Woody plants diversity and its relationship with carbon stock in the tropical moist evergreen closed forest, Dong Nai Cultural Nature Reserve

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Đa dạng thực vật thân gỗ và mối liên hệ của nó với trữ lượng carbon trên mặt đất trong rừng kín thường xanh ẩm nhiệt đới, Khu Bảo tồn thiên nhiên - Văn hóa Đồng Nai

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ABSTRACT
This study was conducted to test the hypothesis of a statistically meaningful existence between woody plant diversity and aboveground carbon stock in the tropical moist evergreen closed forests at Dong Nai Cultural Nature Reserve. The result showed that, in total, 49 plant species of 30 families were recorded. Twenty-one threatened species were listed in Decree 84/2021/ND-CP of the Government, Vietnam Red Data Book (2007), and IUCN Red List (2022). The indicators reflecting the level of diversity were identified: Species richness (S) 15.44±2.69 species; Abundance (A) 51.68±3.42 trees; Margalef (d) 3.66±0.69; Pielou (J') 0.87±0.05; Simpson (Cd) 0.13±0.04; and Shannon-Wiener (H') index 2.36±0.25. The ability to carbon stock aboveground ranged from 78.67 tons/ha to 255.64 tons/ha, with an average of 161.04±54.38 tons/ha. Furthermore, the linear correlation between species richness (S), tree abundance (A), Margalef index (d), Pielou (J'), Simpson (Cd), and aboveground carbon was not found. Meanwhile, a statistically significant but very weak correlation between Shannon-Wiener (H') and aboveground carbon was detected. Thus, the original hypothesis was that woody plant diversity and aboveground carbon did not occur. Therefore, priority should be given to managing and conserving plant diversity instead of promoting the study area's aboveground biomass and carbon accumulation function.

Keywords:
Aboveground carbon stock, correlation, Dong Nai Cultural Nature Reserve, tropical moist evergreen closed forest, woody plant species.

TÓM TẮT
Nghiên cứu này được thực hiện nhằm kiểm định giả thuyết về sự tồn tại có ý nghĩa thống kê giữa đa dạng thực vật thân gỗ và trữ lượng carbon trên mặt đất trong kiểu rừng kín thường xanh ẩm nhiệt đới tại Khu Bảo tồn thiên nhiên - Văn hóa Đồng Nai. Kết quả cho thấy, tổng số 49 loài thực vật thuộc 30 họ đã được ghi nhận. Trong đó, 21 loài bị đe dọa được liệt kê trong Sách Đỏ Việt Nam (2007), Nghị định 84/2021/ND-CP của Chính Phủ và Sách Đỏ IUCN (2022). Những chỉ số phản ảnh mức độ đa dạng thực vật đã được xác định: độ giàu loài 15,44±2,69 loài; độ phong phú 51,68±3,42 cây; chỉ số Margalef (d) 3,66±0,69; Pielou (J') 0,87±0,05; Simpson (Cd) 0,13±0,04; và Shannon-Wiener (H') 2,36±0,25. Khả năng lưu trữ carbon trên mặt đất biến động từ 78,67 tấn/ha đến 255,64 tấn/ha, trung bình đạt 161,04±54,38 tấn/ha. Bên cạnh đó, mối tương quan tuyến tính giữa độ giàu loài (S), độ phong (A), chỉ số Margalef (d), Pielou (J'), Simpson (Cd) và carbon trên mặt đất đã không được tìm thấy. Trong khi đó, mối tương quan có ý nghĩa thống kê nhưng rất yếu giữa Shannon-Wiener (H') và carbon trên mặt đất đã được phát hiện. Như vậy, giả thuyết ban đầu về sự tồn tại mối liên hệ giữa đa dạng thực vật thân gỗ và carbon trên mặt đất đã không xảy ra. Mặc dù mối liên hệ này không được tìm thấy, nhưng những kết quả đạt được cho thấy tiềm năng về đa dạng thực vật và trữ lượng carbon ở khu vực nghiên cứu. Do đó, cần ưu tiên quản lý và bảo tồn đa dạng thực vật thay vì thúc đẩy chức năng tích lũy sinh khối và carbon trên mặt đất ở khu vực nghiên cứu.

Từ khóa:
Khu Bảo tồn thiên nhiên - Văn hóa Đồng Nai, rừng kín thường xanh ẩm nhiệt đới, thực vật thân gỗ, trữ lượng carbon trên mặt đất, tương quan.

