MINISTRY OF EDUCATION AND TRAINING MINISTRY OF AGRICULTURE AND RURAL DEVELOPMENT

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The Silvicultural and Ecological Characteristics of Dalat pine (*Pinus dalatensis* Ferré in the Central Highlands of Viet Nam

Specialization: Silviculture

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Summary of Forestry Doctoral Dissertation

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Related Publications

1. Le Canh Nam, Nguyen Thanh Men, Ho Ngoc Tho, Bao Huy, 2020. Diameter growth and increment models of *Pinus dalatensis* Ferré species in the Central highlands of Vietnam. Science and Technology Journal of Agriculture and rural development, MARD, N_0. 5 (2020), pp: 113 -119.
2. Le Canh Nam, Nguyen Thanh Men, Ho Ngoc Tho, Bao Huy, 2020. Ecological Factors Impacts on density distribution of *Pinus dalatensis* Ferré species in the Central Highlands of Vietnam. Vietnam Journal of Forestry Science. VAFS, N_0. 1 (2020), pp: 62 – 72.
3. Le Canh Nam, Bui The Hoang, Truong Quang Cuong, Hoang Thanh Truong, Luu The Trung and Bao Huy, 2020. Forest structure where *Pinus dalatensis* Ferré distributed in the Central Highland of Vietnam. Science and Technology Journal of Agriculture and rural development, MARD, No. 9 (2020), pp:88 – 98.
4. Le Canh Nam, Bui The Hoang, Truong Quang Cuong, Hoang Thanh Truong, Luu The Trung and Bao Huy, 2020. The Impact of climatic change on tree ring width of *Pinus dalatensis* Ferré in the Central Highlands of Vietnam. Vietnam Journal of Forestry Science. VAFS, No. 2(2020), pp: 40 – 51.

INTRODUCTION

1. Rationale

Dalat pine *(Pinus dalatensis* Ferré), an endemic species to Annamite range (Loc et al., 2011), with high conservation value was listed in group IIA following Decree number 06/2019/ND-CP and in the IUCN Red list of threatened species (IUCN, 2019). The species is now globally distributed in fewer than 10 locations because of the declining habitat in which the number of individuals in these locations is usually less than 100 mature trees (Hiep et al., 2004). Thus, there has not been many studies on this species. Most of the research focused on taxonomy, new distribution area records, describing on phenotype as well as propagation. However, research on silviculture and ecology of Dalat pine remain limited, which would provide fundamental background for conservation and development activities for this species (Hiep et al., 2004; Luu and Thomas, 2004). From these limitations, research on silvicultural and ecological characteristics of Dalat pine in the Central Highlands of Vietnam is needed.

2. Aim and objectives of the study

Aim: Providing basically scientific information on silviculture and ecology for conservation and development of the Dalat pine populations in the Central Highlands of Vietnam.

Objectives:

- To quantify the main silvicultural characteristics of individual and population of Dalat pine, including: Structural modeling, regeneration, growth and increment under impacting of climatic and environemtal factors for application of silvicultural technique and conservation.
- To identify some main ecological key factors impact to the distribution density of Dalat pine for management, silvicultural treatments.

3. Researching species

Dalat pine *(Pinus dalatensis* Ferré).

4. Researching locations

Research was conducted in stands where *Pinus dalatensis* Ferré are distributed at three National Parks: Bidoup-Núi Bà (BD), Chư Yang Sin (CYS) and Kon Ka Kinh (KKK) in the Central Highlands.

5. Scicentific and practical significance

- ***Scientific significance:*** Supplementing the theoretical basis of the silvicultural and ecological characteristics of Dalat pine stands.

- ***Practical significance:*** Providing fundamentals for proposing silvicultural technical measures to conserve and sustainably develop Dalat pine species in the Central Highlands.

6. New contributions of the thesis

- Develop a model for predciting density of Dalat pine under the influence of three main ecological factors: altitude above sea level, soil thickness and average annual rainfall.

- Point out the climatic factors that have influenced the Dalat pine's growth, in which the increasing in temperature during the rainy season will promote the growth of Dalat pine; conversely, increasing in temperature during the dry season will reduce the growth of Dalat pine.

- Development and cross-validation of model system of diameter growth and increment of Dalat pine in three ecological sub-regions of the Central Highlands.

7. Structure of the thesis:

The thesis consists of 150 pages with 32 tables and 55 figures, structured as follows:

Introduction (3 pages); Chapter 1: Overview of research issues (24 pages); Chapter 2: Contents, methods and characteristics of the study area (25 pages); Chapter 3: Results and discussion (78 pages); Conclusions, limitations and recommendations (3 pages).

CHAPTER 1. OVERVIEW OF RESEARCH ISSUES

This chapter provided an overview of research issues based on 79 Vietnamese and 81 English documents, focusing on issues related to the content of the thesis, which are:

• Characteristics and forest population structure and its application;

• Characteristics of regeneration of tropical forests, mixed broad-leaved coniferous forests.

• The influence of ecological factors on individual distribution, forest populations and species ecological relationships within the population.

• Tree ring, individual tree growth, increment and the effects of climate change.

• GIS application in management and conservation of species and forest populations; and

• Studies related to Dalat pine.

General discussion: Studies on Dalat pine only focused on morphological description, recognition of new distribution areas, classification due to its endemism, narrow distribution range; There have only been a few studies related to forest structure, regeneration status of the species but on a separate scale for each area; and there is almost no complete studies on structure, regeneration, biology, species ecology, population dynamics and genetic diversity as well as conservation models for this species (Farjon, 2002). Therefore, the following issues on Dalat pine need to be researched as follows:

- Forest structure: Simulation of the forest structure stand where Dalat pine has natural distribution and the structural characteristics of Dalat pine species in order to provide silvicultural solutions for stable species conservation.

- Ecology:

o Determine the ecological relationship between the Dalat pine and the dominant species in the forest plant community to manage the appropriate species composition based on the positive relationship among species.

o Identify the main ecological factors affecting the distribution, tree density and Dalat pine's regeneration which would provide a basis for the conservation and development of Dalat pine populations in accordance with its ecological requirements.

