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Original article

STRUCTURAL AND FLORISTICS CHARACTERISTICS OF THREE TYPICAL SUCCESSIONAL STAGES OF THE TROPICAL EVERGREEN BROADLEAF FOREST IN KON CHU RANG NATURE RESERVE, GIA LAI PROVINCE, VIETNAM

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Abstract

Background. Structural and floristic characteristics are a crucial aspect in proposing technical solutions for forest ecosystem restoration. The study was conducted in Kon Chu Rang Natural Reserve, Gia Lai, Vietnam. The differences in structure (such as density, tree size, abundance, diversity, species composition, etc.) between secondary and old-growth forests were shown in the several previous researches. However, within secondary forests, different histories of disturbance have resulted in very different stages of forest succession, despite the same length of time since human influence ceased and the same protection conditions. Secondary forests recovering after shifting cultivation, with directly light and fast-growing species, have higher density and abundance, while tree size indices and the number of dominant species are lower compared to secondary forests recovering after logging, which are mainly composed of shade-tolerant species. The research results provided a basis for group classification and the application of silvicultural measures to effectively promote forest recovery processes.

Purpose. To study the potential for natural successional recovery as a basis for proposing the application of silvicultural measures to rehebilitate the evergreen closed tropical rain forest in the Kon Ha Nung Biosphere Reserve.

Materials and methods. The subject of the study was the tropical evergreen broadleaf forest types in Kon Chu Rang Nature Reserve. In this study, satellite imagery (Landsat 8) was collected in the same season from 2013 to 2022 and Normalized Difference Vegetation Index was calculated to determine the forest successional stages of tropical evergreen broadleaf rainforest in Kon Chu Rang Nature Reserve.

The results of classification combined with field survey based on the establishment of 09 permanent sample plots (50×50 m, 2,500 m²) to ensure the forest successional stages. These plots were established in each typical successional stage (secondary forest after logging, secondary forest after shifting cultivation, and old-growth forest). In each plot, all live woody stems with a diameter at breast height greater than 10 cm were measured, including tree diameter at breast height and tree species. All data collected in each plot were then used for data analysis using SPSS software. This research conducted an ANOVA (Analysis of Variance) with a Fisher's Least Significant Difference post hoc test to explore differences between multiple group means of tree density, number of trees distribution in each group of tree diameter, tree diameter, basal area and tree diversity. In addition, to investigate forest structure and diversity, the Impotance Value Index, Shannon-Wiener Index (He') and Simpson Index, and Jaccard's coefficient of similarity were calculated in this study.

Results. Tree density ranged from 347 to 763 stems per hectare and total basal area from 15.5 to 42.8 m² per hectare. No significant difference was observed among the three forest types for tree diameter classes from 10 to 25 cm, while for tree diameter classes greater than 25 cm, old growth forest had the highest tree density, significantly different from the others. A decrease in tree density was observed in all forest types except old growth, which had the highest tree density and basal area for tree diameter classes greater than 25 cm. Diversity was found to be significantly higher in the old-growth forest compared to the secondary forest, which may be due to the duration of the restoration process and the initial stage of disturbance cessation. A total of 31 to 43 tree species were identified in 28-38 genera and 19-22 families, with the lowest species richness observed in the secondary forest after logging and only 3-7 tree species calculated in the tree composition. The dominant species in the post-logging secondary forest were heliophilous and fast-growing tree species such as Machilus parviflora, Macaranga tanarius, Litsea elongata, Clausena sp. and Prunus arborea, whereas in the post-shifting secondary forest they were shade-tolerant such as Rehderodendron truongsonense, Cinnamomum mairei, Castanopsis pseudoserrata, Litsea elongata, Syzygium wightianum. In particular, the associations of Clusiaceae and Myrtaceae species in old-growth forests were a novel finding.

Conclusions. It can be concluded that the structure and diversity characteristics of these successional stages exhibited remarkable variation. The old-growth forest had greater tree density, basal area, tree diversity and evenness than those of in secondary forest, along with the differences in number tree distribution, tree composition and diversity. These differences may come from the regeneration time and site condition. These results suggest that long-term monitoring and research are essential to assess restoration success over time.

Keywords: floristic characteristics; forest structure; Kon Chu Rang natural reserve; successional stages

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Introduction

The Kon Ha Nung Plateau Biosphere Reserve (KHN), situated in Gia Lai province, was designated a World Biosphere Reserve by UNESCO in September 2021. The reserve has a core zone encompasses the Kon Ka Kinh National Park and Kon Chu Rang Natural Reserve (KCR) covering a total area of 413,511.67 hectares. The biosphere reserve is distinguished by its high biodiversity and represents the evergreen closed forest ecosystem of the Central Highlands (Tay Nguyen) region in Vietnam. In addition to its ecological significance, the KHN plays a crucial role in climate regulation and water resources. This reserve contributes to the socio-economic development and ecological balance not only in the Central Highlands but also in the Central Coastal and South - Central regions of Vietnam. Nevertheless, despite its significance, the reserve continues to confront challenges associated with the decline of natural forests, both in terms of area and quality. The forest cover in the Central Highlands has consistently declined from 75-70% in 1976 to 60% during the 1980-1990 period [4]. The trend persists, with further reductions observed from 2019 to 2020, resulting in a loss of over 27,000 hectares of natural forest. Some of this area has been converted to open land or shrubland, while other parts have experienced natural regeneration [15].

