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RESEARCH ON NATURAL REGENERATION CHARACTERISTICS OF *Shorea roxburghii* G. Don IN THE TROPICAL MOIST EVERGREEN CLOSED FOREST IN TAN PHU AREA, DONG NAI PROVINCE.

SUMMARY OF DOCTORAL DISSERTATION

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LIST OF PUBLISHED ARTICLES

1. Tran Quang Bao, Le Hong Viet, 2019. Ecological role of *shorea roxburghii* population in tree species composition of tropical moist evergreen closed forest in Tan Phu zone of Dong Nai province, *Journal of Forestry Science and technology No* 05/2019, Vietnam National University of Forestry, pg 90 - 98.
2. Le Hong Viet, Tran Quan Bao, 2019. The effect of ecological factors to natural regeneration of *Shorea roxburghii* G. Don in tropical moist evergreen closed forest at Tan Phu zone of Dong Nai province, *Journal of Forestry Science and technology No* 03/2019, Vietnam National University of Forestry, pg 77 - 88.
3. Le Hong Viet, Tran Quan Bao, Pham Van Huong, 2019. Role of population *shorea roxburghii* in composition of tropical moist evergreen closed forest in Tan Phu zone of Dong Nai province, *Journal of Agricultural and Rural Development. No* 20/2019, Ministry Of Agriculture & Rural Development, Pg 87 - 95.
4. Le Hong Viet, Nguyen Hong Hai, Tran Quang Bao, Nguyen Van Tin, Le Ngoc Hoan, 2020. The spatial structural characteristics of dominant species in tropical moist evergreen closed forest at Tan Phu zone, Dong Nai, *Journal of Forestry Science and technology No* 01/2020, Vietnam National University of Forestry, pg 72 - 83.
5. Pham Van Huong, Nguyen Ba Trieu, Le Hong Viet, Kieu Phuong Anh, 2019. Regeneration characteristics of *Shorea rox burghii* G. Don under gaps in evergreen closed forest at Binh Chau Phuoc Buu Natural Reserve, *Journal of Agricultural and Rural Development. No* 17/2019, Ministry Of Agriculture & Rural Development , Pg 84 - 91.

INTRODUCTION

1. Introduction

Previously, several authors Le Van Minh, (1986), Thai Van Trung, (1985), Nguyen Van Them (1992), Dao Thi Thuy Duong and Le Ba Toan (2018) has carried out research on the ecological and natural regeneration characteristics of some species of Dipterocarpaceae family such as *Dipterocarpus alatus*, *Dipterocarpus dyeri* Pierre, *Shorea guiso* (Blco) Blume, *Hopea odorata*, and *Anisoptera costata Korth*. However, science and practical production still lacked knowledge about the ecological regeneration of many species of trees in the Dipterocarpaceae family, including the *Shorea roxburghii* G. Don.

Shorea roxburghii G. Don is a woody tree species belonging to the Dipterocarpaceae family. Its wood property is good and is used in construction, boat building, and household furnitrure (Tran Hop and Nguyen Boi Quynh, 2003). *Shorea roxburghii* G. Don was listed in the 2000 IUCN World Red Book at Endangered A1cd. However, because of tropical evergreen closed forest was degraded and converted to agricultural land, the distribution area of *Shorea roxburghii* G. Don has been narrowed. Therefore, researches to provide information to set up an ecological regeneration principles for *Shorea roxburghii* G. Don is necessary. This dissertation focuses on clarifying the following 5 main questions: (1) How are *Shorea roxburghii* G. Don populations formed in environmental conditions? (2) What is the ecological role of *Shorea roxburghii* G. Don population in the tree speciess composition and forest's composition communities; (3) Are *Shorea roxburghii* G. Don populations regenerating continuously or periodically under forest canopy? (4) How many stage does regenerating trees go through in the life related to light requirements; (5) What are the main ecological factors affecting the natural regeneration stages of *Shorea roxburghii* G. Don populations?

From these issues, the study of natural regeneration characteristics of *Shorea roxburghii* G. Don and the factors affecting the regeneration process not only had cientific significance but also high practical significance at Dong Nai

2. Objectives of the study

2.1. General objectives

Research on the ecological characteristics of *Shorea roxburghii* G. Don under the tropical moist evergreen closed forest canopy being the basis for recommendations in forest management and appropriate silviculture practices.

2.2. Specific objective

(1) Identication of regeneration characteristics of the *Shorea roxburghii* G. Don species under the forest canopy.

(2) Evaluating the quantity and quality of regeneration trees of *Shorea roxburghii* G. Don species; behaviour and role of saplings of *Shorea roxburghii* G. Don species in communtity under the canopy.

(3) Identifying and analyzing the factors affecting the regeneration stages of *Shorea roxburghii* G. Don species as the basis for the proposed restoration techniques of this species in the study area.

3. Subject and scope of research

3.1. Research subject: regenerative trees of *Shorea roxburghii* G. Don species under the tropical moist evergreen closed forest canopy

3.2. Research scope

There are 4 main contents: (1) the environmental conditions under the forest canopy; (2) The ecological role of *Shorea roxburghii* G. Don population in tree species composition and forest's composition communities in rich, medium and poor forest status; (3) the phenological and fruit dispersion patterns of *Shorea roxburghii* G. Don population; and (4) the main factors affecting on natural regeneration of *Shorea roxburghii* G. Don.

The study was conducted in forest land of Tan Phu Protection Forest Management Board in Dong Nai province. The research area consists of 13,594.0 ha of natural forest occupied by mainly closed tropical humid evergreen forest with the dominance of Dipterocarpaceae family. Research period lasted from 2016 to 2019.

4. Meaning of research

Theoretically, the topic provides information to set up the principles of natural regeneration of *Shorea roxburghii* G. Don population in

particular and Dipterocarpaceae family in general in closed tropical humid evergreen forest in the Southeast area. In practice, this research offers information to develop forest management measures and harvesting - regeneration methods for the closed tropical humid evergreen forest in the study area.

