The diversity of tree species in plant communities with the prevalence of the *Dipterocarpaceae* family tree species in Binh Chau–Phuoc Buu Nature Reserve - Vietnam

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**Abstract.** This work analyzes the biodiversity of evergreen rainforests in Binh Chau – Phuoc Buu Nature Reserve, Vietnam. 4 combinations of the dominant tree communities of the *Dipterocarpaceae* family were observed in the park: *Dipterocarpus* formation, *Shorea* formation, *Anisoptera* formation, and *Vatica* formation. The study found 104 species from 38 families (*Dipterocarpus* formation – 45 species, *Shorea* formation – 86 species, *Anisoptera* formation – 21 species, *Vatica* formation - 26 species). The most common are woody plants from the *Anacardiaceae* family - 8 species, the plants from the *Clusiaceae* and *Dipterocarpaceae* family are on the second place - 6 species. In general, the four studied plant formations have a different number of various tree species in their composition. The study shows that under the dominance of *Shorea roxburghii* G. Don, the plant community has the greatest biodiversity of plant species, whereas the smallest number of plant species is observed in phytocoenoses dominated by *Anisoptera costata* Korth. Fluctuations in the values of biodiversity indices are caused by the heterogeneity of the growth areas and previous anthropogenic impact.

1. Introduction
Over the past few centuries, more than a billion hectares of forest land have been degraded or deforested, which underlies large-scale climate change, increases soil erosion, increases surface temperature and intensity of dry seasons creates food system instability, as well as patterns and rates of species extinction [1, 2]. Rainforests, as a key category of terrestrial ecosystems, include some of the most diverse types of habitats in the world, while at the same time facing the highest levels of biodiversity loss.

The low-lying plains of the Southeast Asia Torrid Zone are characterized by one of the highest deforestation levels in the world, followed by creation of mono-species stands or leaving the land fallow. In the lowlands of tropical Asia, trees of the *Dipterocarpaceae* family are the dominant ecological and structural components of forest plant communities. The tree species of this family have an important ecological and economic role for tropical rainforests in Southeast Asia [3-5]. Most of *Dipterocarpaceae* families belong to *Shorea, Dipterocarpus, Hopea,* and *Vatica* genera.

The Dipterocarpaceae forests of Southeast Asia widespread from the humid regions of Sumatra in Indonesia to Malaysia, Thailand, Laos, Vietnam, and Cambodia [6-9]. In Vietnam, the *Dipterocarpaceae* family has 6 genera (*Anisoptera, Dipterocarpus, Hopea, Parashorea, Shorea,
Vatica) with 42 species and 3 subspecies; of these, the genus Dipterocarpus is common (14 species), the genus Anisoptera - 2 species, the genus Hopea - 11 species, the genus Shorea - 8 species, the genus Vatica - 8 species and 1 subspecies, the genus Parashorea - 2 species. Many authors studied the dynamics of the plant communities of tropical rainforests with the prevalence of the Dipterocarpaceae family trees since this information provides the basis for understanding the sustainability of the forest [10, 11]. According to Okuda et al. the structure and diversity of tree species of the Dipterocarpaceae family in Peninsular Malaysia vary depending on the intensity of forest utilization [12]. The thickness of trees in tropical primary forests ranges from 300 to 700 pcs per ha. The morphology of the N/D distribution varies greatly, and many associations have a large number of trees with \( D \geq 60 \) cm [13, 14]. Factors affecting the thickness and size of trees also affect the diversity of tree species [15]. The diversity of tree species and the productivity of the tree community are related to the structure and species composition of the phytocoenosis [16]. A tropical moist evergreen closed forest in southern Vietnam attracts the attention of many foresters. The association with the predominance of the Hopea odorata tree and the association with the predominance of the Dipterocarpus alatus tree are quite common in tropical rainforests of southern Vietnam [17, 18]. The Dipterocarpaceae forests occupied a large area in Vietnam at altitudes below 700 m until the 1950s of the 20th century. With an area of more than half a million hectares, which is as much as one third of the Dipterocarpaceae forests of Southeast Asia. The Dipterocarpaceae forests have large wood species of high economic value. Non-timber forest products, such as resins, tannins, medicinal herbs, etc., are no less important for the economy of a country [17-19]. The forests cover the plains on ancient alluviums, shales and basaltic plateaus like a "carpet". And Vietnam has become a representative model for studying the development patterns of forest plant communities of Mainland Southeast Asia.

