MINISTRY OF EDUCATION AND TRAINING
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STUDY ON STRUCTURE AND CONSTRUCTION OF DIAMETER INCREMENT MODELS OF NATURAL EVERGREEN BROADLEAF FOREST IN NORTH VIETNAM

Speciality: Silviculture

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LIST OF PUBLICATION RELATED TO PhD DISSERTATION

1) **Nguyen Thi Thu Hien**, Tran Van Con, Tran Thi Thu Ha (2014), "Research on characteristics of evergreen broad-leaved natural forests in the Ba Be National Park, Bac Kan province", *Journal of Agricultural and Rural Development, N 6, Pg.* 187-191.
2) **Nguyễn Thi Thu Hien**, Tran Van Con Tran Thi Thu Ha (2014), "Dynamic structure of evergreen broad-leaved natural forests in the Ba Be National Park", *Journal of Forest Science, N 3, Pg*. 3417-3423.
3) **Nguyen Thi Thu Hien**, Tran Thi Thu Ha (2014), "Research on characteristics of evergreen broad-leaved natural forests in the Vu Quang National Park, Ha Tinh province", *Journal of Forest Science, N 3,* Pg. 3408-3416.
4) **Nguyen Thi Thu Hien**, Tran Thi Thu Ha (2015), "Modelling of mortality, recruitment and outgrowth processes in Vu Quang National Park and proposal application", *Journal of Agricultural and Rural Development,* N 3- 4/February, Pg. 250-256.
5) **Nguyen Thi Thu Hien**, Tran Van Con, Tran Thi Thu Ha (2015). "Studying grouping species according to some growth characteristics to construct diameter growth models for four Specieal - Use Forests regions in Northern Vietnam", *Journal of Forest Science,* N 2, *(Accepted).*

INTRODUCTION

1. Rationale of study

Natural forests in the worldwide scale, are decreased alarm in both area and quality following many corollaries related to ecological crisis. Therefore, forest sustainable management of natural forests were, are and will be a hot topic concerned by governments, organizations and public on over the world. To develop a comprehensive technical plan of sustainable forest management (SFM) for natural tropical forests, three essential basis need to be addressed are as below: (i) adiameter increment is used to determine the logging rotation, cutting diameter limit; (ii) volume increment is used to determine the sustainable annual allowable cut (AAC); (iii) stand structure dynamics can be used to know stand structure condition in the future.

The natural forests in Vietnam have been managed for many decades but the knowledge of such process and reaction of the forest is still scarce. Most data used for determine diameter and volume increment and stand structure dynamics are resulted from temporary sample plots and stem analyses providing unreliable data.

Thus, the project *"Study on the structure and building diameter increment models of natural evergreen broadleaf forests in Northern Vietnam"* is need to be carried out by us.

2. Study aim

The aim of the study is to improve the methodology and determine the simulation models of dynamic processes including diameter increment, mortality and recruitment of natural evergreen broadleaf forests in some Special Use Forests areas in North Vietnam.

3. Scientific and practical implication of study

3.1. Scientific implication

The dissertation contributes to improve research methods on forest increment and stand structure dynamics by permanent sample plots which is known as one of the difficult areas and few studied. The research results are good references in researching and teaching on forest growth domain.

3.2. Practical implication

The findings are used to predict the dynamics of structure and growth of natural evergreen broadleaf forest at study sites in particular and Vietnam in general.

The results will be a basis for proposing activities of forecasting impacts on natural forests in managing business processes if it is applied to the production forest with the same conditions.

4. New contribution of dissertation

- It is one of the first studies in Vietnam on process as increment, mortality and recruitment in natural forests by permanent sample plots.
- It provided scientific background for predicting forest increment and stand structure dynamics as basic of SFM.

5. Dissertation outline

The dissertation is divided as introduction, conclusion and three main chapters: Literature review; Study object, subjects and methods; and Results and discussion. The dissertation includes 24 tables and 17 figures, 103 references, of which 49 in Vietnamese and the others were in English.

CHAPTER 1
LITERATURE REVIEW

1.1. In the world

Based on 54 references in English, the dissertation has been reviewed research results related to following issues: (1) studies on stand structure of natural forests such as: species composition, N-D distribution, H-D relationships; (2) species grouping: there are many different methods for grouping species based on different criteria for different purposes. However, which grouping methods are most appropriate to use in forest modelling and for summarizing the state of the natural mixed forests, were and are being test based on several variables of species, such as mean diameter increment (zD) and maximal diameter observed for a tree species (D_{max}); (3) growth models of natural forests: there are many publications reported about research results on modeling processes as increment, mortality and recruitment in forest, ecosystems, mostly in pure even aged plantation. In compare with plantation research results on natural forest is still limited due to the complex of the object. The reviews indicated that predicting mortality and recruitment rate and diameter increment plays an important role in predicting and developing silvicultural treatment plan for sustainable development of the forest ecosystem in the future.

3.2. In Vietnam

Based on 49 references in Vietnamese, following issues has been reviewed: (1) studies on stand structure of natural forests such as species composition, N-D distribution, H-D relationships; (2) sspecies grouping; and (3) growth models of natural forests.

3.3. Discussion

Many research have been developed simulation models of dynamic processes as diameter increment, mortality and recruitment in natural forests. However, in Vietnam, those research are newly and were concerned in several last years. Specially, research on forest growth based on data derived from permanent sample plots is newly begun in Vietnam. To have scientific background of essential in natural forests, thus, the study focus on following research issues as below:

- Study on some properties of stand structure of natural forests in four Special Used Forest Areas in the North of Vietnam to understand the fact of dynamic processes in natural forests.
- Study on dynamic processes: diameter increment, mortality and recruitment to have a general view on forest structure dynamics. Mathematical functions are used to simulate those processes in forest stands as scientific backgrounds to predict the trend of forest stand developing in the future. These are also scientific backgrounds for further research and for developing silvicultural treatments in effective and sustainable ways.

CHAPTER 2

STUDY SCOPE, CONTENT AND METHODOLOGIES

2.1. Study objects and scope

2.1.1. Study objects

Study objects are all trees with diameter at breast height ($D_{1,3}$) ≥ 10cm in natural evergreen broadleaf forest at the some Special Use Forests in the Northern of Vietnam.

