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Relationship Between Some Structural Elements of Macedonian Pine (*Pinus peuce* Gris.) in Different Elevations in National Park Pelister in North Macedonia

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Abstract

*The influence of elevation on the forest development and also on more structural elements is evident. The aim of this paper is to research the impact of elevation on the relationship between diameter at breast height (*DBH*), tree height (*H*), crown length (*L*) and stem volume (*V*). In the area of the Pelister National Park in North Macedonia, 22 experimental plots (EPs) were established in the even-age* Pinus peuce *Gris. stands with an average age of 90 years. The EPs were of a circular form and covered an area of 500 m^2 each; 6 of them were established at 1150 meter above sea level (m asl), 7 at 1350 m asl and 9 at 1550 m asl.* DBH*, tree height, and crown length of 481 trees were measured in all EPs. The* DBH – H *model was prepared in accordance with Prodan, as well as nonlinear (polynomial) regression for the relation between* DBH *and* L *and nonlinear (power) regression for the relation between* DBH *and* V*. The stem volume was calculated with a formula by Parishko for* Pinus peuce *Gris. The quadratic mean of* DBH*, average Loray height, average crown ratio, and the density of the stands were also calculated. The relationship between* DBH *and* H, L, *and* V *was examined with Pearson correlation and root mean square deviation (*RMSE*). The differences between averages of* H, L, *and* V *from the EPs were tested with analysis of variance (ANOVA) with an elevation class (1150, 1350 and 1550 m asl) as single factor. The density of stands was 490, 429 and 409 trees per ha on 1150 m, 1350 m and 1550 m asl, respectively. The average* DBH *was 39.8 cm, 46.5 cm and 45.5 cm, and Loray height was 23.9 m, 24.1 m and 22.6 m at 1150 m, 1350 m and 1550 m asl, respectively. Crown ratio (*CR*) pointed out different results on the different elevations, with the average value of 40.5%, 43.7%, and 39.3% at 1150 m, 1350 m, and 1550 m asl, respectively. Differences between average structural elements at different elevations can be confirmed with ANOVA with a significance of* $p<0.05$ *and* F *of 3.4 for* H*, the significance of* $p<0.05$ *and* F *3.2 for* L *data and* $p<0.05$ *and* F *of 9.7 for the value of V. In that way, the regression model for H is higher at a lower elevation, the tree has a longer crown length at lower elevation and also has a bigger volume at lower elevation. From the results, it can be concluded that the elevation has an influence on the relationship between* DBH *on the one hand and* H, L *and* V *as structural elements on the other hand. It can be said that at higher elevation trees have a smaller average height,* DBH*, and volume and have longer crown length than trees at lower elevation.*

Keywords: elevation, Pinus peuce *Gris., diameter at breast height, height of trees, crown length*

1. Introduction

Macedonian pine forests are relict with selective distribution on the Balkan Peninsula. The native area of this species is on the Baba mountain in the Pelister National Park, as well as on the mountain Kozuvand Nidze (Mandzukovski et al. 2009), Shar Planina and Galicica (Em 1969), on the Jablanica mountain (Trajkovski 1973, 1977) in North Macedonia. In Bulgaria, the area is located on the Pirin mountain, around Blagoevgrad (Pejovski 1971), and on Stara Planina (Horvat 1950). It is also present in Montenegro and Albania (Koshanin 1924), and in Serbia and Greece. In these regions, Macedonian pine grows in different conditions and elevations. Macedonian pine is distributed on a wide range of elevations from the lower border of the submontane belt to the upper border of the sub-alpine belt, ie from 1100 m to more than 2300 m asl (Lines 1985). The best stands are found in areas with deeper soils at lower elevations (1300–1500 m), e.g., on Mt Baba, North Macedonia and at rather higher elevations in the Rila Mts, Bulgaria, where individual trees have attained 36–42 m in height with diameters of 60–80 cm (Mayer 1979).