Despite the implementation of substantial restoration initiatives within the KHN, certain areas remain significantly impacted, impeding their natural recovery [8]. The considerable extent of the forested area and the diversity of the local population present a complex set of management challenges. It is of paramount importance to gain an understanding of the dynamics of forest recovery if we are to be able to implement effective technical interventions with the aim of promoting restoration. Consequently, the KHN must prioritize the advancement of scientific knowledge and the development of effective conservation strategies for these invaluable forested areas.

Classifying and identifying the characteristics of forest restoration objects based on forest succession research is a crucial aspect in proposing technical solutions for forest ecosystem restoration. Although there are several criteria for assessing forest restoration, there are few comprehensive criteria specifically for natural forest restoration in biosphere reserves. These criteria fall into two main groups: (1) structural and diversity criteria, and (2) functional criteria, including ecological and social functions [7; 17]. To flexibly apply previous research methods [8; 9; 16], characteristic forest objects for the study area were preliminarily identified using Normalized Difference Vegetation Index (NDVI) and field surveys conducted during 2013-2023. Sample plots will be established to represent three characteristic forest conditions: minimally impacted or undisturbed forest (old growth forest), post-logging recovery forest, and post-shift cultivation regrowth forest and used to determine the structural and floristic characteristics of these forest types.

In this study, our objective is to describe the floristic composition, species richness and similarity between two stages of forest regeneration using ecological indices in a tropical evergreen broadleaf forest in Kon Chu Rang Natural Resever. Emphasis will be placed on assessing structural characteristics and species composition across successional stages in an attempt to describe and manage the variability in physiognomy inherent in a regenerating forest. Satellite imagery and historical ground truth analysis were used to determine the successional stages of forest.

Material and methods

Research site

The Kon Chu Rang Nature Reserve encompasses an area of 719 km², with a designated conservation zone of approximately 159 km². This zone includes the Strict Protection Zone (~87.5 km²) and the Ecological Restoration Zone (~71.5 km²). It is notable that nearly 70% of the study area is comprised of rich forests, with a total forest volume exceeding 200 $m^3.ha^{-1}$, representing the highest proportion of mature forests within the Kon Ha Nung plateau. The reserve's forest ecosystem serves as an exemplary model of the evergreen broad-leaved forest typology found in the Central Highlands of Vietnam. A comprehensive botanical survey has documented 881 species and subspecies of plants within KCR, belonging to 547 genera and 162 families. Of particular note, 22 of these species are included in the Vietnam Red Book. It is also important to note that the reserve contains areas of poor forests, low-yield recovery forests, and non-forested land. Geographically, KCR is situated entirely within the Kon Ha Nung Plateau, with an average elevation ranging from 800 to 1,100 meters above sea level. The climatic conditions of the reserve are typified by an average annual humidity of approximately 82% and an annual average temperature range of 18°C to 25°C. Moreover, the reserve experiences an average annual precipitation range of 2,000mm to 2,400mm year^{-1} [12]. In the study area, there are several types of soil, the most common of which are reddish brown soil on basalt (distributed in the southwest of the site) and gray soil on basalt (distributed in the northeast of the site) [8].

