STRUCTURE OF TROPICAL FOREST ECOSYSTEM HISTORY AND DEVELOPMENT - A REVIEW

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SUMMARY

In recent decades, forest area in Vietnam has significantly decreased. The forest lost has decreased the number of species and influenced the forest quality in terms of structure, timber volume and biodiversity. Forest structure plays an important role in forestry research. Forest structure greatly impacts the habitat of fauna and flora species. Complex forest structures diversify microclimates, niches and habitats for creatures. Forest structure is the key to understanding and determining ecosystem functions. This article provides a full picture about the history and development of overstorey structure analysis for forest ecosystems. Before the 16^{th} century, a pioneer of knowledge about tropical forests for Europeans was Alexander the Great, when he visited the Khyber Pass in 327 BC. In 16^{th} and 17^{th} centuries, there were more voyages and European colonial expansion such as: Francis Drake and English. Now, the study of the rainforest canopy structure can be divided into five categories based on canopy definition and scale. There are five types: the collection of all crowns, the whole volume between upper and lower crowns, the collection of crowns touching the canopy surface, the whole volume between the canopy surface crowns and the whole above-ground forest volume. Many attributes have analyzed such as: foliage, canopy cover, tree diameter, tree height, tree spacing, stand biomass, tree species and dead wood. These analyses are valuable bases to manage the forest ecosystem sustainably in the future.

Keywords: Canopy, dead wood, forest structure, overstorey, tree diameter, tree species.

I. INTRODUCTION

In recent decades, forest area in Vietnam has significantly decreased (Figure 1). The forest lost has decreased the number of species and influenced the forest quality in terms of structure, timber volume and biodiversity (Hung, 2009; Hung, 2016).

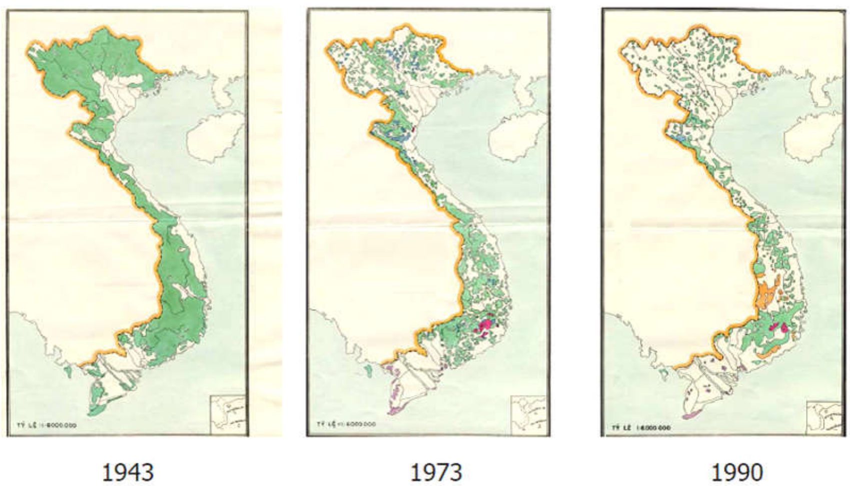

Figure 1. Serious deforestation in Vietnam 1943 - 1992
The green is forest area (Meyfroidt and Lambin, 2008)

Currently, one of most important challenges for natural forest management, which has been mentioned in many documents, is that research capacity is limited, knowledge and understanding of the natural forest has been low, especially issues related to forest structure and silvicultural techniques (MARDa, 2004; MARDb, 2004; Nghia, 2007; Hung, 2011).

