Research paper

Tree diversity and species composition of tropical dry forests in Vietnam's Central Highlands Region

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Abstract. Tree species inventories, particularly of poorly known dry forests, are necessary to protect and restore them in degraded landscapes. The present research has been conducted to compare taxonomic diversity and community composition in four dry forests (DF) categories with different standing volume levels: very low (DFV), low (DFP), medium (DFM) and high (DFR). This quantitative assessment of taxonomic diversity, forest structure and species composition were obtained from 103 sample plots (0.1 ha each). The regeneration potential of trees was assessed in 515 subplots (4 m × 4 m) located within the 103 plots. A total of 1,072 trees representing 87 species belonging to 37 families were recorded in 10.3 ha of total sampled area. The ranges of diversity indices observed in the four forest types were: Margalef's (5.44–8.43), Shannon-Wiener (1.80–2.29), Simpson diversity (0.76–0.87) and evenness (0.32–0.35). The regeneration potential of rare and threatened species *Dalbergia oliveri, Hopea recopei, Dalbergia bariensis, Sindora siamensis, Parashorea stellata* was observed to be poor. Conversely, *Cratoxylon formosum, Shorea obtusa, Dipterocarpus tuberculatus, Dipterocarpus obtusifolius, Terminalia alata, Shorea siamensis and Xylia xylocarpa* were the most dominant species at the seedling and sapling stage, showing a strong potential for regeneration. Overall, this study provides useful information on tree species diversity and composition for tropical dry forests which can be used as baseline data to develop incoming plans for forest management and conservation in Vietnam's Central Highlands Region.

Key words: tropical dry forests of Vietnam, species composition, tree diversity, tree regeneration, forest type.

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Introduction

A plant community is a collection or association of plant species within a specific location, which forms a relatively uniform patch, distinguishable from neighbouring patches of different forest types (Singh *et al*., 2016). Plant community descriptions provide information regarding the status of tree population, regeneration, diversity, habitat and associated species (Malik & Bhatt, 2015). The knowledge of plant community provides a common framework for ecologists, foresters, environmental planners, and others to use in a variety of ways, including vegetation mapping, ecological restoration, environmental planning, planning and implementation of the conservation strategy of the community (Rahman *et al*., 2011; Bhatta & Devkota, 2020).

Although the tropical dry forests (DF) of Vietnam have been disturbed by humans for years, they still cover approximately 650,000 ha of the country's land surface (Huy *et al*., 2016, 2018, 2019). DF are a unique and valuable forest type in need of better consideration in global, regional and local strategies for biodiversity conservation (Wohlfart *et al*., 2014), because they provide a number of ecological services which are essential for different communities in the ecosystem, such as species conservation, water and air regulation, carbon and nutrient cycling, prevention of soil erosion and preservation of habitats for many endemic animals (Rabha, 2014; Nguyen & Baker, 2016; Deb *et al*., 2017; Bhatta & Devkota, 2020; Sharma *et al*., 2020). However, the economic and human pressure experienced have resulted in DF to become one of the most deforested and least protected ecosystems in tropical Vietnam (Nguyen & Baker, 2016). DF of Vietnam's Central Highlands Region are located in areas with good or excellent conditions for agricultural practices, which results in conversions of these forests into industrial crops such as rubber, coffee, pepper, cashew and acacia species. However, this conversion also leads to changes of species composition, forest structure and the destruction of natural habitats for native species. (Nguyen & Baker, 2016; Huy *et al*., 2019). Moreover, natural disturbances such as forest fires are also an important abiotic factor that causes changes in the vegetation cover of DF, and it tends to have higher occurrence during the dry season (Huy *et al*., 2019). Due to high rates of deforestation and restricted and fragmented distribution of remaining DF covered areas, these ecosystems are considered the most threatened in Vietnam. Deb *et al*. (2017) has predicted that the suitable area for the tree species *Shorea robusta* C.F. Gaertn. and *Dipterocarpus turbinatus* C.F. Gaertn., which are important components of dipterocarp forests of Continental South and North Southeast Asia, will decline from 17% to 34% by 2070 under global climate change. Hence, there is the necessity for more specific information about DF, including the composition, growth patterns, dominance, abundance and distribution of tree species. This information can be used to justify and express the need for developing and strengthening the protection and restoration measures of natural habitats, which in turn, would enhance biodiversity and productivity to directly benefit the communities depending on the resources of these forests (Das *et al*., 2018). However, the structural dynamics and tree species diversity of DF are inadequate and lack consistent research (Gopalakrishna *et al*., 2015). Most of the research on DF dynamics has been carried out in continental South and Southeast Asia, particularly in India, Bangladesh, Thailand, Nepal and Indonesia (Wanthongchai *et al*., 2014; Manuri *et al*., 2016; Das *et al*., 2018; Lal *et al*., 2019; Bhatta & Devkota, 2020), and very few in tropical Vietnam (Do *et al*., 2017). DF researchers in Vietnam have primarily focused on developing growth models, allometric equations, to estimate forest biomass and silvicultural studies (Luong *et al*., 2015; Huy *et al*., 2016, 2018, 2019).

Despite tropical dry forest communities of Vietnam are of outstanding relevance concerning biodiversity levels, international scientific literature on the characterisation of vegetation communities is clearly in lack of research (Do *et al.*, 2017), with only a few exceptions, such as the ones carried out by Nguyen & Baker (2016) and that of Do *et al.* (2017). However, these studies only focused on the characterisation of vegetation communities at small spatial scales, and they lack information about the regeneration potential of tree species. In fact, the structure and vegetation diversity of each plant community is influenced by soil type, topography, climate and human disturbance (Das *et al.*, 2018; Khaine *et al.*, 2018). Furthermore, it is important to record the most important plant species of the region in relation to other factors that may affect the diversity, structure and species composition of this particular forest type. Therefore, in order to address this research gap, we conducted the present work to evaluate the changes in tree species composition, diversity and community structure in four DF types with different standing volume levels from Vietnam's Central Highlands Region in relation to human disturbances.

Study area and Methods

Study sites

The study area is situated in the Central Highlands, which is one of the eight agroecological regions of Vietnam. It is located between the north latitude 12°45′N–13°20′N and east longitude 107°30′E–108°30′E. This region has an average altitude of 500–600 m.a.s.l., with a hot and humid equatorial climate during the entire year. The area has a unimodal rainfall regime of up to 1600 mm of mean annual rainfall, considering the period of interest from 2004 to 2020. The longer dry season stretches from November to April. The mean annual temperature is about 25.5˚C, while 12.4˚C and 28.3˚C are the minimum and maximum temperatures, respectively (Huy *et al.*, 2019). The study area considered is characterized by igneous rock parent material. Based on the FAO soil classification, there are four soil types in the study sites: chromic luvisols, pelvic vertisols, orthic luvisols and eurtic nitisols. The major forest type in the study area is a mixed dipterocarp forest that is distributed primarily on a soil type of igneous rocks.

Field methods

The classification of the Forest Inventory and Planning Institute of Vietnam for tropical dry forests is based on their different standing volume levels. For instance, rich dry forests (DFR) comprise standing woody volume levels of > 200 m^3 ha^{-1}, the medium dry forest (DFM) of 101–200 m^3 ha^{-1}, the poor dry forest (DFP) of 51–100 m^3 ha^{-1} and the very poor dry forest (DFV) of 10–50 m^3 ha^{-1}, respectively. This is how the four different explored DF types were classified in this study.

