Relationship between ring-width growth of *Pinus kesiya* royle ex Gordon and climatic factors in the Duc Trong area of Lam Dong province

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Quan hệ giữa tăng trưởng bề rộng vòng năm của thông ba lá (*Pinus kesiya* royle ex Gordon) với một số yếu tố khí hậu tại khu vực Đức Trọng thuộc tỉnh Lâm Đồng

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https://doi.org/10.55250/jo.vnuf.10.1.2025.011-021

Article info:
Received: 16/02/2025
Revised: 17/03/2025
Accepted: 16/04/2025

Keywords:
Climate, Pinus kesiya, response equation, ring-width index, tree ring-width.

Từ khóa:
Bề rộng vòng năm, chỉ số bề rộng vòng năm, hàm phản hồi, khí hậu, Thông ba lá.

ABSTRACT

The paper presented the study results on the response of Pinus kesiya Royle ex Gordon to variations in climatic variables in the Duc Trong area of Lam Dong province. This study was carried out to identify the key climatic factors that significantly influence the ring-width growth of P. kesiya. The research data included series of P. kesiya ring widths from 1905 to 2014 and climatic data from 1980 to 2014. The relationship between the ring-width growth of P. kesiya and climatic parameters was determined using Pearson correlation coefficients. The role of climatic factors on the ring-width growth of P. kesiya was analyzed using stepwise multivariate linear response Equations. The results showed that: (1) The increase in temperature in September and October, precipitation in March and total precipitation in November, and December, sunshine hours in November, and hydrothermal coefficient in June all led to a decrease in the growth of P. kesiya. (2) On the contrary, the high air humidity during the dry season from January to April was a favorable condition for the growth of P. kesiya. (3) The four strongest controlling parameters for the growth of P. kesiya were total precipitation in November and December, air humidity during January to April, hydrothermal coefficient in June and air temperature in September.

TÓM TẮT

Bài báo này trình bày kết quả nghiên cứu về phản ứng của Thông ba lá đối với biến động của những yếu tố khí hậu ở khu vực Đức Trọng thuộc tỉnh Lâm Đồng. Nghiên cứu này được thực hiện nhằm xác định những yếu tố khí hậu đóng vai trò lớn nhất đối với tăng trưởng bề rộng vòng năm của Thông ba lá. Số liệu nghiên cứu bao gồm chuỗi bề rộng vòng năm của Thông ba lá từ năm 1905 đến 2014 và số liệu khí hậu từ năm 1980 đến 2014. Quan hệ giữa tăng trưởng bề rộng vòng năm của Thông ba lá với các yếu khí hậu đã được phân tích bằng các hệ số tương quan Pearson. Vai trò của những yếu tố khí hậu đối với tăng trưởng của Thông ba lá đã được phân tích bằng các hàm phản hồi tuyến tính đa biến từng bước. Kết quả nghiên cứu cho thấy: (1) Sự nâng cao nhiệt độ tháng 9 và 10, lượng mưa của tháng 3 và tổng lượng mưa của tháng 11 và 12, số giờ nắng tháng 11 và hệ số thủy nhiệt của tháng 6 đều dẫn đến giảm tăng trưởng của Thông ba lá. (2) Trái lại, sự nâng cao độ ẩm không khí trong mùa khô từ tháng 1-4 là điều kiện tốt cho tăng trưởng của Thông ba lá. (3) Bốn yếu tố ảnh hưởng rõ rệt nhất đến tăng trưởng bề rộng vòng năm của Thông ba lá là tổng lượng mưa tháng 11 và 12, độ ẩm không khí từ tháng 1 đến 4, hệ số thủy nhiệt tháng 6 và nhiệt độ tháng 9.

1. INTRODUCTION

Pinus kesiya Royle ex Gordon is a geographically widely naturally distributed tree species in the subtropical region in the Central Highlands [1]. This tree species contributes to the development of subtropical moist mixed broadleaf-coniferous forests in the areas of Lac Duong, Don Duong, Di Linh, Duc Trong, and Bidoup-Nui Ba National Park in Lam Dong province [1, 2]. *P. kesiya* wood was used to build houses and household furniture and make packaging and raw materials for pulp processing. Hence, the forestry sector of the Central Highlands provinces has planted *P. kesiya* forests in large areas. To plant and nurture *P. kesiya* forests, science and production practices need to understand the ecological characteristics of *P. kesiya* populations clearly. Numerous studies [2, 3] have used the dendroclimatology method to measure the ecological features of tree species and restore past climatic parameters. In Vietnam, this method has been applied to explore the impact of climate on the growth of *P. kesiya* [4, 5], *Dacrycarpus imbricatus* (Blume) de Laub [6] and *Keteleeria evelyniana* Masters [7]. However, previous studies on the response of *P. kesiya* to climate change were only conducted in plantations under 40 years old. The relationship between the growth of tree species and climate varies depending on geographical location, forest type, and site conditions [8]. Thus, research on the response of *P. kesiya* growing in natural conditions to fluctuations in climatic factors is still needed. Based on the aforementioned factual information, the objective of the study was to evaluate the climatic variables that have the greatest influence on the ring-width growth of *P. kesiya*. The findings from the present study serve as the scientific foundation for formulating a theory on the ecological traits of the *P. kesiya* population and developing technical measures for planting and nurturing *P. kesiya* forests.