- Tree rings, Dalat pine's growth: Ring width studying, identify the impacts of climatic factors and distribution areas on the tree ring width of Dalat pine as a basic for determining suitable development areas and estimating Dalat pine's yield.

- GIS: Establishing a map and database of the distribution and density along with ecological and regeneration data of Dalat pine species which is necessary for the protection, conservation and selection of rehabilitation areas.

CHAPTER 2. STUDIED CONTENTS, METHODS AND CHARACTERISTICS OF THE STUDY AREA

2.1. Studied contents

i) Identifying and modeling structural stand characteristics in which Dalat pine distributed

- Determining the structure of species composition of the stands
- Simulation of diameter distribution (*N/D*), height distribution (*N/H*) and ground structure for both forest stands and Dalat pine species.

ii) Modeling the relationship between ecological factors and population distribution of Dalat pine.

iii) Identifying the ecological relationship between Dalat pine species and dominant species in forest plant communities.

iv) Researching on tree ring width, tree diameter growth and increment of Dalat pine under the influences of climate factors and sites:

- To identify the climatic factors affecting on the standardized tree ring width index of Dalat pine.

- To establish the Dalat pine's diameter growth and increment models impacted by different sites.

v) Establishing GIS database on Dalat pine's density distribution, ecology.

vi) *Summarizing applications for conservation and development of Dalat pine based on research results.*

2.2. Methods

2.2.1. **Research approach**

The thesis focused on the study of silvicultural and ecological characteristics for the conservation and development of Dalat pine's individual and stand, including:

- The studies on forest structure for the forests as well as Dalat pines were carried out, following the typical sampling method in which the forests remain non-degraded. The plot area was large enough to reflect the forest structure of the studied sites in terms of species, *N/D* and *N/H* distributions. Forest structure were statictically simulated in oder to detect, evaluate the forest distribution patterns and propose standard structural models.

- Approach to discover the ecological factors affecting the density, distribution of Dalat pine species based on typical - systematic sampling with a sufficiently large number of sample plots to ensure the fluctuation of ecological factors aong with diferent density; At the same time, the weighted non-linear multivariate models were applied to detect the ecological factors affecting the density and to create a model with this complex ecological relationship. In addition, the statistics analysis was also used to determine the ecological relationship between the dominant species and Dalat pine species.

- Using increment bore for studying tree ring width to limit felling of trees as the traditional method. The tree ring width was affected by the age of

trees and the ecological - environmental factors. This study has removed the effect of age on the tree ring width by using standardized ring width index. Studying the direct impacts of major climatic factors such as monthly temperature, rainfall; annual precipitation to standardized ring width index without caring for other environmental ecological factors, meaning that the influence of climatic factors on the diameter growth of Dalat pine. Based on tree ring width, annual growth and diameter increment could be determined. Modeling the diameter growth of Dalat pine following method of weighted non-linear with random effects models fit by Maximum Likelihood was used to select environmental and climate factors affecting the parameters of models. For cross validation we used K-Fold method to assess the model errors.

- Combining the density relationship model of Dalat pine with the influencing ecological factors in GIS, a map illustrating density distribution class in each ecoregion was built up.

2.2.2. Research methods for structural stand characteristics

2.2.2.1. Collecting data

We used typical sampling method to collect data for forest structure studies. Where the forests remain non-degraded and having Dalat pine distributed, we established 17 plots 2.500 m^2 (50 m x 50 m) in three ecological sub-regions (Bảo Huy, 2017a). We divided each plot into 25 subplots 100 m^2 (10 m x10 m) to collect data on tree species name, tree height (H, m), diameter at breast height ($D \geq 6$, cm), the distance from a tree to the nearest tree. If a Dalat pine appears in the plot, we will measure two distances: the distance from the pine to the nearst pine and the ones from the pine to other nearest species. We also measured potential regeneration seedling ($H \geq 0,5$ m and $D < 6$ cm) in 4 subplots 4 m^2 (four subplots in the coners and one in the centrer). In each subplot, we identified all tree species and measured tree height (H, m).

2.2.2.2. Method for determining the structure of species composition

The Importance value index (IV, %) was used to identify dominant species (Curtis and McIntosh, 1950; Narayan and Anshumali, 2015; Bảo Huy, 2017a).

2.2.2.3. Method for simulation the structure of the diameter (N/D) and height (N/H) distributions

iameter and height intervals were tested to access suitable N/D and N/H distributions. Finally D class interval was spaced by 10 cm and H class interval was spaced by 2m.

To check the uniformity of N/D, N/H distributions , we used $\chi 2$ test (Bảo Huy, 2017a).

The structure of the diameter distribution (N/D) and height (N/H) was simulated by the Mayer, Distance, and Weibull functions, and checked by $\chi 2(0,05, df)$ test with P value < 0,05 (Nguyen Hai Tuat et al., 2006; Bao Huy, 2017a).

2.2.2.4. Method to access the structure of trees coordination on the ground

The structure of trees coordination on the ground was assessed by the U test (Clark and Evans, 1954).

2.2.3. The research method influences ecological factors on the density of Dalat pine

2.2.3.1. Collecting Data

In each area where Dalat pine is distributed, we selected area of 1 km^2 following typical sampling method. In each point, we established 2 parallel transects spacing 500 m away and 5 nested plots 1.000 m^2 (R = 17.84m) per transect. In each 1.000 m^2 plot, we measured all woody trees and seedlings in subplots of 100 m^2 (R = 5.64 m). In each point (10 plots/point), eight plots were measured only Dalat pine (mother trees and seedlings) and 2 plots were measured all tree species (woody trees and seedlings).

We set up 19 areas 1 km^2, however, total of 173 plots 1.000 m^2 were conducted successfully. We measured all tree species (D>6 cm) for studying ecological relationship between dominant species with Dalat pine as well as dominant regenerated seedling with regenerated Dalat pine in 38 plots 1000 m^2 and 33 subplots 100 m^2.