2.1.2. Study scope

- Study content: The dissertation carries out the structure and modeling diameter growth of forest natural forest in studied areas.

- Spatial scope of study: This study conducts at the four Special Use Forests places as: Vu Quang National Park, Ha Tinh province (06 standard positioned plots); Xuan Son National Park, Phu Tho province (03 standard positioned plots); Ba Be National Park in Bac Kan province (06 standard positioned plots); NR Hang Kia - Pa Co, Hoa Binh province (06 standard positioned plots).

- Temporal scope of study: This study looks at natural forests with 5 years, from 2007 to 2012.

2.2. Study contents

(1) Study on some forest structure features of natural evergreen broadleaf forests in study sites (species composition; N-D distribution; H-D relationships).

(2) Research on species grouping based on some growth characters of species.

(3) Study on building models of diameter increment, mortality and recruitment in natural evergreen broadleaf forests in study sites.

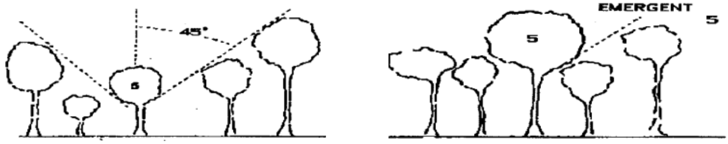
(4) Modeling stand structure dynamic of natural evergreen broadleaf forests in study sites.

2.3. Study methodologies

2.3.1. Overview of approach

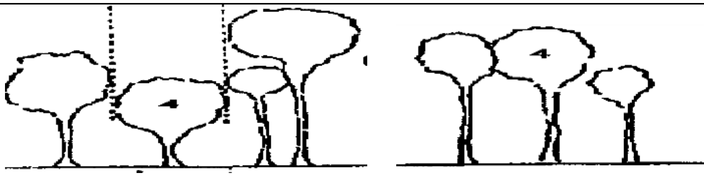
2.3.2. Field method

Data used in this study are derived from 21 permanent sample plots established in 2007 by research project "Research on structure properties of some main natural forest ecosystems of Vietnam" leaded by associate professor Tran Van Con, Forest Science Academy of Vietnam. The dissertation inherits data of the first census curried out in year 2007 and take part in the second senses done in year 2012 together with research team. Methods for establishment of plots and data measurements are following guideline of the research project (Tran Van Con *et al*., 2008). All trees with $D_{1.3}$ ≥10cm were measured of $D_{1.3}$, H and PC. PC is crown position after Dawkins (1958) with the values from 1-5 (see figure 2.7). Lists all trees died and in growth in the least diameter class.

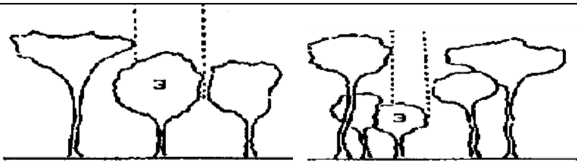


5

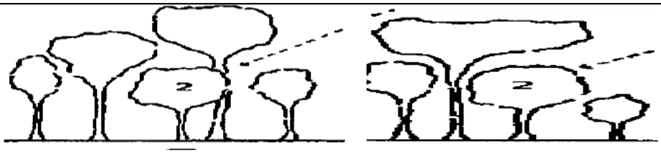
Emergent: Crown plan fully exposed vertically and free from lateral competition at least within the 90^0 inverted cone subtended by the crown base.



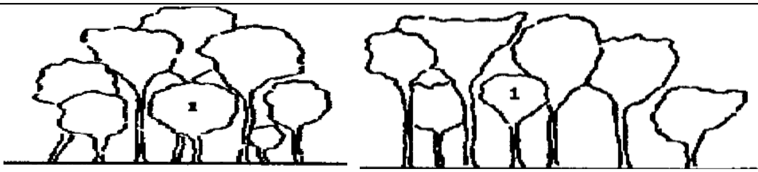
4 **Full overhead light:** Crown plan fully exposed vertically but adjacent to other crowns of equal or greater height within the 90^0 cone.



3 **Some overhead light:** Crown plan partly exposed vertically but partly vertically shaded by other crowns.



2 **Some side light:** Crown plan entirely vertically shaded but exposed to some direct light due to a gap or edge of overhead canopy.



1

No direct light: Crown plan entirely shaded vertically and laterally.

Figure 2.7: Dawkins crown position classification (after Synnott, 1979)

2.3.3. Methods of data analyses

2.3.3.1. Determining species composition, diversity indexes, N-D distribution and H-D relationships

- Determining species composition by important value of species IV%.

- Determining species diversity by: species mixed ratio: HL= S/N, Shannon-Wiener Index; Simpson Index; Renyi Index.

- Diameter distribution (N-$D_{1.3}$) has been examined with distance, Meyer and Weibull functions.

- H-$D_{1.3}$ relationships has been examined by Logarit, Compound, Power and S functions.

2.3.3.2. Species grouping methods

Some indicators as mean diameter increment (zD) and maximal diameter observed for a tree species (D_{max}) and life forms were used for grouping species. The method adopted for species grouping in this study is a three steps approach: (i) a clustering method for species with sufficient data ($n \geq 50$) by K-Means strategy on SPSS and reliable estimates; (ii) a discriminated method for less frequent species ($n < 50$ but ≥ 30) to assign to the group created in step 1; and (iii) a more subjective method for species with few data (based on expert knowledge).

Due to the species collected from four different study sites, we have examined the difference in zd of each species between different study sites before poolling together. Test results showed there was no significant difference in zd of species between different study sites, so it could be pooled species collected from different sites together to build species groups. The test is done as follows:

- If trees have distributed in 3 or 4 study areas, analysis of variance factor is conducted as according command line: Analyze/Compare Means /One - Way Anova /Ok in SPSS.

- If trees have distributed in two study areas, then check the difference of zd by T-test which is conducted according to the command line: Analyze /Compare Means/indecent - Samples T Test/Ok in SPSS.