2. RESEARCH METHODS

2.1. Study area

The study site was conducted in the Duc Trong area (108°08′01″ to 108°34′43″E and 11°33′47 to 11°48′47″N, 1000 ~ 1700 m a.s.l.), Lam Dong province, Central Highland Region, Vietnam. The climate in this region was dominated by a tropical monsoon climate with an average annual temperature of 20.6 to 23.8°C and an average yearly precipitation of 2400 mm. The soils from the sampling sites are red-yellow soil developed on granite rocks.

2.2. Data collection

The ring-width growth series of *P. keysia* was collected from 5 sample trees with D > 80cm; good vitality; round and even crown; no top-cut; and no pests or wind damage. These sample trees live in a subtropical moist mixed broadleaf - coniferous forest with a stock of over 400 m^3/ha. The collection location of the sample trees is 30km from the Da Lat hydrometeorological Station. Ring samples on the stem of the sample trees were collected by Pressler's growth borer in 2 perpendicular directions at 120-130cm from the ground. The ring-width of the sample trees was calculated as an average of these two drilling directions. The mean ring-width series of the 5 sample trees was 109 years. After processing the wood samples with fine sandpaper, the width of the rings was measured by an electron microscope with an accuracy of 0.001mm. The rings of *P. keysia* corresponding to the calendar years were measured by comparing the time from the current ring at the position close to the bark. The climatic parameters were obtained from Nhan (2012) [7].

2.3. Data analysis

(1) Determine the dry season and the rainy season in the Duc Trong area. These two indicators were determined according to the dry-humid regime of Trung (1999) [1]. The dry-humid regime was represented by formula 1; in which P is the average annual precipitation (P, mm/year), X is the drought index, Rh is the lowest average relative air humidity of the year (Rh, %). The X index was represented by formula 2; in which S is the number of dry months (precipitation of dry months, PS ≤ 50 mm/month), A is the number of drought months (precipitation of drought months, PA ≤ 25 mm/month), D is the number of drought months (precipitation of drought months, PD ≤ 5mm/month). The study then proceeds to construct a Gaussen-Walter diagram to measure the dry season and the rainy season

in the Duc Trong area. The dry season is the months with $P < 50$ mm/month, and the rainy season is the months with $P > 50$mm/month.

$$P \times X = X \times Rh \quad (1)$$

$$X = S \times A \times D \quad (2)$$

(2) Determine the response of P. keysia to changes in climatic factors. This content was analyzed in the following 8-step sequence:

Step 1: Determine the ring-width index (Kd) on sample trees and the climatic indexes of 12 months of the year. To eliminate the influence of tree age on the ring-width growth of *P. keysia*, the Kd indexes on sample trees were determined by the 3-year moving average method with a 1-year step (Formula 3). In Formula 3, Kd_A is the ring-width index at year A, and Zr_A, Zr_{A-1}, and Zr_{A+1} are the ring-width at year A, A-1 of the previous year, and A+1 of the following year, respectively. The climatic parameters of the months of the year were also converted into climatic indexes similar to the Kd index.

$$Kd_A = \frac{Zr_A}{[(Zr_{A-1} + Zr_A + Zr_{A+1})/3]} \quad (3)$$

Step 2: Determine the standardized Kd index. The standardized Kd index was the average Kd index of 5 sample trees. This index was used to determine the general response of the sample trees to changes in climatic factors.

Step 3: Determine the descriptive statistical characteristics (average, minimum, maximum, and coefficient of variation) for the standardized Kd index series.

Step 4: Determine the relationship between the annual ring-width of the previous year and the following year. This index was determined by the Pearson correlation coefficient (Symbol: R+). The result shows the influence of growth in the previous year on growth in the following year.