5. The new contributions of the thesis:

(1) Scientifically, the study has identified the characteristics of basic regeneration of *Shorea roxburghii* G. Don species that divided into 2 stages: the seedling stage needed canopy cover > 0.7 and tree regeneration stage contributed to forest cover that requiring canopy cover from 0.5 to 0.7 and an appropriate gaps from 200 – 300 m^2.

(2) Practically, the research has identified the ecological factors and intrinsic factors in the forest composition affecting the quantity and quality of regeneration of *Shorea roxburghii* G. Don species as the basis for technical proposals for rehabilitation and increased the rate of species in the community composition.

Chapter 1
BACKGROUND

The thesis has reviewed studies in the world and Vietnam on natural regeneration and ecological characteristics of tropical forests as well as Dipterocarpaceae family. This review is summarized from 124 references are as follows.

(1) Most research on regeneration of trees and forests only focused on phenological characteristics and the response of regenerated trees to the ecological factors that were under control. This study concentrated on analyzing the reaction of regenerated trees to the changing of tree species composition, canopy, cover of shrubs and vegetation, size of gaps and several features of the soil layer (humidity and pH_{H2O}).

(2) Natural regeneration of wooden trees and forests underwent many various stages such as reproductive organ formation, flowering, fruiting, fruit ripening and spreading, seed germination and the stage of seedling and sapling formation until they reached the base of the canopy. Each

stage was influenced by different environmental factors. Therefore, forest regeneration must be studied in different phases. This study showed 3 stages of natural regeneration trees of *Shorea roxburghii* G. Don species. Stage 1 from the formation of the reproductive organs until the fruit was ripe and dispersed. Stage 2 from when the seedling appeared until the seedling reached H ≤ 100 cm. Stage 3 from when seedlings reached H > 100 cm until they reached D ≤ 6.0 cm. The response of the regenerating tree of *Shorea roxburghii* G. Don species to the environmental changes was clearly analyzed in stages 2 and 3.

(3) The relationship between forest regeneration and environmental factors could be determined by qualitative and quantitative methods. Qualitative methods were applied in cases where both the dependent variable and the independent variable was difficult to measure by certain units of measure. On the contrary, for the dependent variables measured by binary variables (encountered = 1, unseen = 0), the scientist could analyze the relationship between the regenerated plants and the environmental factors by Gauss logistic regression method. This method allowed the precise determination of ecological parameters (optimum, tolerance and ecological amplitude) for each tree speciess. In this study, the relationships between regenerated trees of *Shorea roxburghii* G. Don species and the dominance of mother trees in flora community, tree species composition, competition index among trees and some characteristics of the soil layer (humidity and pH_{H2O}) were analyzed.

(4) The results pointed out the stand characteristics and regeneration state depended on sample plot size, sampling method and data processing method. In this study, forest stand characteristics were recorded from sample plots with a size of 0.25 ha. Regeneration status under forest canopy was determined from sample plots with the size of 16 m^2. The regeneration status under shrub and vegetation was collected from sample plots with the size of 4 m^2. Rectangular sample plots were selected by typical methods.

(5) The outcomes of reporting on regeneration forest depended on the indicators and standards used for the assessment. In this research, natural regeneration of *Shorea roxburghii* G. Don species was evaluated

through 7 criteria: composition of regenerated tree species, density, origin (seed, bud), distribution of trees by grade of height, quality of seedlings (good, medium, bad), number of promising seedlings (H> 200 cm and healthy) and distribution characteristics of regenerated trees on the ground.

Chapter 2
CONTENT AND RESEARCH METHODOLOGY

2.1. Research content

(1) Environmental conditions in the place of growth of *Shorea roxburghii* G. Don population
(2) Ecological role of *Shorea roxburghii* G. Don species in the forest plant communities.
(3) Vegetation composition for three different forest states.
(4) Natural regeneration characteristics of *Shorea roxburghii* G. Don species and the influent factor.

2.2. Methodology

2.2.1. Literature review

This methodology was based on four concepts as follows:
First of all, regenerating trees were an integral part of the forest ecosystem. Secondly, forest regeneration took place through many different stages and each stage required different environmental conditions. Secondly, the results of forest regeneration must be assessed on the base of silviculture - economic point of view. Last but not least, the descriptive method and modeling method that can be applied to analyze the relationship between regenerated plants and environmental factors.

The approach of the topic started from studying environmental conditions (climate, topography, soil) to form populations of *Shorea roxburghii* G. Don species, following by research on the role of *Shorea roxburghii* G. Don species in the forest plant communities. Finally, study of the regeneration process (phenology, the formation of seedlings and saplings) and factors affecting natural regeneration of *Shorea roxburghii*

G. Don species.

2.2.2. Research questions and hypotheses

The research focused on clarifying the following 5 main questions: (1) How was the *Shorea roxburghii* G. Don populations formed in environmental conditions? ? (2) What was the ecological role of *Shorea roxburghii* G. Don population in the tree species composition and forest's composition communities; (3) Were *Shorea roxburghii* G. Don populations regenerated continuously or periodically under forest canopy? (4) how many stages did the regenerating trees go through in the life related to light requirements; (5) What were the main ecological factors affecting on the natural regeneration stages of *Shorea roxburghii* G. Don populations?

To answer the 5 questions above, this thesis tested 5 hypotheses.

Hypothesis 1: *Shorea roxburghii* G. Don populations were formed under different environmental conditions. Hypothesis 2: The *Shorea roxburghii* G. Don populations played a dominant ecological role in the forest plants communities. Hypothesis 3: *Shorea roxburghii* G. Don population regenerated continuously under the forest canopy. Hypothesis 4: The life of a regenerating tree of *Shorea roxburghii* G. Don went through two stages of shade tolerance and photophilic phase. Hypothesis 5: The natural regeneration stages of the *Shorea roxburghii* G. Don population depended on the forest status, the dominance of the parent tree, the canopy, the growth of shrubs and vegetation, the size of gaps, stand structure, competition between trees in forest and topsoil character.