We measured 10 ecological factors within 173 plots 1.000 m^2, including: forest status (TrThai) (Circular N_0. 34/2009/TT-BNNPT), forest canopy (DTC, 1/10), forest storey (TCG), slope (DD, degree), position site (VT), altitude (DC, m), annual precipitation (P, mm/year), annual temperature (T, ^oC), humidity (DA, %), soil thickness (TDD, cm). Climatic data were collected at three local meteorological stations: Bidoup – Nui Ba for 38 years (1979 – 2016), Chu Yang sin and Kon Ka Kinh for 32 year (1980 – 2011).

2.2.3.2. Modeling the relationship between ecological factors and tree density of Dalat pine.

Using single/multi-variables, weighted linear or non-linear models to detect the main ecological key factors impacting on the density of Dalat pine distribution (Bảo Huy, 2017a). including steps: i) Collection of the density of Dalat pine along with 10 ecological factors in 173 sample plots 1.000 m^2; ii) Coding ecological factors follow the variation of the density Dalat pine based on Kruskal Wallis and Duncan tests; iii) Determine eco-variables affecting the density of the Dalat pine by using Cp index of Mallows (1973); iv) We tested weighted linear or/and nonlinear equations with multi-variables and combination of variables fit by Marquardt method (Picard *et al*., 2012); the models were selected based on highest R^2_{adj} and lowest errors of root mean square error (RMSE) and mean absolute percent error (MAPE) (Swanson *et al*., 2011; Huy *et al*., 2016a, b, c, 2019).

2.2.4. Species relationships detection methods.

We used the ρ and χ^2 (Wratten and Fry, 1986; Bảo Huy et al.,1997) to determine ecological relationship of species in tropical rain forests, of which

we studied the relationship between Dalat pines with other species that have IV% ≥ 3%.

The dataset for this pupose was 38 plots 1.000m^2 and for regenneration 33 sub-plots 100 m^2 in 19 areas 1 km^2 from three different ecological sub-regions.

2.2.5. Study on the influence of climatic factors on Dalat pine growth and tree ring width in three different ecological sub-regions.

We used increment borers to collect tree cores from 56 mature trees representing for all diameter classes and in all gradient, of which 26 trees from BD; 14 trees from CYS and 16 trees from KKK. Trees were sampled along topographic gradients (Dymond et al., 2016) in three ecological sub-regions to assess tree-ring growth responses to changes in environmental and climatic factors. The selection of trees from which to collect increment cores was proportional to the diameter distribution of Dalat pine.

We applied standard chronology (Stokes và Smiley 1968), crossdating method together with COFECHA (Fritts, 1976; Holmes, 1983) in order to exactly determine tree age, tree ring width (*Zr*, cm), diameter increment (*Zd*, cm), annual diameter increment $Pd = Zd/D$.

2.2.5.1. Method of determining the influence of climatic factors on tree ring width.

Climate data includes: monthly (*Ti*), and annualy temperature (*Ttb*), monthly (*Pi*) and annualy precipitation (*Ptb*).

In order to eleminate the influence of age on tree ring width, we used standardised tree ring index (*Zt*) calculated by Arstan (Cook, 1985).

We modeled the relationship between *Zt* and climatic factors using linear and nonlinear functions. We applied weight variable= $1/Ti/Pi^a$ where *Ti/Pi* are the most influence factors, $a = \pm 20$. We adjusted *a* to figure out the most fit model with the highest R^2 and lowest values of RMSE and MAPE (Bảo Huy, 2017a).

2.2.5.2. Modeling method for Dalat pine growth in three ecological regions and cross validation.

Height-Diameter relationship of Dalat pine was modeled following Power function. Model of Diameter - Age followed Exponential function (Archontoulis và Miguez, 2015) and the parameter was adjusted along with ecological sub-regions (Bảo Huy, 2017a, b). Tree diameter increment rate *Pd /D* (*Pd = Zd/D*) was modeled using Power and Hyperbol function.

K-Fold cross validation where K = 10 was used to evaluate the errors and to select the most suitable model based on lowest value of AIC, high value of R^2_{adj}, and the lowest values of Bias (%), RMSE (%) and MAPE (%) (Swanson *et al*., 2011; Huy *et al*., 2016a, b, c; 2019).

2.2.6. Method of mapping distribution area of Dalat pine

We used coordinator of Dalat pine together with data on density, ecological factors, to reconcile database and to map the density distribution for the studied species in all three national parks and for the Central Highlands of Vietnam. (Bao Huy, 2009).

2.3. Study sites

The study was conducted in the Central Highlands, one of the eight ecological regions of Vietnam. Study sites were chosen in three ecological sub-regions with Dalat pine distribution and located in three mountains of Bi Dup Nui Ba (BD), Chu Yang Sin (CYS), and Kon Ka Kinh (KKK),

a) Bidoup - Núi Bà national park is located in Lac Duong district and a part of Dam Rong district. The elevation ranges from 1470 m to 1600 m with average temperature is 18.4 ^{0}C and 1.920 mm of average precipitation. The national park had yellow-red ferralsols soil.

b) Chư Yang Sin national park is situated in Krong Bông and Lak districts of Đak Lắk province. The elevation varies from 440 m-2405 m asl. The average temperature is about 22^{0}C and average precipitation is about 1800 mm – 2000 mm. The national park had yellow-red Ferralsols soil .

c) Kon Ka Kinh national park is located in Mang Yang and Đak Đoa districts of Gia Lai province. The elevation varies from 600 m – 1748 m asl. The average temperature is about 21,5^{0}C and average precipitation is about 2000 mm – 2500 mm. The national park had yellow-red ferralsols soil .

CHAPTER 3: RESULTS AND DISCUSSION

3.1. Characteristics of forest structure in which Dalat pine is distributed

3.1.1. Species composition structure.

Dalat pine is mainly distributed in evergreen broadleaf forests mixed with some conifer species. The number of woody species ranges from 107 to 130, belonging to 61-78 genus of 35-42 families. Dominant species with IV ≥ 3% are about 5-8 species in which Dalat pine is dominant (IV% from 3,6% to 12,2%.