Tree growth depends on many environmental factors (climate, elevation, relief, available water, sunlight, etc.), to which they react in different ways. The effects of climate on the ecosystem in European mountain forests fluctuate over time and largely depend on site-specific characteristics, such as species composition and susceptibility to climate, elevation, and topography (Vizzarri et al. 2022). At different elevation zones, the climate is different, and therefore the impact of climate on forest growth is also different. Some reasons have been proposed to explain these shifts in tree growth-climate relationships, such as temperature-induced drought stress (Barber et al. 2000, Jacoby and D'Arrigo 1995, Lloyd and Fastie 2002), non-linear thresholds, or time-dependent responses to recent warming (D'Arrigo et al. 2004, Rossi et al. 2007, Wilmking et al. 2004), delayed snowmelt (Vaganov et al. 1999), air pollution (Wilson and Elling 2004, Yonenobu and Eckstein 2006), and differential growth/climate relationships inferred for maximum, minimum and mean temperatures (Wilson and Luckman 2002, Wilson and Luckman 2003). Influences of temperature are essential for forest productivity in high-elevation areas, whereas moisture-sensitive sites are widespread at low elevations in central and southern Europe (Babst et al. 2013). Mountain regions at higher elevations warmed at a greater rate than regions at low elevations (Beniston et al. 1997, Diaz and Bradley 1997, Liu et al. 2009, Pederson et al. 2010, Qin et al. 2009, Rangwala et al. 2009). The tree growth is different at different locations, with accelerating growth in the northern latitudes and higher altitudes and declining growth in the Mediterranean and dry continental zones (Pretzsch et al. 2022a). This means that they change their growth due to the modified potential growing conditions (Pretzsch et al. 2022b). Environmental changes at high altitudes may happen in much narrower spaces and in a shorter time range with severe consequences (Pretzsch et al. 2020, Seidl et al. 2019).

By using the relationship of stem diameter at breast height (*DBH*) with tree height, and crown length, it is possible to model growth and yield (Peper et al. 2001). These are also the most important variables used in forest inventory (Li et al. 2015). Tree height and *DBH* are allometrically related, and the allometric relationship between them is valuable and commonly used in stand-level planning for silviculture alternatives and effectiveness monitoring (Cutini et al. 2013, Rojo et al. 2005). Thus, accurate prediction of tree heights is critical in forest inventory compilation, yield modeling, and management decision-making (Leduc and Goelz 2009, Peng et al. 2004, Vassileva and Diéguez-Aranda 2012). The relationship between tree height and *DBH* is highly dependent upon the growth conditions and upon stand characteristics such as stand density, stand age, basal area, site index, mean and dominant heights, and diameters (Li et al. 2015). Nonlinear connection between *DBH* and *H* in Macedonian pine stands was also observed by Gogushevski et al. (1973), Gogushevski and Parisko (1970).

Crown size is an important factor for tree growth, which determines the amount of solar radiation intercepted by a tree (Acharya 2006) and therefore the crown is strongly correlated to tree growth (Kazmierczak and Najgrakowski 2012).The lack of data and the difficulty of accurately measuring the height of the live crown base – more pronounced in species with asymmetric crowns – may justify the relatively little research done on modeling crown parameters. Because of crown size, firm position, and longevity, tree crowns both reflect and determine many ecosystem characteristics, functions, and services (Pretzsch 2014).The crown ratio represents the relatiochip between the length of the crown and the height of the stem. Crown ratio and crown length reflect the potential of a released tree to use available resources such as increased growing space (Daniels et al. 1979). Predictions of tree crown ratio have been based on allometric relations between stand and tree variables (Belcher et al. 1982, Dyer and Burkhart 1987, Hasenauer and Monserud 1996, Zhang et al. 1996). The crown ratio can be predicted directly from the tree and/or stand variables or indirectly from estimates of the height to the live crown base (Soares and Tomé 2001). Tree crown length and crown ratio of Macedonian pine were studied by Michailov and Gogushevski (1956), who presented nonlinear connection between *DBH* and *L*.