For the data collection of tree species, a total of 103 quadrats of 0.1 ha each (31.63 m × 31.63 m) were laid randomly as follows: 10 plots in DFR, 19 in DFM, 25 in EBP and 45 in DFV, respectively (Figure 1). Within each sample plot several variables were measured for all trees ≥ 5 cm in diameter, including species name, diameter at breast height (*DBH*, in cm) and tree height (*H*, in m). Tree height was measured using the Häglof Vertex Hypsometer, while DBH was measured using a diameter tape. The volume (V) of each individual stem was calculated as follows:

$$G \times H \times f, \quad (1)$$

where G is stem basal area ($G = \frac{3}{4} DBH^2 \times 0.0001$), H is stem height and f is the form factor parameter, which is equal to 0.4826 (Hinh, 2012). Total standing volume was then calculated as the sum of all trunk volumes present within the sampled quadrats. The individuals that were recorded within the quadrats were identified to species-level according to the regional flora dataset (Ban *et al.*, 2007; Ho,

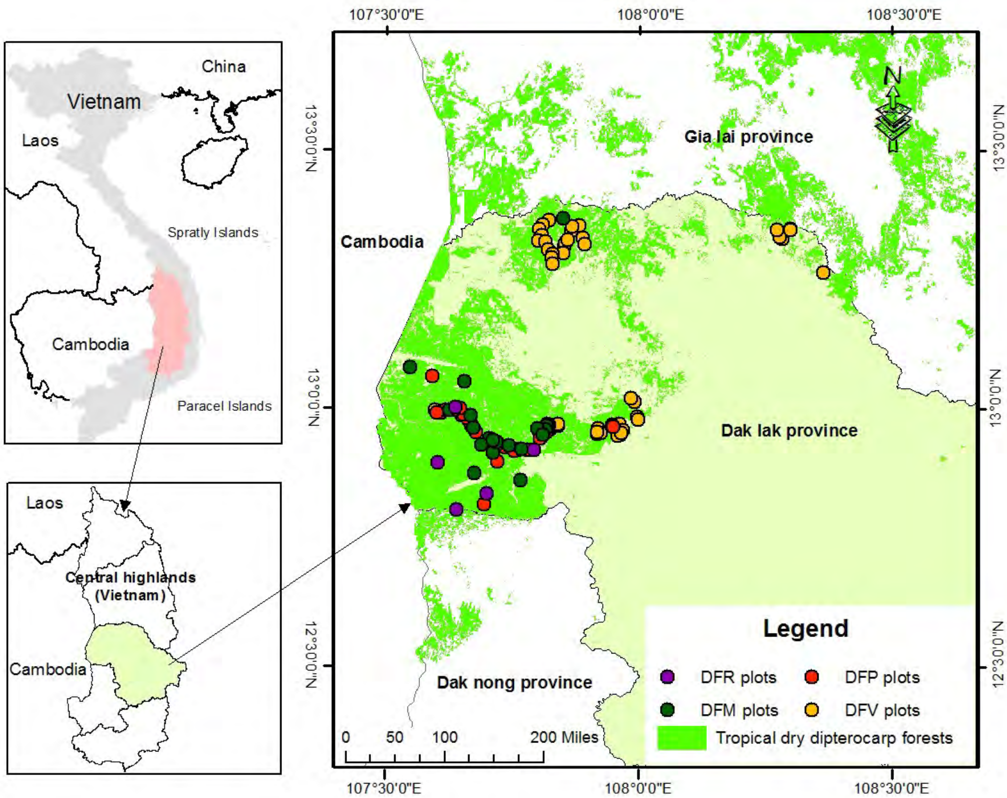

Figure 1. Geographic location of the study area. The upper left panel shows the location of Vietnam's Central Highlands Region (pink colour); the lower left panel shows the location of the study area (light green colour) and the right panel shows the vegetation cover of tropical dry dipterocarp forests (fluorescent green colour) and the distribution of sampled plots for the four different dry forest (DF) types.

2003). The individual stems that could not be identified in the field were taken to the National University of Forestry of Vietnam for identification and verification of their species name.

For the seedling and sapling survey (i.e., individuals with height > 30 cm and DBH < 5 cm), five subsample plots of 4 m × 4 m, i.e., each of 16 m^2, were laid out in four corners and in the centre of the sampled plot (31.63 m × 31.63 m). Therefore, a total of 515 plots covering 0.824 ha were used for the seedling and sapling survey.

Data analysis

The data were analysed to quantify tree species diversity, composition, density, and forest structure across the four DF types. The importance value index (IVI) was used to assess the distribution of species abundance. It was computed as a sum of relative density, relative frequency, and relative basal area. The IVIi for species and *i* in each forest type was calculated as (Curtis & McIntosh, 1951):

$$IVIi = (RF_i+Rd_i+RBA_i), \qquad (2)$$

where RF_i (relative frequency of species i) was calculated as:

$$RF_i=100\times F_i/TF, \qquad (3)$$

where F_i is the number of plots (frequency) in which species i is present, and TF is the sum of all frequencies for all species.

Rd_i (relative density of species i) was calculated as:

$$Rd_i = 100 \times d_i / Td, \tag{4}$$

where d_i is the total number of stems of species i, and Td is the total number of stems of all species.

RBA_i (relative basal area of species i) was calculated as:

$$RBA_i = 100 \times BA_i / TBA, \tag{5}$$

where BA_i is the total basal area of species i, and TBA is the total basal area of all species.

The quantitative tree species diversity indicators that were used in this study include:

Margalef's Index (Margalef, 1958):

$$R = (S-1)/Log(N). \tag{6}$$

Diversity Index (Shannon, 1948):

$$H' = -\sum_{i=1}^{s} p_i ln p_i . \tag{7}$$

Dominance Index (Simpson, 1949):

$$D = 1 - \sum (p_i)^2. \tag{8}$$

Equitability Index (Pielou, 1969):

$$E = H'/H'_{max}, \tag{9}$$

where N = total number of individuals, $p_i = n_i / N$ (ni = number of individuals of a species, N = total number of individuals of all the species).

Species rank distribution curves were also used to determine the relative importance of tree species in terms of diversity (Matthews & Whittaker, 2015) in the four forest types. Further, species similarity among different regions was computed using Jaccard's Coefficient of Similarity (Jaccard, 1912). The value of the coefficient varies between 0 and 100%, where 100 means the two sites have the same composition (they share the same number of species), and 0 means the two sites do not share any species.

Tree population structure was analysed using different DBH size class distributions across the four types of forest. To improve the visualization and comparison of tree diameter distribution among the four forest types, the individual stems recorded in each forest type were classified into fourteen different DBH classes with 5 cm interval between one another.

Due to lack of normality and homogeneity of variance, Kruskal–Wallis tests were used to determine significant differences between the forest types. Post hoc pairwise multiple comparisons were performed using Wilcoxon rank sum test. Finally, we performed Chi square tests to determine significant differences between tree diameter distributions for the four forest types. All significant differences reported here refer to $p < 0.05$, if not stated otherwise. R statistical software was used for all statistical analyses (R Core Team, 2017).

Results

Vegetation characteristics

Figure 2 shows a 'collector's curve' of woody species densities plotted as a function of the number of sites enumerated. Cumulative densities of species substantially increased with each additional plot enumerated.

However, the rate of increase diminished with increasing numbers of plots after the seventh site. The 'collector's curve' flattened out as more woody species specimens were enumerated.

A total of 4914 trees belonging to 87 species from 37 families were recorded within a sampled area of 10.3 ha (103 plots). Of the total recorded individuals, 32 species (19 families) were found in DF rich forest, 54 species (30 families) were found in DF medium forest, 52 species (28 families) were found in DF poor forest, and 66 species (30 families) were found in DFV.