Step 5: Determine the sensitivity (mSx) of *P. keysia* to changes in climatic parameters. This characteristic was determined by formula 4 [9]; where Kd_A and Kd_{A+1} are the standardized annual ring-width indexes of years A and A + 1, respectively, n is the number of standardized annual rings, and the vertical dash represents the absolute value.

$$mS_x = \frac{1}{n-1} \sum |2(Kd_{A+1} - Kd_A)/(Kd_{A+1} + Kd_A)| \quad (4)$$

Step 6: Analyze the response of *P. keysia* to the fluctuations of climatic factors. The climatic parameters analyzed include air temperature (T^0C), precipitation (M, mm), air humidity (Rh%), sunshine hours (N, hours), evaporation (P, mm), and hydrothermal coefficient (K) of 12 months from 1980 to 2014. The hydrothermal index K of the months in the year was determined according to Xelianhicov's method (Formula 5) [10]; in which M (mm) and T (^0C) are the total precipitation and total temperature in the month, respectively. The variation of the Kd index depended not only on the climatic index of each month in the year but also on the aggregate of many months in the year. In the following case, this study analyzed the relationship between the Kd index and the set of months of the rainy season (May - October), the end of the rainy season (November - December), the end of the rainy season of the previous year (November) to the beginning of the dry season of the following year (March) and 4 months of the dry season of the current year (January - April). The direction and intensity of the relationship between the Kd index and the climatic factors were analyzed using a univariate linear correlation matrix, i.e. $Kd = a + bX_i$; where Xi is the index (T, M, Rh, N, P, and K) of 12 months in a year. The outcomes of step 6 demonstrate which monthly climate variables are most closely associated with the Kd index of *P. keysia.*

$$K = \frac{M}{0.01 \times T} \quad (5)$$

Step 7: Analyze the role of climatic parameters on the ring-width growth of *P. keysia*.

Step 7.1: Use the partial correlation regression method to determine the role of each climatic factor on the ring-width growth of *P. keysia*. In this case, the regression model only included climatic factors that had a close relationship ($P < 0.05$) with the Kd index. The response Equation of *P. keysia* with each climatic factor was in the form of Equation 6;

in which Kd is the ring-width index, X_k is the climatic factor of month k in the year (k = 1-12 and a set of many months), b_k is the regression coefficient. The purpose of this step was not only to detect each climatic factor of the months in the year that had a close relationship with the Kd index but also to eliminate the collinearity diagnostics between climatic parameters. The role of each climatic factor on the ring-width growth of *P. keysia* was determined by the standardized regression coefficient (Beta coefficient). The high or low role of climatic factors was evaluated by the absolute value of the Beta coefficient; in which $Beta_{Max}$ and $Beta_{Min}$ are the climatic factors that have the greatest and least influence on the annual ring-width growth of *P. keysia*, respectively.

Step 7.2: Use the partial correlation regression method to analyze the combined influence of many different climatic parameters (X, Y, Z) on the ring-width growth of *P. keysia*. The response Equation of *P. keysia* with many climatic factors was the form of Equation 7; in which X_k, Y_k, and Z_k are climatic factors that have a close relationship with the Kd index, bk is the regression coefficient of X_k, Y_k, and Z_k factors, and k is the month and the set of months. The high and low roles of climatic parameters on the annual ring-width growth of *P. keysia* were assessed by the absolute magnitude of the Beta coefficient.

$$Kd = b_0 + b_1X_1 + b_2X_2 + \ldots + b_kX_k \quad (6)$$

$$Kd = b_0 + b_1X_k + b_2Y_k + \ldots + b_kZ_k \quad (7)$$

Step 8: Build a model to estimate the Kd index of *P. keysia* (Equation 8). In Equation 8, Xk', Yk', and Zk' are the climatic factors that play the largest role in the ring-width growth of *P. keysia*.

$$Kd = b_0 + b_1X_k' + b_2Y_k' + \ldots + b_kZ_k' \quad (8)$$

Assessment of regression Equation errors

The regression coefficients and error statistics of Equations 6-8 were measured by the regression and partial correlation methods. The reliability of these regression Equations was evaluated by the coefficient of determination (R^2; Equation 9), the standard error of estimation (SEE; Equation 10), the mean absolute error (MAE; Equation 11), and the mean absolute percentage error (MAPE; Equation 12). In Equations 9-12, Kd_i and Kd_J are the actual and estimated Kd indices, respectively; Kd_{Bq} is the actual average Kd index; n is the observation size; p = number of parameters of the regression Equation. The regression and correlation analysis steps were carried out using the statistical software STATGRAPHICS Centurion XV.I 15.1.02.