1. INTRODUCTION

Tropical forests play an essential role in carbon stock through aboveground biomass (AGB) and are considered the most biodiverse ecosystems on earth [1, 2]. However, the quantitative relationship between AGB and plant diversity has not been satisfactorily resolved [1, 3].

There are currently two hypotheses about the correlation between biodiversity and carbon stocks. The first hypothesis is that there is a relationship between them. This hypothesis is divided into two trends; the first trend is that there is a positive association between species diversity and productivity [4-8]; the second trend is a negative relationship between species diversity and carbon stock [9]. The second hypothesis is that there is no relationship between plant diversity and carbon stock [10-14]. Up to the present time, the debate about the hypothesis of this relationship continues and has not ended.

In Vietnam, a study on the relationship between aboveground carbon and species diversity has been carried out in the tropical evergreen broad-leaved primary forests, deciduous forests belonging to six ecological regions from North to South Central Vietnam [1]; in evergreen broad-leaved secondary forests in the Central Highlands of Vietnam [14]. While Vietnam stretches across many different latitudes, diverse ecosystems, vegetation, and land-use types have yet to be discovered [15]. In particular, the tropical moist evergreen closed forest in Dong Nai Province is a typical example. Does this relationship exist in the tropical moist evergreen closed forests in Dong Nai Cultural Nature Reserve (NR)? A hypothesis for a statistically significant correlation between woody plant diversity and aboveground carbon stocks in the tropical moist evergreen closed forests has been proposed.

The objective of this study was to determine (i) the diversity components: species composition, species richness (S), tree abundance (A), and diversity indices Margalef (d), Simpson (Cd), Shannon-Wiener (H'), Pielou (J'); (ii) estimation of carbon stocks; and (iii) consider whether carbon stocks are related to tree species diversity?. The research results are the basis for managers to develop a management strategy to manage and conserve plant diversity, promote forest carbon stock, or perform both functions simultaneously.

2. RESEARCH METHODOLOGY

2.1. Study area

This study was conducted from November 2022 to December 2022 at coordinates 11°19'31" North latitude, 107°4'42" East longitude, belonging to medium forest status in NR, Dong Nai Province (Fig. 1). The total area of the NR was about 100,571 ha (68,051 ha of forest and forestry land, 32,520 ha of water surface). The climate was characterized by a monsoon climate with two distinct seasons: the rainy season from May to October and the dry season from November to April next year. The average annual temperature was 26.4ºC. Relative humidity was 80-82%, and average annual rainfall was 2,000-2,800 mm. The typical topography was lowland hills; the average altitude was 110 m above sea level; the slope was 5º-20º [16].

2.2. Field investigation

A typical temporary sample plot was established, with 1ha (100 m ×100 m) [17], representing the medium forest status in the NR. The sample plot was equally divided into 25 subplots with an area of 400 m^2 (20 m x 20 m) and numbered from 1 to 25 to collect the necessary information. In each subplot, information about trees with a diameter at breast height (DBH) > 5 cm was collected, including DBH was measured by callipers with an error of 0.5 cm, overall height (Hvn) was measured by Blume–Leiss with an error of 0.5 m; determine the species name and relative coordinates of each tree in the subplots using a tape measure and a compass.