Across the four forest types studied, we found 15 rare and threatened species

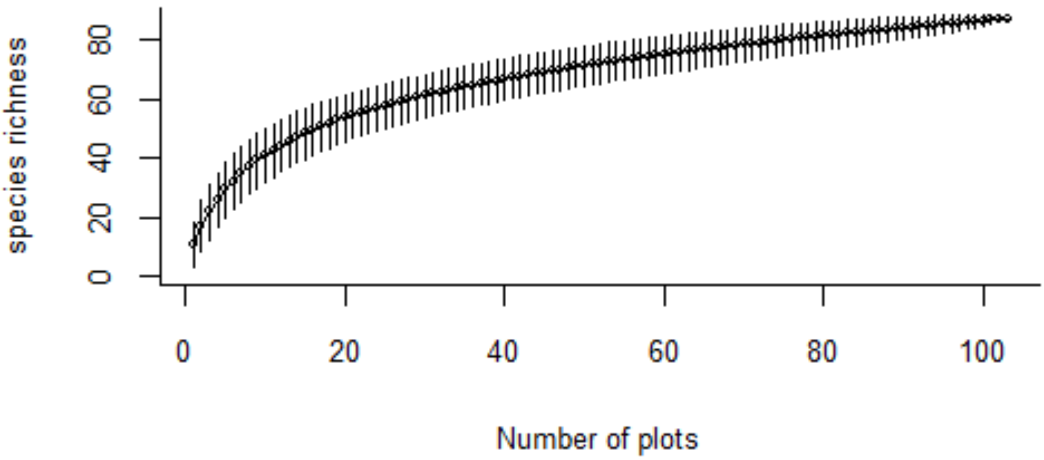

Figure 2. Tree species-area curve between species richness and the 103 main plots that were sampled within a total of 10.3 ha of natural forest in Vietnam's Central Highlands Region.

listed on the International Union for Conservation of Nature (IUCN) Red List (Supplementary Table S1), ranging from Near Threatened (NT) to Endangered (EN). The communities with the highest number of rare and threatened species were DF medium forest and DF very poor forest.

The five most abundant families were Dipterocarpaceae (n = 2953), Combretaceae (414), Fabaceae (254), Phyllanthaceae (230) and Leguminosae (158) and their most dominant species in each family were *Shorea roxburghii* G. Don (n = 868), *Terminalia calamansanai* (Blanco) Rolfe (231), *Xylia xylocarpa* Roxb. (222), *Aporosa villosa* (Lindl.) Baill. (210), *Dalbergia bariensis* Pierre (69), respectively (Supplementary Table S2). 24 species (27.59% of the total number of species) were common to all four forest types. Two (2.3%) species, including *Terminalia catappa* L. and *Artocarpus lakoocha* Roxb., were exclusively found in DF rich forest; 8 (9.2%) species, including *Engelhardtia roxburghiana* Wallich, *Parashorea stellata* Kurz, etc., were only found in DF medium forest; 6 (6.9%) species, including *Mallotus philippinensis* (Lam.) Müll.Arg., *Engelhardtia chrysolepis* Hance, etc., were only found in DF poor forest, while 17 (19.54%) species, including *Litsea cambodiana* Lecomte, *Garcinia oblongifolia* Champ. ex Benth., etc., were only found in DF very poor forest.

Basal area ranged from 5.74 m^2 ha^{-1} (DFV) to 23.7 m^2 ha^{-1} (DFR) while stem density ranged from 431.05 stems ha^{-1} (DFM) to 562.40 stems ha^{-1} (DFP) (Figure 2). DFR had significantly higher species richness, family richness, basal area, mean diameter and mean height than DFP and DFV. There were no significant differences between DFR and DFM, except for species richness and basal area which were significantly higher in DFR than in DFM. Similarly, no significant differences in stem density were observed among forest types (Figure 3).

Species abundance

Species rank abundance distribution curves show a similar pattern with inverted J-shaped species distributions with relatively flatter curves with high species richness and evenness for the four forest types. All of them had 5–10 species with high richness (larger distance between two adjacent species). *Shorea obtusa* Wall. ex Blume, *Shorea siamensis* Miq. and *Xylia xylocarpa* had high species richness in the four forest types. Similarly, *Dipterocarpus tuberculatus* Roxb., *Dipterocarpus obtusifolius* Teysm. ex Miq. and *Shorea roxburghii* had the highest species richness in DFM, DFP and DFV, re-

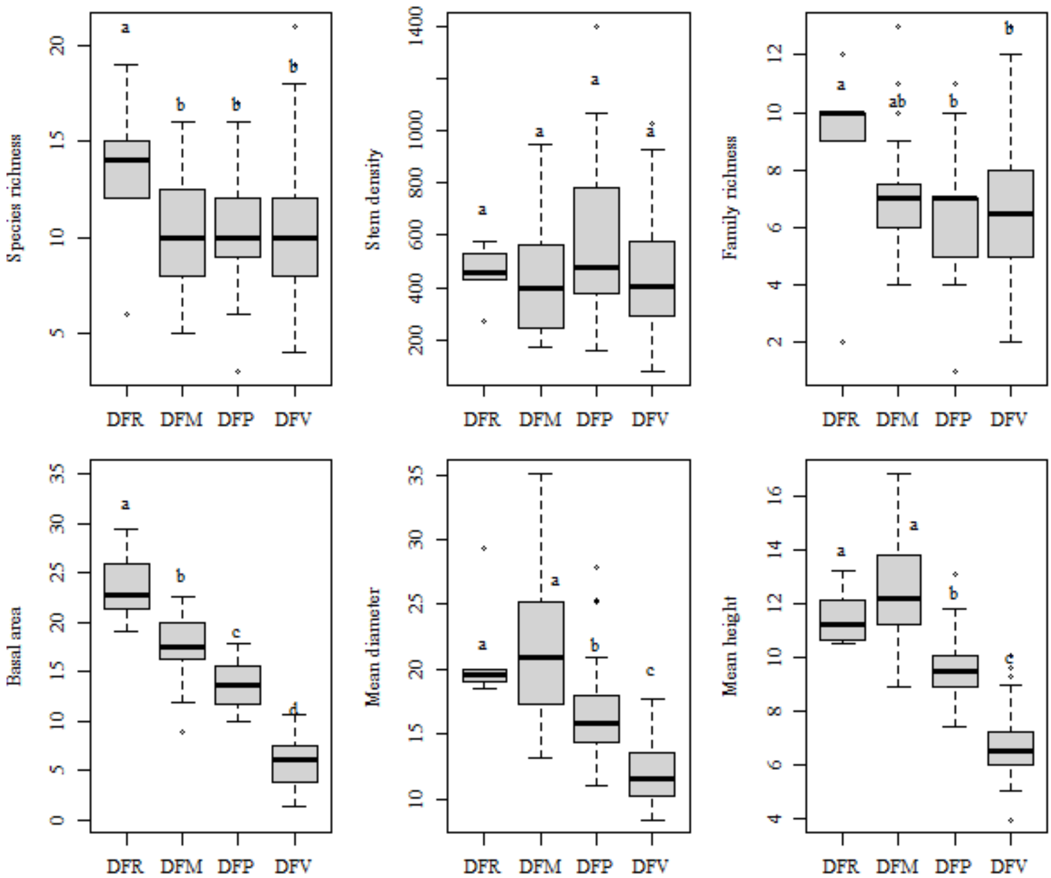

Figure 3. Species richness (number of species per plot); stem density (number of individual stems per plot); family richness (number of families per plot); basal area (sum of basal area per plot); mean diameter (mean diameter per plot); mean height (mean height per plot) for the four dry forest (DF) types studied.

spectively (Figure 4).

Analysis of the Jaccard's Coefficient of Similarity showed that all the DF types in the Central Highlands of Vietnam have an average similarity of more than 49% in terms of tree species presence. DFM and DFP shared the maximum similarity of 59.09% followed by DFP and DFV (58.11%) respectively. However, the lowest similarity (36.11%) in tree species occurrence was observed between DFR and DFV (Table 1).

Table 1. Similarity Index (J') matrix between four dry forest (DF) types in Vietnam's Central Highlands Region.