Groups of dominant species in three ecological sub-regions are ecologically different, which was consistent with a study of Narayan và Anshumali (2015).

3.1.2. Natural regeneration of woody species in which Dalat pine is distrubuted.

The total number of regeneration woody species ranged from 36-97 species. Dominant species with IV ≥ 3% varied from 4 to 7 species. Where mature Dalat pine trees appear, seedlings of this species are likely less being seen, whereas the Dalat pine regeneration appears in gaps in the forest canopy or at the edge of the forest. Composition of woody species and regeneration was different, which is the results of mosaic regeneration, a typical forest dynamics in tropical rain forest regeneration (Richard, 1952; Baur, 1976; Thai Van Trung, 1978; Phung Ngoc Lan, 1986).

3.1.3. N/D distribution

N/D distributions)Fig. 3.2) in all stands was aligned with that of tropical rain forests, which is negative exponential or J shaped model (Nguyễn Văn Trương 1973, 1983; Đồng Sĩ Hiền, 1974; Phùng Ngọc Lan, 1986; Trần Văn Con, 1991, Bảo Huy, 2017a).

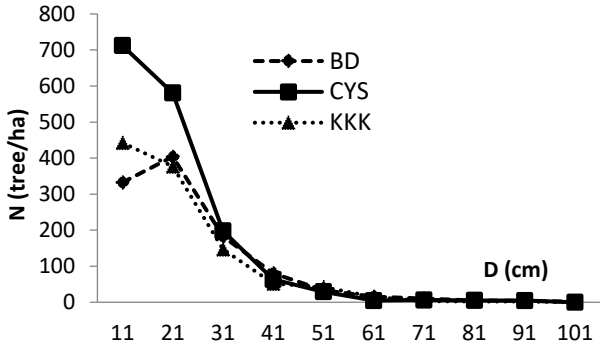

Fig. 3.2. N/D distribution of the stands with Dalat pine.
BD: Bidoup - Núi Bà, CYS: Chư Yang Sin, KKK: Kon Ka Kinh

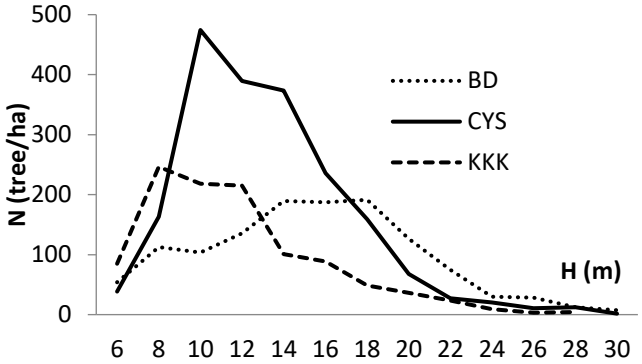

Fig. 3.6. N/H distribution of the stands with Dalat pine.
BD: Bidoup - Núi Bà, CYS: Chư Yang Sin, KKK: Kon Ka Kinh

Results of homogeneity test for N/D showed that there were three groups of plots capable of stimulating the distance distribution. Nine out of 17 plots (53%) had $\chi^2 < \chi^2_{(0,05)}$, the others could not be able to stimulate with 4 theoried functions. The distance distributions is considered a standard model in adjusting forest structure towards sustainability.

3.1.4.N/H distribution

The general distribution of N/H had positively skewed distribution. However, N/H distribution was very variable and had many types of distribution and changed accordingly to ecological conditions. This type of N/H distribution is similar to the N/H distribution pattern of tropical broadleaf mixed forests described by Dong Si Hien (1974) and Nguyen Van Truong (1973, 1983).

Results of homogeneity test for N/H showed that six out of 17 plots were fit to Weibull function with positively skewed distribution. The remaining plots were not able to fit with any of three tested functions, demonstrating

that the N/H varied tremendously depending on ecological factors and regions.

3.1.5. Ground structure of the stands and Dalat pine

Eight plots showed cluster distribution, accounting for 53%, while seven plots had random distribution (47%). The results aligned with the general distribution of tropical rainforests in which cluster distribution happens when the forests are in middle age; and turning into random distribution when the forests are mature. (Nguyễn Văn Trương 1973, 1983; Bảo Huy, 2017a).

Dalat pine has cluster distribution. However, Dalat pine in KKK had random distribution. This result coincided with the fact that Dalat pine is distributed and recruited in gaps.

3.1.6. N/D and N/H distributions of Dalat pine

The three N/D distributions of Dalat pine in each ecoregion shown in Fig. 3.9 indicated that the distribution of this species within those stands had apical forms focusing from left to right, focusing on the mature diameter class (D = 51-91cm), showing that Dalat pine had no continuous regeneration process on a given stand.

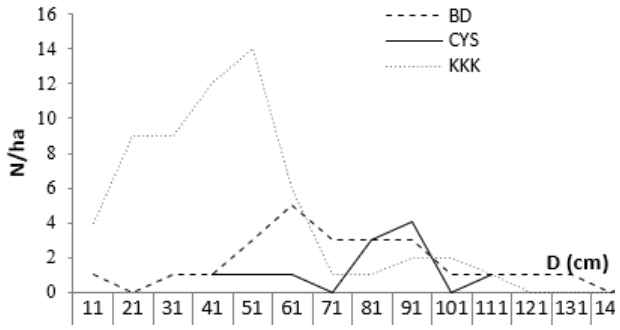

Fig. 3.9. N/D distributions in three study sites

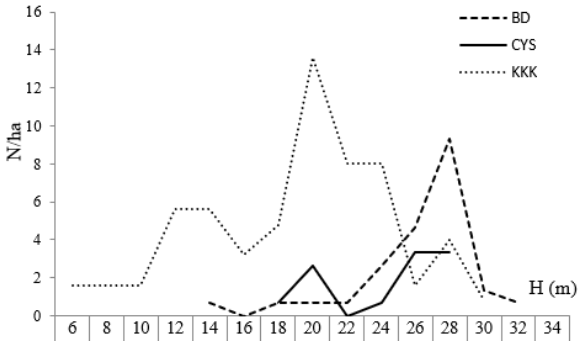

Fig 3.11. N/H distributions in three study sites

Validation test showed that Weibull function could stimulate the N/D distribution for Dalat pine in Bidoup Nui Ba and Kon Ka Kinh National Parks. Our results confirmed that Dalat pine had no continuous recruitment on a given site, but had mosaics regeneration.

