four forest types in Ben En National Park, Vietnam.

Species	Family	The abundance of poles [n/ha]				Total counts
		DLF	UDLF	DNLF	UNLF	
Koilodepas longifolium	Euphorbiaceae	36	22	-	-	58
Diospyros pilosula	Ebenaceae	27	12	-	-	39
Wrightia laevis	Apocynaceae	1	-	19	5	25
Cinnamomum parthenoxylon	Lauraceae	6	3	7	2	18
Actinodaphne obovata	Lauraceae	5	11	-	-	16
Saraca dives	Caesalpiniaceae	8	7	-	-	15
Erythrophleum fordii	Caesalpiniaceae	-	-	12	1	13
Streblus ilicifolius	Moraceae	7	6	-	-	13
Mellettia lasiopetala	Fagaceae	3	3	2	4	12
Ficus vasculosa	Moraceae	-	-	11	1	12
Gironniera cuspidata	Ulmaceae	-	-	9	2	11
Cinnamomum mairei	Lauraceae	2	6	2	-	10

Table 5. The number of the stems, species, and families of the seedlings and saplings found in the four forest types in Ben En National Park, Vietnam. The largest values of seedlings and saplings are respectively represented by uppercase A and B, while the smallest values are given in lowercase a and b.

Forest site	Plots sampled [n]	Abundance [n/0.1 ha]	Species [n/0.1 ha]	Family [n/0.1 ha]
DLF				
Seedlings	25	87[a]	18[a]	11[a]
Saplings	25	211	35	19
Total		**298**	**38**	**19**
ULF				
Seedlings	25	127	27	13
Saplings	25	126[b]	27[b]	14[b]
Total		**253**	**32**	**14**
DNLF				
Seedlings	25	168[A]	39	18[A]
Saplings	25	169	45	22[B]
Total		**337**	**61**	**24**
UNLF				
Seedlings	25	111	41[A]	11[a]
Saplings	25	334[B]	67[B]	21
Total		**445**	**72**	**25**

Table 6. The 15 most dominant families of seedlings and saplings found in the four forest types in Ben En National Park, Vietnam, as ranked in descending tree abundance.

Families	DLF		ULF		DNLF		UNLF	
	Abundance [n/0.1 ha]	**Species** [n/0.1 ha]	**Abundance** [n/0.1 ha]	**Species** [n/0.1 ha]	**Abundance** [n/0.1 ha]	**Species** [n/0.1 ha]	**Abundance** [n/0.1 ha]	**Species** [n/0.1 ha]
Lauraceae	50	9	42	9	58	15	91	15
Ebenaceae	53	1	75	2	6	2	2	2
Sapindaceae	8	3	29	3	46	-	40	4
Caesalpiniaceae	49	3	6	2	36	4	15	1
Moraceae	61	2	28	1	8	2	6	3
Meliaceae	9	2	13	4	4	3	48	6
Myrtaceae	3	1	-	-	28	4	39	4
Euphorbiaceae	34	-	16	1	3	3	16	3
Ulmaceae	2	1	-	-	20	1	44	2
Burseraceae	5	3	11	3	12	3	18	4
Dipterocarpaceae	1	1	-	-	43	1	1	1
Theaceae	-	-	3	1	17	1	24	2
Apocynaceae	4	2	2	1	20	2	14	2
Fagaceae	5	2	5	2	7	4	20	5
Sterculiaceae	9	2	14	1	-	-	2	1

A total of the 43 families were identified in the park (Table 2), 21 of which occurred in all sites. With regard to the number of species found within families, ten families were represented by a single species (23% of the total family number) and five families had only one individual. About 40% (17) of the families were represented by two to three species, and 12 families were represented by more than four species. The most dominant families across all forest types were Caesalpiniaceae, Lauraceae, Sapindaceae, and Ulmaceae. Lauraceae was the most diverse family in all sites; a total of seven species were counted in the DLF, 12 in the ULF, 15 in the DNLF, and 16 in the UNLF. Several families (such as Alangiaceae, Araliaceae, Bombacaece, Lythraceae, and Tiliaceae) were absent in the limestone forests; Rutaceae's two species were found *only* in the limestone sites. Species belonging to Caesalpiniaceae had five to seven individuals, but the family was dominant in the limestone sites; only two Caesalpiniaceae species were sampled in the non-limestone sites.