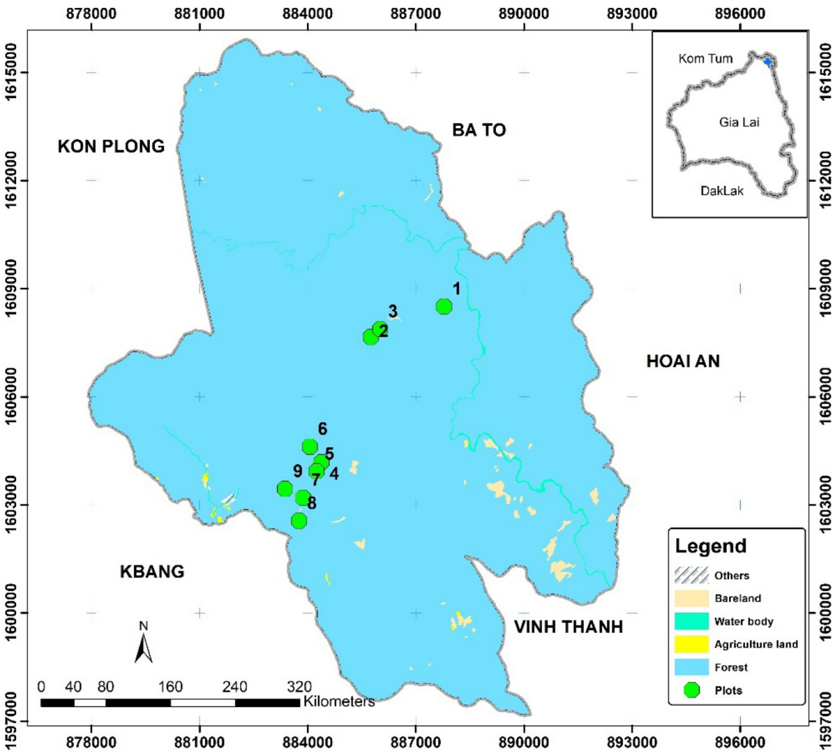

Fig. 1. Location of the research site and sample plots in the research area.

Site selection and field measurements

In order to identify the typical forest types in this study, a combination of satellite image analysis and field characterization was employed to select the study sites. Specifically, we employed LANDSAT 8 Collection level-2 images, which comprise two spectral bands (B4 and B5) with a spatial resolution of 30 meters during a same seasons from 2013 to 2022. The primary tool employed for the assessment of vegetation was the Normalized Difference Vegetation Index (NDVI), a metric that has gained considerable traction in the field. The NDVI is derived from the red and near-infrared bands. The NDVI index values range from -1 to +1, with higher values indicating greater green vegetation cover. To establish thresholds for different forest stages, we referenced previous studies [5, 9]. In particular, NDVI values below 0,7 were indicative of intermediate succession stages, while NDVI values above 0,7 indicated late succession stages.

$$NDVI = (Band\ 5 - Band\ 4) / (Band\ 5 + Band\ 4) \quad (1)$$

In which: Band 4, Band 5 are Red and Near Infrared band of LANDSAT 8.

A total of 9 permanent sample plots (50×50 m, 2.500 m^2) were established in August 2022, divided into each forest type, including old-growth forest (OGF), secondary forest after shifting cultivation (SCF), and secondary forest after logging (LCF). The diameter at breast height (DBH) of all living woody stems with a DBH equal to or greater than 10 cm was identified and measured. For multi-stemmed individuals, each stem with a DBH greater than 10 cm was considered a separate entity. All surveyed trees were assigned a unique code to facilitate the monitoring of successional dynamics. The descriptions of the three main forest types were adapted from Tab. 1.

Table 1.

The characteristic of three main forest type in the research site.

Successional stage	Canopy	Definition	Restoration time (year)
OGF	Evergreen broadleaf forest, more than 2 canopy layers.	Old-growth forest, less or non impacting by human activities, stable structure ∑ G (Basal area) >26 $m^2.ha^{-1}$	Minimally impacted / undisturbed forest
SCF	Evergreen broadleaf forest, more than 2 canopy layers.	Good restoration forest, more than 2 forest layers, ∑G (16-26 $m^2.ha^{-1}$)	30
LCF	Evergreen broadleaf forest, more than 2 canopy layers.	Good restoration forest, ∑G (10-16 $m^2.ha^{-1}$)	30

Species identification: Collaborating experts in plant classification (the Department of Botany and the Institute of Ecology and Biological Resources) join forces to identify species. During the fieldwork, unidentified plants were photographed, sampled, and their pertinent details-such as collection location, coordinates, key characteristics, local names, and collector information were meticulously recorded. The primary purpose of this data is to facilitate subsequent laboratory analysis and species identification.

Data analysis

In this study, we assessed floristic composition, diversity, and similarity using both quantitative and qualitative indices. To calculate floristic composition, we employed the Importance Value Index (IV%), which combines relative dominance (Gi%) and relative abundance (Ni%). The IV% helps evaluate the significance of different species within a community.

$$\text{Relative dominance - Gi\%} = \frac{\text{Total basal area of the species}}{\text{Total number area of all species}} \text{ x } 100 \qquad (2)$$

$$\text{Relative abundance - Ni\%} = \frac{\text{Number of individual of the species}}{\text{Total number of individuals}} \text{ x } 100 \qquad (3)$$

$$\text{IVi\%} = \frac{\text{Gi\%+Ni\%}}{2} \qquad (4)$$

The Importance Value (IV) of each high trees species was determined as the sum of relative density (%) and relative dominance (%) to divide by two. For high trees species with IV ≥ 5% is really ecological significant and dominant species which participates in the composition formula of the communities. If a group of less than 10 species has IV index ≥ 40%, they are considered the dominant species group [24].