$$R^2 = [1- \frac{\sum_{(i=1,n)}(Kd_i - Kd_J)^2}{\sum_{(i=1,n)}(Kd_i - Kd_{Bq})^2}]\times 100 \quad (9)$$

$$SEE = \sqrt{\frac{SSR}{n - p}} \quad (10)$$

$$SSR = \sum_{(i=1,n)}(Kd_i - Kd_J)^2$$

$$MAE = \frac{|(Kd_i - K_J)|}{n} \quad (11)$$

$$MAPE = \frac{MAE}{Kd_i}\times 100 \quad (12)$$

3. RESULTS AND DISCUSSION

3.1. Climatic characteristics in the Duc Trong area

Table 1 summarizes the Duc Trong area's January through December air temperature (T, ^0C), precipitation (M, mm), air humidity (Rh, %), sunshine hours (N, hours), evaporation (P, mm), and hydrothermal coefficient (K). The average monthly temperature in the Duc Trong area was 18.10°C, the average monthly and annual precipitation was 151.9 mm and 1825 mm, respectively, the average air humidity was 84.1%, the average number of hours of sunshine was 168 per month, and the hydrothermal coefficient was 2.70. Heavy precipitation occurs from May to October. According to the dry-humidity classification of Trung (1999) [1], the dry-humidity regime in the Duc Trong area is classified as Level II (slightly humid: 1200-2500 mm/year). This classification includes three dry months (PS < 50 mm/month) from December of the previous year to February of the following year, 2 drought months (PA < 25 mm/month; January and February), and no extreme drought month (PD < 5 mm). Thus, the dry season in the Duc Trong area only lasts 3 months from December of the previous year to February of the following year. However, if we consider months with an M/P ratio < 1 as periods of water shortage, the dry season extends to five months, from December to March of the following year.

Table 1. Climatic traits in the Duc Trong area

Months	T (^{0}C)	M (mm)	Rh (%)	N (hours)	P (mm)	K
1	15.8	8.9	81.3	236	97.1	0.15
2	16.8	19.7	73.0	229	103.7	0.39
3	17.9	76.5	77.3	237	111.2	1.39
4	19.0	179.7	81.8	200	77.9	2.95
5	19.5	216.2	86.9	189	61.2	3.50
6	19.1	201.8	87.6	153	51.9	3.45
7	18.7	222.2	89.4	145	50.5	3.80
8	18.5	242.2	91.1	135	47.0	4.44
9	18.5	277.6	90.6	125	43.5	4.94
10	18.1	246.0	86.8	143	53.6	4.46
11	17.5	99.8	83.7	169	75.6	1.88
12	16.2	32.0	79.9	210	88.2	0.68
Average	***18.0***	***151.9***	***84.1***	***181***	***71.8***	***2.70***

3.2. Characteristics of ring-width index of *P. keysia*

The standardized Kd index series of *P. keysia* was 107 years (1905-2013). The statistical characteristics of the Kd index series are summarized in Table 2. The average Kd index was 1.0; the Kd range was from 0.42 to 1.64 and the coefficient of variation (CV%) was 21.8%. Based on the range of the Kd index, the ring-width growth of *P. keysia* was divided into 3 levels: good (Kd > 1.05), normal (Kd = 0.95-1.05), and poor (Kd < 0.95). From 1905-2013, *P. keysia* had poor, normal, and strong growth for 40, 36, and 33 years, respectively. The recurrence period of poor growth was 3 years, and strong growth was 4 years. The autocorrelation between the growth of ring-width from the previous year and the following year was quite high (R^+ = -0.673). *P. keysia* exhibited a quite high sensitivity (mS_x = 0.310) to climate variations.

Table 2. Statistical characteristics of ring-width index of *P. keysia*

Statistics	Average	Min	Max	SEE	CV%
Kd	1.00	0.42	1.64	0.22	21.8
R^+	-0.673				
mSx	0.310	0.000	1.114	0.248	80.0

3.3. Response of *P. keysia* to changes in climatic factors

The relationship between the ring-width growth of *P. keysia* and T, M, Rh, N, P, and K of the months in the year are given in Tables 3 to 8, respectively. As demonstrated in Table 3, the ring-width growth of of *P. keysia* was negatively impacted by the increase in air temperature from January to July and September to November. On the contrary, heavy rain in August and December had a positive impact on the ring-width growth of *P. keysia*. Nonetheless, the Kd index only exhibited a substantial correlation with T_4 (r = -0.354; P = 0.043), T_6 (r = -0.360; P = 0.040), T_7 (r = -0.481; P < 0.01), T_9 (r = -0.546; P < 0.01), T_{10} (r = -0.431; P = 0.012), and T_{5-10} (r = -0.468; P < 0.01).

Table 3. Relationship between the ring-width growth of *P. keysia* and air temperature across different months of the year

Months	r	P	N	Months	r	P	N
1	-0.157	0.383	33	9	-0.546	0.001	33
2	-0.169	0.347	33	10	-0.431	0.012	33
3	-0.019	0.914	33	11	-0.096	0.595	33
4	-0.354	0.043	33	12	0.013	0.941	33
5	-0.265	0.137	33	1-4	-0.224	0.210	33
6	-0.360	0.040	33	5-10	-0.468	0.006	33
7	-0.481	0.005	33	11-12	-0.034	0.851	33
8	0.074	0.683	33	11-3	-0.140	0.438	33

As shown in Table 4, the increase in precipitation in the months of January - February, April, September - December, the total precipitation in the rainy season (M_{5-10}) and the dry season (M_{1-4}) positively affected the ring-width growth of *P. keysia*. In contrast, heavy rain in May - August and November - December negatively affected the ring-width growth of *P. keysia*. Nonetheless, the Kd index only displayed a clear relationship with M_2 ($r = 0.328$; $P = 0.062$), M_3 ($r = -0.323$; $P = 0.066$), M_{11-12} ($r = -0.549$; $P < 0.01$) and M_{11-3} ($r = -0.335$; $P = 0.056$).