2. Methods and Materials

2.1. Objects of study
Binh Chau – Phuoc Buu Nature Reserve is situated in the southeast of the Republic of Vietnam within the Xuyen Moc District of Ba Ria - Vung Tau Province. Founded in 1984, the Binh Chau – Phuoc Buu Nature Reserve has the following geographical coordinates: 10°28’-10°38’ north latitude, 107°25’-107°36’ east longitude. The total area of the Binh Chau – Phuoc Buu Nature Reserve is 10 326.0 ha [20]. According to Thai Van Trung, when a forest has developed to a stable stage, the external morphology and tree species composition do not change significantly in time, at least comparable to the lifetime of the longest-living trees [17]. However, it is very difficult to identify in fact that the forest has developed to its climax stage. According to Nguyen Van Truong, when the forest entered a stable stage, the condition of the forest is equivalent to the state of the forest from IIIA3 to IV following the classification of Loeschau [21]. Thus, the object for data collection is dominant Dipterocarpaceae family plants from the forest in the state IIIA3 and higher following the classification by Loeschau [21]. The analysis of the most representative sample plots shows that the forest in the Binh Chau – Phuoc Buu Nature Reserve is composed of many different tree genera, including 4 species of tree plants of the Dipterocarpaceae family: Dipterocarpus costatus Gaertn, Shorea roxburghii G. Don, Anisoptera costata Korth., and Vatica odorata (Subsp.). To simplify and make easy the data synthesis and analysis, the above four dominant groups of the Dipterocarpaceae family were named respectively the “Dipterocarpus formation”, “Shorea formation”, “Anisoptera formation”, and “Vatica formation”.

The dominant Dipterocarpaceae family groups were studied on sample plots with a total area of 2000 m² (40x50 m). To describe and analyze the characteristics of the four dominant groups of the Dipterocarpaceae family, 12 sample plots were selected following the methodology, in which each dominant group of the Dipterocarpaceae family was present on 3 sample plots [18, 19].

To analyze the silvicultural characteristics of the four dominant groups of the Dipterocarpaceae family, the data collection on each sample plot was as follows:
Determination of the composition of large tree species. Ordinary large trees are 1.3 m trees with a diameter starting from 8 cm or more ($D_{L3} \geq 8$ cm). They all are listed by the name of a species, then organized by genera and family.

Data collection from sample plots to determine the components of plant species or the role of tree species in the formation of the *Dipterocarpaceae* family.

Data collection about the components of the dominant plant species in species units and the analysis of tree species diversity in the four dominant plant groups.

Description and comparison of the number of species ($S$), species diversity, the diversity of large trees, and the distribution of species richness among the four dominant groups of the *Dipterocarpaceae* family. The degree of biodiversity or species richness of the trees ($d$) is determined by the Margalef's $d$ index [22, 23]. Index $d$ is given as:

$$d = \frac{S-1}{\log N}$$  \hspace{1cm} (1),

where, $S$ is the number of tree species found in the community, $N$ is the total number of specimens of plant species.

Tree species diversity is calculated using the Simpson index (1949) and the Shannon-Weiner diversity index. Different Simpson indices include 1 - D and 1 / D; where D is given as:

$$D = \frac{\sum(n_i \times (n_i - 1))}{(N\times(N-1))}$$  \hspace{1cm} (2)

The Shannon-Weiner diversity index ($H''$) is calculated by the formula:

$$H'' = -\sum(n_i /N) \times \ln(n_i /N),$$  \hspace{1cm} (3)

where $n_i$ is the number of specimens found in the community, $N$ is the total number of specimens of plant species that comprise the community.

The distribution of plant species diversity can be uniform or non-uniform, as estimated by Pielou index ($J''$). Index $J''$ is calculated as:

$$J'' = H''/\ln(S),$$  \hspace{1cm} (4)

where, $H''$ is the Shannon-Weiner index, $S$ is the total number of plant species in the *Dipterocarpaceae* families.