2.2.3. Data collection

(1) Determining the environmental conditions of forming dominant trees

The climate conditions for the year was collected including mean air temperature (T, ^{o}C), average rainfall (M, mm) and average air humidity (Rh,%). The forest status was examined according to the forest status map of the Tan Phu Protection Forest Management Board in Dong Nai Province in 2017. The land type was determined based on the land map with map scale 1 /100.000.

2) Identifying the role of *Shorea roxburghii* G. Don species in the

forest plant communities

The role of *Shorea roxburghii* G. Don species in tree composition and three forest states were scrutinized from 12 typical sample plots with an area of 0.25 ha. The natural regeneration status (speciess composition, N/H distribution, origin, quality) of the *Shorea roxburghii* G. Don population in three forest states (poor, medium, rich) was dissected from 60 sub- sample plots with an area of 16 m^2 (4*4 m); in which each state occupied of 20 sample plots.

(3) Determination of the phenological character of *Shorea roxburghii* G. Don population

The phenological character of *Shorea roxburghii* G. Don population was studied: (a) The beginning and ending stages of the reproductive stages (flowering, young fruit, ripe fruit, ground-falling fruit and seed germination) ; (b) Yield of fallen fruit; (c) The period of raining.The yield of fallen fruit on the forest floor was determined from 64 sub-sample plots with a size of 1 m^2 (100 * 100 cm). The phenological phenomena were collected repeatedly in 3 consecutive years (2017-2019).

(4) Determining the factors that influence on regeneration of *Shorea roxburghii* G. Don species

(a) Influence of forest status on natural regeneration of *Shorea roxburghii* G. Don species. Each forest state was measured repeatedly 4 sample plots with an area of 0,25ha (50*50 m). A total sample plots in three forest states were 12.

(b) The effect of *Shorea roxburghii* G. Don dominance in the forest stand, tree composition and competition among trees on natural regeneration of *Shorea roxburghii* G. Don species were analyzed from 9 sample plots in rich forest state. Natural regeneration of *Shorea roxburghii* G. Don species in 9 sample plots was determined from 90 sub-sample plots with an area of 16m^2 (4 * 4 m); in a sample plots encompassed 10 sub-sample plots. The natural regeneration status of *Shorea roxburghii* G. Don species was assessed by density, N / H distribution, source and quality.

(c) Determining the effect of canopy cover (C_R) on natural regeneration of *Shorea roxburghii* G. Don. Firstly, division of forest

cover into 4 levels: <0,4; 0,5 – 0,6; 0,7 – 0,8 và 0,9 – 1,0. Each C_R level was measured repeatedly 3 plots with size of 100 m^2 (10 * 10 m). A total of 4 C_R levels was 12 sub-sample plots with an area of 100 m^2. C_R indicators were measured indirectly by photos taken from cell phones Iphone 6; 12 mega pixels resolution. Natural regenerated trees of *Shorea roxburghii* G. Don under each C_R level were identified from 5 sub-sample plots with an area of 4 m^2 (2 * 2 m). A total of 4 C_R levels was 60 sub-sample plots (area of 4 m^2). Each sub-sample plot was placed on 2 diagonal lines of a 100 m^2 plot.

(d) The effect of shrubs on natural regeneration of *Shorea roxburghii* G. Don was assessed through the coverage (C_{CB}) and height - H (cm) of the shrub. The C_{CB} indicator was determined on a sub-sample plot with the area of 4 m^2 (2 * 2 m). The H index of the shrub was measured with a pole with an accuracy of 0,10 m; then divided into 3 levels (H <100; H = 100 - 200 and H = 200 - 300 cm). Each C_{CB} level and H level of shrub were measured repeatedly 3 times on sub-sample plots with an area of 2 * 2 m (4 m^2). A total of 4 C_{CB} levels and 3 H levels of shrub were collected in 80 sub-sample plots. In each sub-sample plot, density statistic, stem height, source and quality of regenerated trees were recorded.

(e) The effect of vegetation on natural regeneration of *Shorea roxburghii* G. Don was evaluated through coverage. The coverage of vegetation (C_{TT}) was estimated on a sub-sample plot of 4 m^2 (2 * 2 m). Then divided into 4 levels: C_{TT} <25%; 25 – 50%; 50 – 75% and > 75%. Each C_{TT} level was gauged repeatedly in 10 sub-sample plots with an area of 4m^2 (2 * 2 m). A total of 4 C_{TT} levels were recorded in 40 sub-sample plots. In each sub-sample plot, examined the density statistics, stem height, source and quality of regenerated trees

(f) Effect of gaps (LT) in forest canopy on natural regeneration of *Shorea roxburghii* G. Don were scrutinized from 12 gaps. The gap size were divided into 4 grades: <100, 100 - 200, 200 - 300 and> 300 (m^2). Each gap level was measured repeatedly 3 times. In each gap level, the regeneration status of *Shorea roxburghii* G. Don was determined from 10 sub-sample plots (area of 2 * 2 m (4 m^2)) in the center of gap. Total of 4 gap levels were recorded in 40 sub-sample plots. In each gap, the density,

stem height, source and quality of regenerated tree were conducted statistically.

(g) The relationship of the regenerating tree of *Shorea roxburghii* G. Don with the two characteristics of the topsoil layer (moisture and pH_{H2O}) was studied from 90 sub- soil profile. Regenerative tree of *Shorea roxburghii* G. Don was identified by two signs as encountered (1) and not encountered (0).

2.2.4. Data analysis methods

The climate conditions forming *Shorea roxburghii* G. Don populations were described monthly and yearly as rainfall, average air temperature, average humidity, annual water evaporation, monthly sunny hours and dry humid condition of Thai Van Trung (1999). Topography was depicted according to absolute altitude and slope. Soil was described by soil type.