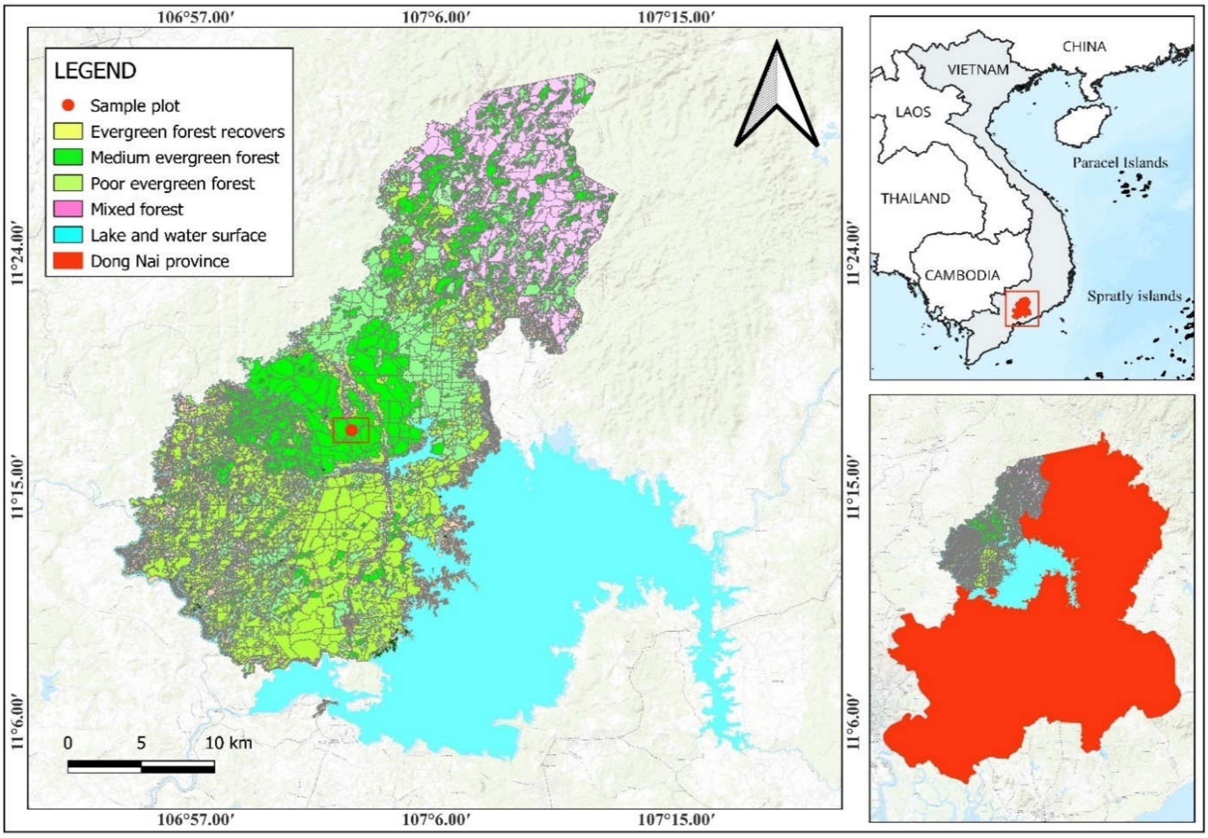


Figure 1. The study area map and sample plot location

2.3. Data analysis

Plant species identification: Plant species names were determined in the field by plant taxonomists. For undetermined species, specimens were collected, processed, and morphological comparisons were used to identify species names. Materials used include An Illustrated Flora of Vietnam, volumes 1-3 [18]; Timber Resources in Vietnam [19]. The scientific name of the species was corrected by POWO (2022) [20]. The threatened plant species composition was determined by Decree No.84 (2021) of the Vietnam Government [21], Vietnam Red Data Book (2007) [22], and IUCN Red List 2022 [23]. Forest status was determined based on Circular 33/2018/TT-BNNPTNT of the Ministry of Agriculture and Rural Development [24].

Some diverse indices: The Margalef (d), Shannon – Wiener (H'), Simpson (Cd), and Pielou (J') index were calculated by PRIMER 6.1.6 software. Diversity level (H') was divided into very low (H'<1), low (2>H'≥1), moderate (3>H'≥2), high (4>H'≥3), and very high (H'≥4) [25].

Estimates of biomass and carbon stocks: Aboveground biomass (AGB) of each tree; total of AGB per hectare; and the tree's carbon stock (AGC) were determined by the formula (1) [26], (2), and (3) [27]: In which: AGB was the aboveground biomass of the tree (kg/tree); DBH (cm) was the DBH; AGB (kg/ha) was the total biomass per plot in hectares; AGB (otc) was the total biomass per plot; S (plot) was the plot area in m^2; AGC was the carbon stock of the tree (kg/tree); 0.5 was the IPCC default carbon fraction coefficient.

AGB (kg/tree) = exp(-2.134 + 2.530*ln(DBH)), với DBH = 5 – 148 cm, n = 170 tree, R^2= 0.97 (1)

$$\text{AGB (kg/ha)} = \frac{\text{AGB (plot)} \quad 10.000}{\text{S (plot)}} \quad (2)$$

AGC (kg/tree) = AGB (kg/tree)*0.50 (3)