The relation between *DBH* and tree volume is a very significant parameter for forestry, but the connection depends on a few factors such as species, age of trees, forest structures, etc. The connection of tree volume and *DBH* can be determined with a linear or nonlinear regression model. This connection is very useful for many forest operations, such as forest inventory, and forest calculations.

Many authors have studied this topic (del Río et al. 2021, Moser et al. 2008, Moser et al. 2009, Muñoz

Mazón et al. 2019, Pretzsch et al. 2020, Primicia et al. 2015), but very little research has been made about Macedonian pine (Gogushevski et al. 1973, Gogushevski and Parisko 1970, Iliev and Donov 1970).

In this study, the impact of elevation on the relationship between diameter at breast height as an independent variable and tree height, crown length, and stem volume as dependent variables was analyzed. The focus was on the following questions:

⇒ Do different elevations have an impact on distribution of structural elements (*H*, *L*, *V*)?

⇒ Which altitude is most suitable for the distribution of the same structural element of the Macedonian pine forest?

⇒ What is the influence of altitude on tree height, crown length, and tree volume?

2. Materials and Methods

2.1 Study Area

The three elevations transects with experimental plots were established in the Baba Mountain (41°00′11′ N, 21°11′07′′ E), a north-west oriented mountain in the central part of the Pelister National Park. The area of research is located between 950 and 1700 m asl covered by pure even-aged Macedonian pine (*Pinus peuce* Gris.) forests with an average age of 90 years. The transects were established at 1150 m, 1350 m, and 1550 m asl. Experimental plots (EPs) at 1150 m and 1350 m asl are located at geological type Pelisterian granite, and at 1550 m asl at green slate. The EP at 1150 m and 1350 m asl is located at eutric cambisol, and at 1550 m asl at rankers. Climate data were compiled for each elevation location covering the period (1954–2017), including mean annual temperature (°C) and annual precipitation (mm). Data from the nearest weather station in Bitola (12 km) were used and corrected for the difference in elevation. The climate in the study location is moderately continental and mountainous, mean annual temperatures and annual precipitation totals varied from 6.4 to 9.1°C and from 745 to 1245 mm, respectively. According to Lazarevski (1993), in this climate region, temperature decreases by 0.49 °C, while precipitation increases by 50 mm with rising in elevation at every 100 m.