2.3.3.3. Method for diameter increment modeling

Using empirical increment data of all species collected in permanent sample plots to develop mathematical model predicting diameter increment by diameter classes. Following functions have been tested:

- Quadratic: $zD = a + b*D + c*D^2$ (2.16)
- Power-Exponential: $zG = a*(G)^b*\exp(c*G)$ (2.17)
- Modified Beta:

$$zD = a*(D_{max} - D)^b*D^c \quad (2.18)$$

$$zD = a*(D_{max} - D)^b*D^c*(PC)^d \quad (2.19)$$

In which: zD is average diameter increment, D is diameter at breast height, G is stand basal area, D_{max} is maximal diameter and PC is crown position.

In the equations (2.18) and (2.19) with b = 1, the function can be linearized by dividing both sides by (D_{max} - D) and taking logarithms, given a two and three - parameter regression equations as bellow:

$$Ln(zD/(D_{max} - D)) = a + c*Ln(D) \quad (2.18')$$

$$Ln(zD/(D_{max} - D)) = a + c*Ln(D) + d*PC \quad (2.19')$$

Both equations (2.18') and (2.19') can be rewritten to:

$$Y = a + c*X \quad (2.18'')$$

$$Y = a + c*X_1 + d*Z \quad (2.19'')$$

In which: $Y= Ln(zD/(D_{max} - D))$; $X= Ln(D)$ and $Z = PC$.

Using empirical data array to fit parameter a and c in equation (2.18'') and a, c and d in equation (2.19'') by regression analysis.

2.3.3.4. Method for modeling mortality

Mortality rate is a function of tree size and forest density and can be written in general form as:

$$Mp = f(N, D) \text{ or } Mp = f(G) \quad (2.20)$$

In which: Mp is mortality rate, N is number of trees, D is diameter and G is stand basal area.

Mortality rate: Mp = (M/No) x 100 (2.21)

Mortality index: Mr = (LnNo - LnNs)/t (2.22)

In which: Mp, Mr is mortality rate and mortality index; No, Nt is number of trees at the time point 0 and t; Ns is number of surviving trees; and M is number of died trees until time point t.

Mortality data can be analyzed by regression using procedure similar to those applied for increment as above. In this study, we examine the empirical data to fit by following equations: logarit, power, compound and S.

2.3.3.5. Diameter class projection method

Mathematically, the process of diameter class projection can be described as:

$$N_{k,t+1} = N_{k,t} + I_k - O_k - M_k - H_k \qquad (2.27)$$

In which:

- $N_{k,t+1}$ is the number of trees in the k'th class at period t+1;
- $N_{k,t}$ is the number of trees in the k'th class at period t;
- I_k is the ingrowth into the k'th class during the period;
- O_k is the outgrowth from the k'th class during the period;
- M_k is the mortality from the k'th class during the period;
- H_k are the trees harvested from the k'th class during the period.

Values of ingrowth, outgrowth and mortality are, in general, derived from permanent sample plot data measured over intervals of 5 years. It will be apparent that ingrowth into class k will be numerically equal to outgrowth from class k-1. The ingrowth into the smallest class is called "external ingrowth" symbolized by R (recruitment), then the equation (2.27) can be written as:

$$N_{k,t+1} = N_{k,t} + R_k + O_{k-1} - O_k - M_k - H_k$$

The outgrowth from class k can be determined by equation as:

$$O_k = N_{k,t} + R_k - M_k - H_k - N_{k,t+1} \qquad (2.28)$$

In many cases, it is often difficult to compile outgrowth rates directly from PSP data due to various reasons as:

- Not all diameter classes may be represented, making it impossible to estimate outgrowth for some classes.

- The data may be sparse or unevenly distributed between classes, requiring some methods of smoothing be applied to obtain reasonable projections.

- Only processed or published increment rate data may be available.

- Data may only be available from tree increment plots, not from PSPs with complete measurements of the stocking.

In those cases, it is necessary to estimate outgrowth from mean increment for a class as:

$$O_k = t*zd/w \qquad (2.29)$$

In which: zd is mean increment for class k; w is class width; t research intervals.

CHAPTER 3
RESULTS AND DISCUSSION

3.1. Structural features of natural evergreen broadleaf forests

3.1.1. Characteristics of the structure and composition, diversity of tree species

3.1.1.1. Structural characteristics of tree species composition

Research results showed that the relative dominance of the most common species are varies from site to site and correlated with species richness in the plots.

- Forest stands in Ba Be National Park and Reserve Hang Kia - Pa Co have dominant species showing clearly (represented by IV%) compared to the Xuan Son National Park forest and Vu Quang National Park.

- Forest stands in Vu Quang National Park, Ba Be National Park have more diverse combined dominant species than those in Xuan Son National Park, NR Hang Kia - Pa Co, reached 18, 16 dominant species, respectively.

3.1.1.2. Diversity of tree species

Within the scope of the study, the results used a cofficiency of mixed systems and Simpson diversity index, Shannon-Wiener, Renyi to assess species diversity showing in the research cycle, the forest area in Vu Quang National Park has abundance of species and the highest uniform, followed by the Xuan Son National Park, and then NR in Hang Kia - Pa Co and lowest in Ba Be National Park.

3.1.2. Distribution of tree number by diameter (N/D)

The results showed that as using distance function to shape distribution of N/D, within 21 standard positioned plots, there are 15 plots with the value of χ^2 smaller than χ^2_{05} in survey panel, accounting for 71.43%. In the case of using a function Weibull distribution diversions N/D, the standard results are 17/21 valuable plots with the value of χ^2 smaller than χ, representing 80.95%. This results confirm that distribution Weibull distribution is most appropriate theory to describe the distribution of the diameter of the tree stands in study areas. Calculations of α parameter ranged from 0.85 to 1.26, thus the distribution curve N/D stands reduced form.