Forest types	DFR	DFM	DFP	DFV
DFR		45.76%	43.10%	36.11%
DFM			59.09%	53.85%
DFP				58.11%
DFV				

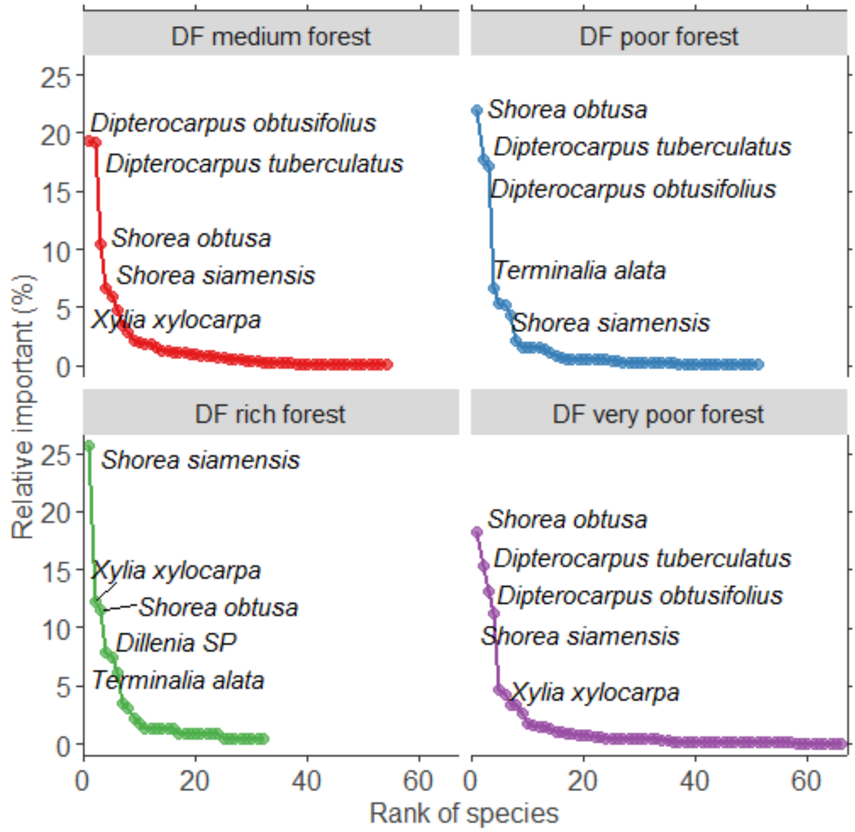

Figure 4. Relationship between species relative importance and species rank in abundance for the top 5 tree species recorded in the four dry forest (DF) types studied.

Relative Importance value index (IVI) of the species

As in other tropical dry dipterocarp forests of Vietnam, *Shorea siamensis*, *Shorea obtusa*, *Dipterocarpus tuberculatus*, *Dipterocarpus obtusifolius* were found to be predominant (Figure 5). Out of 87 tree species, the IVI of the 10 dominant tree species contributed to 225.42%, 201.76%, 224.28% and 201.42 % of the total IVI values in the DFR, DFM, DFP and DFV, respectively (Supplementary Table S2). *Shorea obtusa* had the highest IVI in DFP and DFV, while *Shorea siamensis* and *Dipterocarpus tuberculatus* were DFR and DFM, respectively.

Tree diversity across forest types

Generally, the diversity of the four forest types is at a moderate level with the index of 1 < H' < 3 (Table 2). DFR had a higher species richness (R), species diversity (H') and dominance (D) than other vegetation types (p < 0.05). However, no significant differences in the evenness index (E) were observed between any forest types (p = 0.6838).

Tree diameter distributions

In the tropical dry dipterocarp forests of the region, the density of individual tree species decreased with increasing tree size. The average number of individual trees in 0.1 ha plots was 47.71 ± 24.92 (ranging from 15 to 140 individuals). The maximum density of trees per unit area was 410.38 stems ha^{-1} and it was observed in the DBH class of 5–25 cm, which contributed to 86.02% of the total tree population (Figure 6). About 15.7% of the trees in the sampled plots were included in the

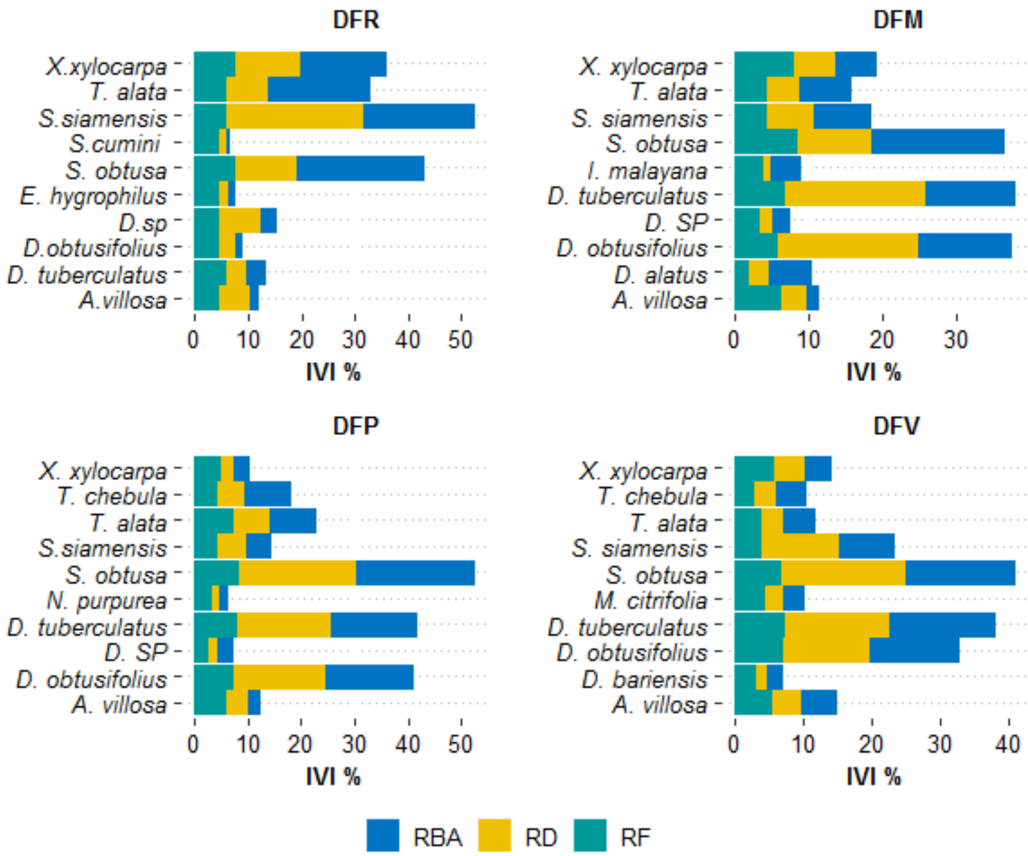

Figure 5. Top ten tree species and their contribution based on their importance value index (IVI), in terms of relative basal area (RBA), relative density (RD) and relative frequency (RF) for the four dry forest (DF) types studied in Vietnam's Central Highlands Region.

Table 2. Consolidated details of tree diversity in four types of tropical dry dipterocarp forests in Vietnam's Central Highland Region.

Forest types	Margalef's Index (R)	Shannon-Wiener diversity (H')	Simpson Index (D)	Evenness Index (E)
DFR	8.43±1.03^{a}	2.29±0.16^{a}	0.87±0.02^{a}	0.32±0.02^{a}
DFM	5.90 ±1.62^{b}	1.85±0.38^{b}	0.78±0.12^{b}	0.34±0.04^{a}
DFP	5.44±1.80^{b}	1.80±0.32^{b}	0.77±0.08^{b}	0.35±0.07^{a}
DFV	5.88±2.00^{b}	1.81±0.37^{b}	0.76±0.11^{b}	0.34±0.06^{a}
Kruskal-Wallis chi-squared	10.553	10.572	9.9064	1.4935
p-value	0.0144	0.01428	0.01938	0.6838

Note: Different letters (a, b) within the same column denote significant differences among indices (p<0.05). All variables were computed for all stems ≥5 cm of diameter.

5–10 cm diameter class, while the 10–15 cm class accounted for 34.3%. The highest tree stand density and species richness were found in these two diameter ranges, which accounted for 49.9% of enumerated trees. The above 15 cm of DBH classes contributed 50.1% to the total number of sampled trees. In other words, there was a normal population structure or 'inverted J-shaped' distribution of diameters in four forest types. This type of tree population structure implies good reproduction but hinders recruitment capacity (Angessa *et al*., 2020). However, there were substantial (*Chi Square test*, $p < 0.05$) variations in size class distribution of the individuals across the different management zones. In DFV, distribution of DBH classes was from 5–45 cm, while large trees DBH > 45 cm of DFR, DFM and DFP were 42, 21 and 9 stem ha^{-1}, respectively. Especially, the average stand basal area of trees with DBH ≥ 70 cm was much higher than the basal area occupied by trees of the two preceding DBH classes (75–85 cm and 85–95 cm DBH) despite their lower population size in DFR.