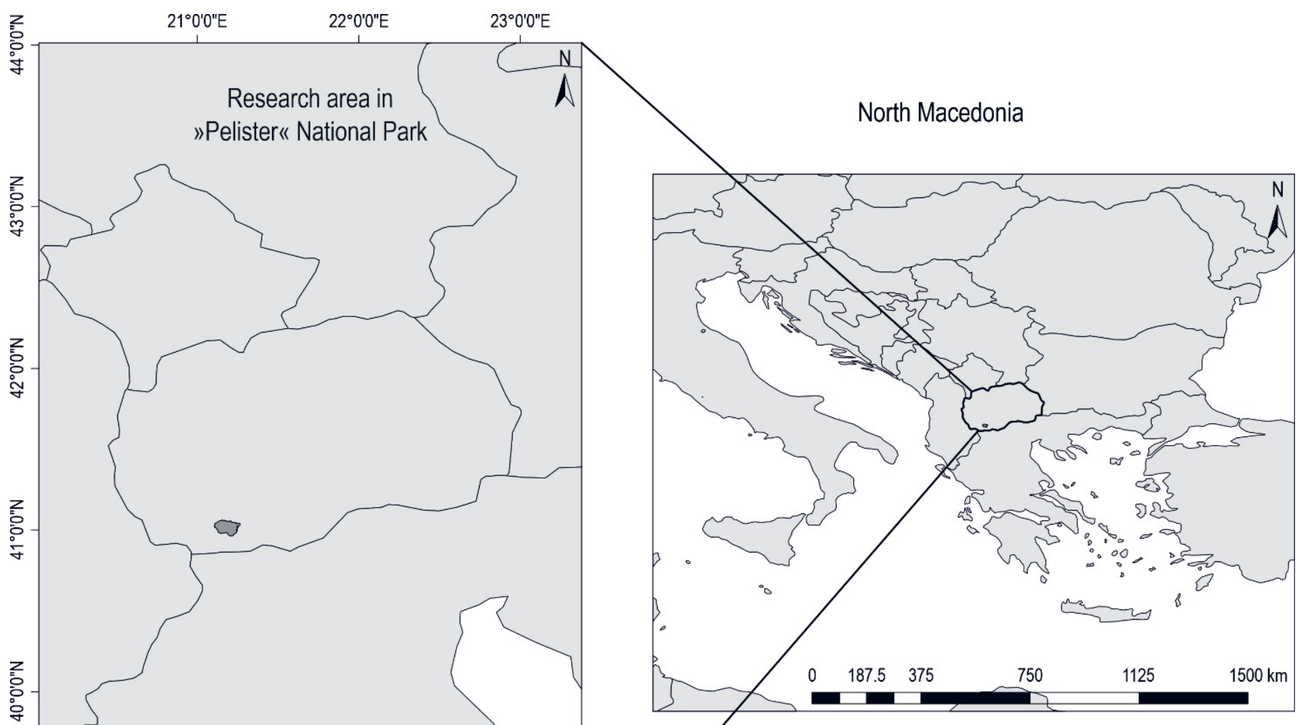

Fig. 1 Position of research area

2.2 Field Measurement and Analysis

The aim was to determine the impact of elevation on the relationship between diameter at breast height as an independent variable and the total height of trees, length of the crown, and volume of the stem. For this purpose, a total of 22 experimental circle plots (EPs) were established with an area of 500 m^2 each. Randomly, in three transects, 6 EPs were established at 1150 m asl, 7 EPs at 1350 m asl and 9 EPs at 1550 m asl. In all Eps, diameter at breast height (*DBH*)>10 cm was measured with Haglof Caliper; total tree height (*H*), and height to 1st live branch (for calculating the length of tree crown) were measured with Nikon Forestry Pro with an accuracy of 10 cm for all trees in EPs. Tree core samples were collected with Haglof increment borer from 10 randomly selected trees at the basal area in each EP for calculating the average age of stands. Also, from each EP, stand characteristics were collected such as precise elevation, slope, aspect, management form, and reproductions (off spring). A total of 479 trees were used for the analysis, i.e. 117, 178, and 184 trees at 1150 m, 1350 m, and 1550 m asl, respectively. The stem volume (*V*) was calculated from the volume table prepared by Parisko (1962) for Macedonian pine. Quadratic mean of *DBH*, average Loray height, length of the crown (*L*), average crown ratio (*CR*), and density of the stands were also calculated. Crown ratio presents the ratio of live crown length to tree height and is widely used to predict the growth and yield of trees and forests (Bella 1971, Sprinz and Burkhart 1987). From the data of EPs, the connection between *DBH* and *H* were determined throught the height model (M1) developed by Prodan (Prodan 1961), as the best compatible regression model. A nonlinear 2nd order polynomial model (M2) was prepared for the relation between *DBH* and *L* and a nonlinear (power) regression model (M3) for the relation between *DBH* and *V*. All data were calculated for all three elevation positions.

Models used for calculating the connections:

$$h-1.3=\frac{DBH^2}{(a+b\cdot DBH+c\cdot DBH^2)} \tag{M1}$$

$$L=a\cdot DBH^2-b\cdot DBH+c \tag{M2}$$

$$V=a\cdot DBH^b \tag{M3}$$

Where:

a, *b* care model parameters estimated using Statistica 12.0, option Nonlinear Estimation.