Forest structure plays an important role in forestry research. Forest structure greatly impacts the habitat of fauna and flora species. Complex forest structures diversify microclimates, niches and habitats for maintaining the majority of terrestrial biodiversity (Pan et al., 2013). Forest structure is the key to understanding and determining ecosystem functions (Spies, 1998; Valbuena, 2015). The structure and distribution of forest patches regulates habitat structure, wildlife distribution and determines the delivery of ecosystem services (Valbuena, 2015). In other words, the structure directly affects the biodiversity, erosion control, water availability and carbon storage functions of the forest (Gao et al., 2014). Changing forest structure leads to changes in carbon stocks and evapotranspiration (Valbuena, 2015). Indicators of forest structure are also a component that should be considered for sustainable forest management (MCPFE, 2002; Valbuena, 2015). Species diversity can be influenced by tree diameter distributions (Spies and Franklin, 1991). Forest structure classifications can be practical and meaningful for ecological assessment and monitoring (Gao et al., 2014; Valbuena, 2015). In conclusion, structural analysis provides foresters an overview of the stands. Understanding forest structure will unlock an understanding of the history, function and future of a forest ecosystem (Spies, 1998), assist in forest management planning (Valbuena, 2015), propose silvicultural treatments and enable sustainable use of forest resources (Sau, 1996; Gadow et al., 2011).

However, there many reasons which limit forest structure analysis ability of researchers, especially in Vietnam. The first reason is limited accessable resources, because of copyright and lack of financial support. This results in many mistakes or misunderstandings. The second reason is lack of reviews about forest structure, especially for tropical forest. With above reasons and necessity, this paper will present a review of tropical forest structure. It provides a full picture about the history and development of overstorey structure analysis, based on new, sufficient and reliable references.

II. TROPICAL FOREST STRUCTURE ANALYSIS

2.1. History

Before the 16th century, a pioneer of knowledge about tropical forests for Europeans was Alexander the Great, when he visited the Khyber Pass in 327 BC (Whitmore, 1998). After his discovery, there was no significant improvement in understanding of the tropical forest in the nearly two thousand years that followed.

In 16th and 17th centuries, there were more voyages and European colonial expansion. In 1530, the English started trading in West Africa. In 1581, Francis Drake visited the Cape of Good Hope. In 1663, the English built Fort James in Gambia (Wikipedia, 2016). This has also contributed to expand the understanding of tropical forests (Whitmore, 1998).

In the 19th century, there were more expeditions of biologists and natural historians to tropical forest areas (Bermingham and Dick, 2005). The German Alexander von Humboldt arrived in Venezuela in 1799, Martius had a journey to Amazonia from 1817 to 1920 (Jacobs, 1981) and Darwin visited Brazil in 1832 (Whitmore, 1998). In 1848 Bates went to the Amazon (Bates, 1873) and in 1868 Belt went to Nicaragua (Belt, 1874).

From these trips, the ecologists gained knowledge and deeper understanding of the rainforest. Initially, it was only descriptions of plant species, herbs and animals they saw, observed in the tropical region. These descriptions were focused mainly on differences between animals and plants in tropical regions with animals and plants in temperate regions. Specifically, Alexander the Great saw banana trees, cotton plants and banyans (Whitmore, 1998). In 1750, the Dutch naturalist G.E. Rumpf began describing a species in tropical forests used by indigenous people to make poison arrows. He wrote that there were no other trees or shrubs under canopy of these trees, but that the soil underneath the tree was dark and sterile (Whitmore, 1998). In 1752, during an expedition to China, Osbeck saw a characteristic of tropical trees, which is having blossoms on the main trunk. And at that time, cauliflower was unknown in the North of Europe. Another example is the description of palm species in Venezuela with a height of 50 - 60 ft. and red flowers, parasitic plants and elegant grasses (Whitmore, 1998). They were impressed by the species richness of tropical forests (Bates, 1864; Belt, 1874, Wallace, 1878).

Also starting in the 19th century, tropical forest structure began to be studied and described along with another research approach, which is the identification of plant and animal species. These studies were often carried out in a few months to understand changes and differences of tropical forests from one place to another (Whitmore, 1998). Furthermore, during this time, an idea of the forest structure, which is related to wood providing capacity of the forest, was a topic written about (Montagnini and Jordan, 2005). In 1898, the German botanist A.F.W. Schimper classified a tropical forest into 4 types: rain-forest, monsoon-forest, savanna-forest and thorn-forest (Schimper and Fisher, 1903). He also described effects of climate and soil to plants in tropical forests in the West Indies, Brazil, Ceylon and Java.