### 2.2. Experimental part
Our study has shown that in the 4 dominant tree species formations of the Dipterocarpaceae family there are 104 species from 38 families (*Dipterocarpus* formation – 45 species from 39 genera, 26 families; *Shorea* formation – 86 species from 62 genera, 34 families; *Anisoptera* formation – 21 species, from 20 genera, 16 families; *Vatica* formation - 26 species from 24 genera, 18 families (table 1). The most common are woody plants from the *Anacardiaceae* family - 8 species, the plants from the *Clusiaceae* and *Dipterocarpaceae* family are on the second place - 6 species. Some species, such as *Dipterocarpus costatus* Gaertn, *Vatica odorata* (Subsp.) Sym, *Diospyros* sp., *Aporusa dioica*, *Vitex pinnata*, *Xerospermum noronhianum*, *Knema sp.*, *Syzygium sp.* are widespread in all 4 forest formations.

**Table 1.** Systematic structure of stands in formations.

| Family      | Dipterocarpus formation | Shorea formation | Anisoptera formation | Vatica formation |
|-------------|-------------------------|-----------------|----------------------|-----------------|
|             | #1                      | #2              | #1                   | #2              | #1           | #2           |
| Hypericaceae| -                       | -               | 1                    | 1               | 1            | 1            |
| Combretaceae| 1                       | 1               | 1                    | 4               | -            | -            |
| Sapindaceae | 2                       | 2               | 3                    | 3               | 1            | 1            |
| Clusiaceae  | 1                       | 1               | 2                    | 6               | 1            | 1            |
| Malvaceae   | -                       | -               | 1                    | 1               | -            | -            |
| Rubiaceae   | 3                       | 3               | 4                    | 4               | 1            | 1            |
3. Results and Discussion

The *Dipterocarpus* formation comprises 45 tree species from 26 families (table 1). Among them, the *Dipterocarpus* family has the greatest number of species (11.1%), with 5 species: *Dipterocarpus costatus* Gaertn., *Vatica odorata* (Subsp.) Sym, *Dipterocarpus alatus* Roxb., *Dipterocarpus dyeri* Pierre, and *Anisoptera costata* Korth. The Annonaceae family is in the second place (8.9%). The average thickness of these dominant plants is 808 pcs per ha (100%); out of which 6 dominant species give 428 pcs per ha, or 53%, 5 species of the *Dipterocarpaceae* family contribute with 270 pcs per ha, or 33.4%, *Dipterocarpus costatus*, in particular, gives 184 pcs per ha, or 22.8%. Six dominant species constitute the *Important value* of 56.0%. These dominant species are: *Dipterocarpus costatus* Gaertn., *Irvingia malayana*, *Vatica odorata* (Subsp.) Sym., *Xerospervum noronhianum*, *Vitex pinnata* L., *Dimocarpus fumatus* (Blume) Leenh. The *Shorea* formation comprises 86 tree species from 34 families. Of those, the greatest number of species belongs to the *Myrtaceae* and *Anacardiaceae* family (7.0%). Five dominant species constitute the *Important value* of 52.9%. The dominant species: *Shorea roxburghii* G. Don, *Irvingia malayana*, *Xerospervum noronhianum*, *Vatica odorata* (Subsp.) Sym, *Lagerstroemia calyculata*. The *Dipterocarpaceae* family comprises 5 species – *Shorea roxburghii* G. Don, *Vatica odorata* (Subsp.) Sym, *Dipterocarpus alatus* Roxb., *Dipterocarpus costatus* Gaertn., and *Anisoptera costata* Korth. The stand thickness of the *Shorea* formation is 387 trees/ha, the thickness of the dominant species - 145 trees/ha, which constitutes 38.4%, 5 species from the *Dipterocarpaceae* family - 125 pcs per ha, constituting 33.0%, of those, *Shorea roxburghii* G. Don – 96 pcs per ha (giving 25.4%).