N/H distribution of Dalat pine could not fit with any functions, showing that Dalat pine population created a stand in each period of time, creating the distribution chart with different peaks.

3.2. The influences of environmental factors on density distribution of Dalat pine.

Ten environmental factors were examined to figure out the key factors affecting the density of Dalat pine following index of Cp (Mallow, 1973). Results showed that elevation (DC), soil thickness (TDD) and average precipitation (P) had major impacts on the density of our studied species. From these three factors, we examined the suitable model to estimate the density of Dalat pine. This result was shown in Table 3.10.

Table 3.10**.** Results on selection of relationship between environmental factors with density of Dalat pine

Seg.	Models	Weight	$R_{adj.}$	RMSE %	MAPE %
1	$\boldsymbol{N/P = 0{,}890614 \times DC^{-0{,}0451131} \times TDD^{0{,}540172} \times P^{-0{,}9126}}$	**1/P**	**0,651**	**0.283**	**31,64**
2	$N/P = 1{,}28798 \times exp(-0{,}0037156 \times DC + 0{,}272688 \times TDD - 0{,}585141 \times P)$	$1/P^{-0,5}$	0,659	0,316	31,79
3	$N/P = 0{,}899798 + 0{,}086599 \times DC + 0{,}254437 \times TDD - 0{,}426971 \times P$	$1/P^{0,5}$	0,653	0,319	32,74

Notes: n = 173; N: Code for density class of Dalat pine; DC: Elevation; TDD: Soil thickness; P: average precipitation. Selected model is bolded.

All testing models had the same value of $R_{adj.}$, thus, we select the model based on the lowest errors. The best fit Power model was as follow

$$N = P \times (0{,}890614 \times DC^{-0{,}0451131} \times TDD^{0{,}540172} \times P^{-0{,}9126}) \quad (3.1)$$

Density class of Dalat pine was projected with 4 classes and 3 environmental factors presented in Table 3.12

Table 3.12. Ecological factors were along with density classes of Dalat pine.

Trees density classes of Dalat pine	Precipitation (P, mm/year)	Elevation (m)	Soil thickness (TDD, cm)
High: Class 4: > 100 trees/ha	1.800 – 2.200	1.500 – 1.900	>50
Average: Class 3: 51 – 100 trees/ha	1.800 – 2.200	1.000 – 1.500	>50
Low: Class 2: 10 - 50 trees/ha	≥ 2.200	1.500 – 1.900	>50
Rare: Class 1: < 10 trees/ha	< 1.800	< 1.000	≤ 30

3.3. Relationship of Dalat pine with other dominant species

Our results on ecological relationship of Dalat pine with other dominant species (IV ≥ 3%) showed that Dalat pine had random relationship with Cho xot (*Schima wallichii* Choisy), De da (*Lithocarpus* sp.) and positive relationship with Hong quang (*Rhodoleia championii* Hook. f.). In addition, Dalat pine regeneration had consistant random relationship with *Lithocarpus silvicolarum* (Hance) Chun, *Syzygium* sp, *Rhodoleia championii* Hook. f. and *Phoebe tavoyana* (Meisn) Hook. f. and had possitive relationship with *Engelhardia roxburghiana* Wall.. We suggested that Dalat pine should be planted with other species that had possitive and/or random relationship such as Cho xót, Hong quang và De da rather than planting pure Dalat pine plantation when it comes to forest plantation.

3.4. Tree ring width, growth and increment of Dalat pine diameter along with climatic and ecological factors.

3.4.1. Climate variability in studied sites

Results showed that variability of temperature and precipitation influenced our forest ecosystems. Thus, we investigated the impacts of these two factors on the variability of tree ring width of Dalat pine in the Central highlands of Vietnam.

3.4.2. Variability of tree ring width in three studied sites.

We created three tree ring chronologies for Dalat pine for three studied sites, in which the chronology for BD national park extended for 446 years (1572-2017), that of CYS and KKK national parks dated back for 318 (1700 – 2017) years and 73 years (1945 – 2017), respectively.

3.4.3. The effect of climate on tree ring index (Zt) in Bidoup-Nui Ba.

Dalat pine's standardised tree ring index (*Zt*) was positive relationship with the average monthly temperature of June (T_6) with $P\text{-}_{Value}$ = 0,0161and R = 0,388 and November rainfall (P11) with R = 0,370 and $P\text{-}_{Value}$ = 0,022.

Testing with some models and selecting suitable model for describing relation between $Zt = f(T_6)$ and $Zt = f(P_{11})$ at BD site, as follows:

$$Zt = (-0{,}201515 + 0{,}00344819 \times T_6^2)^2 \quad (3.2)$$

$$Zt = \text{sqrt}(1{,}11474 + 0{,}0000158857 \times P_{11}^2) \quad (3.3)$$

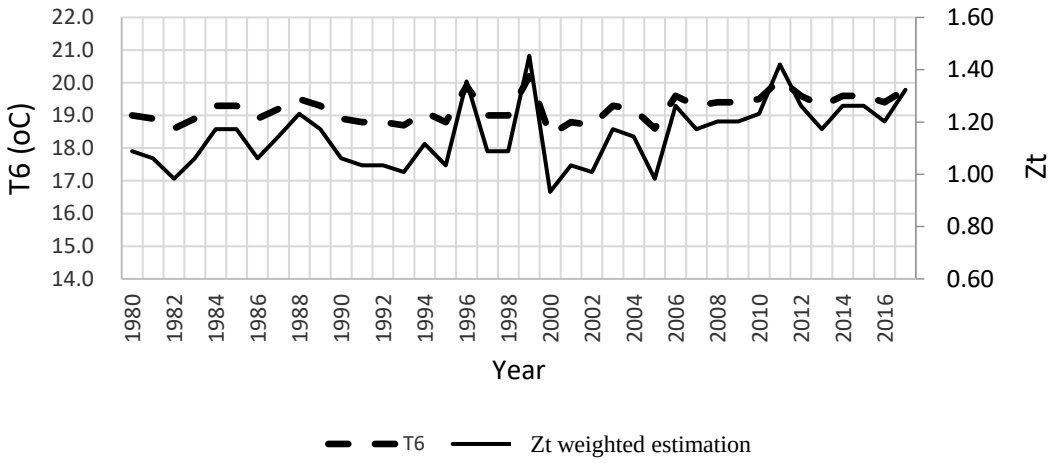

Fig. 3.21. The positive correlation between June temperature (T_6) and standardized ring width index (Zt) is estimated by the weighted model for 38 years at Bidoup – Nui Ba site

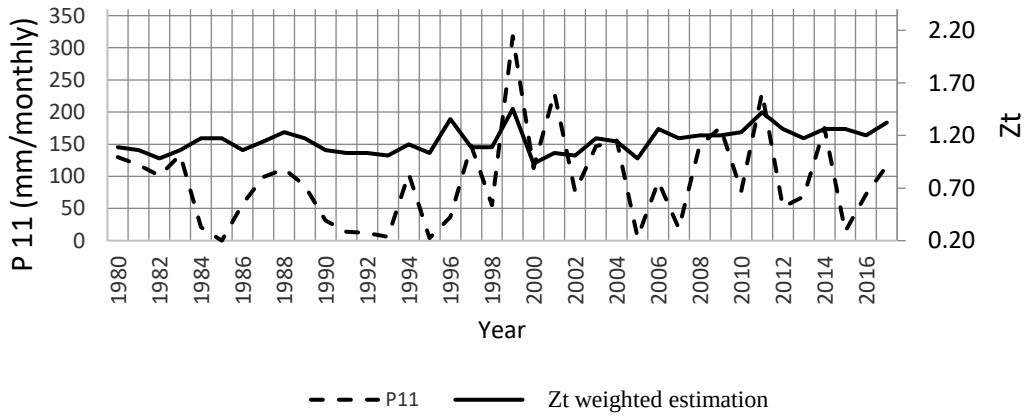

Fig 3.23. The positive correlation between November rainfall (P_{11}) and standardized ring width index(Zt) is estimated by the weighted model for 38 years at Bidoup – Nui Ba site

Fig. 3.21 and fig 3.23 showed a high correlation by models between estimated *Zt* and T_6 and P_{11}. When T_6 and P_{11} increased, as the *Zt* increased and vice versa.

3.4.4 and 3.4.5. The effect of climate on Zt in Chu Yang Sin và Kon Ka Kinh

Dalat pine's *Zt* had negative relationship with monthly March temperature (T_3) R = -0,3871, P = 0,0286 and April (T_4) R = -0,3765, P = 0,0337. Monthly rainfall and *Zt* did not have relation (P-Value > 0,05). Similarity, results showed that in Kon Ka Kinh *Zt* had negative relation with monthly April temperature (R = - 0,396, P = 0,0248 < 0,05) and did not have relation with monthly rainfall (P > 0,05).

Testing with some models and selecting suitable model for describing relation between $Zt = f(T_3 \times T_4)$ in Chu Yang Sin site and $Zt = f(T_4)$ in Kon Ka Kinh site, as follows:

$$Zt = 1/(3{,}07484 - 1321{,}32/(T3 \times T4)) \quad (3.4)$$

$$Zt = (1{,}78723 - 0{,}00142461 \times T4^2)^2 \quad (3.5)$$

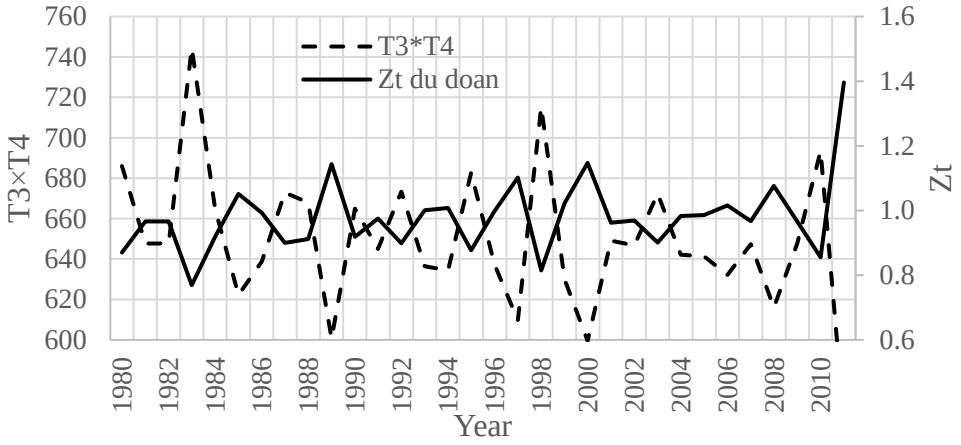

Fig 3.26. The negative correlation between monthly March and April temperature (T3×T4) and standardized tree ring width (*Zt*) for 32 years (1980 – 2011) in Chu Yang Sin site.