In the first half of the 20th century, the world experienced two severe wars: World War I and II. The wars had a major influence on the research conducted in tropics. Economic and traveling difficulties also affected the publications in this period. A typical example is the printing of the book “The Tropical Rain Forest” by Richards in 1952, which was delayed for four years due to the shortage of paper as a result of the war (Whitmore, 1989a). Therefore, in this time period, the number of publications seemed much less, compared to the second half of the 19th century. This conclusion is drawn by the list of references which have been used in Richards’ 1996 book and “The tropical Rain Forest: A first encounter” by Jacobs in 1981.

During this time, an exemplary study is Richards’. He summarized the results of his research and field work in Guyana, Borneo and Nigeria. He described and analyzed the tropical rainforest structure vertically and horizontally (Richards, 1996). He also worked with profile diagrams and pointed out that tropical forests usually have 5 strata.

During the first half of the 20th century, research describing forest structure was mainly based on the profile diagram. Frequency distributions and analyses of species composition were started to be implemented. Davis and Richards (1933) drew the first profile diagrams to describe the structure of tropical forests in Guyana. These authors also generated height frequency distribution charts in 1933 and forest tree species composition in different slope positions in 1934 (Davis and Richards, 1933; Davis and Richards, 1934). Beard (1944) also presented profile diagrams of the structure climax species in tropical America. Richards also presented numerous diagrams to explain the tropical forest structure in his book from 1952. Authors used a method of drawing diagrams with different sizes depending on the purpose of research. The diagram brings a general picture about canopy structure and the distribution of trees on the horizontal plane, which can help to draw comments and suggest practical applications.

Since the 1950s, there have been many studies on the structure of tropical forests. The study of the rainforest canopy structure can be divided into several categories based on canopy definition and scale. Five canopy definitions are mentioned in figure 2. They are the collection of all crowns (A), the whole volume between upper and lower crowns (B), the collection of crowns touching the canopy surface (C), the whole volume between the canopy surface crowns (D) and the whole above-ground forest volume (E) (Bonger, 2011).

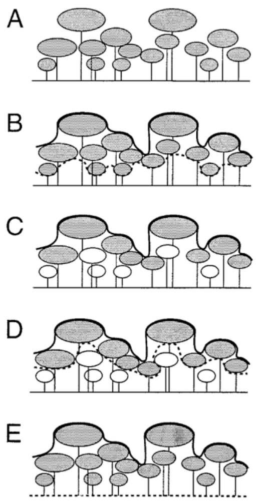

Figure 2. Five different approaches to define the forest canopy (Bonger, 2011)

Forest structure analysis is also performed on different scales: from small-scale levels to the large ones. Each level requires different methods and techniques. This is shown in table 1.

Table 1. Different scale levels for canopy structure analysis (Bonger, 2011)

Level of integration	Stratification into components
Forest in a landscape mosaic	Forest-non forest, at various spatial scales
Forest types	Different (types of) forest communities
Within-forest patches	Successional development phases Local environmental differences in, e.g., soil conditions
Individuals	Species (genera, families, life forms, architectural models, guilds) Size (height, diameter, developmental phase) Resource availability (light, soil, water)
Plant parts (nested within individuals)	Crown (ramification levels, reiteration complexes, age classes, leaves, branches, flowers, fruits) Stem (position and type of buttresses, bark, form) Roots
Plant organs, aboveground (without taking individuals into consideration)	Leaves Metamers Growth units Branches Stem Buttresses Flowers Fruits Seeds Branching points

Considering the individual level, up to now, the tropical forest structure has been analyzed in all different aspects. Both qualitative and quantitative analyses have been applied. Delang and Li (2013) have pointed out that there is no overall measure to evaluate and analyze the forest structure. Analyzed aspects are aboveground biomass, abundance, basal area, canopy height, plant density and so on (McElhinny, 2005; Delang and Li, 2013). Statistical applications, GIS, remote sensing and new technologies can be implemented to analyze the structure at different levels of scale. These analyzed attributes and statistical applications will be presented in more detail in the next sections.

In Vietnam, forestry research in general and forest structure studies in particular began in the 1960s and 1970s, especially in the North. This is because the war ended in the North in 1954 and in the South in 1975. Therefore, universities and research institutes in forestry were established afterwards. There are some examples: Vietnam National University of Forestry in 1964 (VNUF, 2009), Forest Inventory and Planning Institute in 1961 (FIPI, 2016), Vietnamese Academy of Forest Sciences in 1961 (VAFS, 2016).