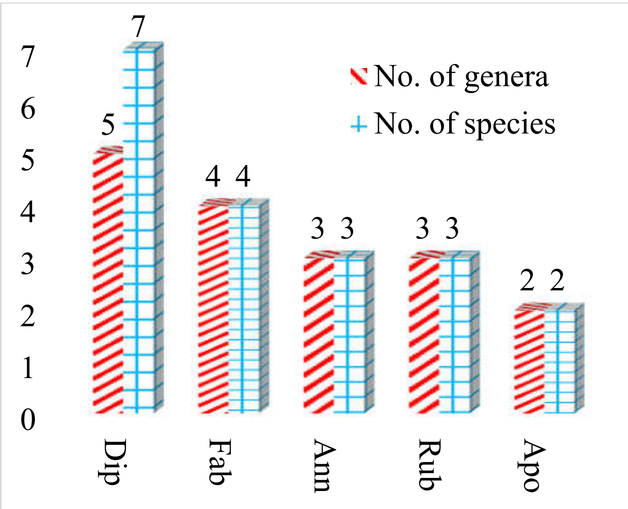
Identification of the relationship between plant diversity and aboveground carbon stocks: Excel spreadsheets were used to calculate AGB, AGC, species composition, genera, and plant families. Meanwhile, SPSS ver. 23 software was used to analyze the relationship between plant biodiversity and aboveground carbon stocks.

3. RESULTS

3.1. Diversity of plant species

3.1.1. Plant taxon diversity

The results of the investigation and data analysis, a total of 1292 trees of 49 species in 42 genera belonging to 30 families were recorded. The families with genera and species richest: Dipterocarpaceae was represented by five genera (11.90%) and seven species (14.29%). Fabaceae with four genera (9.52%) and four species (8.16%); Annonaceae and Rubiaceae together have three genera (7.14%) and three species (6.12%); Apocynaceae was two genera (4.76%) and two species (4.08%) (Fig. 2). The families with trees abundances (more than 50 trees) include Dipterocarpaceae, with 452 trees (34.98%), followed by Lecythidaceae with 219 trees (16.95%), Sapindaceae with 108 trees (8.36%), Ebenaceae with 77 trees (5.96%), Polygalaceae with 75 trees (5.80%), and Clusiaceae with 53 trees (4.10%) (Fig. 3).



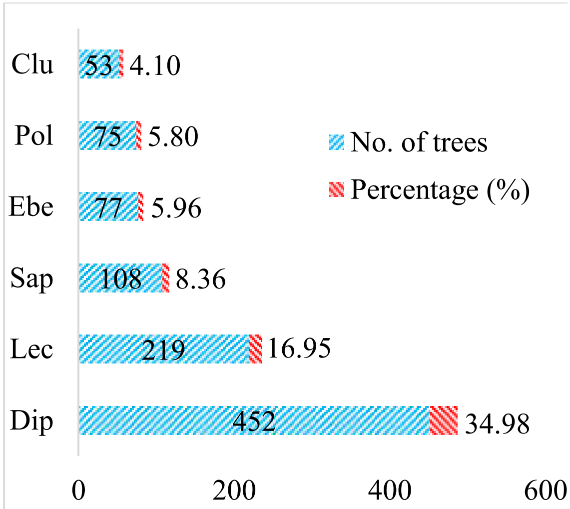


Figure 2. Five families with genera and species richest **Figure 3. Six families with trees abundances**

(Dip: Dipterocarpaceae; Fab: Fabaceae; Ann: Annonaceae; Ru: Rubiaceae; Apo: Apocynaceae; Lec: Lecythidaceae; Sap: Sapindaceae; Ebe: Ebenaceae; Pol: Polygalaceae; Clu: Clusiaceae)

Twenty-one species (42.86%) were identified as threatened plants. Three species were found in group IIA of Decree 84/2021/ND-CP of the Government; 7 species in the Vietnam Red Data Book (2007): 4 Endangered (EN), 3 Vulnerable (VU)); 21 species in the IUCN Red List (2022): 4 Endangered (EN), 5 Vulnerable (VU), and 12 Least Concern (LC)).

3.1.2. Some plant diversity indices

The analysis results showed that the diversity of woody plants was moderate and ranged between subplots. In which tree abundance (A) ranged from 46-63 trees, average 51.68±3.42 trees; species richness (S) from 10-21 species, average 15.44±2.69 species (Fig. 4); the Margalef (d) ranged from 2.27-5.04, average 3.66±0.69; Pielou (J') 0.73-0.93, average 0.87±0.05; Simpson (Cd) 0.08-0.23, average 0.13±0.04; and Shannon-Wiener index (H') 1.87-2.68, average 2.36±0.25 (Fig. 5).