To estimate diversity we calculated the Shannon-Wiener index (He') and Simpson index (D1) [10] as below equations:

Shannon-Wiener index (He'):

$$He' = -\sum_{i=1}^{s} pi ln(pi) \qquad (5)$$

Simpson index (D1):

$$D_1 = 1 - \sum_{i=1}^{s} pi^2 \qquad (6)$$

Where, s - is the number of species and pi is the abundance of the species - As a propotion of the total number of stems accounted for all species), pi = $\frac{ni}{N}$.

In order to examine the floristic similarity between sample plots of all successional stages, we calculated Jaccard's coefficient of similarity (Cj) [14, 19].

$$Cj = \frac{a}{a+b+c} \qquad (7)$$

Where: a - is the number of species found in both forest types;

b – is the number of species in forest type No1 but not in forest type No 2;

c – is the number of species in forets type No2 but not in forest type No 1.

All statistics analysis were performed using the SPSS v20.0.

Results and discussion

Site selection

NDVI is a widely used remote sensing index that quantifies vegetation greenness based on the difference NIR and RED band. Adapting to the previous research, this research employed continuous NDVI values within the range of <0.7 and >0.7 during the study period (2013-2023) and utilized LANDSAT 8 satellite imagery that was performed using Google Earth Engine [5, 9]. Using NDVI data continuously over multiple years could helps mitigate risks associated with using only the NDVI value from the most recent year. The preliminary phenological stages determined using this method were summarized in Tab. 2.

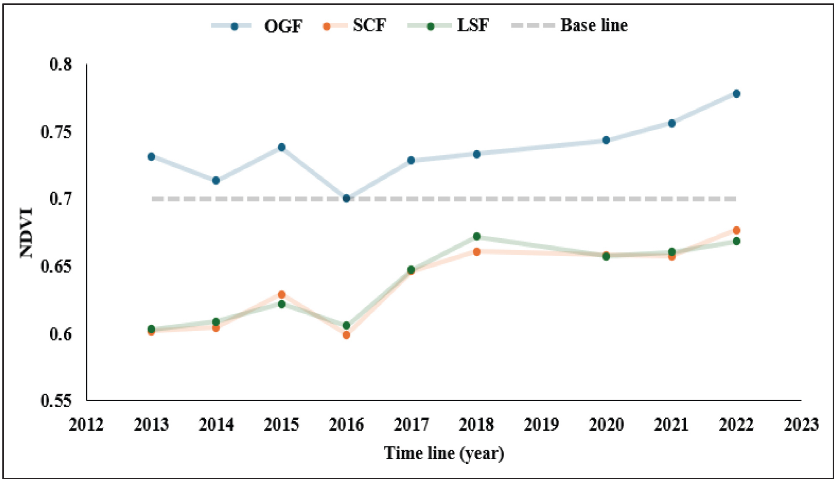

Table 2.

NDVI range of sample plots in the study site.

	OGF	SCF	LCF
NDVI range	0.736 ± 0.004	0.637 ± 0.006	0.630 ± 0.006

Fig. 2. NDVI change during 2013-2022.

In our study, we carefully selected sample plots that corresponded to the NDVI range and effectively represented different successional stages. The NDVI trend from 2013 to 2022 exhibited an upward trajectory, indicating successful forest restoration in the research areas (SCF and LCF) and stable forests (OGF). Consequently, using NDVI as a reliable indirect indicator provides valuable insights into forest successional stages. In comparing 03 methods for determining forest successional stages in Dong Nai Biosphere Reserve using NDVI, forest volume based on the log-log diagram of forest structure (H (Total Height) = 100*DBH), and Non-Metric Multidimensional Scaling, the results showed reasonably high similarity in stage determination [5]. Additionally, NDVI was well-suited for identifying phenological stages in tropical dry forests in Costa Rica. Specifically, the early, middle, and late successional stages correspond to NDVI values in the following order: 0.43-0.58, 0.58-0.7, and 0.7-0.83 [9]. The NDVI-based classification results align well with field-collected data on successional stages. Similary conlusion also found that satellite imagery performs accurately in identifying successional stages [6; 16].

Fig. 3. Image of sample plots (a: LCF, b: OGF, c: SCF).

Structural and diversity characteristic

Canopy tree density varies significantly across three forest types. Specifically, tree density (stems.ha^{-1}) were 763 ± 54 for OGF, 696 ± 17 for SCF, and 347 ± 10 for LCF (Tab. 3). LCF had the lowest tree density, significantly different from both OGF and SCF (Sig. < 0.05). However, no significant difference was observed among the three forest types for DBH classes ranging from 10 to 25 cm (Fig. 4). For trees with a DBH larger than 25 cm, OGF showed the highest tree density, significantly different from the others (Sig. < 0.05). The total basal area values (G, m^2.ha^{-1}) for different DBH classes in OGF, SCF, and LCF were 42.8±2.4, 19.6±2.7, and 15.5±0.1, respectively. Post-hoc LSD tests in SPSS indicate that OGF's average basal area was significantly higher than the other forest types (Sig. < 0.05). However, there was no significant difference between SCF and LCF (Sig. > 0.05). The distribution of basal area by DBH classes shows higher values in secondary forests compared to OGF for all DBH classes under 25 cm (Fig. 5).