There are some first exemplary studies in Vietnam. Phuong (1970) has pointed out structural characteristics of the forest vegetation in the North of Vietnam based on survey results in the North from 1961 to 1965. Truong (1973) has also considered a quantitative stratification direction. This author used the basis of height to classify storeys. Hien (1974) carried out studies on various localities and concluded that the general form of the diameter frequency distribution is decreasing, but due to selection harvest process, so that the observed distribution often has small peaks like the teeth of a saw. Trung (1978) divided tropical forest stands in Vietnam into five layers: upper dominant storey (A1), ecological dominant layer (A2), under canopy storey (A3), scrub layer (B) and grass layer (C).

Until now, in Vietnam, forest structure research has been conducted by several scientists and in different provinces, especially in the North. Analyses have been performed for different forest layers, species compositions, spatial distributions and other attributes. And researchers have also applied statistics and new technologies for analyzing and quantifying the forest structure. These studies will be presented in more detail in the next parts.

2.2. Structural attributes of tropical forests

Features or attributes of the individual structural elements and spatial patterns of elements are often analyzed in forest structure studies (Pan et al., 2013). The spatial forest structure is a vertical and horizontal arrangement of individual plants in the forest at one time (Pretzsch, 2009). The forest structure, especially the canopy storey structure, has been studied by many researchers. Delang and Li (2013) have shown that there are many attributes that need to be measured in order to express and quantify the forest structure, because there is no overall solution for this.

The ecological structure of tropical rain forests has been presented by Lamprecht (1989), Golley (1991), Richards (1996), Pretzsch (2009) and so on. These studies have raised viewpoints, concepts and quantitative descriptions of species compositions, life forms and storeys of the forest. These authors have also studied other forest structure indicators such as: diameter frequency distributions, diameter and height regression and so on. They have also mentioned some silvicultural treatments applied for different natural rain forest types. In these studies, regenerating trees, species composition and diversity have also been analyzed by these authors. Based on these, some silvicultural treatments have been proposed to improve the forest quality for different purposes.

Most quantitative methods have been developed and applied to temperate forests. In tropical areas, foresters have begun developing and applying statistical tools and mathematical models to study the forest structure (Golley, 1991). The author also points out three reasons why vertical patterns of tropical forests are more important than those of temperate forests: "(1) the high diversity of species of any size; (2) the generally impressive number of individuals regardless of the species at any level beneath the canopy; (3) the height of the tallest trees".

In general, research on the tropical forest structure has the same general direction, which is to build the theoretical, scientific basis. That can make forest business more effectively and meet increasingly demands about forest products and biodiversity. Another trend is applications of statistics and information technology to model and visualize the forest structure, moving from qualitative analysis to quantitative analysis approaches in combination with statistics and information technology (Golley, 1991).

a. Analyzed attributes

Many attributes have been studied, analyzed by many scientists around the world. The table below summarizes the analyzed attributes.

Table 2. Analyzed structural attributes
(Golley, 1991; Delang and Li, 2003; McElhinny, 2005)

No.	Stand element	Attribute
1	Foliage	Foliage high diversity Number of strata Foliage density within different strata
2	Canopy cover	Canopy cover Gap size classes Average gap size and the proportion of canopy in gaps Proportion of tree crowns with broken and dead tops
3	Tree diameter	Tree dbh Standard deviation of dbh Tree size diversity Horizontal variation in dbh Diameter distribution Number of large trees
4	Tree height	Height of overstorey Standard deviation of tree height Horizontal variation in height Height class richness
5	Tree spacing	Clark Evans Index, Cox Index, percentage of trees in clusters Number of trees per ha
6	Stand biomass	Stand basal area Stand volume
7	Tree species	Species diversity/richness Relative abundance of key species
8	Dead wood	Number, volume or basal area of stags Volume of coarse woody debris Log volume by decay or diameter classes Log length or cover Coefficient of variation of log density Litter biomass or cover

b. Relevant attributes to structure analysis of the tropical forest

- Stand information

The basic information about stands needs to be calculated, analyzed and described. This information will provide researchers an overview of the stand before analyzing other contents further. Such information is stand volume, stand basal area, diameter and height averages, stand density and layers. These indicators are essential when analyzing forest structures (Bowers et al., 2004; McElhinny, 2005; Pretzsch, 2009; Delang and Li, 2013).