Table 4. Relationship between the ring-width growth of *P. keysia* and precipitation across different months of the year

Months	r	P	N	Months	r	P	N
1	0.185	0.303	33	9	0.149	0.409	33
2	0.328	0.062	33	10	0.388	0.026	33
3	-0.323	0.066	33	11	0.256	0.150	33
4	0.269	0.130	33	12	0.127	0.483	33
5	-0.231	0.196	33	1-4	0.037	0.837	33
6	-0.425	0.014	33	5-10	0.197	0.273	33
7	-0.220	0.219	33	11-12	-0.459	0.007	33
8	-0.238	0.182	33	11-3	-0.335	0.056	33

High air humidity in January - July and September - October positively affected the growth of the ring-width growth of *P. keysia*. In contrast, the high air humidity in August, November, and December negatively affected the ring-width growth of *P. keysia*. However, the Kd index only had a significant relationship with Rh_1 ($r = 0.467$; $P < 0.01$), Rh_4 ($r = 0.392$; $P = 0.024$) and Rh_{1-4} ($r = 0.632$; $P < 0.01$) (Table 5).

Table 5. Relationship between the ring-width growth of *P. keysia* and air humidity across different months of the year

Months	r	P	N	Months	r	P	N
1	0.467	0.006	33	9	0.107	0.552	33
2	0.080	0.658	33	10	0.201	0.262	33
3	0.294	0.097	33	11	-0.251	0.159	33
4	0.392	0.024	33	12	-0.103	0.570	33
5	0.238	0.182	33	1-4	0.632	0.000	33
6	0.042	0.817	33	5-10	0.184	0.305	33
7	0.027	0.882	33	11-12	-0.248	0.165	33
8	-0.256	0.151	33	11-3	0.287	0,106	33

High sunshine hours in January - May, July, September, January - April, and May - October positively affected the growth of the annual ring width of *P. keysia*. On the contrary, the high sunshine in June, August, October, November - December, and November - March negatively affected the ring-width growth of *P. keysia*. However, the relationship between the Kd index and sunshine hours was only clearly demonstrated in September (r = 0.360; P = 0.040) and November (r = -0.391; P = 0.024) months (Table 6).

Table 6. Relationship between the ring-width growth of *P. keysia* and number of sunshine hours across different months of the year

Months	r	P	N	Months	r	P	N
1	0.110	0.543	33	9	0.360	0.040	33
2	0.209	0.244	33	10	-0.052	0.774	33
3	0.303	0.087	33	11	-0.391	0.024	33
4	0.094	0.605	33	12	-0.002	0.993	33
5	0.268	0.132	33	1-4	0.294	0.097	33
6	-0.008	0.966	33	5-10	0.193	0.282	33
7	0.057	0.753	33	11-12	-0.198	0.269	33
8	-0.208	0.246	33	11-3	-0.005	0.980	33

The data in Table 7 showed that the increase in evaporation in the months of January, March, May - August, May - October and January - April had a positive effect on the ring-width growth of *P. keysia*. On the contrary, the strong evaporation in the months of February, April, September - December, November - December and November - March had a negative effect on the ring-width growth of *P. keysia*. However, the Kd index only showed a significant relationship with P_3 (r = 0.313; P = 0.076), P_8 (r = 0.493; P < 0.01) and P_{11} (r = -0.320; P = 0.069).

Table 7. Relationship between the ring-width growth of *P. keysia* and evaporation across different months of the year

Months	r	P	N	Months	r	P	N
1	0.205	0.252	33	9	-0.107	0.553	33
2	-0.139	0.442	33	10	-0.237	0.185	33
3	0.313	0.076	33	11	-0.320	0.069	33
4	-0.035	0.847	33	12	-0.143	0.429	33
5	0.079	0.662	33	1-4	0.095	0.600	33
6	0.093	0.605	33	5-10	0.176	0.326	33
7	0.196	0.275	33	11-12	-0.262	0.141	33
8	0.493	0.004	33	11-3	-0.039	0.830	33

The increase in hydrothermal coefficient in January, February, April, September - December, and January - April positively affected the ring-width growth of *P. keysia*. On the contrary, the increase in hydrothermal coefficient in March, May-August, and May-10 negatively affected the ring-width growth of *P. keysia*. However, the Kd index only had a significant relationship with K_3 (r = -0.329; P = 0.062), K_6 (r = -0.435; P = 0.011) và K_{10} (r = 0.376; P = 0.031) (Table 8).