| Family                  | #1 | #2 | #3 | #4 | #5 | #6 | #7 | #8 | Total |
|-------------------------|----|----|----|----|----|----|----|----|-------|
| Irvingiaceae            | 1  | 1  | 1  | 1  | -  | -  | -  | -  | 39    |
| Rutaceae                | 1  | 1  | 1  | 1  | -  | -  | -  | -  | 45    |
| Chrysobalanaceae        | 1  | 1  | 1  | 1  | -  | -  | -  | -  | 62    |
| Elaeocarpaceae          | 1  | 1  | 1  | 2  | -  | -  | -  | -  | 86    |
| Dipterocarpaceae        | 3  | 5  | 4  | 5  | 4  | 4  | 4  | -  | 20    |
| Moraceae                | 1  | 1  | -  | -  | -  | -  | -  | -  | 21    |
| Fabaceae                | 3  | 3  | 5  | 5  | 1  | 1  | -  | -  | 24    |
| Tiliaceae               | 3  | 3  | 3  | 3  | 1  | 1  | -  | -  | 26    |
| Lauraceae               | 1  | 2  | 1  | 1  | -  | -  | -  | -  | 39    |
| Crypteroniaceae         | 1  | 1  | -  | -  | -  | -  | -  | -  | 45    |
| Myristycaceae           | 2  | 2  | 2  | 2  | 1  | 1  | 1  | 1  | 62    |
| Melastomaceae           | 1  | 1  | 1  | 2  | -  | -  | -  | -  | 86    |
| Annonaceae              | 3  | 4  | 3  | 5  | 1  | 1  | 2  | 2  | 20    |
| Verbenaceae             | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 21    |
| Euphorbiaceae           | 2  | 2  | 4  | 5  | 1  | 1  | 1  | 1  | 24    |
| Ebenaceae               | 1  | 2  | 1  | 3  | 2  | 2  | 1  | 2  | 26    |
| Sterculiaceae           | 1  | 1  | 2  | 2  | -  | -  | -  | -  | 39    |
| Apocynaceae             | 1  | 1  | -  | -  | -  | -  | -  | -  | 45    |
| Myrtaceae               | 1  | 2  | 2  | 6  | 1  | 1  | 1  | 1  | 62    |
| Dileniaceae             | 1  | 1  | -  | -  | -  | -  | -  | -  | 86    |
| Anacardiaceae           | 1  | 1  | 2  | 6  | 1  | 2  | 3  | 3  | 20    |
| Lecythidaceae           | 1  | 1  | 2  | 2  | -  | -  | -  | -  | 21    |
| Primulaceae             | -  | -  | 2  | 2  | -  | -  | 1  | 1  | 24    |
| Rhizophoraceae          | -  | -  | 2  | 2  | 1  | 1  | 1  | 1  | 26    |
| Connaraceae             | -  | -  | 1  | 1  | -  | -  | -  | -  | 39    |
| Ochnaceae               | -  | -  | 1  | 1  | -  | -  | -  | -  | 45    |
| Capparaceae             | -  | -  | 1  | 1  | 1  | 1  | 1  | 1  | 62    |
| Icacinaceae             | -  | -  | 1  | 1  | -  | -  | -  | -  | 86    |
| Sapotaceae              | -  | -  | 1  | 1  | -  | -  | -  | -  | 20    |
| Lythraceae              | -  | -  | 2  | 2  | -  | -  | -  | -  | 21    |
| Burseraceae             | -  | -  | 1  | 2  | -  | -  | -  | -  | 24    |

total number           39 | 45 | 62 | 86 | 20 | 21 | 24 | 26 | 96    |

*Where, #1 number of tree genera, #2 number of tree species*
The *Anisoptera* formation comprises 21 tree species and 16 families (table 1). Among them, the *Dipterocarpaceae* family presents the greatest number of species (19.0%), 4 species—*Anisoptera costata* Korth., *Hopea odorata* Roxb., *Dipterocarpus costatus* Gaertn., and *Vatica odorata* (Subsp.) Sym. Five dominant species constitute the Important value of 76.8%. The dominant species: *Anisoptera costata* Korth., *Melanorrhoea usitata* Knema sp., *Millietia ichthyotonia*, *Diospyros* sp., *Syzygium* sp., *Xylopia vieina*, *Garcinia vilersiana*. The stand thickness of the *Anisoptera* formation is 855 pcs per ha, the thickness of the dominant species – 649 pcs per ha, constituting 75.8%; 4 species of the *Dipterocarpaceae* family – 372 pcs per ha, giving 43.5%, of those, *Anisoptera costata* Korth – 308 trees/ha (36.0%). The *Vatica* formation comprises 26 tree species from 18 families (table 1). Nine dominant species constitute the Important value of 56.6%. The dominant species: *Vatica odorata* (Subsp.) Sym, *Irvingia malayana*, *Vitex pinnata*, *Xylopia pirei*, *Syzygium* sp., *Hopea odorata* Roxb., *Dipterocarpus costatus* Gaertn. The *Dipterocarpaceae* family includes 4 species—*Vatica odorata* (Subsp.) Sym, *Hopea odorata* Roxb, *Dipterocarpus costatus* Gaertn., and *Shorea roxburghii* G. Don. The stand thickness of the *Vatica* formation is 360 pcs per ha, the thickness of the dominant species – 139 pcs per ha, comprising 38.6%; 4 species from the *Dipterocarpaceae* family – 100 pcs per ha, giving 27.8%, among those, *Vatica odorata* (Subsp.) Sym – 64 pcs per ha (comprising 17.8%).