Tree regeneration

Among the four types of tropical dry dipterocarp forests, the best tree regeneration was observed in DFV with 21,734 seedlings and saplings per hectare. The number of seedlings and saplings was the lowest (6,825 individuals) in the sampled areas of DFR. Adequate regeneration of trees was noticed in DFM (13,829 individuals) and DFP (13,095 individuals) as compared to the other forest types under study. The regeneration status of species like *Cratoxylon formosum* (Jacq.) Benth. & Hook.f. ex Dyer, *Shorea obtusa*, *Dillenia* sp., *Dipterocarpus tuberculatus*, *Dipterocarpus obtusifolius*, *Terminalia alata* B. Heyne ex Roth, *Shorea siamensis* and *Xylia xylocarpa* on the forest floor is better than other species. *Shorea obtusa*, with 2,898 individuals per hectare

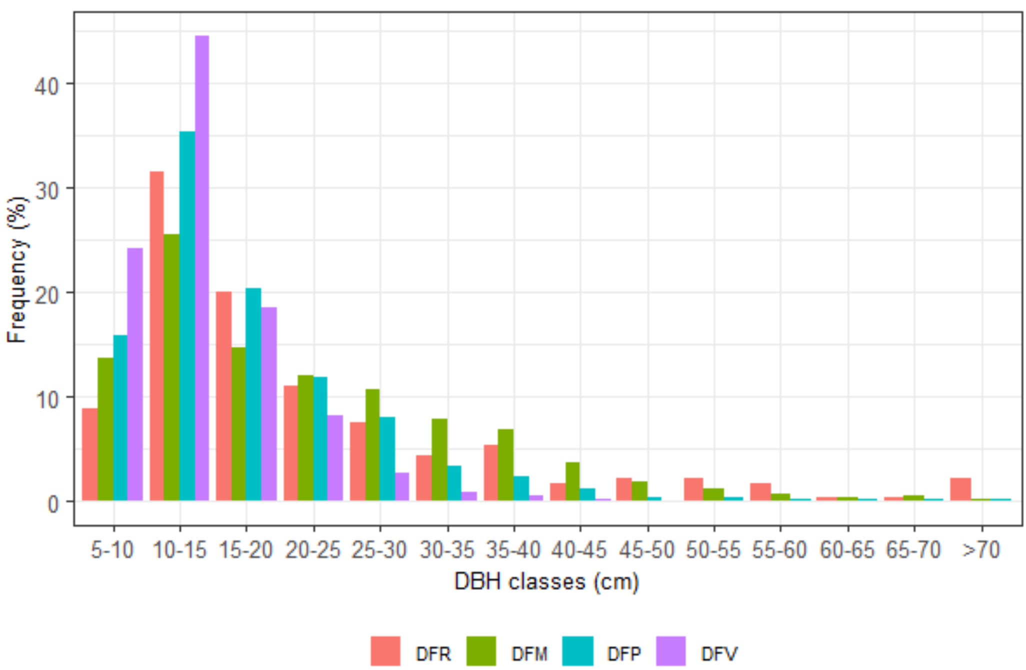

Figure 6. Frequency (%) of trees according to different DBH classes for the four dry forest (DF) types studied. Notes: DFR: rich dry forest; DFM: medium dry forest; DFP: poor dry forest; DFV: very poor dry forest.

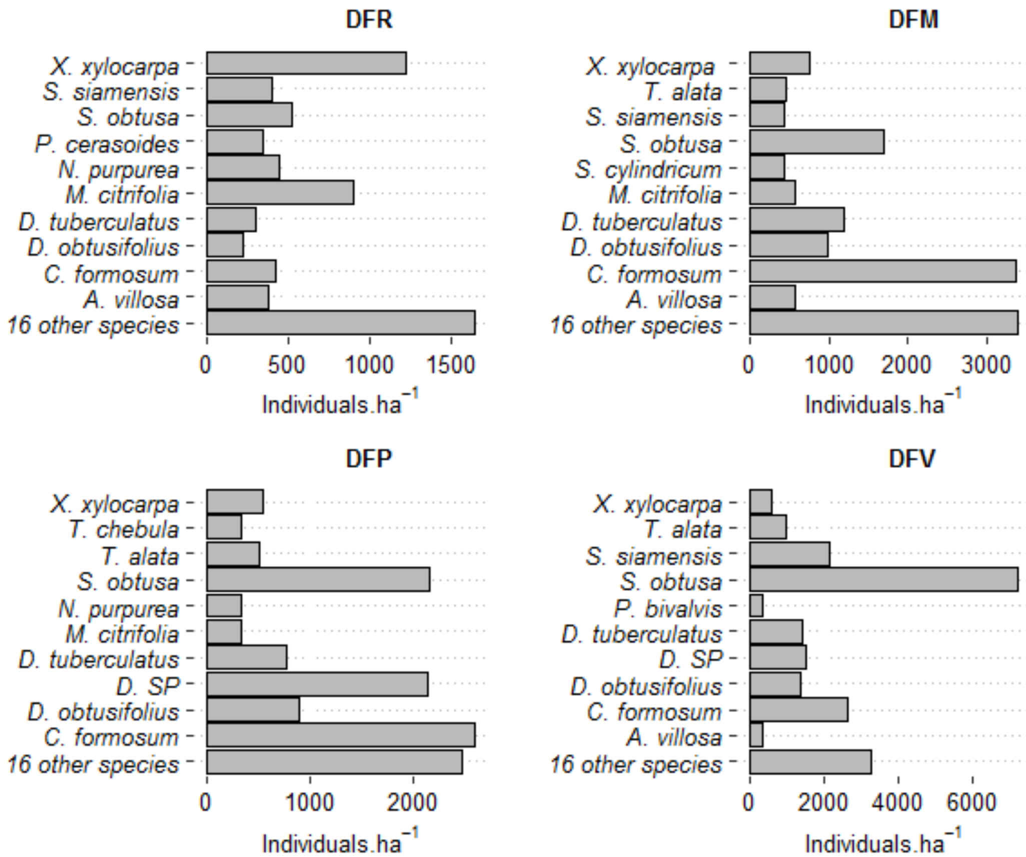

Figure 7. Regeneration status for the top 10 tree species recorded in the four dry forest (DF) types studied. Notes: DFR: rich dry forest; DFM: medium dry forest; DFP: poor dry forest; DFV: very poor dry forest.

was higher in the list, followed by *Cratoxylon formosum* (2,252 individuals per hectare) (Figure 7).