These stand attributes will be the basis for proposing forest exploitation or thinning measures as well as to describe forest stands

(Bower et al., 2004). This information is also necessary for conservation and restoration of degraded lands (West, 2009). Tree diameter and basal area are easy measurable. They will provide information on stand productivity. The relationship between basal area and tree volume is linear (Golley, 1991). The tropical rainforest is an ecosystem which has higher productivity than any other forest type in the world (Golley, 1991). The author also points out that the net primary productivity of tropical forests ranges from 520 to 4840 g/m^2/year. The average is about 2530 g/m^2/year. Brown and Lugo (1984) summarized data from the Food and Agriculture Organization (FAO) and showed that the average volume of tropical forests in Asia is 215.60 m^3/ha for undisturbed forests and 102.52 m^3/ha for logged forests. However, it can reach 750 - 850 m^3/ha. In Vietnam, reserves of natural woody forests range from 80 - 250 m^3/ha (UN-REDD, 2013). Ha and Hong (2010) showed that the volume of type IIIA (heavily logged forests) in Kon Tum province ranges from 207 - 247 m^3/ha. Sau (1996) conducted a study in Kon Ha Nung, in the Central Highland, and showed that forest volumes ranged from 75.9 - 508.6 m^3/ha.

Tree density is a quantitative term to describe the degree of forest crowding per area unit. The stand density is also a key element to build models for forest growth and yield prediction (Burkhart and Tomé, 2012). The density of trees in primary tropical forests often depends on many different factors. The number of trees with a diameter greater than 10 cm is 300 - 700 trees/ha. In mountainous areas, the density in mountain or hill tops is often greater than that in slopes (Richards, 1996). The density in Vietnam for type IIIA in Kon Tum province is 242 - 574 trees/ha (Ha and Hong, 2010). Another example is the tree density in Bidoup national park. It ranges from 951 - 1056 trees/ha (Binh, 2014). In Kon Ha Nung, density lies between 361 and 1186 trees/ha (Sau, 1996). In Phu Tho province, the tree density runs from 80 - 370 trees/ha for forest II and III (Quang et al., 2014).

Regarding the storey, there are many different opinions on tropical rainforest stratification because it is difficult to see the total forest height from the ground (Richards, 1996). Trees belong to the same tier if they are influenced by the same set of environmental conditions (Golley, 1991). However, most authors have shown that evergreen broadleaf forests often have 3 to 5 storeys. Some researchers have classified storeys qualitatively and put limits on the height of each storey as Richards (1996). The author also has indicated that there are five strata in the tropical rainforest. They are called A, B, C, D and E.

In Vietnam, the evergreen tropical rain forest is very abundant. It is distributed in different provinces, including the Central Highlands. This forest type has 5 layers: upper storey A1, ecological dominance storey A2, lower storey A3, bushes storey B and climber and grass storey C (Trung, 1978; UN-REDD, 2013).

- Descriptive statistics for diameter and height variables

Descriptive statistics are often used to calculate diameter and height variables. These values will help understand the magnitude, variation and shape of datasets (Philip, 1998; Poorter et al., 2008; Tuat and Hinh, 2009). Average, standard deviation, variance, skewness and kurtosis are often calculated. Nijman (2004) has pointed out that for old secondary forests, the average diameter is 23.8 cm and standard deviation is 8.8. Meanwhile, for old-growth forests, they are 31.1 cm and 9.8, respectively.

In Vietnam, Hai (2014) analyzed IIa forests and concluded that the diameter ranged from 9.94 to 11.6 cm. Variance was from 10.5 to 17.5. With variable height, it ran from 7.36 to 8.24 m. The variance of height variable lied between 2.28 and 4.37. For old forests (IIIA forest) in Kon Tum, Ha and Hang (2010) showed that the average diameter was from 20.55 to 33.77 cm. The value for the height ranged from 12.78 to 18.04 m. Anh (1998) indicated that the average diameter for forest IIb and IV in Hue province is 14.87 cm and 34.36 cm, respectively. Standard deviation values for both types are 6.87 and 12.63. For the height variable, Anh (1998) found that the average height runs from 7.64 to 18.03 m. Standard deviations for the height lie between 1.92 to 4.82 m.