3.1.3. Correlation between height and diameter (H/D)

With results inherited from several mathematical functions selected to test for correlation H/D, the study has identified Logarit functional equations (Y = a + b*LnX), is the global equations of extensive simulations the best for correlation of H/D with coefficients determined highest R^2, standard error of regression (SE) small and parameters exist in the overall Sig.f <0.05 . The test results on correlation equation H/D in Table 3.6 - 3.9 also identified common equation (Total) for standard positioned plots in each study area are as follows:

- Ba Be NP: $H_{vn} = -12,009 + 9,067*\text{Ln } D_{1.3}$ (3.7)
- Vu Quang NP: $H_{vn} = -12,595 + 8,701*\text{Ln } D_{1.3}$ (3.14)
- Xuan Son NP: $H_{vn} = -16,957 + 10,967*\text{Ln } D_{1.3}$ (3.18)
- Hang Kia PA - Pa Co: $H_{vn} = -11,194 + 8,763*\text{Ln } D_{1.3}$ (3.25)

3.2. Classification of group species by growth characteristic

The data are used to categorize species collected from 21 plots (21 ha) with two times of measurements in 2007 and 2012. A total of 10

224 trees ($D_{1.3} \geq$ 10 cm) of 442 species recorded, including 2382 trees belonging to 260 species dead and 1147 trees belonging to 238 species of additional regeneration in the period of 5 years; 6695 trees of 373 species were measured 2 times and can calculate the diameter growth, of which only 50 species have n ≥ 30 trees and 323 species with n <30 trees. Within 323 species, 40 species have not been identified their names yet (sp 191 trees), so these species will not be used in grouping species. Total species with enough data at 2 measurements using clustering species are summarized in Table 3.10.

Table 3.10: Summary of statistics for species grouping

ID	Group	Total species	Observation (tree)	Tree proportion (%)	Tree proportion (%)	Note
1	n ≥ 50	25	3.576	15,02	69,28	Cluster analysis
2	30 ≤ n < 50	25	930			Discriminant analysis
3	n < 30	283	1998	84,98	30,72	Subjective group
	Total	**333**	**6504**			

Results of 25 species grouped with n ≥ 50 under strategic K-Means on SPSS with two criteria: the largest diameter species gain (D_{max}) and yearly average diameter growth of species (zd) in the command line: Analyze/Classify/K-Means Cluster/Ok. The results generated are 7 taxa shown in the diagram of species grouping in Figure 3.4 and Table 3.11.

Table 3.11: Results of species grouping by strategic K-Means with criteria D_{max} and zd for 25 species with n ≥ 50

Species	Scientific names	Observation (tree)	Zd (cm/year)	D_{max} (cm)	Note
(1)	(2)	(3)	(4)	(5)	(6)
		Group 1			
Pterospermum argenteum	*Pterospermum argenteum*	51	0,33	60	***GOT***
Polyalthia lawii	*Polyalthia lawii*	58	0,30	64,4	***GOT***
Trema orientalis	*Trema orientalis*	116	0,53	59,2	GON
Streblus saper	*Streblus saper*	133	0,25	58,0	GON
Glycosmis cymosa	*Glycosmis cymosa*	285	0,24	59,2	GON
		Group 2			
Diospyros sylvatica	*Diospyros sylvatica*	157	0,24	116,2	GOL
		Group 3			
Knema lenta	*Knema lenta*	52	0,38	80	GOL
Barringtonia acutangula	*Barringtonia acutangula*	53	0,30	76,4	***GOT***
Alangium ridleyi	*Alangium ridleyi*	76	0,30	86,1	GOL
Lithocarpus ducampii	*Lithocarpus ducampii*	82	0,33	80	GOL
Vatica odorata	*Vatica odorata*	94	0,32	80	GOL
Xylopia pierrei	*Xylopia pierrei*	123	0,31	79	***GOT***
Garcinia fagraeoides	*Garcinia fagraeoides*	146	0,23	80	GOL
Gironniera subaequalis	*Gironniera subaequalis*	102	0,43	76,1	***GOT***
		Group 4			
Castanopsis indica	*Castanopsis indica*	351	0,24	116,2	GOL
		Group 5			
Diospyros pilosula	*Diospyros pilosula*	61	0,30	55,0	GON
Alphonsea philastreana	*Alphonsea philastreana*	299	0,22	54,3	GON
Streblus ilicifolius	*Streblus ilicifolius*	548	0,25	55,8	GON
Diospyros apiculata	*Diospyros apiculata*	74	0,37	55,1	GON
		Group 6			
Caryodaphnopsis tonkinensis	*Caryodaphnopsis tonkinensis*	70	0,34	100	GOL
Excentrodendron tonkinense	*Excentrodendron tonkinense*	176	0,28	105,4	GOL
Vatica odorata	*Vatica odorata*	82	0,29	100	GOL
		Group 7			
Saraca indica	*Saraca indica*	97	0,26	92	***GOT***
Lithocarpus dealbatus	*Lithocarpus dealbatus*	181	0,32	93,6	GOL
Syzygium wightianum	*Syzygium wightianum*	108	0,29	95	***GOT***

Note: Columns (3) is the average diameter growth of the species; column (4) is the largest diameter species gained; column (5) denotes the life forms: GOL, GOT, GON are large wood, medium wood, small timber, respectively. This column was added after synthesis of the results based on SPSS.

Results from Table 3.11 shows that:

- The largest diameter (D_{max}) of species obtained in this studied period for each group of species is relatively uniform.

- Volume growth in the average diameter (zd) between species in group 6 and group 7 have several similarities. Three species groups 1, 3 and 5 have the variation, in particular: zd value fluctuations of taxa 1 from 0.24 to 0.53 cm/year; in group 3 species from 0.23 to 0.43 cm/year; taxa 5 from 0.22 to 0.37 cm/year. This result is reordered to achieve similarity both zd when proceeding discriminant analysis subgroup species.

- In the second and four groups of species, only one species De Ab and Thi Rung in each group with observation capacity with 157 trees and 351 plants were observed.

To test the relevance of results of species grouping on SPSS by strategic K-Means. This study was used documentary sources: Vietnam Forest trees (FIPI, 2000), the name of forest trees in Vietnam (MARD, 2009), Forest plants (Le Mong Chan and Le Thi Huyen, 2000) and expert knowledge to retest all species of life forms grouped in column 5 (Table 3.11). Results showed that apart from small fluctuations in zd species in some groups, also the remaining small fluctuation in life forms of some few species in species group.