Table 8. Relationship between the ring-width growth of *P. keysia* and hydrothermal coefficient across different months of the year

Months	r	P	N	Months	r	P	N
1	0.184	0.304	33	9	0.134	0.459	33
2	0.319	0.070	33	10	0.376	0.031	33
3	-0.329	0.062	33	11	0.247	0.165	33
4	0.264	0.138	33	12	0.125	0.490	33
5	-0.237	0.184	33	1-4	0.153	0.395	33
6	-0.435	0.011	33	5-10	-0.260	0.144	33
7	-0.223	0.213	33	11-12	0.285	0.108	33
8	-0.240	0.179	33	11-3	0.177	0.324	33

3.4. The role of climatic factors on *P. keysia* growth

3.4.1. The role of air temperature

As indicated in Table 3, the Kd index of *P. keysia* had a significant relationship with six parameters: T_4, T_6, T_7, T_9, T_{10}, and T_{5-10}. The results of regression analysis and partial correlation (Table 9) showed that the Kd index of *P. keysia* had a very close relationship (r = 0.70) with these six factors (Equations 13 and 14). From Equation 14, it can be seen that the factor with the greatest influence on the growth of the ring-width of *P. keysia* was T9 (Beta coefficient = |-0.487|); followed by T_{10} (Beta coefficient = |-0.361|) and T_{5-10} (Beta coefficient = |0.329|); the lowest was T_6 (Beta coefficient = |-0.150|).

Table 9. The role of air temperature factor on the growth of *P. keysia*

Factors	Regression Coefficients		r	±SEE
	Unstandardized	Standardized (Beta)		
Constant	11.862		0.70	0.13
T_9	-7.194	-0.487		
T_{10}	-2.823	-0.361		
T_{5-10}	5.490	0.329		
T_4	-2.561	-0.236		
T_7	-2.202	-0.181		
T_6	-1.566	-0.150		
Equations	(13)	(14)		

3.4.2. The role of precipitation

The Kd index of *P. keysia* illustrated a strong correlation with six parameters: M_2, M_3, M_6, M_{10}, M_{11-12}, and M_{11-3} (Table 4). The results of regression analysis and partial correlation (Table 10) indicated that the Kd index had a very close relationship (r = 0.73) with these six factors (Equations 15 and 16). According to Equation 16, M11-12 (Beta coefficient = |-0.515|) had the biggest impact on the growth of the ring-width of *P. keysia*, followed by M_3 (Beta coefficient = |-0.390|) and M_6 (Beta coefficient = |-0.275|); M_{11-3} (Beta coefficient = |-0.007|) had the least impact.

Table 10. The role of precipitation factor on the growth of *P. keysia*

Factors	Regression Coefficients		r	±SEE
	Unstandardized	Standardized (Beta)		
Constant	1.389		0.73	0.12
M_{11-12}	-0.132	-0.515		
M_3	-0.100	-0.390		
M_6	-0.158	-0.275		
M_2	0.040	0.236		
M_{10}	-0.024	-0.046		
M_{11-3}	0.003	0.007		
Equations	(15)	(16)		

3.4.3. The role of air humidity

The Kd index of *P. keysia* only had a significant relationship with three factors: Rh_1, Rh_4 và Rh_{1-4} (Table 5). The results from regression analysis and partial correlation (Table 11) demonstrated that the Kd index had a very close relationship (r = 0.70) with these three factors (Equations 17 and 18). It is evident from Equation 18 that Rh_{1-4} (Beta coefficient = |0.476|) has the greatest influence on the increase of the annual ring width of *P. keysia*, followed by Rh_4 (Beta coefficient = |0.256|) and the lowest is Rh_1 (Beta coefficient = |0.199|).

Table 11. The role of air humidity factor on the growth of *P. keysia*

Factors	Regression Coefficients		r	±SEE
	Unstandardized	Unstandardized		
Constant	-3.247		0.70	0.12
R_{1-4}	2.647	0.476		
Rh_4	0.857	0.256		
Rh_1	0.751	0.199		
Equations	(17)	(18)		

3.4.4. The role of sunshine hours

As shown in Table 6, the Kd index of *P. keysia* was related to the two factors: N_9 and N_{11}. The results of regression analysis and partial correlation (Table 12) showed that the Kd index was closely related (r = 0.56) to these two factors (Equations 19 and 20). Equation 20 revealed that the increase in the ring width of *P. keysia* was more significantly affected by the number of sunshine hours in November (N_{11}) (Beta coefficient = |-0.428|) than by September (N_9) (Beta coefficient = |-0.400|).