The role of *Shorea roxburghii* G. Don species in forest communities which belonging to three forest states was determined according to the method of Thai Van Trung (1999). The similarity of tree species composition among three forest states was determined by the similarity coefficient of Sorensen. The level of mixture (HG) of tree species is verified by the formula HG = S / N, with S = number of tree species, N = population density. The N / D distribution of the three forest states was modeled with a negative exponential distribution function. The N / H distribution was modeled by the distance distribution. Forest complex structure index (SCI) was determined by the formula SCI = (S*N*H*G)/10^6. The natural regeneration status of the three forest states was valued according to the regeneration tree speciess composition, density, source, N / H distribution and vitality status.

Analysis of the phenological character of *Shorea roxburghii* G. Don population was illustrated by a table, including the period of flowering, young, ripe and fallen fruit, germination and weather conditions corresponding to the above periods.

The relationship between natural regeneration of *Shorea roxburghii* G. Don with 6 environmental characteristics (C_R, C_{CB}, C_{TT}, LT, SCI and competitive index (CCI)) was analyzed by table and graph method. The

suitable environmental conditions for natural regeneration of *Shorea roxburghii* G. Don were evaluated according to three criteria: the highest density of regenerated trees, the number of best regenerated trees and the number of potential regenerating trees (H > 200 cm). Assuming the other environmental factors were homogeneous, the feedback function between the regenerated *Shorea roxburghii* G. Don tree and the topsoil properties was analyzed by the Gaussian logit regression functions.

The calculation tool was an Excel spreadsheet, statistical software Statgraphics Plus version 4.0 and SPSS 10.0. Excel spreadsheets were used to gather data and draw charts and graphs. Two statistical softwares Statgraphics Plus version 4.0 and SPSS 10.0 were used to analyze tree species composition, forest stand structure and relationship between regenerating *Shorea roxburghii* G. Don trees and environmental factors.

Chapter 3
RESULTS AND DISCUSSION

3.1. Enviromental conditions forming *Shorea roxburghii* G. Don populations

The *Shorea roxburghii* G. Don populations were formed on a tropical monsoon climate in the Southeast area. The dry humid condition of level II (moisture, rainfall = 1,200 - 2,500 mm / year; number of dry months S = 4 - 6 months; number of severe dry months A = 1-2 months; number of extreme dry months D = 0 - 1 month. The *Shorea roxburghii* G. Don populations were established on the low terrain along La Nga river; absolute altitude from 70 m to 100 m above sea level; the slope was not more than 10^0; gray soil on granite.

3.2. The role of *Shorea roxburghii* G. Don species in the forest plant communities

3.2.1. Tree species composition

Analysis of tree speciess composition of the forest plants in three forest states (Table 3.1) indicated that the total number of tree species being encountered was 92 species in 64 genera of 42 families. Number of tree speciess encountered the most in rich forest state (64 species), the lowest in the medium forest state (61 species). The number of tree families in the three forest states to be similar (about 32 - 33 families). The number

of dominant and co-dominant trees was highest in the poor forest state (7 families), while the medium forest state and the rich forest state were the same (4 families). Diterocarpaceae family dominated in all three forest states. The dominance of *Shorea roxburghii* G. Don increased from the poor forest state (IVI = 21.8%) to the medium forest state (IVI = 26,8%) and the rich forest state (IVI = 29,2%).

Table 3.1. Family and tree species compsition of the three forest states of tropical moist evergreen closed forest in the study area. (unit: 1 ha)

No	Criteria	Forest state		
		Poor	Medium	Rich
(1)	(2)	(3)	(4)	(5)
1	Number of family	33	32	33
2	Number of dominant family	4	4	7
3	Number of species	63	61	64
4	Number of dominant species	5	5	5
5	IVI% index of *Shorea roxburghii* G. Don species	21,8	26,8	29,2
6	IVI% index of other species	78,2	73,2	70,8

Similarity coefficient on family was the highest; reaching the average of 82% in the two forest states, ranging from 80% to 83%. The similarity coefficients on species also received a very high value; it's average between the two forest states was 70%, ranging from 66% to 74%. The density, cross-section and timber volume of the forest community of these three forest states differed markedly. The tree species composition of these three forest states was quite rich; in which *Shorea roxburghii* G. Don played a dominant ecological role. The high timber reserves of forest community, the higher the dominance of *Shorea roxburghii* G. Don.

3.3. Forest stand composition of three forest states

3.3.1. Diversity of tree species

The results indicated the total number of tree species was counted in the forest communities of three forest states being 92 species. The number of tree species encountered the most in rich forest state (64 species), the lowest in the medium forest state (61 species). The average number of tree

species was counted in the sample plots of 0,25 ha in all three forest states was similar (35 - 36 species / 0,25 ha). Tree species richness index ($d_{Margalef}$), uniformity index (J'), Shannon diversity index (H') and Gini-Simpson diversity index (1 - λ') in poor forest status ($d_{Margalef}$ = 7,1; J'= 0,86; H' = 3,05; 1 - λ'= 0,93 respectively) obtained higher value than rich forest status (dMargalef = 6,7; J'= 0,82; H' = 2,90; 1 - λ '= 0,90 respectively) and medium forest state ($d_{Margalef}$ = 6,7; J' = 0,80; H '= 2 , 87; 1 - λ '= 0,91 respectively).

Analysis of tree species diversity data showed that the tree species diversity was the highest in the rich forest state, followed by the poor forest state, and the lowest being the medium forest state. The distribution of the richness of the species in the poor forest state was more homogeneous than that of the medium and rich forest state. In general, the Shannon H 's diversity index had an average value (H' = 2 - 3). On the other hand, when *Shorea roxburghii* G. Don was dominant in forest communities, the diversity of tree species had stronger variation.

3.3.2. Distribution of trees according to diameter and height classes

The mean diameter of the forest stand of the rich forest state (19,9 cm) was greater than that of the medium forest state (15,7 cm) and the poor forest state (16,0 cm). The range and coefficients of diameter variation of the forest stand in rich forest state (respectively 10 - 64 cm and CV = 62,3%) was larger than that of the medium forest states (respectively 10 - 52 cm and CV = 58,6%) and poor forest status (respectively 10-40 cm and CV = 47,5%). The distribution of N / D of these three forest communities was consistent with the exponential distribution function (fomular 3.1 - 3.3).