Table 3.

Structural characteristics of the three plots in each of the three typical successional stages

Successional stage	Plot No.	Tree density (*Stems.ha^{-1}*)	Shanon (*He'*)	Simpson (*D_1*)	G ($m^2.ha^{-1}$)
OGF	1	656	3.42	0.95	38
	2	808	3.29	0.95	44.9
	3	824	3.1	0.93	45.4
	Mean±SE	763 ± 54	3.27 ± 0.16	0.94 ± 0.01	42.8±2.4
SCF	1	720	2.97	0.9	20.4
	2	704	2.92	0.89	20.2
	3	664	3.07	0.92	18.27
	Mean±SE	696 ± 17	2.99 ± 0.08	0.90 ± 0.02	19.6±2.7
LCF	1	352	2.97	0.92	15.23
	2	360	3.14	0.94	15.66
	3	328	3.12	0.94	15.67
	Mean±SE	347 ± 10	3.08 ± 0.09	0.93 ± 0.01	15.5±0.1

SE: standard error.

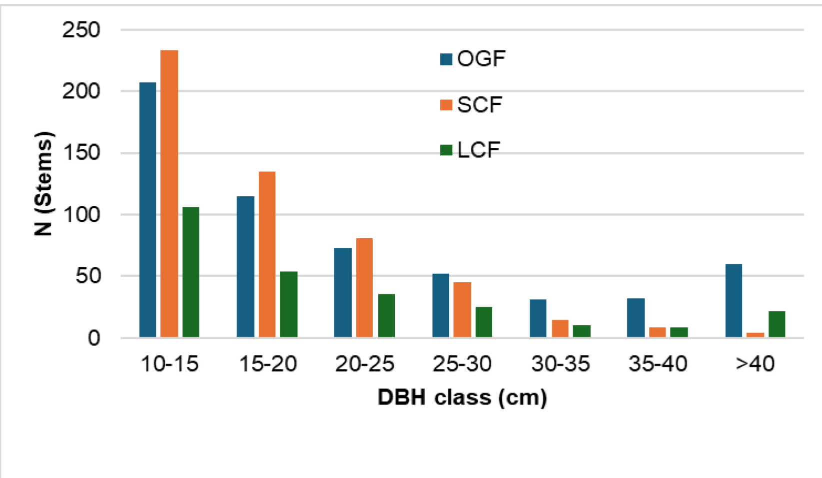

Fig. 4. The tree density of canopy trees in OGF, SCF, LCF of study area.

Diversity indices, especially D1 and He', were 0.94 and 3.27 for OGF, exceeding those of secondary forests (Tab. 3). In the case of the OGF was considered as the climax community, this suggests that the old-growth forest had greater diversity and evenness. D1 and He' were significantly higher in OGF than in the two secondary forests. This finding was consistent with a general increase in diversity during the process of natural succession toward the climax community [18]. Notably, SCF showed an inverse trend in tree species diversity despite a significantly lower tree density than LCF. Floristic similarity between forest types, denoted as (Cj), ranged from 0.24 to 0.35, with the highest (Cj) value of 0.35 found between LCF and SCF. In this study, the floristic similarity (Cj) between SCF, LCF and OGF was low, in`dicating a significant difference in floristics. The reason may be due to the regeneration time. The short time of regeneration in SCF and LCF could explain the low similarity, because restoration time determines the degree of similarity between forest types in different successional stages. The low similarity between the primary and secondary forests owning to the short time during which secondary forests have regenerated [18]. SCF and LCF had similar floristics owning to being same as in their successional stages.

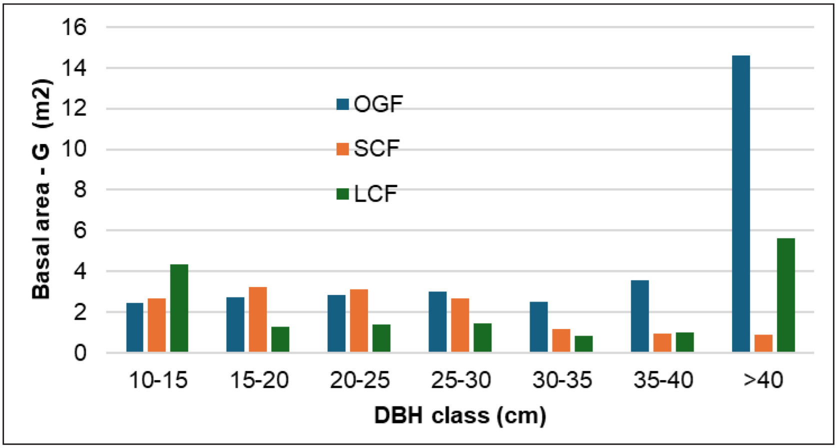

Fig. 5. Distribution of basal area of canopy tree by DBH class in three forest types.