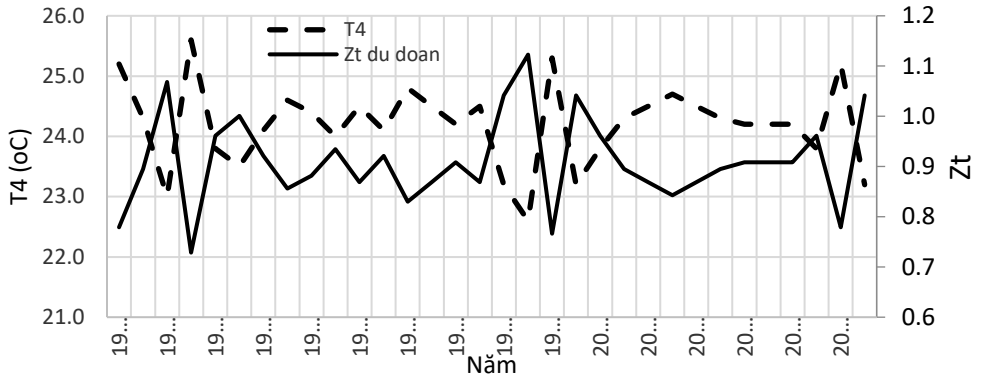

Fig. 3.21. Negative correlation between monthly temperature april (T4) and standardized tree ring width (*Zt*) for 32 years (1980 – 2011) in Kon Ka Kinh.

Fig. 3.26 showed the negative correlation between T3×T4 and *Zt* for 32 years (1980 – 2011) in Chu Yang Sin site. When (T3×T4) increased, *Zt* decreased. Fig 3.21 also showed that the Zt had negative relation with T_4, showing that projected Zt had a negative relationship with April temperature (T4) in KKK site.

The *Zt* was affected by climatic, environmental factors. When considering only the effects of climatic factors, such as *Ti* and *Pi* to *Zt*, result showed that climate factors affect the D's growth of Dalat pine at 40-50% (according to percent value of R^2).

3.4.6. Diameter growth and increment models of Dalat pine in diffetent ecological areas

3.4.6.1. Height – Diameter (H/D) relationship model for Dalat pine's distribution areas in Central Highlands of Vietnam

The Power function was suitable for describing H/D relationship of Dalat pine. The variation of H in all the studied site is quite high; therefore, we set up the Power model with the random effects of each eco-subregion (Table 3.21)

Table 3.21. Parameters of selected model: $H = a_i \times D^b$ along with random effects of each eco-sub-region of Dalat pine in the Central highlands

Eco-sub-regionsz	n_i	Parameters and its Std. Erros (SE_i) changed along with eco-sub-region i, with P = 95%			
		a_i	SE_i	b	SE
All		5.705349	1.097362	0.291650	0.046342
Bidoup - Nui Ba	26	6,333565	0,093976	0,291650	0,046342
Chu Yang Sin	14	5,392624	0,128068		
Kon Ka Kinh	16	5,389860	0,119797		

Note: After K-Fold cross validation, using all dataset n = 56 for estimating parameters along with ecological sub-regions.

3.4.6.2. Diameter diameter model of Dalat pine in the three studied ecological sub-regions in the Central highlands

Conducted exploration of the Dalat pine's suitable diameter (*D*) growth model follows common functions, such as: Chapman-Richards, Korft, Gompertz và Mitscherlich; Using K-Fold Cross – Validation method with K=10 to evaluate and sellecte model. The Mitscherlich (Monomolecular) function was selected for modeling Dalat pine's diameter growth. Although AIC and R^2 values of the models were quite similar, the Mitscherlich's errors (Bias, RMSE and MAPE) is smallest.

If Mitscherlich function *D/A* was used for all study sites, the variability and error will be maximised. We applied random effects technique in Weighted non- linear mixed effect model to determine the environmental factors influenced the papameters of the model. Results showed that parameter a_i of selected Mitscherlich drasmaticaly changed among three studied sites (Tabe 3.25 and Fig. 3.37).

Table 3.25. Diameter growth of Dalat pine function: Mitscherlich $D = 300 \times (1 - e^{(-ai \times A)})$ for the Central highlands and three studied sites.

Ecological Su-Regions	n_i	Parameters and its Standard Error (SE_i) with P = 95%	
		a_i	SE_i
Central Highlands	4566	0.001505	0.000321

Ecological Su-Regions	n_i	Parameters and its Standard Error (SE_i) with P = 95%	
		a_i	SE_i
Bidoup - Núi Bà (BD)	2780	0,000961	1,054e-05
Chư Yang Sin (CYS)	1297	0,001285	1,544e-05
Kon Ka Kinh (KKK)	489	0,002268	2,515e-05

Note: Cross validation using K-Fold to select the best fit model, parameters were projected based on the entire dataset n = 4566

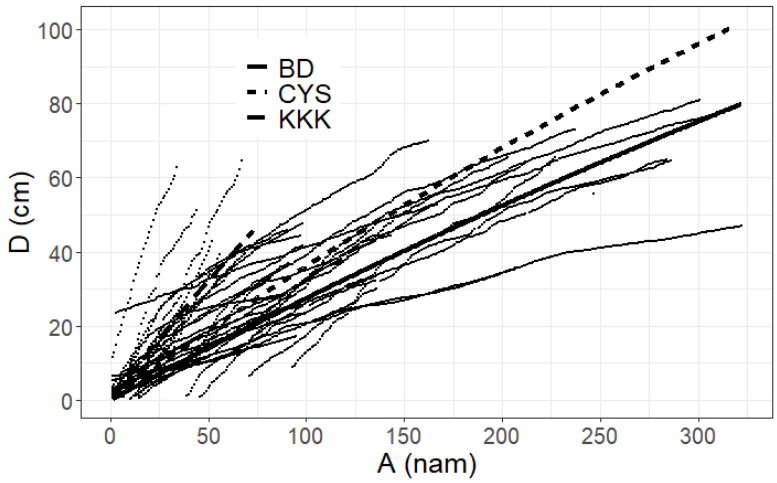

Fig 3.37. *D/A* and diameter growth model of Dalat pine with Mitscherlish model: $D = D_m \times (1 - e^{-ai \times A})$ for three distribution sites: BD: Bidoup - Núi Bà, CYS: Chư Yang Sin, KKK: Kon Ka Kinh

Different distribution areas had different influences on tree growth (Timilsina và Staudhammer, 2013). In the Central Highlands of Vietnam, the highest annual increment of Dalat pine is in KKK, followed by CYS and BD that had a statistically correlation with annual precipitation.