The biodiversity of a territory is defined by three indicators: species richness, species diversity, and uniformity of species abundance or dominance [2, 21, 23]. The species richness of plant communities is expressed as the number of species found and can be measured using the Margalef and Menhinick indices. Species diversity is often measured by Simpson (1949), Shannon-Weiner (1948, 1949), McIntosh (1967), Berger-Parker (1970), Hill (1973) và Brillouin indices [21, 23]. The Simpson dominance Index or the Gini-Simpson diversity index is used to determine the biodiversity of plant communities in a given environment. The Shannon - Weiner diversity index is used to compare biodiversity between different habitats. The distribution of species richness (uniform index) in a plant community can be measured using the Shannon, Simpson, Pielou, Hill indices; the most commonly used are Shannon - Weiner and Pielou indices.

### Table 2. Indices of stands' species diversity in forest formations.

| Formation         | S (species) | pcs per ha | Margalef d | Shannon-Weiner H' | Pielou J' |
|-------------------|-------------|------------|------------|-------------------|-----------|
| 1                 | *Dipterocarpus costatus* | 45 | 808 | 6.6 | 3.0 |
| 2                 | *Shorea roxburghii* | 86 | 378 | 14.3 | 3.7 |
| 3                 | *Anisoptera costata* | 21 | 855 | 3.1 | 2.4 |
| 4                 | *Vatica odorata* | 26 | 360 | 4.2 | 3.1 |

Species richness (Margalef index d) is greatest in communities dominated by the *Shorea roxburghii* G. species. Don (d = 14.3), the smallest is in the community dominated by *Anisoptera costata* Korth (d = 3.1).

The distribution of tree species diversity (Pielou index J’) in the communities of the four dominant plants of the *Dipterocarpaceae* family also differs. In communities in which the dominant species is *Vatica odorata* (Subsp.), Sym (Griff.) Symington, the species richness index (J’ = 0.955) is more uniform than in communities dominated by *Shorea roxburghii* G. Don (J’ = 0.821), *Dipterocarpus costatus* Gaertn (J’ = 0.798), and *Anisoptera costata* Korth (J’ = 0.778).

The diversity (H' index) of the four dominant plants of the *Dipterocarpaceae* family is also different. The greatest species diversity was observed in plant communities dominated by *Shorea roxburghii* G. Don (H' = 3.7), followed by *Vatica odorata* (Subsp.) Sym (Griff.) Symington (H’ = 3.1), and *Dipterocarpus costatus* Gaertn (H’ = 3.0), and the smallest value is in communities dominated by *Anisoptera costata* Korth (H’ = 2.4).

The analysis above shows that under the dominance of *Shorea roxburghii* G. Don, the plant community has the greatest biodiversity of plant species, whereas the smallest number of plant species is observed in phytocoenoses dominated by *Anisoptera costata* Korth. Fluctuations in the values of
biodiversity indices are caused by the heterogeneity of the growth areas and previous anthropogenic impact.

Compared to the rainforests in Pahang National Park (Malaysia), here the diversity of tree species is much lower. According to Suratman, the number of tree species ($D > 10$ cm) found on a sample plot of 0.20 ha in tropical forests with a predominance of the Dipterocarpaceae family in Pahang National Park (Malaysia) varies from 31 to 53 species; an average of 46 species [21].

4. Conclusion
The conclusion about the diversity of the four dominant plants of the Dipterocarpaceae family, based on the Shannon index, is consistent with the Simpson index. In general, the four studied plant formations have a different number of various tree species in their composition. Tree species of the Dipterocarpaceae family form plant communities, where dominant plants comprise from 18.3% to 38.9% of the community. The largest number of tree species is found in the Shorea formation (86 species), while the lowest in the Anisoptera formation (21 species). Variations in biodiversity indices are determined by differences in the position of plant communities and in sample size. Besides, it is also related to previous anthropogenic influence.

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