Table 12. The role of sunshine hours factor on the growth of *P. keysia*

Factors	Regression Coefficients		r	±SEE
	Unstandardized	Unstandardized		
Constant	1.031		0.56	0.14
N_{11}	-0.336	-0.428		
N_9	0.308	0.400		
Equations	(19)	(20)		

3.4.5. The role of evaporation

As seen in Table 7, the Kd index of *P. keysia* was significantly related to only three factors: P3, P8, and P11. The results from the regression analysis and partial correlation (Table 13) indicated a strong relationship between the Kd index and these three factors (r = 0.61) (Equations 21-22).

According to Equation 22, the increase of the ring-width of *P. keysia* was more strongly influenced by factor P_8 (Beta coefficient = |0.549|) than by P_3 (Beta coefficient = |0.268|) and P_{11} (Beta coefficient = |-0.270|).

Table 13. The role of evaporation factor on the growth of *P. keysia*

Factors	Regression Coefficients		r	±SEE
	Unstandardized	Unstandardized		
Constant	0.390		0.666	0.133
P_3	0.297	0.278		
P_8	0.622	0.549		
P_{11}	-0.304	-0.270		
Functions	(21)	(22)		

3.4.6. The role of hydrothermal coefficient

The Kd index of *P. keysia* illustrated a strong correlation with two factors (K_6 and K_{10}) (Table 8). The results of regression analysis and partial correlation (Table 14) showed that the Kd index was quite closely related (r = 0.40) to these two factors (Equations 23 and 24). As can be shown from Equation 24, K_6 factor has a greater impact on the growth of the ring-width of *P. keysia* (Beta coefficient = |-0.330|) than K_{10} factor (Beta coefficient = |0.216|).

Table 14. The role of hydrothermal coefficient factor on the growth of *P. keysia*

Factors	Regression Coefficients		r	±SEE
	Unstandardized	Unstandardized		
Constant	1.079		0.474	0.154
K_6	-0.187	-0.330		
K_{10}	0.115	0.216		
Equations	(23)	(24)		

3.4.7. Relationship of P. keysia with various climatic factors

According to the data in Table 9-14, T_9, T_{10}, M_3, M_{11-12}, Rh_{1-4}, N_{11} and K_6 were the eight climate variables that most obviously impacted the ring-width growth of *P. keysia*. Regression analysis and partial correlation (Table 15) showed that the Kd index of *P. keysia* was very closely related (r = 0.845) to these 8 factors (Equations 25 and 26). As identified by Equation 26, M_{11-12} (Beta coefficient = |-0.380|), Rh_{1-4} (Beta coefficient = |0.352|), K_6 (Beta coefficient = |-0.221|) and T_9 (Beta coefficient = |-0.199|) were the four elements that most obviously impacted the ring-width growth of *P. keysia*. T_{10}, M_3 and N_{11} were the three elements that had less noticeable effects on *P. keysia* 's ring-width growth.

Table 15. The role of various climatic factors on the growth of *P. keysia*

Factors	Regression Coefficients		r	±SEE
	Unstandardized	Unstandardized		
Constant	3.652		0.845	0.102
M_{11-12}	-0.097	-0.380		
Rh_{1-4}	1.958	0.352		
K_6	-0.125	-0.221		
T_9	-2.936	-0.199		
T_{10}	-1.405	-0.180		
M_3	-0.025	-0.099		
N_{11}	-0.008	-0.010		
Equations	(25)	(26)		

3.5. Growth prediction model of *P. keysia* based on climatic factors

As revealed in Table 15, M_{11-12}, Rh_{1-4}, K_6 and T_9 were the four climatic factors that had the biggest effects on *P. keysia*'s ring-width growth. Due to the difficulty in determining K_6, the Equation to predict the Kd index of *P. keysia* was estimated based only on three factors: M_{11-12}, Rh_{1-4}, and T_9 (Equation 27). The Equation exhibited a relatively high coefficient of determination (R^2 = 50.8%) and a low mean absolute percentage error (MAPE = 10.1%). As a result, Equation 27 was utilized to estimate the ring-width growth index of *P. keysii* in the study area.

$$Kd = 3.34893 + 2.845216 \times Rh_{1-4} - 2.90546 \times M_{11-12} - 2.28346 \times T_9 \quad (27)$$

R^2 = 50.8%; ±SEE = 0.124; MAE = 0.095; MAPE = 10.1%.