3.4.6.3. Projection of diameter increment (Pd) by D of Dalat pine

Pd/D relationship had negative skewed distribution which is suitable with negative Power model in each distribution regions (Table 3.28).

Table 3.28. Model $Pd = a \times D^{bi}$ was selected for different eco- sub-regions in the Central Highlands

Eco-sub-regions	n_i	Parameters and its Standard Error (SE_i) with P = 95%			
		a	SE	b_i	SE_i
Central Highlands	4566	0,383712	0,019238	-0,977852	0,102341
Bidoup - Núi Bà	2780			-1.100362	0,003327
Chư Yang Sin	1297	0,383712	0,019238	-1,103273	0,004870
Kon Ka Kinh	489			-0,729921	0,007932

Note: Cross validation using K-Fold to select the best fit model, parameters were projected based on the entire dataset n = 4566

3.5. Mapping and GIS database for Dalat pine distribution

The dataset of density distribution of Dalat pine within 19 km^2 in three study sites was used to develop GIS map classifying density classes along with ecological database.

Based on Precipitation, Elevation and soil thickness influencing the density of Dalat pine, our study pointed out detailed density of Dalat pine in each study site with influenced environmental factors

Results showed that density classes of Dalat pine in Bidoup Natonal park ranged from rare to low, from < 10 trees per ha to 10-50 trees/ha, mainly distributed in the southwestern and Easthern of the park; that of Dalat pine in Chư Yang Sin varied from rare to low (<10 trees/ha, 10– 50 trees/ha) and average (51 – 100 trees/ha), mainly distributed in the peak of Chư Yang Sin. On the other hands, density classes of Dalat pine in KKK ranged from rare (<10 cây/ha) to high (>100 trees/ha). Dalat pine distributed across the landscapes of the park demonstrating that KKK is the suitable ecosystem for the Dalat pine, with large distribution area.

3.6. Some main applications for conservation and development of Dalat pine.

We propose some applications and techniques that can be applied for conservation and development of Dalat pine population as follow:

i) Dalat pine population pattern for conservation and development:

Including: i) dominant species structure; ii) ideal regeneration structure; iii) ideal N/D model; iv) ground structure; v) appropriated environmental factors for Dalat pine development; vi) appropriated ecological distribution areaa for Dalat pine.

ii) Approaches and techniques supporting conservation and development of Dalat pine.

- Establishing uneven aged stands for conservation and development.
- Approaching mixed species plantation, assisted natural regeneration, forest enrichment planting using Dalat pine;
- Approaching sustainable forest structure of Dalat pine.
- Planning and establishing conservation sites and restorage Dalat pine population.
- Predicting tree growth, productivity of Dalat pine.

CONCLUSION, LIMITATION AND RECOMMENDATION

Conclusions

1) Structure of forest stands in which Dalat pine distributed in the Central Highlands.

Dalat pine is distributed in broadleaf conifer mixed forests with 107-130 woody species from 61-78 genus belong to 35-42 families. Dalat pine is one the 5-8 dominant species in the stands in which the IV ranged from 3,6% to 12,2%. The number of regeneration species vaied from 36 to 97 with 4-7 dominant species. Dalat pine regeneration followed mosaics regeneration with forest canopy gap requirement. *N/D* distribution modelled by distance distribution function with negative exponential or peaked in the second diameter class. *N/H* distribution varied, positively skewed uni-modal. Ground distribution of the stands had cluster distribution in middle aged class and turned to random distribution in mature phrase.

In general, Dalat pine had cluster distribution, meaning that Dalat pine requires canopy gap to regenerate.

2) Influences of environmental factors on density of Dalat pine.

Density of Dalat pine was affected by some key environmental factors such as elevation (DC), soil thickness (TDD) and precipitation (P) described as follow:

$$N = P \times (0{,}890614 \times DC^{-0{,}0451131} \times TDD^{0{,}540172} \times P^{-0{,}9126})$$

3) Ecological relationship between Dalat pine with dominant species.

Dalat pine is one of the dominant species with IV% = 4,5% that had random relationship with some species such as Cho xot, De da and positive relationship with Honmg quang. In terms of regeneration, Dalat pine had positive relationship with Cho xot and had random relationship with other dominant species.

4) Influences of climate factors and eological sub-regions on Dalat pine growth and development.

Monthly temperature, monthly precipitation affected tree growth. Increasing June's temperature and Novermber precipitation positively accelerated the growth of Dalat pine in Langbiang Plataeu. In Buôn Ma Thuot and Pleiku, growth of Dalat pine decreased as temperature during dry season increased.

Models of tree growth and incremed for Dalat pine were computered and cross validated for three different ecological sub-regions. Results showed that *H/D* relation followed Power function: $H = a_i \times D^b$; diamter growth by age (*D/A*) model well fit the Mitscherlich function: $D = 300 \times (1 - e(-a_i \times A))$; diameter growth rate *Pd/D* was best described by Power function with negative parameter: $Pd = a \times D^{bi}$ where ai and bi changed along with ecological sub-regions.

5) GIS database for Dalat pine density and ecological charateristics.

Study established GIS map based on density classes of Dalat pine together with 10 ecological factors in the Central Highlands to determine the distribution locations for better conservation and management.

6) Application of the results.

There were some results that can be applied for conservation and development of the Dalat pine stands: i) Ideal pattern for Dalat pine population toward conservation and development; ii) Providing some approaches and techniques for conservation and development of Dalat pine forests: establishing uneven aged and/or mixed species forests; ideal forests structure; planning conservation regions for Dalat pine; predicting Dalat pine growth and productivity.

Limitations

1) The study did not efficiently investigate other locations in which Dalat pine is distributed in the Central Highlands
2) Density based GIS map for Dalat pine has not been on site validated

Recommendations

1) Futher research on the influences of climate factors and climate variability on Dalat pine growth is needed to better understand the most suitable climate conditions for the growth adn development of Dalat pine.
2) Research on environmental factors influencing Dalat pine regeneration such as light, temperature, forest fire needs to be deeper studied.