3.3. The abundance and species richness of poles

The highest abundance of poles was found in the DNLF site (172 stems ha^{-1}), whereas the lowest abundance was found in the UNLF site (Table 3). Pair-wise comparisons revealed that there were significant differences in the abundance of poles between the DNLF and two other forest sites (ULF and UNLF) ($p < 0.05$); however, the total number of tree poles did not differ significantly between the DNLF and DLF sites, or between the two limestone forest sites (DLF and ULF) ($p > 0.05$). The species number of poles was lowest in the UNLF site, while the DNLF site held the greatest species richness; a similar trend was apparent at the same sites for the number of families. Pair-wise comparisons showed significant differences in the species number of poles among the four forest sites ($p < 0.05$), with the exception of the DLF and ULF sites ($p > 0.05$).

92 species were found as poles in the four forest sites, the 12 most dominant of which are given in Table 4. Of these 92 species, 43 were recorded in the forest over limestone sites and 65 were identified in the non-limestone forests. 16 species accounting for 17% of the total species were common to all four forest sites and 76 species (83%) occurred in any one of the four sites. Out of these 76 species, 27 were restricted to the DLF and UDLF, and 49 only appeared in the DNLF and UNLF.

The species with the greatest number of individuals was *Koilodepas longifolium* with 58 individuals, followed by *Diospyros pilosula* (39 stems), and *Wrightia laevis* (25). Of these species, the first two were restricted to the two limestone forest sites (DLF and UDLF), whereas the third was most dominant in the two non-limestone forest sites (DNLF and UNLF) but absent from the UDLF site. In the DLF, 19 out of 32 species were represented by only one or two individuals; in the UDLF, such rare occurrences were similarly made by 17 out of 30 species. The DNLF had only one or two individuals for 37 out of the 58 recorded species, and 14 out of 17 species were similarly infrequent in the UNLF.

3.4. The abundance and species/family richness of seedlings and saplings

Descriptions of the tree abundances of seedlings and saplings, as well as the species and families sampled in the four forest sites, are listed in Table 5. The highest abundance of seedlings was found in the DNLF site, whereas the abundance of saplings was greatest in the UNLF. Across all sites, the abundance of saplings was higher than that of seedlings, with the exception of in the ULF site. At the plot level, pair-wise comparisons indicated that a significantly higher tree abundance of saplings was recorded in the UNLF as compared to the three remaining forest sites ($p < 0.05$). However, no statistically significant differences in seedling abundance were observed among the four forest types ($p > 0.05$).

The species richness was higher in the two non-limestone forest types as opposed to their limestone counterparts. The species number of seedlings and saplings was highest in the UNLF, while the DLF and UNLF types held the lowest species richness of seedlings. The identified saplings were lowest in comparison with the two remaining sites (DNLF and UNLF). Although the seedling species richness was higher in the two non-limestone forest sites than in the two limestone ones, the differences were not statistically significant ($p > 0.05$); only a single pair (between the DLF and DNLF) was statistically different ($p < 0.05$).

A total of 31 tree families of seedlings and saplings were recorded in the four forest sites. Most families (Lauraceae, Burseraceae, and Sapindaceae) were common to all the forest sites, but a full third (Amaranthaceae, Elaeocarpaceae, and Magnoliaceae) occurred only in the non-limestone forests (Table 6). Two families (Anacardiaceae and Sterculiaceae) were reversed in that, they were recorded in the limestone forest sites, but were absent from the non-limestone ones. Of all the families investigated, Lauraceae was the most diverse family; as such, it was recorded in all forest sites and had the highest number of species (26). Both the DLF and ULF contained nine Lauraceae species each, with the other 15 species being found in the DNLF and UNLF types. In terms of tree abundance, across all sites, 11 out of 31 families were represented by a single species, and only six had a species number greater than five.