This study demonstrates that following over 30 years of disturbance cessation in SCF and LCF forests, the overall tree density trend was declining. However, recovery potential, as measured by density and total basal area (ΣG), exhibits distinct variations. While SCF density has nearly reached that of OGF, it remained concentrated primarily in smaller diameter classes (<25 cm DBH). This suggests robust recovery for SCF forests, although they have not achieved the same high state as OGF , particularly in terms of ΣG (approximately half that of OGF). This discrepancy may be attributed to specific growth characteristics during forest recovery. Despite a significant increase in tree numbers, a shortage of large-diameter trees persists, resulting in a substantially lower of ΣG. In contrast, LCF, despite having the lowest density, does not significantly differ in total basal area compared to SCF forests. Notably, LCF exhibited a higher density of large trees than SCF (>40 cm DBH). This was also a significant difference of the LCF forest in the study area compared to other areas because the characteristics of LCF forest are concentrated with many small-diameter tree species [20]. The complexity of recovery outcomes over time may arise from several factors such as (1) insufficient cessation duration and mechanical division, failing to fully reflect the essence of succession; (2) varying site conditions leading to different recovery rates despite the same cessation duration [8]; (3) differences in forest states at the time of cessation, resulting in significant fluctuations in their current characteristics; and (4) unidentified factors continuing to influence forests after cessation in the evergreen forest types of the Central Highlands in Vietnam [5]. For instance, at the beginning of disturbance cessation, SCF forests retained forest structure conditions (despite strong exploitation), while LCF forests started from non-forest structure conditions. This underscores the need for in-depth research on site-specific conditions to tailor restoration strategies based on local factors (e.g., soil quality, topography).

Comparing the forest recovery status in this study with a similar context in the Dong Nai Biosphere Reserve in Vietnam, reveals significantly higher tree density (763 ± 54 trees.ha^{-1} vs. 398 ± 142 trees.ha^{-1}), despite similar total cessation duration and initial conditions [5]. In East Kalimantan, 16 years after forest exploitation, pioneer species still dominate, while late-successional species emerge as early as 10 years after fire. Protecting forests from exploitation and fire over an extended period allowed them to recover from their initial state [11]. However, the precise duration for forest recovery remains speculative without empirical evidence. There was a lightly exploited forests recover rapidly [3]. At 12 years post-exploitation, secondary forests still significantly differ from old-growth forests [13]. After 40-55 years of exploitation, secondary forests only partially recover compared to old-growth forests [22]. Another suggestion that structural recovery after exploitation may take up to 112 years, with compositional recovery requiring even more time [2]. Overall, research underscores that forest recovery capacity and extent depend significantly on their pre-exploitation state [1]. Long-term monitoring is essential to assess recovery success over extended periods.

Floristic characteristics

The survey results indicated that each plot contains an average of 31 to 43 tree species belonging to 28 to 38 genera and spanning 19 to 22 families (Tab. 4). Notably, old-growth forests exhibited the highest taxon richness, while this richness is lowest in LCF. Post-hoc LSD tests indicated that there was no significant difference between OGF and SCF in terms of species diversity. However, LCF stands out with significantly lower genera and species compared to both OGF and SCF ($p < 0.05$). At the family level, there was no statistically significant difference among forest types ($p > 0.05$). In terms of total species richness and the diversity index of forest types in the research area, the results indicate that the secondary forest types in the study area has higher species richness (28, 42) and He' (2.91, 3.17) [5]. Both SCF and LCF require more time to reach a state similar to the high peak as OGF. This is clearly reflected in the differences in the Cj index, species richness, and the number of genera between SCF and LCF when compared to OGF, with these indices having lower values for LCF.

Table 4.

Species, genera and families density of successional stages.

Successional stage	Plot No.	No of species	No. of genera	No. of families
OGF	1	48	42	25
	2	42	36	19
	3	39	35	21
	Mean±SE	43±3	38±2	22±2
SCF	1	36	35	21
	2	44	40	21
	3	39	39	23
	Mean±SE	40±2	38±2	22±1
LCF	1	28	25	17
	2	35	33	21
	3	30	26	18
	Mean±SE	31±2	28±3	19±1

The figure at Tab. 5 provides valuable insights into the composition of tree species within different forest types. In each plot, there were 3 to 7 species actively participating in the compositional formulation. Notably, OGF and LCF exhibited a higher number of dominant species involved in the compositional formulation. In these forest types, 5 to 7 species play a significant role (IV%>5%), collectively accounting for 48.7% to 63.8% of the total IV%. In contrast, SCF had a more limited participation, with only 3 to 4 species contributing significantly. These species represented 37.6% to 57% of the total IV%.