$N_{(rich)} = 640,521*exp(-0,0920*D) + 5,9348$ (3.1)

$r^2 = 99,7\%$; $S_e = \pm 4,7$; MAE = 3,3; MAPE = 13,9%.

$N_{(medium)} = 4145,24*exp(-0,22119*D) + 22,6668$ (3.2)

$r^2 = 99,3\%$; $S_e = \pm 15,2$; MAE = 10,6; MAPE = 75,5%.

$N_{(poor)} = 1528,13*exp(-0,17939*D) + 22,8388$ (3.3)

$r^2 = 97,2\%$; $S_e = \pm 21,3$; MAE = 13,5; MAPE = 68,9%.

The average height of the rich forest state (15,2 m) was greater than that of the medium forest state (14,3 m) and the poor forest state (13,8 m).

The range of variation in heigh class of rich forest state (8 - 26 m) obtained the higher value than those of medium forest status (8 - 24 m) and 2 levels compared to those in the poor forest state (8 - 24 m). The height of the tree comunities in three forest states varied quite significantly (CV = 26,0%, 26,9% and 24,3%, respectively). The N / H distribution of these forest communities had a single peak pattern; in which the top of the curve was on the left and slightly pointed in the rich and medium forest states (Ku> 0), slightly stagnant (Ku <0) in the poor forest state. Richards distribution function described well the N / H distribution of forest communities in these three forest states (funtion 3.4 - 3.6).

$F_{H(rich)}$ = (1 + exp(-(H – 12,0997)/2,55896))^- 1,76829 (3.4)

R^2 = 99,7%; S_e = ±0,022; MAE = 0,015; MAPE = 6,4%.

$F_{H(medium)}$ = (1 + exp(-(H – 2,36405)/3,01819))^- 21,2731 (3.5)

R^2 = 99,6%; S_e = ±0,022; MAE = 0,015; MAPE = 5,4%.

$F_{H(poor)}$ = (1 + exp(-(H – 5,73801)/2,60138))^- 9,12799 (3.6)

R^2 = 99,6%; S_e = ±0,025; MAE = 0,016; MAPE = 7,4%.

In these three forest states, *Shorea roxburghii* G. Don distributed in all classes of D and H. In the rich forest state, the proportion of saplings ranged from 24,7% at D = 10 cm to 57,1%, 1% at D = 46 cm; average 29,6%. In the medium forest state, the percentage of *Shorea roxburghii* G. Don ranged from 11,5% at D = 10 cm to 56,1% at D = 34 cm; 17,9% on average. In the poor forest state, the proportion of *Shorea roxburghii* G. Don ranged from 5,4% at D = 10 cm to 42,6% at D = 28 cm; 13,0% on average. In rich forest state, the proportion of *Shorea roxburghii* G. Don ranges from 5,4% at H = 8 m to 49,1% at H = 10 m; average 29,6%. In the medium forest state, the proportion of *Shorea roxburghii* G. Don ranged from 2,5% at H = 14 m to 51,4% at H = 22 m; 17,9% on average. In the poor forest state, the ratio of the *Shorea roxburghii* G. Don ranged from 7,0% at H = 10 m to 48,3% at D = 20 m; 13,0% on average. The above analysis showed that *Shorea roxburghii* G. Don has been regenerating continuously under the forest canopy. This ensures that *Shorea roxburghii* G. Don played a dominant role in the development process of tropical moist evergreen closed forest in the study area.

3.3.3. The complex in tree composition

The results indicated that the mixed index of the tree species in the forest communities belonging to the poor forest state (0,28) was higher than that of the rich forest state (0,22) and the medium forest state (0,19). SCI index decreased gradually in rich forest, medium forest and poor forest states being 0,63, 0,54 and 0,20 respectively. The CCI index rearched the highest value in the medium forest state (1,85), and the lowest in the poor forest state (1,14).

3.4. Natural regeneration characteristics of *Shorea roxburghii* G. Don and influencing factors

3.4.1. Phenological characteristics

Surveys in natural forest showed that *Shorea roxburghii* G. Don species reproduced when D> 25 cm and H> 20 m. The individuals reproduced strongly in the group of D = 50-60 cm. The *Shorea roxburghii* G. Don population shed leaves simultaneously in the last ten days of December to the first ten days of January. Flower buds came at the same time with new leaves. Young fruits appeared in mid-February and lasted until early April. The fruit ripened and fell off on the forest floor from early May and ended in the last ten days of June (Table 3.2). The yield of spreading fruit on the forest floor increased gradually according to the dominance of *Shorea roxburghii* G. Don in the forest. The average rate of seedlings formed annually under the forest canopy was 48,7%.

Table 3.2. The phenological stages of *Shorea roxburghii* G. Don populatiom. Observation period from 2017 to 2019.

	Dry season						Rainy season					
Month	11	12	1	2	3	4	5	6	7	8	9	10
Phenology	S	-	+	*	*	*	0	0	S	S	S	S

Ghi chú: (-) shedding leaves; (+) Flowering; (*) Young fruits; (0) Ripen and fallen fruit; (S) Growth period.

The *Shorea roxburghii* G. Don fruits spreaded due to rain. Scattered rains in the last ten days of April and the early of May were stimulating factors of spreading fruits on the forest floor. Shrubs, vegetations and fallen objects on the forest floor greatly affected the grounding of the fruits and

the formation of seedlings. The 2- winged fruits facilitated the wind spreading but caused disadvantage to the landing. When dispersed, the fruits could be trapped on fallen matter and shrubs. The topsoil contained a lot of sand and moisture being a favorable condition for the germination of *Shorea roxburghii* G. Don seeds. However, severe heat prolonged at the beginning of the rainy season led to the death of saplings.