- Diameter and height frequency distribution

Diameter and height frequency distributions of stands are bases for understanding the forest structure (Hinh and Giao, 1996; Nord-Larsen and Cao, 2006 and Pretzsch, 2009). This has been studied by many researchers. These distributions are often modelled and expressed by different theoretical probability distributions in order to make inferences on forest mature stages, evaluate the forest resources and propose future silvicultural treatments (Nanos and Montero, 2002; Husch et al., 2003; Tuat and Hinh, 2009; Sheykholeslami et al., 2011). Another meaning of diameter distributions is indicated by Rubin et al. (2006), namely that "*Diameter distributions can be used to indicate whether the density of smaller trees in a stand is sufficient to replace the current population of larger trees and to help evaluate potential forest sustainability*". Besides, diameter and height frequency distributions will make some contributions to estimate harvesting costs, expected yield, financial result, etc. (Sheykholeslami et al., 2011).

Many researchers agree that the diameter frequency distribution of uneven-aged mixed natural forests is best approached with an inverse J-shaped distribution/negative exponential distribution (Meyer, 1953; Vanclay, 1994; Philip, 1998; Husch et al., 2003; Pretzsch, 2009; Burkhart and Tomé, 2012; Xuan, 2012; Hai, 2014). Sometimes the function is called the Liocourt distribution. Liocourt studied the size distribution of relatively young natural forest trees and showed that the proportion of trees in the two groups close together is a constant (Vanclay, 1994). Lamprecht (1989) also noted many examples to show that the diameter distribution of natural forests tends to decrease. This means that when the diameter increases, the number of trees will decrease (Burkhart and Tomé, 2012), because of high mortality rate of the smallest trees (Berger et al., 2002; Bongers, 2011). However, in Vietnam, sometimes the diameter frequency distribution has a peak. The peak often ranges from 10 - 16 cm (Khanh, 1996; Binh, 2014).

In contrast to the diameter frequency distribution, height frequency distributions often have a peak and are right-skewed. This is proven by studies of Xuan (2012), Hai (2014) and Khanh (2014).

- Diameter-height regression

Regression analysis provides a functional relation between a dependent variable and one or many independent variables (Pretzsch, 2009). Regression analysis is very important to understand stand structure. The diameter-height relationship is a basis for determining the corresponding height for each diameter size class. Therefore, it is not necessary to measure all tree heights (Hinh and Giao, 1996; Pretzsch, 2009). The relationship is a structural characteristic of trees which reflects a stem form and the volume of the harvestable stem

(Osman et al., 2012). The diameter-height regression also influences the wood product quality, which is also used to build volume tables and determine the size index (Hinh and Giao, 1996).

The diameter at breast height (DBH) and height are commonly measured variables in forest inventories. These variables are also commonly required for forest management activities and research purposes (Osman et al., 2012).

In Vietnam, as well as around the world, mathematical equations representing this relationship are diverse and vary from space to space. A wide variety of different functions such as linear and non-linear function forms with two or more than two parameters have been used to analyze the regression between the diameter and height of trees. Typical function forms are selected as logarithms, such as exponential, power, Chapman-Richards, Weibull, Gompertz, logistic functions and so on. They are applied for different species, different forest types, from temperate forests to tropical moist forests around the world (Khanh, 1996; Hinh and Giao, 1996; Anh, 1998; Pretzsch, 2009; Scaranello et al., 2011; Osman et al, 2012, Binh, 2014).

There is a general rule drawn from many studies, which is that the relationship between the diameter and height is often described by a convex curve or a straight line, especially for old-growth forests. This is explained by the different growth rate of trees between the diameter and height. When trees get mature, the growth rate of the height is lower than that of the diameter, resulting in correlations tending to be flatter (Hinh and Giao, 1996).