Table 5.

Composition formula for canopy tree of three plots of three typical successional stages.

Successional stage	Plot no.	Composition formula
OGF	1	14.1 Da + 10.5 CaC + 7.5 Sc + 6.3 Dai + 5.3 Syz + 56.2 Other species
	2	12.5 Da + 11.9 CaC + 11.1 Syz + 9.0 Mim + 6.8 Syp + 5.8 Syw + 42.8 Other species
	3	14.3 CaC + 10.3 Syz + 10,1 Syp + 7.9 Mim + 7.8 Poa + 6.6 Dai + 43.1 Other species
SCF	1	24.1 Map + 15.4 Mat + 11.4 Cha + 6.2 Li + 43.0 Other species
	2	23.7 Mat + 16.8 Map + 7.9 Tr + 5.1 Cha + 46.5 Other species
	3	20.9 Map + 11.4 Cha + 5.3 Poa + 62.4 Other species
LCF	1	15.8 Ret + 15.5 Cim + 12 Pr + 8.5 Cap + 5.3 Lis + 51.3 Other species
	2	18.1 Ret + 11.2 Map + 11.0 Lis + 8.0 Pr + 6.2 Mim + 45.6 Other species
	3	12 Map + 11.5 Cha + 10.6 Cap + 9.9 El + 7.0 Pr + 6.4 Syw + 6.2 Ca + 36.2 Other species

Note: Ca*: Canthium parvifolium.,* CaC*: Calophyllum calaba,* Cap*: Castanopsis pseudoserrata,* Cha*: Choerospondias axillaris,* Cim*: Cinnamomum mairei,* Dae*: Dacrydium elatum,* Dai*: Dacrycarpus imbricatus,* El*: Elaeocarpus hygrophilus,* Li*: Litsea elongata,* Lip*: Lithocarpus silvicolarum,* Mat*: Macaranga tanarius,* Mim*: Michelia mediocris,* Poa*: Polyosma annamensis:* Map*: Machilus parviflora,* Pr*: Prunus arborea,* Ret*: Rehderodendron truongsonense,* Sc*: Schima wallichii,* Syp*: Syzygium pachysarcum,* Syw*: Syzygium wightianum,* Syz*: Syzygium zeylanicum,* Tr*: Trema angustifolia,* Da*: Dacrydium elatum.*

In OGF, the dominant species include *Calophyllum calaba, Dacrydium elatum,* and *Dacrydium elatum*, with respective IV% of 14.3%, 14.1%, and 12.5%. Additional species with IV% exceeding 10% comprise *Calophyllum calaba, Syzygium zeylanicum, and Syzygium pachysarcum*. In SCF, *Machilus parviflora* and *Macaranga tanarius* are prominent species, exhibiting remarkably high IV% values, reaching 24.1% of the total IV%. Additionally, some pioneer shade-tolerant species contribute to compositional dynamics, such as *Trema angustifolia*, *Choerospondias axillaris*, and *Litsea elongata*. In LCF are characterized by several dominant species with high IV% (ranging from 10.6%

to 18.1%). These species include *Rehderodendron truongsonense, Cinnamomum mairei, Prunus arborea, Machilus parviflora, Choerospondias axillaris, Lithocarpus silvicolarum,* and *Castanopsis pseudoserrata*. Notably, LCF also features the participation of some pioneer species from SCF, such as *Machilus parviflora* and *Choerospondias axillaris*. The figure at Tab. 6 presents the distribution of tree species and ΣG for the top 10 of prevalent families across three forest types.

Table 6.

Percentage of total high tree density and basal area of the most common families in successional stages (SCF, LCF and OGF)

Family	**Secondary forests**				**Old-growth forests (OGF)**	
	LCF		***SCF***			
	N (%)	*ΣG (%)*	*N (%)*	*ΣG (%)*	*N (%)*	*ΣG (%)*
Anacardiaceae	3.85	6.62	8.43	12.77		
Clusiaceae					17.83	9.02
Elaeocarpaceae	2.31	6.44	1.53	3.82	3.50	5.94
Escalloniaceae					4.02	3.26
Euphorbiaceae			24.14	24.61	5.24	2.36
Fabaceae	2.31	3.22				
Fagaceae	12.31	16.62	3.26	5.60		
Lauraceae	17.69	20.66	29.89	25.93	6.99	5.16
Magnoliaceae	5.00	2.75			4.02	9.95
Meliaceae			2.49	4.16		
Moraceae	3.08	1.73				
Myrtaceae					18.53	23.09
Podocarpaceae					8.92	21.35
Proteaceae			2.11	1.95		
Rosaceae	10.00	6.97				
Rubiaceae	8.46	5.32			6.99	2.28
Rutaceae			2.87	1.78		
Styracaceae	11.15	12.19	2.68	2.37		
Theaceae					6.12	7.25
Ulmaceae			4.41	4.74		