3.2. Aboveground carbon stock

3.2.1. Total of aboveground carbon stock

The aboveground carbon stock in the tropical moist evergreen closed forest depends on subplots, ranged from 78.67 (tons/ha) in subplot 7 to 255.64 (tons/ha) in subplot 8, with an average of 161.04±54.38 (tons/ha) (Fig. 4).

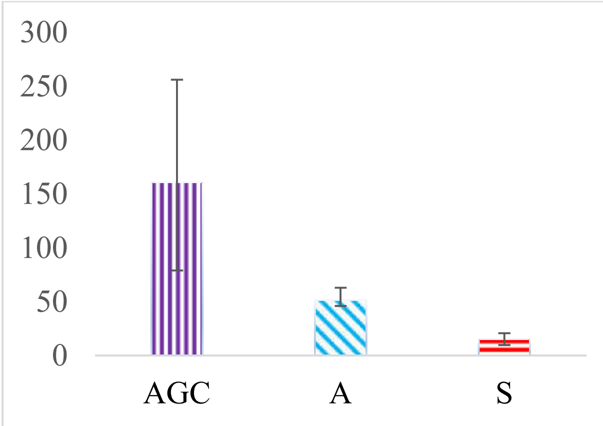


Figure 4. Mean and SD of AGC, A, và S

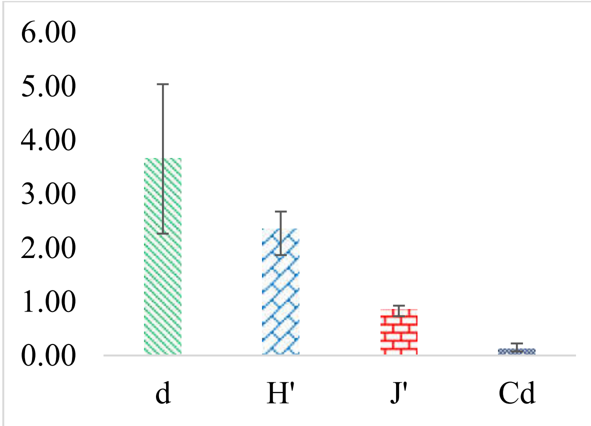


Figure 5. Mean and SD of d, H', J' và Cd

(SD: Standard deviation; AGC: Aboveground carbon stocks; A: Tree abundance; S: Species richness; d: Margalef index; H': Shannon-Wiener index; J': Pielou index; Cd: Simpson index)

3.2.2. Distribution of carbon stocks DBH class

Table 1 shows that the dependence of carbon stock (AGC) on DBH level is much larger than tree abundance. Specifically, in DBH class <10 cm, the number of trees accounts for 26.16%, but the ratio carbon stock accounts for only 2.72%; at 10 cm ≤DBH<20 cm, the number of trees accounted for 55.34%, the percentage of carbon stock was only 18.65%; at 20 cm ≤DBH<30 cm, the number of trees accounted for 9.83%, while the percentage of carbon stocks accounted for 15.50%, at higher DBH, the number of species decreased strongly, while the percentage of carbon stocks accumulation was not significantly reduced.

Table 1. Distribution of carbon stocks by DBH class (cm)

DBH class	Tree abundance		AGC (tons/ha)	
	No. of tree	Percentage (%)	Carbon stock	Percentage (%)
DBH<10	338	26.16	4.38	2.72
10≤DBH<20	715	55.34	30.04	18.65
20≤DBH<30	127	9.83	24.96	15.50
30≤DBH<40	52	4.02	21.43	13.31
40≤DBH<50	25	1.93	18.68	11.60
50≤DBH<60	17	1.32	21.89	13.60
60≤DBH<71	9	0.70	16.14	10.02
70≤DBH<80	6	0.46	15.55	9.66
80≤DBH<90	3	0.23	7.96	4.95
Total	**1292**	**100**	**161.04**	**100**

The results demonstrated that the aboveground carbon stock of DBH trees < 10 cm was negligible (2.72%). Therefore, in practice measuring biomass and carbon stock, we recommend selecting trees with DBH ≥ 10 cm for field measurements. It will contribute to saving time, human resources, and finance. The DBH showed a strong influence on AGC accumulation. For carbon accumulation in plantation models, it is necessary to apply technical measures to maximize tree growth and development in DBH through appropriate density adjustment.