4. Discussion

4.1. A comparison of forest structure and tree diversity in the disturbed/undisturbed tropical limestone and non-limestone forests

The lowest abundance was recorded in the ULF, the highest in the DNLF. This variation in tree abundance directly correlates to topographic factors such as elevation, slope, aspect, and richness [29]; tree abundance can likewise be affected by natural and anthropogenic disturbances or soil conditions [52]. In various soil types, differences in tree abundance may be explained by differences in canopy height [26] and human interference, both past and present [44]. In the disturbed forest sites, selective logging 30 years ago has resulted in gaps in the canopy layer, meaning that seedlings and the seed banks of pioneer trees have a favorable chance to grow up and contribute to the overall tree abundance, particularly in the lowest diameter class [44].

In comparison with the limestone forest, the non-limestone forest in this study displayed slightly higher diversity values. The total number of tree species counted in the two limestone forest sites (85) was lower than in their non-limestone counterparts (149), an observation that agreed with those of other authors. Cao and Zhang's 1997 research on the tree species diversity of four tropical forest vegetation types in Xishuangbanna, Southwestern China, for example, found that the tropical seasonal rain forest showed the highest tree species diversity of all four vegetation types, and the lowest was found in the monsoon forest over limestone. The low tree species diversity in the limestone forest and the accompanying differences in species composition between the limestone and non-limestone forests in the present study may be explained by the extremely harsh microenvironment present, in which a number of large limestone rocks covered the ground, resulting in shallow soil [9]. Soil depth and fertility may have resulted in the differences in tree species diversity between Xishuangbanna forests [62], but species richness was inversely related to the total exchangeable bases in Ghanaian forests [19]. The influence of the climatic regime and topography on the species composition also partially explained the floristic categories of Caribbean and neotropical limestone forests [66]. It can thus be concluded that species richness depends on various factors that may interact in different situations [47].

In regard to disturbances, the species richness identified in the undisturbed forest sites (145 species) was greater than in the disturbed sites (124). Nath et al. (2005) also concluded that tree species richness in Namdapha National Park, Northeast India decreased with the increasing intensity of disturbance. Further studies indicated that the species richness was lowest (16 species ha^{-1}) in the highly disturbed stand, and a larger number of tree species were recorded in the undisturbed site (47 species ha^{-1}) of a tropical wet evergreen forest in Arunachal Pradesh, Eastern Himalayas, India [5]; in the Kolli Hills, Eastern Ghats, India [11]; and in an evergreen lowland rainforest in Western Ghats, India [45]. The variation in species richness and composition between undisturbed and disturbed forests could be explained by elevation and bioclimatic/edaphic factors [4], as selective logging results in a sharp decrease in the total number of tree species in an area unit directly after the disturbance [17]. Species diversity was further affected by the levels of selective felling of trees [41], and as such greatly declined from the undisturbed to the disturbed sites [8, 50].

In the present study, results showed that Lauraceae and Fagaceae (21 and 10 species, respectively) were the most species-rich families in the non-limestone forests, while Lauraceae and Caesalpiniaceae were the most important in the limestone forests. Lauraceae was the most important family in terms of the highest tree abundance and species richness; its species abundance has been reported by several other studies, including in a tropical wet evergreen forest in South Western Ghats, India [44]; Cat Tien National Park, Vietnam [6]; a rainforest in Brunei [57]; and in tropical rainforests in Xishuangbanna, China [33]. The present study found that a high proportion of species consisting of one individual was recorded in the two limestone sites, while the number of diverse families composed of more than four species was rather low. The same result was observed in a limestone forest at three different elevations in Sarawak, Malaysia [1].