To resolve remaining issues of zd variation and life forms of the species groups in Table 3.11 and for more simplicity, we included the species in Table 3.11 based on the initial framework species groups according to the yearly average diameter growth (fast growing, medium, slow) and life forms (large wood, medium wood, small wood). Since then, the study builds up the wooden tree group species under the large, medium, small. In each large timber, medium and small timber will then again be divided into sub-groups with growing fast, medium and slow growth.

Calculating average annual growth of species over 21 plots, results show that most of species only have values of zd at average and slow growth; in particular object of study is the natural forest stands of the

National Park and Reserves - no impact silvicultural measures through thinning, adjusting nutrition space. These findings are confirmed by some authors while studying on natural forests as author Tran Van Con (2007) and Dao Cong Khanh (1996). From this result we can temporarily divided into 3 levels of growth: (i) slow growth: ≤ 0.3 zd cm $year^{-1}$; (ii) the average growth: zd> 0.3 to 0.5 cm $year^{-1}$; (iii) growth: zd> 0.5 cm $year^{-1}$. Simultaneously, we conducted using step 2 as discriminant analysis with 25 species, 50> n ≥ 30 trees and step 3 assigns subjective group 283 species with n <30. The final results grouped species according to the overall 3-steps with 333 species of the study area are recorded in Table 3.13:

Table 3.13: Synthesis of findings from species group for natural forest stands in studied areas

ID	Species group	Total species	Observation (tree)	zd (cm/year)	D_{max} (cm)
(1)	(2)	(3)	(4)	(5)	(6)
1	Slow growing species with small size	53	1738	0,06 ÷ 0,30	59,2
2	Moderate growing species with small size	26	366	0,31 ÷ 0,46	57,3
3	Fast growing species with small size	8	140	0,51 ÷ 0,78	59,2
4	Slow growing species with small size	73	912	0,06 ÷ 0,30	95
5	Moderate growing species with medium size	61	1019	0,31 ÷ 0,49	84,5
6	Fast growing species with medium size	15	58	0,51 ÷ 1,21	70
7	Slow growing species with large size	44	917	0,06 ÷ 0 30	129
8	Moderate growing species with large size	44	1319	0,31 ÷ 0,49	154,4
9	Fast growing species with large size	9	35	0,51 ÷ 0,96	100
	Total	**333**	**6504**		

Note: Column (5) the variation of growth in the average diameter of each taxa; Column (6) is the maximum diameter achieved in each group species.

The results of final species group clasification after performing step to assign subjective observation for small sized species, it has added two species groups: large timber group with faster growth and average timber group with faster growth than results from Cluster group subgroup analysis step and discriminant analysis.

In short, with 4504 individuals of 50 species of large samples *(of which 25 species with $n \geq 50$ and 25 species with $30 \leq n < 50$)* and 1998 individuals of 283 species of small samples ($n < 30$), the study has conducted classification taxa by 3 steps *(as discussed in Chapter 2)* and was classified into 9 taxa as synthesised in Table 3.13.

3.3. Modelling diameter growth, apoptosis and the additional regeneration of natural forest stands

3.3.1. Construction of stand diameter growth model

In order to build the growth diameter model of natural forest stands in the study area, the study inherited the results of selection of functions from other references such as Alder (1995), Alemdag I. S (1978); Rai S. N (1979), West Ward W (1980), K Vanclay J. (1989a), Tran Van Con (2011). The test results have determined the most appropriate model of growth simulation diameter for all species and groups of species from 1 to 9 groups of forests are:

$Ln(zd/(D_{max} - D)) = a + b*Ln(D) + c*PC$ (2.19').

Where: PC is the position canopy; D_{max} is the maximum diameter species gained. D_{max} is a parameter dependent on the position group and canopy species. We have used the equation k + m*PC (3:27) to estimate the position D_{max} under canopy for each species.

From function (3.19), we have $zd = exp(a)*exp(c*PC)*(D_{max} - D)*D^b$. D_{max} replaced by equation (3:27) we have $zd = exp(a)*exp(c*PC)*((k + m*PC) - D)*D^b$ (3:28). Using the parameters a, b, c and D_{max} (via parameter k, m) for each group of species is estimated diameter growth of taxa per diameter. Results showed that the higher canopy position (less competitive), the larger the diameter growth of 9 species and species groups overall. Figure 3.6 is an example of performing the function of diameter growth and under the canopy species group (PC) for some groups of species:

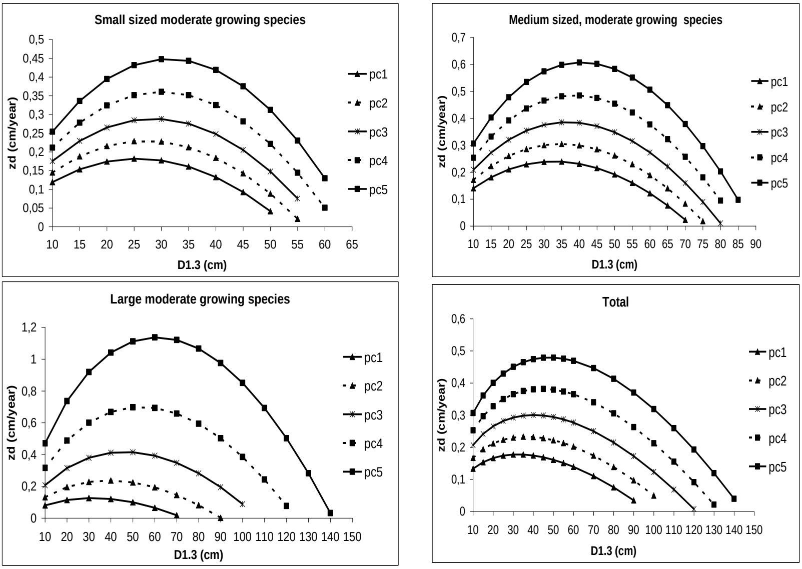


Figure 3.6: Example of diameter growth of some species group and overall species equation zd = exp(a)*exp(c*PC)*((k + m*PC) - D)*D^b (3.28)