3.3. The relationship between plant diversity and aboveground carbon stocks

The analysis results showed that no relationship was found between aboveground carbon stock and species richness (S) (R^2=0.1273, F=3.356, P-value=0.080); tree abundance (N) (R^2=0.0037, F=0.085, P-value=0.773); Margalef (d) (R^2=0.1287, F=3.396, P-value=0.078); Pielou (J')

(R^2=0.1015, F=2.578, P-value=0.122); and Simpson (Cd) (R^2=0.1464, F=3.944, P-value=0.059>0.05) (Fig. 6a, 6b, 6c, 6d, 6e). However, we found that there was a statistically significant but weak positive relationship between aboveground carbon stocks and the Shannon-Wiener index (H') (R^2=0.1585, F= 4.332, P-value=0.049 < 0.05) (Fig. 6f).

4. DISCUSSION

4.1. Plant diversity

The results of the present study indicated that the diversity of woody plants was moderate. This observation was supported by a study at secondary, unstable, and stable forests (H' = 2.57 - 2.71) [28]; at several plant superiorities in the tropical moist evergreen closed forest in the Ma Da area (H' = 2.50-2.88) [29]; The report conducted on medium and rich forests confirmed the diversity at the medium level (H'=2.41) [16]. Several studies in tropical moist evergreen closed forests in Tan Phu, Dong Nai showed similarities with the present study.