3.4.2. Factors influencing the regeneration of the *Shorea roxburghii* G. Don population

3.4.2.1. Forest states

Regenerating trees of *Shorea roxburghii* G. Don under the canopy of three forest states existed at all levels of H (<50cm to > 250cm); mostly distributed in H class <100 cm (65,8% in rich forest state; 56,3% in medium forest state; 55,2% in poor forest state). The number of regenerated trees reached level H> 200 cm was the highest in the medium forest state (344 trees / ha), followed by the rich forest state (281 trees / ha), the lowest in the poor forest state (188 trees/ha) (Table 3.3)

Table 3.3. Distribution of *Shorea roxburghii* G. Don regenerating trees according to height class under the canopy of three different forest states. *Unit: 1,0 ha.*

TT	H class (cm)	Density of *Shorea roxburghii* G. Don regenerated trees according to forest states:					
		Rich		Medium		Poor	
		N (tree)	N%	N (tree)	N%	N (tree)	N%
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	< 50	1.000	42,1	594	29,7	438	36,8
2	50 - 100	563	23,7	531	26,6	219	18,4
3	100 - 150	313	13,2	344	17,2	188	15,8
4	150 - 200	219	9,2	188	9,4	156	13,2
5	200 - 250	156	6,6	219	10,9	125	10,5
6	> 250	125	5,3	125	6,3	63	5,3
	Total	2.375	100	2.000	100	1.188	100

The *Shorea roxburghii* G. Don regenerative trees under the canopy of three forest states came from seeds and shoots. In rich and medium forest states, *Shorea roxburghii* G. Don regenerative trees in the form of shoot only appeared at class of H ≤ 150cm; meanwhile, in the poor forest state at H <200cm class. The number of good quality regenerated trees in the rich forest state (1.031 trees / ha) was higher than that in the medium forest state (1.000 trees / ha) and the poor forest state (531 trees / ha). Number of potential regenerative trees (class of H> 200 cm and good quality) replacing the original trees to be the highest in the medium forest (344 trees / ha), followed by the rich forest state (281 trees / ha), the lowest in the poor forest state (187 trees / ha). Distribution of regenerating trees on forest floor of all three forest states was in the form of cluster distribution (T = -2,95 to -5,41). This distribution was related to the distribution of the original trees in clusters, the fruit distributed according to gravity and the uneven topography, soil and trees under canopy.

3.4.2.2. *Shorea roxburghii* G. Don tree dominance

The results showed that the dominance of *Shorea roxburghii* G. Don in the forest communities significantly affected the natural regeneration of it. *Shorea roxburghii* G. Don constantly regenerated under the forest canopy. The density of regenerated trees of *Shorea roxburghii* G. Don was highest in the forest communities with IVI index ranging from 25-35%; the lowest in forest communities with IVI index less than 25%. Regenerative trees of *Shorea roxburghii* G. Don were in the form of seed trees and shoots; in which most shoots could be seen at H <100 cm class. The number of potential regenerating saplings (class H> 200 cm and good quality) was highest in forest communities with IVI levels from 25 to 35%, followed by forest communities with the IVI greater than 35%, the lowest in those with IVI index of less than 25%.

3.4.2.3. Forest canopy

According to the table 3.4, *Shorea roxburghii* G. Don species naturally regenerated under class CR = 0,4 – 1,0. These saplings could be found at all height class (H <50cm to H> 250cm), but the majority (65 - 82%) existed only at H <100cm. The appearance at all H level indicated that *Shorea roxburghii* G. Don had been continuously regenerating under

the forest canopy. Although the density of *Shorea roxburghii* G. Don increased markedly with the increase in canopy cover, the number of regenerated trees of good quality reached the highest at CR = 0,5 – 0,6 class. Class of CR> 0,7 was the factor preventing the survival and reaching the forest canopy of regenerating trees.

The chlorophyll content in leaves at H <100cm class and H > 100 cm class was similar; average 2,132 mg/g leaf. On the contrary, when changing from H <100cm to H> 100cm, the chlorophyll A content in the leaves at H > 100cm class was 1,1 times greater than that of H <100cm class.

Table 3.4. Distribution of *Shorea roxburghii* G. Don regenerated trees according to H class under different canopy class.

H class (cm)	Distribution of *Shorea roxburghii* G. Don regenerated trees according C_R class:							
	≤ 0,4		0,5 - 0,6		0,7 - 0,8		≥ 0,9	
	N/ha	N%	N/ha	N%	N/ha	N%	N/ha	N%
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
< 50	-	-	1.375	43,4	1.917	49,5	2.417	55,2
50 - 100	500	30,8	708	22,4	1.000	25,8	1.167	26,7
100-150	375	23,1	375	11,8	417	10,8	416	9,5
150-200	250	15,4	292	9,2	208	5,4	167	3,8
200-250	250	15,4	250	7,9	208	5,4	125	2,9
> 250	250	15,4	167	5,3	125	3,2	83	1,9
Total	1.625	100	3.167	100	3.875	100	4.375	100

From the tendency to change the density and quality of regenerated trees according to the CR levels and the chlorophyll A/B ratio, it showed that the lifetime of *Shorea roxburghii* G. Don regenerating trees went through 2 phases of shade-tolerance and light-demanding. The shade-tolerance phase occurred in the these regenerating trees in class H <100cm. The light-demanding phase happened in period of *Shorea roxburghii* G. Don regenerating trees in the class of H> 100cm. In the stage of shade-tolerance, *Shorea roxburghii* G. Don regenerating trees had not formed branches, the stem was gray, the leaves were small focused on the top.

They mainly gathered under the canopy of the original trees or under the canopy of other trees. Characteristics of this stage required high shade tolerance, suitable for class CR > 0,7; Unstable vitality and mass death in the dry season from January to April. Therefore, CR <0,7 class was the limiting factor for the survival of regenerating trees in the period H <100cm. In the light-demanding stage (grade H> 100cm), the regenerating trees were low in density and grew in clusters under the forest canopy. They needed more light; appropriate CR class was 0,5 – 0,6. When reaching class H> 100cm, if still living below the CR > 0,7 class, the regenerating trees had small stems and branches, very little leaves. Therefore, class CR > 0,7 was the limiting factor for the survival and development of regenerated trees.