- Gap analysis

Gaps are a studied subject in the rainforest by many different causes. It is an indispensable component of forest ecosystems, both tropical and temperate forests (Homeier and Breckle, 2008, Wagner et al., 2011). Gaps affect components of the forest environment such as: light, nutrient availability and soil moisture (Denslow, 1987). Therefore, it is an influential factor to natural regeneration, species composition and plant species diversity, especially regeneration, even mangrove forests (Denslow, 1987; Whitmore, 1989b; Yamamoto, 2000; Numata et al., 2006; Berger et al., 2008; Homeier and Breckle 2008; Wagner et al., 2010).

Runkle (1992) has pointed out four aspects related to the gap that should be analyzed. They are rates in which gaps form, total gap area proportion, gap size distribution and gap closure process. The author also illustrated that there are two gap definitions: canopy gap and expanded gap. The first definition is the areas directly under the vertical projection of the canopy opening. The expanded gap includes tree bases bordering the gap. Necessary methods and information, when investigating the gap, were presented by Runkle (1992). The survey information comprises gap maker, gap size, gap microhabitat, gap age, adjacent forest, site characterization, gap aperture and vegetation within the gap.

Gap and gap dynamics research results in tropical forests have shown some rules. Firstly, the gap size frequency distribution tends to descend, like the J-shaped distribution/negative exponential distribution (Barnes et al., 1998; Yamamoto, 2000; Numata et al., 2006). The average gap size in young forests or regenerating forests is often less than in old-growth forests. The gap area proportion and the average gap size of tropical forests are 3 - 23% and 90 - 250 m^2 (Brokaw, 1985, Yamamoto, 2000). The total gap area and the average gap size are linearly proportional to the forest age (Tyrrell and Crow, 1994). However, this is not true for all cases (Spies et al., 1990; Numata et al., 2006). Numata et al. (2006) conducted a gap research for the rainforest in Malaysia. The results indicated that the gap area rate of primary forests was from 0.045 to 0.160, while that one of regenerating forests ranged 0.007 to 0.043. In addition, the number of gaps in the primary forest is higher. The average gap size and number of large gaps are higher in primary forests, compared to secondary forests (Nicotra et al., 1999; Numata et al., 2006).

- Tree spatial distribution

Another aspect when analyzing the forest structure is the spatial distribution of plant species on the ground. Point pattern analysis is commonly used to analyze the arrangement of individuals on the ground. This is a basis to describe forest structure (Fangliang et al., 1997). Spatial distribution of forest tree species is also a basis to propose reforestation measures (Hung, 2013). The spatial distribution is very diverse, because of different species, time and locations (Fangliang et al., 1997). Clear understanding on the tree species distribution of in evergreen broad-leaved forests is very limited, especially in Vietnam (Luo et al., 2009; Hung, 2013).

Research results of the tree spatial distribution have shown several trends. Tropical forest tree distributions are commonly clustered or random (Fangliang et al., 1997; Condit et al., 2000; Luo et al., 2009; Rejou-Méchain, 2011; Hung, 2013; Hai et al., 2014). Another trend has been pointed out indicating that the population spatial distribution often shifts from clustered distributions to random or regular distributions, because of succession proceeds (Christensen, 1977; Sau, 1996; Fangliang et al., 1997). However, distribution patterns are often influenced and changed by many different reasons, such as scale, plot size, self-thinning, species and age (Kenkel, 1988; Fangliang et al., 1997; Li et al., 2009; Hai et al., 2014).

- Tree species diversity

Species diversity of the overstorey has been conducted by many foresters. The tropical rainforest is a peculiar ecosystem. The tropical forest is an area with a large number of species, compared to other ecosystems (Jacobs, 1981; Richards, 1996; Whitmore, 1998). Currently, to assess the biodiversity of tropical forests, scientists have used many different indices such as: richness, species importance value, Simpson, Shannon - Wiener, Shannon evenness (Cao and Zhang, 1997; Kindt and Coe, 2005; Podong and Poolsiri, 2013; Binh, 2014; Khang, 2014; Thang et al., 2015).

Podong and Poolsiri (2013) pointed out that richness ranged from 14 to 138 species/ha. The number of species in some national parks in Thailand ranged from 14 to 138 species/ha. Khang (2014) showed that there were 67 species per 15,000 m^2 (about 44 - 45 species per ha) for type IIb and 61 species per 15,000 m^2 (about 40 - 41 species per ha) for type III. In Bidoup - Nui Ba national park, there were 36 - 50 species/6,000 m^2 (approximate 60 - 83 species/ha) (Binh, 2014).