It could be stated that Elaeocarpaceae and Lauraceae demonstrate a high prevalence, ranking among the top ten families in all three forest types. In the OGF, the most abundant families in terms of tree stems were Myrtaceae (18.53%), Clusiaceae (17.83%), and Podocarpaceae (8.92%). With respect to the sum G, Myrtaceae (23.09%), Podocarpaceae (21.35%), and Clusiaceae (9.02%) were the most dominant families. In the LCF, the Lauraceae, Fagaceae, and Styracaceae families stand out as particularly noteworthy, with individual species representing 17.69%, 12.31%, and 11.15%, respectively. The corresponding ΣG% for these families was 20.66%, 16.62%, and 12.19%. In the SCF, the three most prevalent families were Lauraceae (29.89%), Euphorbiaceae (24.14%), and Anacardiaceae (8.43%). The Lauraceae family contributed the highest value of ΣG (25.93%), followed by the Euphorbiaceae (24.61%) and Anacardiaceae (12.77%) families. The findings of this study align with those of previous research on forest plant communities in the Kon Chu Rang region [12]. The dominant tree species in secondary forests were from the families Euphorbiaceae, Lauraceae, and Magnoliaceae. In contrast, the associations of species from the families Clusiaceae and Myrtaceae in old-growth forests represent a novel discovery compared to previous studies and reports in the area (Kon Chu Rang National Reserve, 2018) [12].

The results of the species composition structure assessment at different successional stages demonstrated that the majority of research plots exhibited a dominance of three to seven species. The floristic characteristics of the successional stages of LCF were dominated by species belonging to the heliophilous, fast-growing tree group, including *Machilus parviflora, Macaranga tanarius, Litsea elongata, Clausena sp.*, and *Prunus arborea*, among others. In contrast, the dominant species in the SCF contained numerous species of shade-tolerant forest trees, such as *Rehderodendron truongsonense, Cinnamomum mairei, Castanopsis pseudoserrata, Litsea elongata, Syzygium wightianum*, and others were identified. These characteristics were consistent with the features of post-logging forests and secondary forests in Vietnam [21; 23]. In the initial successional stages of LCF, the dominant species were heliophilous trees, which colonized the bare land or small shrubby areas. In contrast, the initial successional stages of SCF were characterized by the presence of old-growth forest, which allowed for the establishment of a diverse species composition, including both heliophilous and shade-tolerant forest tree species. These differences in species composition between SCF and LCF, as well as between secondary and old-growth forests, can be attributed to the distinct initial successional characteristics of each state. It should be noted that the recovery rates of the two forest states, SCF and LCF, also differ. Despite the comparable cessation period of 30 years, the recovery rate in terms of biodiversity does not exhibit a significant discrepancy between the two subjects. However, the SCF forest type demonstrates a more rapid recovery in terms of tree and family number compared to LCF when OGF is considered as the climax forest (Tab. 3 and Tab. 6). These findings were consistent with those reported for the Hainan forest and Costa Rica [9; 18].

Conclusion

Our findings indicated that continuous NDVI values serve as a suitable indicator for classifying forest successional stages, with a threshold value of 0.7. The structural anddiversity characteristics of the three typical successional satges exhibited notable variation. The tree density ranged from 347 to 763 stems per hectare, while the total basal area varied from 15.5 to 42.8 m² per hectare, with significant differences among them ($p < 0.05$). A decreasing trend in tree density distribution by DBH class was observed across all forest types. However, the OGF exhibited the highest tree density and basal area for DBH classes larger than 25 cm. The diversity of the old-growth forest was significantly higher than that of the two secondary forests. This is attributed mainly to the duration of restoration and the initial state at the beginning of disturbance cessation. A total of 31 to 43 tree species, belonging to 28 to 38 genera and spanning 19 to 22 families, were identified. The lowest species richness was observed in the LCF. Three to seven species were identified as actively contributing to the compositional structure. In the LCF, dominant tree species were heliophilous and fast-growing, whereas in the SCF, they were shade-tolerant. Of note, the associations of the species belong to Clusiaceae and Myrtaceae in old-growth forests represented a novel finding compared to previous studies in the research area. Long-term monitoring and research are crucial to assess recovery success over extended periods.

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Tran T.T. Huong: Formation of the idea and development of objectives, its critical revision with the introduction of valuable comments of intellectual content, final approval of the manuscript for publication.

Nguyen D. Hoi: Preparation and approval of the final version of the article.

Dang H. Cuong: Data collection, interpretation of the results obtained, application of statictical for the analysis research data.

Nguyen T. Minh: Data collection, interpretation of the results obtained, mathematical computational methods for the analysis of GIS data, drafting the manuscript.

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