Discussion

There are large variations in species richness, basal area, and stem density in tropical dry forest ecosystems due to different climatic conditions, topography, and elevation gradients (Supplementary Table S3). Our results showed that DFR had significantly higher species richness, family richness, basal area, tree size and diversity than DFP and DFV, respectively. This variation may be due to the difference in management activities and past disturbance between both categories of forests (Sapkota *et al*., 2019; Angessa *et al*., 2020). Our findings suggest that tree species richness in the study area was greatly affected by anthropogenic disturbances. Although the outcome of the effects of disturbances on plant species richness likely differs based on the nature of disturbance (e.g., tree cutting, fuel-wood collection or agricultural expansion), and according to the intensity of disturbance. In general, tree species richness declined markedly from less disturbed in DFR to highly disturbed in DFP. 87 tree species in dry dipterocarp forest of the Central Highlands Region were recorded, which falls within the range of 16–204 species with sampled area from 0.12 to 20 ha reported for tropical dry forests all over the world. Additionally, six rare and threatened species (*Dalbergia oliveri* Gamble ex Prain, *Hopea recopei* Pierre ex Laness., *Shorea siamensis*, *Dalbergia tonkinensis* Prain, *Parashorea stellata*, *Hopea odorata* Roxb.) were the least abundant, namely one to two individuals, suggesting that they are rare species and need to be protected. On the one hand, in comparison with the other tropical dry forests, the number of species reported in the present study is higher than the results reported in previous studies (42 species on 1.5 ha) in the Dadeldhura district in Western Nepal (Bhatta & Devkota, 2020), in the Fasiakhali Wildlife Sanctuary in Bangladesh (32 species on 3.2 ha) (Das *et al*., 2018), in the Minas Gerais in Brazil (59 species on 1.8 ha) (Calvo-Rodriguez *et al*., 2017), in the Vindhyan highlands in India (52 species on 20 ha) (Chaturvedi & Raghubanshi, 2014), in the YokDon National Park in Vietnam (38 species on 2.8 ha) (Nguyen & Baker, 2016). On the other hand, the number of species in the present study is lower than the dry tropical forests in Eastern Ghats, Southern India (128 species on 7.9ha) (Gopalakrishna *et al*., 2015), in the North-Western coast of Costa Rica (96 species on 0.9 ha) (Hilje *et al*., 2015), in Central America (204 species on 0.7 ha) (Gillespie *et al*., 2000), in the Guanacaste Province in Costa Rica (135 species on 13.44 ha) (Hubbell, 1979), and in the North West Region of Cameroon (178 species on 12.3 ha) (Sainge *et al*., 2020). Additionally, diversity values recorded in the present study are lower than 157 species, which is the number reported in 3 study sites of the Central Highlands Region in Vietnam (Do *et al*., 2017). The lower number of species found in this study is mainly due to past anthropogenic disturbance, but could also be attributed to a combination of factors related to climate, soil types, topography, species interaction (i.e., competition and niche diversification), and stand density (seed dispersal and survival and resource extraction) (Bhatta & Devkota, 2020; Gopalakrishna *et al*., 2015; Imai *et al*., 2017).

Similarly to other tropical dry forests of Vietnam, the five most abundant families in the study area were Dipterocarpaceae, Combretaceae, Fabaceae, Phyllanthaceae and Leguminosae (Nguyen & Baker, 2016; Do *et al*., 2017). Fabaceae was also found to be the dominant family in tropical dry forests of Central America and South America (Coelho *et al*., 2012; Gillespie *et al*., 2000). Thirukkumaran *et al*. (2017) also reported Euphorbiaceae, Sapotaceae, Rutaceae, Ebenaceae in a tropical dry forest of Northern Sri Lanka. Disparities in family composition values could be attributed to anthropogenic activities and environmental effects. The dominance of a family reflects the environmental conditions of the area where it lives such as soil, climatic conditions, insects, mammals, human disturbance that impact the pollination, dispersal and establishment of species (Coley & Barone, 1996; Panda *et al*., 2013; Gopalakrishna *et al*., 2015).

In this study, the total basal area ranged from 5.74 $m^2 ha^{-1}$ in DFV to 23.7 $m^2 ha^{-1}$ in DFR. The basal area of the present study was very similar to that found in the tropical dry forests of Nepal (Bhatta & Devkota, 2020), India (Chaturvedi & Raghubanshi, 2014), Brazil (Coelho *et al*., 2012; Calvo-Rodriguez *et al*., 2017), Thailand (Wanthongchai *et al*., 2014), Central America (Méndez-Toribio *et al*., 2014; Gillespie *et al*., 2000), Sri Lanka (Karthigesu *et al*., 2019), and Cameroon (Sainge *et al*., 2020). However, the basal area of the present study was higher than that of Eastern Ghats and Vindhyan highlands of India (Chaturvedi & Raghubanshi, 2014; Gopalakrishna *et al*., 2015). The variation in basal area may be due to differences in species composition, density, tree age, disturbances and altitude (Fu *et al*., 2017; Naidu & Kumar, 2016; Sapkota *et al*., 2010). Tree stem density found in this study was 477 stem ha^{-1} (ranging from 150 to 1400 stem ha^{-1}). Similarly, the tree density obtained from dry dipterocarp forest in the three provinces together (Daklak, Daknong, Gialai) (Do *et al*., 2017), and in

YokDon National Park in Vietnam (Nguyen & Baker, 2016) were 622 and 1,229 stems ha^{-1}, respectively. A rich community has a large Shannon-Wiener (H′) value, while an ecosystem with a low value has low species diversity and the index values ranged from 0 to 5, usually from 1.50 to 3.50 (Meragiaw *et al.*, 2018). In this study, H′ value ranged from 1.8 to 2.29, suggesting that the dry forest of the Central Highlands Region had a low tree species diversity. The index measured in this study was similar to one previously published, which reported a value of 2.06 for the same area (Do *et al.*, 2017). However, it was greater than the previously published H′ value ranging from 0.9 to 1.3 for the tropical dry forest of Minas Gerais, Brazil (Calvo-Rodriguez *et al.*, 2017). Simpson Index (D) ranged from 0.76 to 0.87. These values are similar to those reported formerly for tropical dry forests in the Fasiakhali Wildlife Sanctuary in Bangladesh (Das *et al.*, 2018), and in Michoacán, Mexico (Méndez-Toribio *et al.*, 2014).

Tree diameter distribution reflects the disturbance effect within the forests and it is helpful in detecting trends of regeneration patterns (Poorter *et al.*, 1996; Sahoo *et al.*, 2017). In the present study, only 9 to 42 individuals ha^{-1} with DBH of above 45 cm contributed to only 1.8% to 8.8% of the overall tree density. In contrast, the contribution to tree density by individuals of lower diameter class (5–15 cm) was as high as 86.02%. The low diversity, the density of trees of a higher diameter class, and the predominance of plants of lower diameter observed revealed a reverse J-shaped structure in both forest categories and large forest disturbances, such as logging, forest fires and expanding agricultural crop production. For example, a higher stem density in a lower diameter class is due to the restriction of cutting of small-sized trees and regeneration processes, while a lower stem density in a higher diameter class is caused by the selective harvesting of large-sized trees.

The forest wealth depends on the potential regenerative status of species composing the forest stand, in space and time (Jones *et al.*, 1994). The regeneration of a forest is a vital process in which old trees die and are replaced by young ones (Malik & Bhatt, 2016). Furthermore, regeneration is a critical phase of forest management, because it maintains the desired species composition and stocking after disturbances (Duchok *et al.*, 2005). The regeneration status of tree species of any forest is determined by the densities of seedlings and saplings. The ratio of various age groups in a population determines the reproductive status of the population and it indicates the future course (Odum, 1971). In this study, seedling density ranged from 6,825 in DFR to 21,734 individuals ha^{-1} in DFV. The various forest types showed that canopy opening might be in favour of seed germination and seedling establishment through increased solar radiation on the forest floor (Kadavul & Parthasarathy, 1999). For instance, very poor DF with sparse density of a higher diameter class shows that a low canopy cover is suitable for forest regeneration. Our results are consistent with the findings published by Sapkota *et al.* (2009). The research indicated that mild disturbance supports species regeneration in five seasonally dry deciduous Sal forests in the Nawalparansi district of Nepal. The density of seedlings and saplings in the present study showed similar results if compared to previous research in the tropical dry forests. For instance, Nguyen & Baker (2016) reported seedling density to be 13,383 in YokDon National Park, Vietnam. Bhatta & Devkota (2020) studied the community structure and the regeneration status of *Shorea robusta* forests in the Dadeldhura district in Western Nepal, and they recorded 15,905 seedlings ha^{-1} and 1,876 saplings ha^{-1}. Wanthongchai *et al.* (2014) recorded a seedling density ranging from 13,000 to 40,000 individuals ha^{-1} and a sapling density from 573 to 4,570 individuals ha^{-1}. While, Karthigesu *et al.* (2019) studied the diversity of tree community in a tropical dry forest of Northern Sri Lanka and could record a seedling density ranging from 694 to 3,400 individuals ha^{-1} and a sapling density from 773 to 4,475 individuals ha^{-1}, respectively.