Regarding biodiversity indices, the Shannon index in some of Thailand's national parks ran from 2.078 to 4.280, while the Simpson index lay between 0.726 and 0.974 (Podong and Poolsiri, 2013). Some researchers in Vietnam have shown species diversity levels in several national parks and nature reserves. Khang (2014) calculated diversity indicators for forest types II and III in Dong Nai province. Results indicated that in type IIb, Shannon and Simpson indices were 2.986 and 0.915, respectively. These results were 3.129 and 0.937, respectively for type III. Biological diversity and number of species in secondary forests are generally lower, compared to old-growth forests (Brown and Lugo, 1990; Richards, 1996). However, this trend is not usually correct for all cases (Richards, 1996, Khang, 2014).

III. CONCLUSION

The review provides a comprehensive picture of tropical forest structure analysis. The review summarizes the history of forest structure analysis development over different stages and centuries. Over time, more attributes have been analyzed. Many new statistical methods have also been applied. Many attributes of the tropical forest structure have been analyzed by researchers such as: frequency distribution, difference analysis, regression, gap and spatial distribution.

Forest structure analysis is an interesting research topic and it is very popular in Vietnam. Review is an essential basis and an important and important reference for forestry scientists to look back at the history of the research problem and what foresters around the world have done. This will be a solution to deal with forest resources decline in Vietnam and contribute to improve the effectiveness of sustainable forest management in the future.

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PHÂN TÍCH CẤU TRÚC HỆ SINH THÁI RỪNG NHIỆT ĐỚI LỊCH SỬ VÀ PHÁT TRIỂN

Bùi Mạnh Hưng

Trường Đại học Lâm nghiệp

TÓM TẮT

Trong những thập kỷ gần đây, diện tích rừng tại Việt Nam đang bị suy giảm nghiêm trọng. Sự mất rừng đã làm ảnh hưởng tới số lượng loài, chất lượng rừng trên các mặt như cấu trúc, trữ lượng gỗ và đa dạng sinh học. Cấu trúc rừng đóng một vai trò rất quan trọng trong nghiên cứu lâm học. Cấu trúc rừng ảnh hưởng rõ rệt tới môi trường sống của các loài động, thực vật. Một cấu trúc phong phú sẽ là điều kiện tốt về nơi ở cho các loài sinh vật. Cấu trúc rừng cũng là chìa khóa để chúng ta có thể hiểu và quyết định các chức năng của các hệ sinh thái. Bài báo này sẽ cung cấp cho độc giả một bức tranh toàn diện về lịch sử và sự phát triển trong phân tích cấu trúc tầng cây cao của các hệ sinh thái rừng. Trước thế kỷ XVI, người khai sinh ra lâm nghiệp nhiệt đới là vua Alexander đệ nhất, khi ông thăm Khyber Pass năm 327 trước Công nguyên. Vào thế kỷ XVI và XVII, có nhiều nhà thám hiểm của Châu Âu như Francis Drake và người Anh đã tiếp tục khám phá lâm nghiệp nhiệt đới. Hiện nay, nghiên cứu về cấu trúc được chia thành 5 nhóm dựa vào các định nghĩa khác nhau của tầng tán. Các định nghĩa tầng tán bao gồm: toàn bộ tán cây, toàn bộ phần giữa tán thấp nhất và cao nhất, toàn bộ phần trên tiếp xúc với bề mặt tán rừng hoặc chỉ là phần tán tầng cao tiếp xúc phía trên, hoặc toàn bộ phần trên mặt đất của rừng. Tới nay, đã có rất nhiều các khía cạnh được phân tích như: cấu trúc tán, độ che phủ, đường kính, chiều cao, khoảng cách cây, trữ lượng lâm phần, loài cây và cây chết. Những kết quả phân tích này là cơ sở quan trọng và giá trị để quản lý các hệ sinh thái rừng một cách bền vững trong tương lai.

Từ khóa: Cấu trúc rừng, cây chết, đường kính, loài cây, tán rừng, tầng trội.

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