From the results of equation selection, $Ln(zd/(D_{max} - D)) = a + b *c*LnD + PC$ (3:28), we add variables of study areas through which the study has improved the accuracy determination of the equation. The coefficient of determination R^2 is higher, standard error of regression (SE) as well as the total squared deviation between the theoretical value and the actual value (RSS) are much smaller than the equation (2.19'). Diameter growth model common for all species (Total) and from group 1 to group species 9 are recorded in equation (3.30) ÷ (3.39) below:

$Zd_{Total}=exp(-8,074)*exp(0,091*PC)*[(85,95+11,8*PC)-D]*D^{0,763} *exp(0,131)$

$Zd_1= exp(-8,818)*exp(0,24*PC)*[(49,2+3,2*PC)-D]*D^{0879}*exp(0,229)$

Zd_2= exp(-8,633)*exp(0,117*PC)*[(50,4+3,2*PC)-D]*$D^{1,094}$*exp(-0,164)

Zd_3= exp(-8,388)*exp(0,216*PC)*[(18,9+7,5*PC)-D]*$D^{1,198}$*exp(0,623)

Zd_4= exp(-8,391)*exp(-0,053*PC)*[(47+11,6*PC)-D]*$D^{0,939}$*exp(0,083)

Zd_5= exp(-8,092)*exp(0,164*PC)*[(67,7+4,3*PC)-D]*$D^{0,795}$*exp(-0,17)

Zd_6= exp(-8,224)*exp(0,053*PC)*[(34,5+7,1*PC)-D]*$D^{1,615}$*exp(-0,596)

Zd_7=exp(-7,145)*exp(-0,338*PC)*[(37,8+19,4*PC)-D]*$D^{0,773}$*exp(-0,272)

Zd_8=exp(-8,678)*exp(0,257*PC)*[(56,2+17*PC)-D]*$D^{0,737}$*exp(0,281)

Zd_9=exp(-5,363)*exp(-1,232*PC)*[(11,8+8,4*PC)-D]*$D^{2,403}$*exp(0,812)

Also, from the equation of the total for all species at 4 Special Use Forest in study zone, the study can also build separately for each region. The different equations by ecoregion Dummy variables (expressed in value d1 to d4). Four equations built for Vu Quang National Park area, NR Hang Kia - Pa Co, Xuan Son National Park and Ba Be National Park were reported in equation (3.40) ÷ (3.43) as follows:

Zd_{VQ} = exp(-8,074)*exp(0,091* PC_{Vq})*[(85,95+11,8*PC_{Vq}) - D_{Vq}]* $D_{Vq}^{0,763}$

Zd_{HK} = exp(-8,074)*exp(0,091* PC_{Hk})*[(85,95+11,8* PC_{Hk}) - D_{Hk}]* $D_{Hk}^{0,763}$

Zd_{XS} = exp(-8,074)*exp(0,091* PC_{Xs})*[(85,95+11,8* PC_{Xs}) - D_{Xs}]* $D_{Xs}^{0,763}$

Zd_{BB} = exp(-8,074)*exp(0,091* PC_{Bb})*[(85,95+11,8* PC_{Bb}) - D_{Bb}]* $D_{Bb}^{0,763}$

3.3.2. Construction process of dead model

Examinatinon of results of relationship between two quantities of dead trees with stand diameters as the ratio correlation all show that there are a relationship between 2 dead trees and stand trees.

Use the form of mathematical functions Logarit, Compound, Power and S for simulating models apoptosis, we achieve results showed in table 3.21:

Table 3.21: Synthesis of mathematical function selections explaining dead process in studied areas

Location	Functions	R^2	SE	RSS	Sig.f	Siga	Sigb	a	b
Hang Kia - Pa Co PA	Logarit	0,691	8,944	479,92	0,011	0,007	0,011	97,674	-26,93
	Compound	0,817	0,662	2,628	0,002	*0,178**	0,000	69,784	0,90
	Power	0,931	0,407	0,994	0,000	*0,406**	0,000	63012,5	-3,01
	S	**0,973**	**0,255**	**0,391**	0,000	0,000	0,000	-1,746	70,434
Xuan Son NP	Logarit	0,712	2,571	39,67	0,008	0,005	0,008	30,40	-8,15
	Compound	0,811	0,447	1,201	0,002	*0,065**	0,000	16,89	0,932
	Power	0,922	0,287	0,494	0,000	*0,252**	0,000	1516,04	-1,989
	S	**0,97**	**0,179**	**0,192**	0,000	0,000	0,000	-1,141	46,704
Ba Be NP	Logarit	0,837	2,47	36,62	0,001	0,001	0,001	41,836	-11,26
	Compound	0,853	0,467	1,306	0,001	*0,074**	0,000	31,676	0,918
	Power	0,936	0,308	0,568	0,000	*0,282**	0,000	6514,14	-2,376
	S	**0,939**	**0,301**	**0,545**	0,000	0,002	0,000	-1,277	54,479
Vu Quang NP	Logarit	0,724	5,476	179,95	0,007	0,005	0,007	65,313	-17,85
	Compound	0,843	0,542	1,76	0,001	*0,112**	0,000	46,997	0,91
	Power	0,94	0,335	0,673	0,000	*0,319**	0,000	19029,6	-2,668
	S	**0,965**	**0,255**	**0,392**	0,000	0,000	0,000	-1,469	61,897

Notes: RSS is the total squared deviation between the actual value and the theoretical value; SE is the standard error of regression.

Results from Table 3.21 shows that although the two functions of Power and Compound have high coefficient of determination R^2, standard error of regression (SE) is lower, the total deviation squared (RSS) parameters a little but does not exist in overall (Siga> 0.05), so can not use this function to simulate 2 apoptosis for study subjects; S and Logarit function can simulate the process of dead model for natural forests in study area. However, S function is the most appropriate due to its coefficient determined for the highest R^2 and regression standard error (SE) as well as the total squared deviation (RSS) smallest.