3.4.2.4. Shrubs and vegetation

The results of the study indicated that natural regeneration of the *Shorea roxburghii* G. Don population depended on the development of shrubs and vegetation under the forest canopy. Continuous distribution of regenerating trees from class H <50 cm to class H> 250 cm. It demonstrated that *Shorea roxburghii* G. Don constantly regenerated under the shrub cover. However, the distribution of regenerative tree generations not only changed according to CCB level, but also according to shrub H class. When class CCB <0,6, regenerating trees could be found at all H class. On the contrary, when class CCB > 0,7, regenerating trees were only available from level H> 50 cm. When CCB level <0,4, regenerating trees derived from seeds being presented at all H class. On the other hand, when class CCB > 0,5, regenerating trees only existed in shoot form. Good quality regenerated trees only came out at CCB <0,4 class and CCB = 0,5 – 0,6 class (Table 3,60). The density of regenerated trees decreased gradually with the increase in coverage of the vegetation. Class of CTT <25% ensured the best regeneration of *Shorea roxburghii* G. Don. In contrast, the CTT class > 25% was the limiting factor for the natural regeneration capacity of the *Shorea roxburghii* G. Don population (Table 3.63).

3.4.2.5. Gaps in forest canopy

The results indicated that *Shorea roxburghii* G. Don' presence in the gap class at all H class from less than 50 cm to over 250 cm. That proved that *Shorea roxburghii* G. Don had constantly regenerating in the gap. The density of regenerated trees increased gradually from gap class <100 m^2 (2.075 trees/ha or 100%) and reached the highest at gap class = 200 - 300 m^2 (3.025 trees/ha); then gradually decreasing to gap class > 300 m^2 (1,450 plants/ha). In the gaps, the most of *Shorea roxburghii* G. Don regenerating trees existed at class H <100 cm; ranging from 50% at gap class > 300 m^2 to 66,7% at class of gap = 100 - 200 m^2. The number of regenerated trees reaching H > 200 cm class had the lowest value at gap <100 m^2 and class of gap > 300 m^2 (225 trees/ha); the highest at class of gap of 200-300 m^2 (400 trees/ha). From the above analysis, it demonstrated that gaps in the forest canopy was a control factor for the natural regeneration capacity of the *Shorea roxburghii* G. Don population. The gap with the size from 200 - 300 m^2 assured the best regeneration of *Shorea roxburghii* G. Don. In contrast, the gaps less than 100 m^2 and greater than 300 m^2 being factors that limit the natural regeneration of the *Shorea roxburghii* G. Don population.

3.4.2.6. Tree composition

The results illustrated that the density of *Shorea roxburghii* G. Don regenerated tree decreased gradually from the forest community with SCI index < 0,5 (3.550 trees/ha) to the forest community with SCI index = 0,5 – 0,8 (2.850 trees ha) and forest community with SCI index > 0,8 (2.350 trees/ha). Regenerating trees under the canopy of these forest communities distributed continuously according to H class. The number of potential regenerating trees (class of H > 200 cm and good quality) also decreased markedly with the increasing complex composition of forest communities. This proved that the tree composition of forest comunity controlled the natural regeneration of the *Shorea roxburghii* G. Don population. The more complex the tree composition, the less natural regeneration of *Shorea roxburghii* G. Don. These well regenerated in the forest communities with

SCI index <0.5.

3.4.2.7. Tree competition in forest community

It could be easily seen from the results , density of *Shorea roxburghii* G. Don regenerating trees decreased gradually in forest communities with CCI index <1,5 (3.800 plants/ha) to other forest communities with CCI index = 1,5 – 1,7 (2.850 trees/ha) and SCI> 1.7 (2,350 trees / ha) respectively. Regenerating trees under the canopy of these forest communities distributed continuously according to H class. It evidenced that had been continuously regenerating under the forest canopy. The number of regenerated trees with good quality decreased gradually from forest canopy with CCI index <1,5 (1.800 trees/ha) to other forest communities with CCI index> 1,7 (1.225 trees/ha). The number of potential regenerating trees (class of H> 200 cm and good quality) replacing the original tree also decreased gradually from the forest communities with CCI index <1,5 (450 plants/ha) to other the forest communities with CCI index > 1,7 (225 trees/ha). This proved that the competition of trees in the forest communities was the factor controlling the natural regeneration ability of *Shorea roxburghii* G. Don. The more competitition of trees took place, the less the natural regeneration capacity of *Shorea roxburghii* G. Don population. *Shorea roxburghii* G. Don significantly regenerated in the forest communities with CCI index <1,5

3.4.2.8. Topsoil characteristic

The *Shorea roxburghii* G. Don regenerating trees existed in the soil with high humidity (73,3%) and relatively strong fluctuations (CV> 18,1%). The soil was slightly acidic (pH_{H2O} < 4,5) and fluctuated relatively strongly (CV = 15.2%). The fluctuation of soil moisture and pH_{H2O} due to the heterogeneity of topography, soil, canopy cover, fallen objects condition, development of shrubs and vegetation ...

The results pointed out that the probability of encountering regenerating trees at different class of H (H <100 cm; H> 100 cm) and two characteristics in the topsoil (X_1, X_2) had a quite close relationship (r2 = 17,2 – 28,1%; P <0,001). The estimation function $P_{(X)} = f(X_1, X_2)$ had the

same form as function (3.7) - (3.12) (Tables 3.5 and 3.6).

Table 3.5. The functions to estimate the probability of encountering *Shorea roxburghii* G. Don regenerating tree according to the moisture content of the topsoil.