3.6. Discussion

The climate in a certain geographical area had the greatest influence on the growth of trees and forests. In addition, the influence of climatic factors on the growth of trees and forests varied depending on the time of year and many years [1, 3, 9, 11]. The results of this study showed that *P. keysia* required a low-temperature regime. Therefore, this tree species was often distributed in temperate region and on tropical high mountains. In the Duc Trong area, the growth of *P. keysia* 's ring-width greatly depended on air temperature, precipitation, air humidity, sunshine hours, and hydrothermal coefficient of the months in the year. The increase in temperature in September and October, precipitation in March, total precipitation in November and December, monthly evaporation from November to April, sunshine hours in

November and hydrothermal coefficient of June all led to a decrease in the growth of *P. keysia*. In contrast, the increase in air humidity in the dry season from January to April was favorable conditions for the growth of *P. keysia*. In general, the four strongest controlling factors for the ring-width growth of *P. keysia* were total precipitation in November and December (M_{11-12}), air humidity during January to April (Rh_{1-4}), hydrothermal coefficient in June (K_6) and air temperature in September (T_9) were the four strongest factors controlling *P. keysia* growth.

This study only uses three factors Rh_{1-4}, M_{11-12}, and T_9 to build the growth prediction Equation of *P. keysia*. In practice, firstly, the three factors Rh_{1-4}, M_{11-12}, and T_9 of the year were counted. Then, these three factors were substituted into Equation 27 to find the Kd index of *P. Keysia*. In the evaluation of results, the ring-width growth of *P. keysia* was divided into 3 levels: good (Kd > 1.05), normal (Kd = 0.95-1.05), and poor (Kd < 0.95).

Research by Nhan et al. (2011) [4] revealed that the response of *P. keysia* in planted forests varies based on geographical location. In the Bao Loc area, changes in air temperature and sunshine hours in March significantly impacted the growth of *P. keysia*. In the Da Lat area, *P. keysia* reacted most clearly to changes in air temperature in January and June, precipitation in October, and air humidity in December. In the Di Linh area, changes in air temperature in February and March and air humidity in May most clearly affected the growth of *P. keysia*. Overall, *P. keysia* clearly responds to variations in climatic factors, and this response can differ depending on both geographical location and forest origin. However, a limitation of this study is that the mechanisms by which climatic parameters influence the growth of *P. keysia*'s ring-width have not yet been fully investigated.

4. CONCLUSION

Climate significantly influences the ring-width growth of *P. keysia* in the subtropical moist mixed broadleaf-coniferous forests in the Duc Trong area of Lam Dong province. Specifically, increases in air temperature during September and October, precipitation in March, and total precipitation in November and December, sunshine hours in November as well as hydrothermal coefficient in June have resulted in a decrease in *P. keysia* growth. Conversely, the increase in air humidity during the dry season from January to April was a favorable condition for *P. keysiya* growth. Total precipitation in November and December, air humidity during January to April, hydrothermal coefficient in June and air temperature in September were the four strongest factors controlling *P. keysia* growth.

REFERENCES

[1]. T.V. Trung (1999). Tropical forest ecosystems in Vietnam. Science and Technology Publishing House, Hanoi.

[2]. E.R Cook & L. Kairiukstis (1990). Methods of dendrochronology: Applications in the environmental science. Kluwer Academic Publishers, Dordrecht. 394.

[3]. H.C Fritts (1976). Tree-Rings and Climate. New York, London, San Francisco. Academic Press. 567.

[4]. P.T. Nhan, N.D. Quang & N.V. Them (2011). The influence of climate on the growth of annual ring width of *Pinus keysia* ex Gordon in Bao Loc, Di Linh and Da Lat areas, Lam Dong province. Journal of Forestry Science. 3: 1884 – 1894.

[5]. N.V. Them (2003). Response of *Pinus keysia* to climatic factors in Lac Duong, Lam Dong province. Journal of Agriculture and Rural Development. 3: 89-93.

[6]. N.V Them (2012). Response of *Darcrycarpus imbricatus* (Blume) de Laub to climate in Ong Mountain area, Binh Thuan province. Journal of Forestry Science. 4: 2527 - 2535.

[7]. N.V Nhan (2012). Effects of climate on annual ring width growth of *Keteleeria evelyniana* Masters in Duc Trong area, Lam Dong province. Journal of Forest Science. 4: 2517 - 2526.

[8]. N.V Them & P.M. Toai (2024). Forest ecology. Science and Technology Publishing House, Hanoi.

[9]. E.R Cook & L. Kairiukstis (1990). Methods of dendrochronology: Applications in the environmental science. Kluwer Academic Publishers, Dordrecht. 394.

[10]. V.V. Quynh & T.T. Hang (1996). Forest hydrometeorology. Agriculture Publishing House, Hanoi.

[11]. A. Jansons, R. Matisons, L. Puriṇa, U. Neimane & J. Jansons (2015). Relationships between climatic variables and tree-ring width of European beech and European larch growing outside of their natural distribution area. Silva Fennica. 49(1): 1255.