Modelling stand apoptosis in areas, such as in the form of the S equation functions 3.44 to 3.47 as the following:

$$M_{hk} = Exp(-1,746 + 70,434/D) \quad (3.44)$$

$$M_{xs} = Exp(-1,141 + 46,704/D) \quad (3.45)$$

$$M_{bb} = Exp(-1,277 + 54,479/D) \qquad (3.46)$$

$$M_{vq} = Exp(-1,469 + 61,897/D) \qquad (3.47)$$

From equation (3.44) ÷ (3.47), study identifíes the curve model for regional apoptosis research in Figure 3.7:

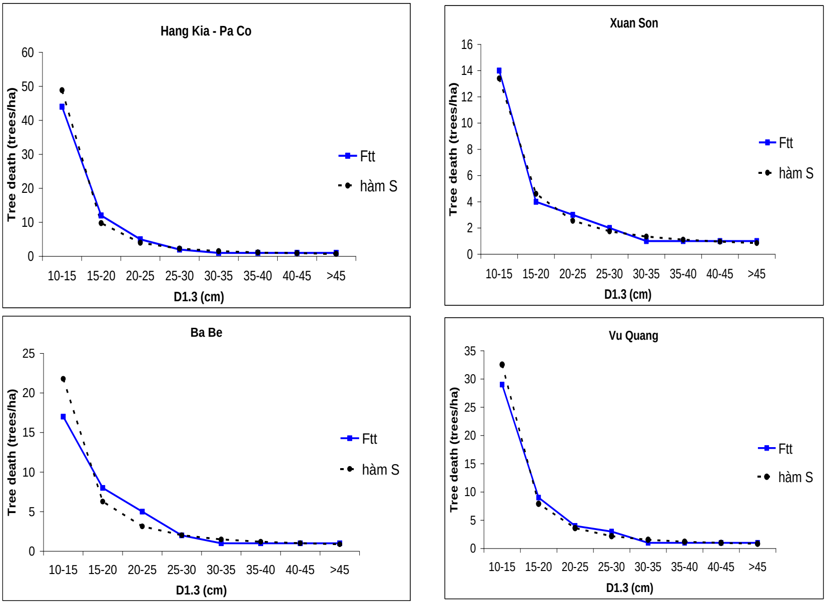


Figure 3.7: Simulation of number of death trees by stand diameter in the study area as a function S

3.3.3. Building additional regenerating model

Inheriting results of a linear function selection of the stand basal area (m^2/ha) and trees (trees/ha) has simulated additional regeneration from some authors in the world and Tran Van Con (2011) to test additional regenerating model based on observation data of 21 plots. The results can not be determined these correlations. However, the relationship between additional regeneration with stand basal area and stand density is well- explained by some nonlinear functions, confirming that there is a relationship between additional regeneration and stand density in the study areas.

Table 3.22. Synthesis of finding selections of mathematic simulation functions of additional regeneration for Special Use Forests

Correlation functions	**R**	**R^2**	**SE**	**RSS**	**Sig.f**	**Siga**	**Sigb**	**a**	**b**
Logarit	0,572	0,328	13,358	3390,3	0,007	0,02	0,007	-174,9	34,788
Compound	**0,576**	**0,331**	**0,403**	**3,079**	0,006	0,012	0,000	10,858	1,002
Power	0,575	0,33	0,403	3,083	0,002	*0,637*[*]	0,006	0,054	1,056
S	0,568	0,323	0,405	3,117	0,007	0,000	0,007	4,488	-419,6

Therefore, Power function is not appropriate for simulating correlation between the additional regeneration and forest stand density for the study area, due to Siga > 0.05. Logarit, S and Compound functions and are satisfied with the overall standard deviation squared (RSS) and small regression standard error (SE), existence of parameters in overall Sig.f <0,05, the correlation coefficient is relatively strong levels (corresponding to the coefficient of determination R^2 from moderate level of relations and R^2 = 0,323 to 0,331). However, Compound function has the smallest value of RSS and SE, with the highest R^2, so the Compound is believed to be the most appropriate equation: $R_{TSBS} = 10,858*(1,002)^N$ (3.48).

3.4. Modelling dynamics of stand structures of natural evergreen broadleaf forests

The above research results are used to predict structural dynamics of natural forest stands of evergreen broadleaf forests in Special Use Forest in the future. For detailed algorithms, the study gives an example of the application model was built for 1 ha stands of evergreen broadleaf forests in Ba Be National Park.

By the equations of 3.7, 3.43, 3.46 on the relationship H/D, diameter growth, apoptosis model in natural forest stands Ba Be National Park built, the study has used these models to simulate structural dynamics in the future stand and has drawn key findings of the structural dynamics change from 2012 - 2022 in natural forests in Ba Be National Park through Figure 3.8, 3.9, 3.10.

* Since 2012 – 2022, distribution of diameter trees from 10-20 cm has reduced, from diameter of 20-25 cm onwards, the density has increased as the diameter ($D_{1.3}$) has increased. In general, curves of tree

density in 2012 - 2022 with a 5 year cycle have increased relatively with uniform diameter of 25-30 cm and 40-45 cm; final diameter is the sum of the diameters larger than 45 cm, therefore it should have a density of more trees than previously diameters (Figure 3.8).

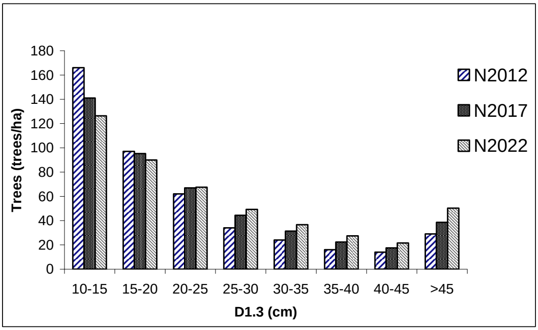


Figure 3.8: Schematic simulation of predicting structural dynamics of N/D evergreen broadleaf forests of Ba Be National Park

* Similar to the distribution of trees, basal area with diameter from 10-20 cm from 2017 to 2022 have all decreased compared to 2012. However, basal area has increased gradually with diameter from third levels onwards (D > 20 cm) and reached climax in diameter 30-45 cm. Basal area growth will reach the highest value in 2017 and 2022 in diameter 35-40 cm and 40-45 cm, respectively. Final diameter is the sum of the diameters larger than 45 cm and should have a value of basal area with dramatically increase in comparison with the previous diameters (Figure 3.9).