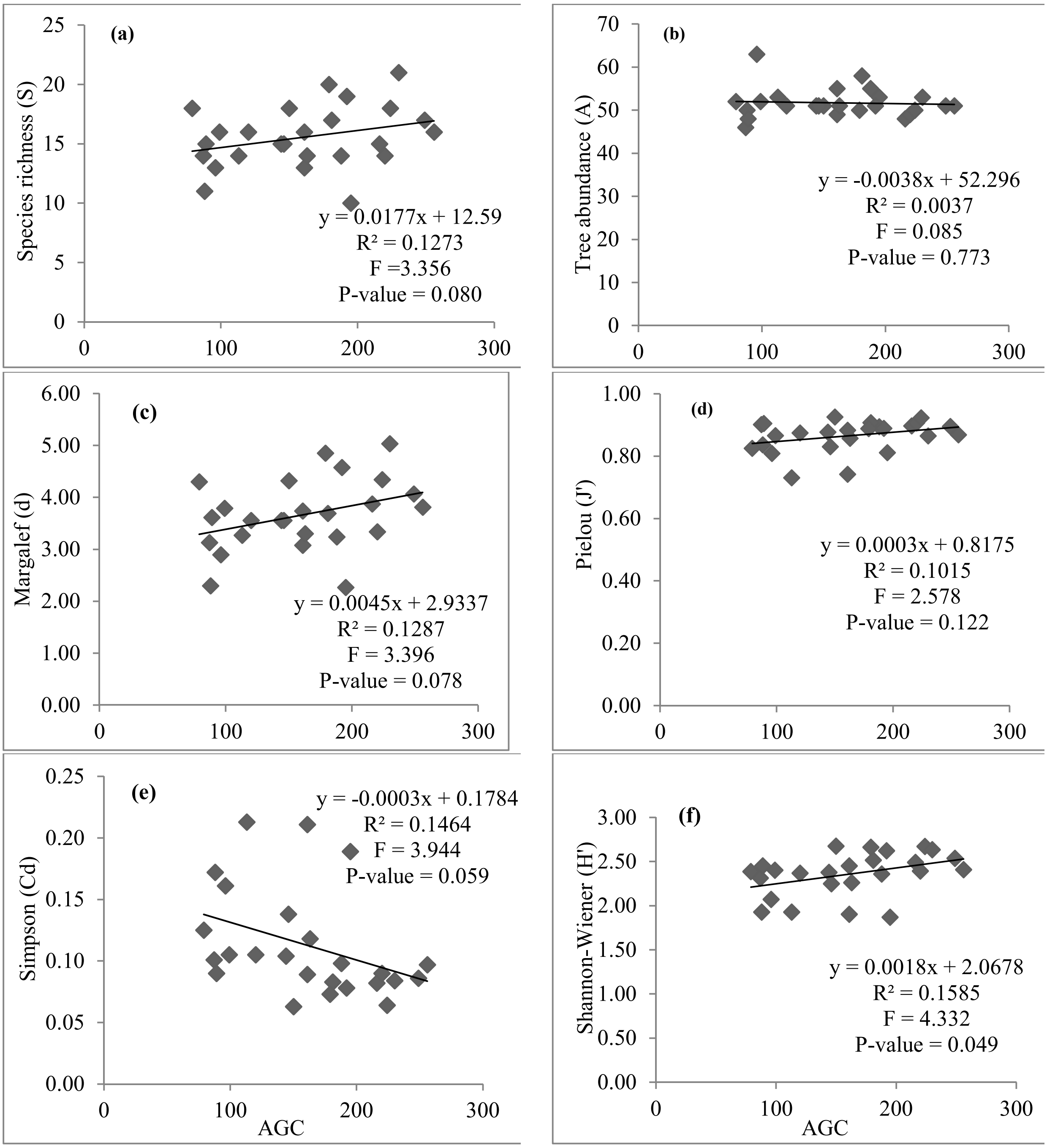


Figure 6. The relationship between AGC and (a): species richness (S); (b): tree abundance (A); (c): Margalef (d); (d): Pielou (J'); (e): Simpson (Cd); (f): Shannon-Wiener (H')

Five dominant plant communities of Dipterocarpaceae were *Dipterocarpus dyeri, D. alatus, Hopea odorata, Shorea roxburghii,* and *Anisoptera costata* (H'= 2.87) [30], at three states of the dominant forest *Shorea roxburghii* (H'= 2.94) [31]; at three forest states poor, medium and rich (H' = 2.42 ± 0.46) [32]; while at three poor, medium, and rich forest status of evergreen broad-leaved forest in the Central Highlands also supports the results of this study (H' from 2.17 ± 0.48 to 2.31 ± 0.35) [14]. A study at the dominant forest of *Dipterocarpus chartaceus* in Binh Chau-Phuoc Buu Nature Reserve recorded to indicate a low to moderate diversity (H' = 1.66 - 2.79) [33]. This shows that plant diversity depends on the forest status, dominant community, and vegetation type. In the same forest state, the level of woody plant diversity also depends on the size of the sample plots studied [34]. Besides, in different ecological sesame, variety depends on the conditions of climate, geography, latitude, and forest style. When environmental factors change, it will shift plant diversity through changes in composition, number of species, and individual trees [35].

4.2. Carbon stock

This study was first conducted in the NR's tropical moist evergreen closed forest. Aboveground carbon stocks were recorded on average 161.04 ± 54.38 tons/ha. Some studies in a similar forest type in Tan Phu showed negligible differences. The results of the present study were higher than that of the Tan Phu forest, where carbon stocks at the states of *Shorea roxburghii* dominant forest ranged from 53.07 (tons/ha) to 141.32 (tons/ha) [31]. A report carried out at five plant communities of Dipterocarpaceae has determined that the carbon stocks ranged from 108.89 (tons/ha) to 174.61 (tons/ha) [30]. Some studies in the Central Highlands also showed lower results than the present study. A discovery in the evergreen broad-leaved forest in the Tuy Duc district, Dak Nong province, identified an aboveground carbon stock from 36.38 (tons/ha) to 153.16 (tons/ha) [3]. A study found in the evergreen broad-leaved forest in the Central Highlands recorded carbon stocks ranged from 37.58 ± 13.42 (tons/ha) to 123.20 ± 33.28 (tons/ha) [14].

The current study was higher than the study conducted in the evergreen broad-leaved forest belonging to some ecological regions of Vietnam [1]. Accordingly, the carbon reserves on the ground in the Northeast were 143 tons/ha, the Northern Center 110.8 tons/ha, the Northwest 75.5 tons/ha, the North Central Coast 86.3 tons/ha, the Coast of Central Vietnam 144.3 tons /ha, and the Central Highlands 143.8 tons/ha [1]. Another report was carried out at the dominant forest of *Dipterocarpus chartaceus* in Binh Chau-Phu Buu Nature Reserve also recorded carbon stocks from 24.07 (tons/ha) to 98.42 (tons/ha), lower than this study [33]. Another report in the Central Highlands, Vietnam, showed increased carbon stocks from the very poor to very rich forests [36].

This difference could be explained by climatic and soil conditions, especially rainfall and humidity, affecting forest trees' growth, development, and productivity [37]. In addition, the difference in the composition of the tree and latitude could also be considered as factors affecting the productivity of the forest. Moreover, the difference in geodetic conditions and the ecological environment of these studies also affected the ability to accumulate carbon [14, 31]. These studies were conducted in different vegetation types and forest states so that carbon reserves would differ [14, 31, 36]. On the other hand, this is a secondary forest restored after selection harvest system activity, valuable and large-sized tree species were exploited, only timber species of low economic value, with a diameter at breast height of small [3, 14, 31].