Conclusion

Floristic inventories and vegetation analysis for the tropical dry forest of the Central Highlands Region in Vietnam showed that tree stem density, basal area and Shannon Index were relatively low in the four forest types studied, particularly due to past disturbance such as anthropogenic, selective logging, deforestation for agricultural purposes and natural fires. The large population and regeneration of sapling trees in DF in the Central Highlands Region, suggest that this is a second-growth forest with high regeneration potential. With agricultural communities located in the buffer zone for the protection of the forest with a fast-growing economy, the pressure on forest resources is increasing. Therefore, a systematic management plan is required for their conservation and sustainable use.

Authors' contributions. Nguyen Thanh Tuan and Tran Quang Bao designed and conceived the study; Tran Quang Bao organised and conducted the fieldwork; Nguyen Thanh Tuan and Tran Quang Bao did all the data analyses; Nguyen Thanh Tuan and Ilaria Gliottone wrote the manuscript; Diego I. Rodríguez-Hernández revised the manuscript.

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Diversity and composition of tree species in four dry forest (DF) types of Vietnam's Central Highlands.

Supplementary Table S1. Nationally rare and IUCN red list of threatened species recorded in four different dry forest (DF) types of Vietnam's Central Highlands.

Species name	IUCN	DFR	DFM	DFP	DFV
Dalbergia oliveri Gamble ex Prain	EN	-	-	-	1
Hopea recopei Pierre ex Laness	EN	-	1	-	-
Dipterocarpus intricatus Dyer	EN	-	-	-	1
Pterocarpus macrocarpus Kurz.	EN	-	1	3	12
Dalbergia bariensis Pierre	EN	5	2	21	41
Sindora siamensis Teysm.	LR	-	1	-	-
Dipterocarpus tuberculatus Roxb.	NT	8	157	250	376
Dipterocarpus obtusifolius Teijsm.	NT	7	158	242	323
Shorea obtusa Wall.	NT	-	15	15	37
Vitex ajugaeflora Dop	VU	-	2	1	33
Dalbergia tonkinensis Prain	VU	-	-	-	1
Parashorea stellata Kurz	VU	-	1	-	-
Dipterocarpus alatus Roxb.	VU	-	24	1	5
Hopea odorata Roxb.	VU	-	-	-	2
Shorea roxburghii G. Don	VU	26	85	309	448

Notes: IUCN: International Union for Conservation of Nature; EN: endangered species; LR: species at lower risk; NT: near threatened species; VU: vulnerable species.

Supplementary Table S2. List of species richness found in four different dry forest (DF) types of Vietnam's Central Highlands. Tree species are ranked from the highest to the lowest based on their importance value index (IVI).

DFR			DFM			DFP			DFV		
No	Species	IVI	No	Species	IVI	No	Species	IVI	No	Species	IVI
1	*Shorea siamensis*	52.1	1	*Dipterocarpus tuberculatus*	37.8	1	*Shorea obtusa*	52.2	1	*Shorea obtusa*	40.8
2	*Shorea obtusa*	42.8	2	*Dipterocarpus obtusifolius*	37.4	2	*Dipterocarpus tuberculatus*	41.6	2	*Dipterocarpus tuberculatus*	37.8
3	*Xylia xylocarpa*	35.6	3	*Shorea obtusa*	36.3	3	*Dipterocarpus obtusifolius*	40.9	3	*Dipterocarpus obtusifolius*	32.7
4	*Terminalia alata*	32.6	4	*Xylia xylocarpa*	19.1	4	*Terminalia alata*	22.6	4	*Shorea siamensis*	23.1
5	*Dillenia* sp.	15.2	5	*Shorea siamensis*	18.1	5	*Terminalia chebula*	17.8	5	*Aporosa villosa*	14.8
6	*Dipterocarpus tuberculatus*	13.1	6	*Terminalia alata*	15.6	6	*Shorea siamensis*	14.1	6	*Xylia xylocarpa*	13.8
7	*Aporosa villosa*	11.6	7	*Aporosa villosa*	11.2	7	*Aporosa villosa*	12.1	7	*Terminalia alata*	11.5
8	*Dipterocarpus obtusifolius*	8.6	8	*Dipterocarpus alatus*	10.2	8	*Xylia xylocarpa*	10.1	8	*Terminalia chebula*	10.2
9	*Elaeocarpus hygrophilus*	7.3	9	*Irvingia malayana*	8.8	9	*Dillenia* sp.	6.8	9	*Morinda citrifolia*	9.9
10	*Syzygium cumini*	6.3	10	*Dillenia* sp.	7.4	10	*Neonauclea purpurea*	6.1	10	*Dalbergia bariensis*	6.8
11	*Dalbergia bariensis*	6.3	11	*Terminalia chebula*	7.1	11	*Dalbergia bariensis*	5.8	11	*Albizia lebbeck*	6.3
12	*Haldina cordiflora*	5.3	12	*Lagerstroemia calyculata*	6.6	12	*Strychnos nux–blanda*	5.1	12	*Dillenia sp.*	5.9
13	*Cratoxylon formosum*	4.9	13	*Lagerstroemia speciosa*	6.5	13	*Shorea roxburghii*	4.3	13	*Shorea roxburghii*	5.6
14	*Barringtonia acutangula*	4.8	14	*Terminalia corticosa*	5.6	14	*Morinda citrifolia*	4.3	14	*Syzygium cumini*	4.6
15	*Lagerstroemia speciosa*	4.6	15	*Shorea roxburghii*	5.6	15	*Lagerstroemia calyculata*	3.5	15	*Neonauclea purpurea*	4.5
16	*Schrebera swietenioides*	4.5	16	*Morinda citrifolia*	5.0	16	*Spondias pinnata*	3.4	16	*Lannea coromandelica*	4.2
17	*Neonauclea purpurea*	4.1	17	*Melia azedarach*	4.2	17	*Barringtonia acutangula*	3.3	17	*Cratoxylon formosum*	4.1

DFR			DFM			DFP			DFV		
No	Species	IVI	No	Species	IVI	No	Species	IVI	No	Species	IVI
18	*Terminalia corticosa*	3.5	18	*Syzygium cumini*	4.1	18	*Cratoxylon formosum*	2.9	18	*Vitex ajugaeflora*	4.0
19	*Lagerstroemia calyculata*	3.3	19	*Spondias pinnata*	3.9	19	*Bombax ceiba*	2.9	19	*Barringtonia acutangula*	3.9
20	*Peristrophe bivalvis*	3.3	20	*Elaeocarpus hygrophilus*	3.9	20	*Semecarpus sp.*	2.8	20	*Strychnos nux–blanda*	3.2
21	*Shorea roxburghii*	3.2	21	*Cratoxylon formosum*	3.4	21	*Bauhinia malabarica*	2.3	21	*Melanorrhoea laccifera*	3.1
22	*Bauhinia malabarica*	3.1	22	*Neonauclea purpurea*	3.4	22	*Syzygium cumini*	1.9	22	*Castanopsis piriformis*	3.1
23	*Strychnos nux–blanda*	3.0	23	*Grewia nervosa*	2.9	23	*Anogeissus acuminata*	1.9	23	*Semecarpus* sp.	2.5
24	*Melia azedarach*	2.6	24	*Millingtonnia hortensis*	2.7	24	*Terminalia corticosa*	1.8	24	*Careya aborea*	2.4
25	*Diospyros maritima*	2.5	25	*Bombax ceiba*	2.6	25	*Grewia nervosa*	1.8	25	*Terminalia corticosa*	2.3
26	*Morinda citrifolia*	2.5	26	*Albizia lebbeck*	2.5	26	*Schrebera swietenioides*	1.8	26	*Spondias pinnata*	2.2
27	*Prunus arborea*	2.4	27	*Strychnos nux–blanda*	2.1	27	*Azadirachta* indica	1.8	27	*Pterocarpus macrocarpus*	2.1
28	*Artocarpus lakoocha*	2.3	28	*Peristrophe bivalvis*	2.0	28	*Pterocarpus macrocarpus*	1.7	28	*Bridelia balansae*	1.9
29	*Terminalia catappa*	2.2	29	*Semecarpus* sp.	1.8	29	*Engelhardtia chrysolepis*	1.6	29	*Prunus arborea*	1.9
30	*Castanopsis piriformis*	2.1	30	*Clausena excavata*	1.5	30	*Fructus Gleditschia*	1.6	30	*Grewia nervosa*	1.7
31	*Peltophorum pterocarpum*	2.1	31	*Vitex ajugaeflora*	1.5	31	*Phyllanthus emblica*	1.6	31	*Peristrophe bivalvis*	1.6
32	*Briedenia cambodiana*	2.0	32	*Barringtonia acutangula*	1.4	32	*Ficus*	1.4	32	*Bauhinia malabarica*	1.5
			33	*Schrebera swietenioides*	1.4	33	*Lagerstroemia speciosa*	1.4	33	*Irvingia malayana*	1.5
			34	*Dalbergia bariensis*	1.2	34	*Elaeocarpus hygrophilus*	1.3	34	*Catunaregam tomentosa*	1.4
			35	*Parinari annamense*	1.1	35	*Albizia lebbeck*	1.1	35	*Lagerstroemia calyculata*	1.4