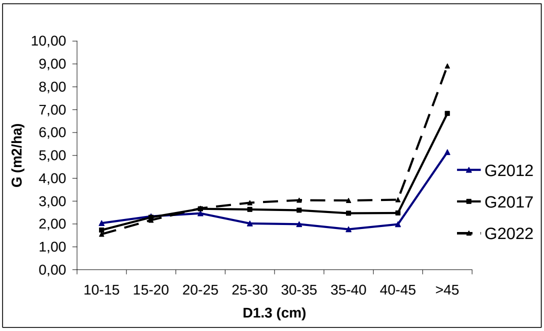


Figure 3.9: Schematic simulation of predicting structural dynamics G/D of evergreen broadleaf forests of Ba Be National Park

* Growth of forest volume shown in Figure 3.10. Forest volume increased from 177.01 $m^3 ha^{-1}$ (2012) to 258.29 $m^3 ha^{-1}$ (in 2022); with growth of forest volume (ZM) in the fifth stage from 2012 to 2017 to reach 1.51 $m^3 ha^{-1}$ per year (2012) up to 7.93 $m^3 ha^{-1}$ per year (2027).

Thus, by using this algorithm, we can simulate prediction of future structural dynamics derived from an original forest that is determined by the investigation and application of forest diameter growth models, death model, additional regeneration model and correlation of H/D. The findings of this dissertation has developed science-based and practical foundation to predict the structure dynamics of natural growth broadleaf forests in Vietnam. In addition, the findings of the study are considered as good references for further research on natural forest growth and are valuable for supporting to both undergraduate and postgraduate curriculums.

CONCLUSION AND FURTHER STUDY

1. Conclusion

1.1. Some structural features of natural forests in study area

- Structural species composition: Basically, natural forests in four study areas have differences in the levels of dominant species and composition dominant species. Vu Quang National Park has the most dominant species richness (18 species), followed by Ba Be National Park (16 species), lowest in NR Hang Kia - Pa Co and Xuan Son National Park (14 species). Dominant species in Ba Be National Park and Ba Hang Kia - Pa Co Protected Area have all expressed very clear dominant role with a high composition ratio and higher total value of the complex IV% dominant species were than that in Vu Quang National Park and Xuan Son National Park.

- Diversity of species: Assessing the species diversity by Shannon diversity index - Wiener, Simpson and Renyi showed the highest species diversity in the forest stands belonged to Vu Quang National Park, followed by Xuan Son National Park , the lowest in NR Hang Kia - Pa Co and Ba Be National Park.

- Structure Distribution $N/D_{1.3}$: Distribution of $N/D_{1.3}$ are all reached the climax in the smallest diameters ($D_{1.3}$ = 10 - 15cm) and decreased when the diameter increases. Weibull function is a simulation function of the best distribution structure $N/D_{1.3}$ with value for α = 0.85 to 1.26.

- Correlation of $H_{vn}/D_{1.3}$: Correlation between height (H_{vn}) and trunk diameter ($D_{1.3}$) has existed with relationships ranging from moderate to strong degree and is expressed as the equation (3.1) - (3.25).

1.2. Species grouping according to growth characteristics

There are 333 species classified into 9 groups of species based on a survey of 21 standard positioned plots in evergreen broadleaf forest types. These classifications are based on growth in average diameter (zd), the maximum size of species achieved (D_{max}) and life types of species. Nine species groups include: (1) small timber group with slow growth; (2) small timber group with medium growth; (3) small timber group with rapid growth; (4) medium-sized timber group with slow growth; (5) medium-sized timber group with medium growth; (6) medium-sized timber group with fast growth group; (7) large timber with slow growth; (8) large timber with medium growth; (9) large timber with fast growth.

1.3. Building diameter growth, apoptosis and additional regeneration process

- Diameter growth model: General function of diameter growth to all species (Total) and 9 taxa with three variables $D_{1.3}$, PC (position canopy), S_i (Dummy variables). The equations were determined and illustrated in the equation (3.30) - (3.39).

- Modelling apoptosis process: It is determined the functional form of S is the best correlation simulating apoptosis process in studied forest stands, with criteria of smallest RSS, SE and highest value of R^2. Equations were determined as indicated in equations (3.44) - (3.47).

- Modelling additional regeneration process: In each individual study area, the study has not determined the relationship between additional regeneration with density and forest basal area yet, because the pair of observations is not large enough. However, on the overall scope of 4 studied areas (total 21 standard positioned plots), the study has identified the Compound function as a good for expressing the relationship between additional regeneration stand density (Equation 3.48).

1.4. Simulation of predicting dynamics of natural stand structures

The study conducted the simulation of dynamics of stand structures from 2012 - 2022 for natural evergreen broadleaf forest in Ba Be National Park that was based on the results of the construction of diameter growth models, apoptosis process and additional regeneration. Similarly, by this method we could also predict the dynamics of stand structures in the remaining areas. Moreover, the study results in this dissertation also have implications for other research purposes in terms of methodology approach.

2. Limitations

- Time tracking and data collection have conduced with 5 year study period (2007 - 2012), so the rules of dynamics of forest structures and forest growth models are not represented clearly enough.

- The study has only conducted modeling rules for the overall growth of the entire subjects at each study location. Predicting dynamics of forest structure based on general equation for the entire object, therefore somehow these results may be limited in application to different characteristics.

3. Further study and suggestions

- There should be a need for further studies in other areas to get a more comprehensive views of the structural characteristics of each object.

- It is necessary to continue research in different cycles (every 5 years) and conduct the same standard positioned plots for a more comprehensive assessment of the growth model in the study objects.

- Modelling rules of growth for each object (or state) should be a need to get the most relevant results.