4.3. Relationship between plant diversity and carbon stock

In this study, we discovered a statistically positive relationship but weak, between Shannon-Wiener (H') and carbon stocks (P-Value <0.05). This result received support from research conducted by Wang *et al.* (2011) [8] and Quo (2007) [38], which found a positive but weak relationship between carbon reserves and biodiversity. Meanwhile, a negative but weak relationship between carbon reserves and the

Pielou index (J') was determined in the style of the evergreen broad-leaved forest, Central Highlands, Vietnam [14]. However, the current study found no relationship between the remaining plant diversity and carbon stocks. This result is similar to the research conducted in the Central Highlands and Vietnam [14]. The study recorded that most plant diversity without a correlation was significant to statistics with aboveground carbon stocks in the evergreen broad-leaved forest [14]. Generally, the change in carbon reserves does not depend on plant diversity [39]. Another report discovered that any significant relationship between carbon stocks and biodiversity was not found [40]. Carbon stocks could explain this depending mainly on the diameter and height of the tree.

In contrast, the diversity level depends on the species richness and individual tree abundance in each species. This statement is consistent with the discovery of Chave *et al.* (2014) [41], who have determined the value of carbon stocks depends on the size of the tree (circumference), the density of the tree, and the height, in which the density of the tree is a significant factor. Besides, carbon stocks increased as the tree's diameter increased [42]. Moreover, carbon values were stored in correlation with the density of trees [43].

In this study, in addition to the Shannon-Wiener index (H), the other diversity indices did not correlate with aboveground carbon stocks. This result was in contrast to findings in primary forest types in Vietnam [1], which reported that the extent of species diversity increased by increased biomass and aboveground carbon stocks. The difference in environmental stability between research locations may cause the effect of the relationship between two diverse variables and carbon stocks due to various relationships in capacity affected by the environment because the study of Tran Van Con *et al.* (2013) [1] was conducted in primeval forests, stable in composition and species structure. Meanwhile, the current research was carried out in the forests that were not stable due to the selection harvest system in the 90s of the last century [14, 44, 45]. Some other studies have found that the degree of distribution by human activities complicates the correlation between carbon and plant diversity [14, 15].

These reports have shown that various environmental factors, such as climate, soil, and disturbance, influenced the spatial distribution of biomass and biodiversity. When the environment was homogeneous, the relationship between linear diversity and productivity was considered, which could be either positive or negative [46]. When the environment is heterogeneous, single relationships that are not statistically significant can occur [47]. However, such associations not found are often more typical for nascent, short-lived plant communities than long-lived, stable biomes [48]. This was consistent with the tropical moist evergreen closed forest in the Nature Reserve. New communities have been formed over the past 20 years due to disturbance by human activities through selection harvest system activity in the 80s-90s of the last century [30, 31]. These disturbances disrupt the species' and tree stratum structures over time. This affects species diversity and forest productivity.

Thus, maintaining the function of plant diversity and promoting biomass productivity and carbon stock simultaneously can hardly be done at present. Due to plant diversity, there was no significant effect on carbon stock in the study area. Moreover, the limitations of human, financial resources and facilities must also be carefully considered. Instead, priority should be given to managing and conserving plant diversity, ensuring the forest ecosystem's stable and sustainable development.

5. CONCLUSION

A total of 1292 trees in 49 species of 42 genera belonging to 30 families were recorded in the NR's medium state of the tropical moist evergreen closed forest. The diversity of woody plants was moderate. The average aboveground carbon stock was 161.04±54.38 (tons/ha).

This study found a weak correlation between the Shannon-Wiener index (H') and aboveground carbon stocks, but the remaining plant diversity indices and carbon stocks were not found. However, the present study also demonstrates the role of plant diversity and the potential of forests to store carbon as a potentially rich carbon sink that contributes to climate change mitigation through biomass accumulation and forest carbon.

Forests and forest vegetation are the most important reservoirs for biodiversity and carbon. Therefore, maintaining existing forest areas, or enhancing and expanding forest areas through the planting of native tree species, limits illegal human impacts on forest resources and, at the same time, manages the forest resources. Effective management of forest fires are measures that bring "double benefits" from forest ecosystems.

It is necessary to carry out further studies for the remaining forest states: poor, restored, and mixed forests, to have a comprehensive view as a basis for formulating a sustainable forest management and development strategy.

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