Function	H class (cm)	Regression coefficients (*) and correlation:				
		b_0	b_1	b_2	r^2(%)	P_α
(1)	(2)	(3)	(4)	(5)	(6)	(7)
3.7	< 100	-26,1504	0,82563	-0,00593	27,8	<0,001
3.8	> 100	-22,8892	0,72173	-0,00514	21,8	<0,001
3.9	Total	-23,9034	0,75075	-0,00532	22,6	<0,001

(*) Response function: $P = \exp(b_0 + b_1X_1 - b_2X_1\text{^}2)/(1 + \exp(b_0 + b_1X_1 - b_2X_1\text{^}2))$.

Bảng 3.6. Functions that estimate the probability of encountering *Shorea roxburghii* G. Don regenerating tree at pH_{H2O} in topsoil.

Function	H class (cm)	Regression coefficients (*) and correlation:				
		b_0	b_1	b_2	r^2(%)	P_α
(1)	(2)	(3)	(4)	(5)	(6)	(7)
3.10	< 100	-44,1541	23,3147	-2,9098	28,1	<0,001
3.11	> 100	-34,8796	18,4250	-2,2833	19,6	<0,001
3.12	Total	-49,9936	24,5884	-2,9037	17,2	<0,001

(*) Response function: $P = \exp(b_0 + b_1X_2 - b_2X_2\text{^}2)/(1 + \exp(b_0 + b_1X_2 - b_2X_2\text{^}2))$.

Survey of 6 functions (3.7 - 3.12) showed that the abundance of *Shorea roxburghii* G. Don regenerating trees changed markedly according to the change of moisture and pH_{H2O} in topsoil. In the stage H<100cm and H>100cm, the regenerating tree needed similar moisture requirements in the topsoil. Requirement of optimum moisture in topsoil was around 70,0%; ecological amplitude from 60 - 80%; resistance ranged from 32 - 100%. Similarly, the optimum pHH2O requirement in the topsoil was around 4,0%; ecological amplitude from 3,8 to 4,6; tolerance ranged from 2,6 – 5,9. The combination of two factors X_1 (moisture) and X_2 (pH_{H2O}) influenced the probability of encountering (P) *Shorea roxburghii* G. Don

regenerating trees.

CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

(1) The *Shorea roxburghii* G. Don populations were formed on a tropical humid climate of level II according to scale of dry and humid condition of Thai Van Trung (1999) with low terrain along La Nga river; absolute altitude from 70 m to 100 m above sea level; the slope < 10^0; gray soil on granite.

(2) *Shorea roxburghii* G. Don played a dominant ecological role in tropical moist evergreen closed forest. The tree composition in the rich forest state was more diverse than those in the medium and poor forest states. *Shorea roxburghii* G. Don distributed at all classes of D and H; in which the number of trees increased gradually with the surge of these classes. The mixed index of the tree speciess in the forest communities in the poor forest state (0,28) was higher than that of the rich forest state (0,22) and the medium forest state (0,19). SCI index decreased gradually in rich forest, medium forest and poor forest states as 0.63, 0.54 and 0.20 respectively. The CCI index was the highest value in the medium forest state (1.85), and the lowest in the poor forest state (1,14).

(3) *Shorea roxburghii* G. Don reproduced from early January. Young fruits appeared in mid-February and lasted until early April. The fruit was ripen from middle to the end of April. The fruit spreaded simultaneously from mid-May to mid-June and ended in last ten days of June. The appropriate time to collect the fruitsd from mid-May to mid-June. The yield of spreading the fruit on the forest floor increased gradually according to the dominance of *Shorea roxburghii* G. Don in the forest. The average rate of seedlings formed annually under the forest canopy is 48,7%.

(4) Natural regenegation of *Shorea roxburghii* G. Don took place continuously under the forest canopy. It could naturally regenerated by

seed and stump shoot. The density of regenerating trees decreased from the rich forest to the medium forest state and the poor forest state respectively. The number of potential regenerating trees appeared most in the medium forest state.

(5) The *Shorea roxburghii* G. Don regenerating trees underwent through 2 phases. The shade-tolerance phase occurred in seedlings stage which was in class H <100cm. The light-demanding phase came about young trees with class of H > 100 cm. In the phase of shade-tolerance *Shorea roxburghii* G. Don suitable with class CR > 0,7. In the light-demanding phase, it required CR class was 0,5 – 0,6 or gaps with size from 200 – 300 m^2.

(6) The dominance of original treess from 25 - 35% ensured the best regeneration of *Shorea roxburghii* G. Don. The shrubs' canopy was greater than 0,6 and the cover of vegetation was greater than 25% to be the limiting factors for natural regenerating trees. The natural regeneration capacity of *Shorea roxburghii* G. Don dropped with increasing complexity and competitiveness of the trees in the forest communities. The humidity in the topsoil ranged from 60-80% and pH_{H2O} ranged from 3,8 to 4,6, which was a suitable condition for natural regeneration of *Shorea roxburghii* G. Don.

2. Limitations

Firstly, the research had not be able to collect enough evidence to determine the factors affecting the breeding season of *Shorea roxburghii* G. Don. Secondly, the research had not yet determined the seed dispersion distance and original tree size for the highest yield and best quality. Thirdly, the research had not determined the appropriate light intensity according to each stage of the *Shorea roxburghii* G. Don sapling. Last but not least, the research was not able to determine the growth characteristics, the ratio of regenerating trees moving from a height class to another class and the natural regeneration mechanism of *Shorea roxburghii* G. Don in the gaps. The shortcomings mentioned above due to limitations in time, means and subjects of research.

3. Recomendations

-It is necessary to have more studies and continute to research to supplement the shortcomings and limitations of this study as identified in the thesis.

- Tan Phu Protection Forest Management Board and other localities in Dong Nai province can apply some research results on regeneration characteristics and factors affecting natural regeneration of *Shorea roxburghii* G. Don in the development of management options or silvicultural methods to promote regeneration, increase the rate of potential regenerating trees in tropical moist evergreen closed forest.

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