DFR			DFM			DFP			DFV		
No	Species	IVI	No	Species	IVI	No	Species	IVI	No	Species	IVI
			36	*Anogeissus acuminata*	0.9	36	*Catunaregam tomentosa*	1.1	36	*Bombax ceiba*	1.3
			37	*Pterocarpus macrocarpus*	0.9	37	*Millingtonnia hortensis*	1.0	37	*Canthium horridum*	1.3
			38	*Prunus arborea*	0.9	38	*Lannea coromandelica*	1.0	38	*Lagerstroemia speciosa*	1.3
			39	*Parashorea stellata*	0.9	39	*Prunus arborea*	1.0	39	*Elaeocarpus hygrophilus*	1.2
			40	*Hopea recopei*	0.8	40	*Canthium horridum*	1.0	40	*Anogeissus Acuminata*	1.1
			41	*Engelhardtia roxburghiana*	0.8	41	*Rhamnus crenatus*	0.8	41	*Terminalia catappa*	1.0
			42	*Neonauclea sessilifolia*	0.8	42	*Machilus odoratissima*	0.7	42	*Phyllanthus emblica*	0.9
			43	*Peltophorum pterocarpum*	0.8	43	*Diospyros ehretioides*	0.6	43	*Quercus kerrii*	0.9
			44	*Rhamnus crenatus*	0.7	44	*Vitex ajugaeflora*	0.6	44	*Senna siamea*	0.9
			45	*Elaeocacpus macroceras*	0.7	45	*Briedenia cambodiana*	0.6	45	*Cratoxylon prunifolium*	0.9
			46	*Stereospermum cylindricum*	0.7	46	*Buchanania latifolia*	0.6	46	*Garcinia oblongifolia*	0.8
			47	*Bauhinia malabarica*	0.7	47	*Dipterocarpus alatus*	0.6	47	*Terminalia triptera*	0.7
			48	*Machilus odoratissima*	0.7	48	*Mallotus philippinensis*	0.6	48	*Wrightia pubescens*	0.7
			49	*Diospyros maritima*	0.7	49	*Terminalia calamansanai*	0.5	49	*Stereospermum cylindricum*	0.7
			50	*Knema lenta*	0.6	50	*Terminalia catappa*	0.5	50	*Haldina cordiflora*	0.6
			51	*Canarium subulatum*	0.6	51	*Peristrophe bivalvis*	0.5	51	*Rhamnus crenatus*	0.6
			52	*Fructus Gleditschia*	0.6	52	*Polyalthia cerasoides*	0.5	52	*Parinari annamense*	0.6
			53	*Lannea coromandelica*	0.6				53	*Terminalia calamansanai*	0.6

DFR			DFM			DFP			DFV		
No	Species	IVI	No	Species	IVI	No	Species	IVI	No	Species	IVI
			54	*Sindora siamensis*	0.6				54	*Dipterocarpus alatus*	0.5
									55	*Hopea odorata*	0.5
									56	*Clausena excavata*	0.5
									57	*Azadirachta* indica	0.5
									58	*Ficus superba*	0.5
									59	*Mallotus philippinensis*	0.4
									60	*Millingtonnia hortensis*	0.4
									61	*Schefflera heptaphylla*	0.3
									62	*Litsea cambodiana*	0.3
									63	*Fructus Gleditschia*	0.3
									64	*Dalbergia tonkinensis*	0.3
									65	*Mangifera* sp.	0.3
									66	*Dalbergia oliveri*	0.3

Supplementary Table S3. Structure, composition, and diversity of tree species in tropical dry forests of the present and previous studies.

ID	Study area	Sampled area (ha)	Minimal DBH (cm)	Number of species	Number of families	Stand density	Stand basal area	Shannon-Weiner	Simpson	Evenness	Margalef's	Seedling (individuals / ha)	Sapling (individuals /ha)
1	Dadeldhura district, Western Nepal (Bhatta & Devkota, 2020)	1.05	>5	42	20	3162.9±194.3	13.77 ±0.88					15905 ±927.3	1876.2 ±143.4
2	3 provinces from Central Highlands of Vietnam (Do *et al.*, 2017)	6.00	>10	157		622		2.06	0.80				
3	Huai Kha Khaeng Wildlife Sanctuary, Thailand (Wanthongchai *et al.*, 2014)	0.75	>4.5	54		667–1558	12.9–23.6					13000–40000	573–4570
4	Fasiakhali Wildlife Sanctuary, Bangladesh (Das *et al.*, 2018)	3.2	>11	32	19	249	46.17	2.05	0.75				
5	Eastern Ghats, Southern India (Gopalakrishna *et al.*, 2015)	7.9	>10	128	45	994	5.1 ±3.6	1.1–3.5	0.4–1.0	0.5–0.9			
6	The North-Western Coast of Costa Rica (Hilje *et al.*, 2015)	0.9	>5	96	41								
7	YokDon National Park, Vietnam (Nguyen & Baker, 2016)	2.8	>1	38		1229 ±523	19.12 ±5.89					13383	

ID	Study area	Sampled area (ha)	Minimal DBH (cm)	Number of species	Number of families	Stand density	Stand basal area	Shannon-Weiner	Simp-son	Even-ness	Marga-lef's	Seedling (indi-viduals / ha)	Sapling (indi-viduals /ha)
8	The Minas Gerais, Brazil (Calvo-Rodriguez *et al.*, 2017)	1.8	>5	59	19	510–1091	3.13–25.34	0.9–1.3					
9	Central America (Gillespie *et al.*, 2000)	0.7	>2.5	204	58	1350–2650	17.7–25						
10	Guanacaste Province, Costa Rica (Hubbell, 1979)	13.44	>2	135									
11	Sri Lanka (Karthigesu *et al.*, 2019)	0.12	>5			446–1500	11.4–44.8			0.6–0.9		694–3400	773–4475
12	The North West Region of Cameroon (Sainge *et al.*, 2020)	12.3	>10	178	42	157–404	6.8–32.4	2.7–3.5					
13	Michoacán, Mexico (Méndez-Toribio *et al.*, 2014)	0.36	>1	78	24	700–5600	9–44	0.41–3.5	0.04–0.71				
14	Bandipur, South India (Suresh *et al.*, 2016)		>1	66				2.46	0.81				
15	The Accra Plains in South-East Ghana (Swaine *et al.*, 1990)	0.49	>10	16		1332							
16	Northern Sri Lanka (Thirukkumaran *et al.*, 2017)	0.12	>5	32	18	446		1.54–2.29		0.86–0.94			
17	Vindhyan Highlands, India (Chaturvedi & Raghubanshi, 2014)	20	>10	52		126–490	3.1–18	1.5–2.5			1.7–3.7	5040–14167	540–1383
18	Minas Gerais, Southeastern Brazil (Coelho *et al.*, 2012)	0.3	>5	50	21	1076–1226	17.8–29.3	1.52–2.58		0.48–0.64			