4.2. The abundance, composition, and species richness of regenerated trees

Seedling abundance varies significantly among species [64], with results indicating that most species had a low abundance of tree seedlings, saplings, and poles. 21 species as seedlings/saplings and 35 species as poles had only a single individual, and most of the investigated species lacked individuals entirely at one or more of the three regeneration categories. This was consistent with other studies conducted in different forest types, such as in the logged and unlogged forest stands of a moist evergreen forest in Kibale National Park, Uganda [10], in Barro Colorado Nature Monumen, Panama [14], and in the Harenna tropical forest on the southern slopes of the Bale Mountains, Ethiopia [63].

The present study found a higher abundance of seedlings but a lower abundance of saplings in the disturbed rather than undisturbed forest. Significant differences in the abundance of saplings and poles among the four forest types were discovered; however, no significant differences in seedling abundance were observed among the four sites. These results were in agreement with Chapman and Chapman's 1997 findings from Kibale National Park, Uganda where there were no differences in the abundance of seedlings between the logged and unlogged forests. Furthermore, the number of seedlings was greater in the logged forest than in the unlogged one; however, sapling abundance was lower in the heavily logged areas. Bhuyan et al. (2003) also confirmed that the abundance of saplings was very poor in highly disturbed stands but high in the undisturbed areas. The differences in tree abundance in the four forest types in this study could be attributed to the degree of disturbance experienced over the years [43, 5]. In addition, the abundance of seedlings is usually influenced by the densities of the surrounding large trees, some of which are mother trees [15]; other processes affecting seed and seedling production were predation, dispersal, and dormancy [27, 28]. In the present study, the absence of saplings and poles as commercial trees could be partially attributed to past logging (both legal and illegal) or other domestic uses by the local people.

Overall, 133 species representing 37 families of saplings, seedlings, and poles were recorded across the surveyed study sites. The observed differences in the species richness of regeneration among the four forest sites showed a higher observed species number in the two disturbed forest sites than in their undisturbed counterparts. The former contained 36 families represented by 106 species, while only 96 species belonging to 26 families were identified in the latter. It is important to highlight that these results were in accordance with a study undertaken in Huong Son forest, Vietnam [65]. Our study indicated that there were no significant differences in the species richness of seedlings in the four forest types, a finding that was consistent with Chapman and Chapman's 1997 study in Kibale National Park, Uganda in which they found no differences in the species richness of seedlings between logged and unlogged forests. In contrast with our results, Bhuyan et al. (2003) investigated the tree species richness of regeneration along the disturbance gradient of different stands in a tropical wet evergreen forest in Arunachal Pradesh, Eastern Himalayas, India. There, about 55% of species were found to be regenerating in the undisturbed stands; the mildly disturbed stands showed the highest species richness (37 species), whereas no regeneration was recorded in the highly disturbed stands.

5. Conclusions

Detailed information on the forest structure and species diversity of the four forest sites as well as the effects of selective logging on stand structure is fundamental for site management and conservation. Out findings suggest that selective logging has a minor effect on forest structure and tree species composition; more study, however, is needed to clarify trends, especially on canopy structure, plant regeneration, and seed banks. Long-term studies or permanent plots established in unlogged and logged forest stands from different sites are therefore, essential to monitoring forest growth dynamics in the strictly protected and ecological restoration zones in the park. Enrichment planting for species with low densities or broken population structures in the disturbed forests is required; assisted natural regeneration will also accelerate the recovery process. Further studies should examine the relationship between environmental factors and tree species composition as well their distribution. Patterns of experimental designs and long-term monitoring data should be generated. All silvicultural interventions should be preceded by reducing the anthropogenic disturbances of local people, e.g., illegal logging, fuel wood collection, or collecting NTFPs. Most importantly, stakeholders at all levels must be involved in designing and implementing solutions for the conservation of this resource.

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