2.3 Statistical Analysis

First of all, the average value of structural elements (*DBH*, *H*, *L*, *CR*, *V*) were prepared. Table 1 presents total trees of stands per ha, quadratic mean of diameter at breast height, average tree height calculated through Loray's formula equation 1 (E1). Also, the crown ratio was determined as a relationship between tree height and crown length (E2), and the average length of the crown and the total volume of trees per ha. Secondly, descriptive statistics for these structural elements were calculated (Table 2). The descriptive statistic includes the variance of data, standard deviation, coefficient of variation and standard error of calculation. Furthermore, Pearson correlation was determined to assess the relationship between structural parameters *DBH* and *H*, *L* and *V*. Also, the Root Mean Square Deviation (*RMSE*) was calculated to present the mean error of the relationship between the measured and calculated tree height (E3), and variation explained by the model (R^2) to observe the strength of the connection between the measured and calculated data of structural elements. The differences between data of *H*, *L* and *V* from the EPs at different elevations were tested with the analysis of variance (ANOVA) with a single factor. Also, a residual analysis was made and normal probability plot was developed to calculate the data accuracy. All statistical analyses were done with Excel, StatSoft Statistica, and R (CranRstudio) software.

$$h_{\mathrm{Loray}}=\frac{h_1\cdot g_1+h_2\cdot g_2+...+h_{\mathrm{n}}\cdot g_{\mathrm{n}}}{g_1+g_2+...+g_{\mathrm{n}}} \tag{E1}$$

$$CR=\frac{L}{H}\cdot 100 \tag{E2}$$

$$RMSE=\sqrt{\frac{1}{n}\sum_{\mathrm{i}=1}^{\mathrm{n}}\left(h_{\mathrm{i}}-H_{\mathrm{i}}\right)^2} \tag{E3}$$

Where

h_1 tree height

g_1 basal area

L crown length

h_{i} measured tree height

H_{i} calculated tree height.

3. Results

First of all, based on the analysis of the obtained data, the number of trees per hectare is 490, 429, and 409 at 1150, 1350, and 1550 m asl, respectively. The

Table 1 Values of structural elements

Elevation of samples	Average value of structural elements					
	Number of trees	Quadratic mean of *DBH*	Loray height	Crown ratio	Length of crown	Volume
m asl	ha	cm	m	%	m	m^3
1150 m	490	39.8	23.9	40.5	9.32	678
1350 m	429	46.5	24.1	43.7	10.34	812
1550m	409	45.5	22.6	39.3	9.38	698

Table 2 Descriptive statistic of structural elements

Descriptive statistic of structural elements												
Element	1150 m asl				1350 m asl				1550 m asl			
	Var	*SD*	*CV*	*SE*	*Var*	*SD*	*CV*	*SE*	*Var*	*SD*	*CV*	*SE*
DBH	102.4	10.12	26.3	0.83	157.6	12.55	28.1	1.03	94.6	9.73	21.9	0.72
H	10.7	3.27	14.5	0.27	12.3	3.50	15.5	0.29	5.7	2.39	10.9	0.18
L	13.4	3.67	39.3	0.30	21.6	4.64	44.9	0.38	12.3	3.51	37.3	0.26
CR	132.7	11.52	28.5	0.95	205.5	14.34	32.4	1.17	168.0	12.96	30.6	0.96
V	0.8	0.88	63.7	0.07	1.7	1.29	68.2	0.11	0.8	0.90	53.0	0.07

Var – variance, *SD* – standard deviation, *CV* – coefficient of variation (%), *SE* – standard error

quadratic mean of *DBH* is 39.8 cm, 46.5 cm, and 45.5 cm, and Loray height is 23.9 m, 24.1 m, and 22.6 m at 1150, 1350, and 1550 m asl, respectively. Then crown ratio points out different results on the different elevation, thus at 1150 m asl the average value is 40.5%, at 1350 m asl the average value is 43.7%, and at 1550 m asl the average value is 39.3%. The average length of trees crown is 9.32 m, 10.34 m, and 9.38 m at 1150, 1350, and 1550 m asl, respectively. The total volume of trees per hectare is 678 m^3, 812 m^3, and 698 m^3 at 1150, 1350, and 1550 m asl, respectively. The analysis clearly shows that the elevation has an impact on the relation between average structural elements (Table 1 and Fig. 2–4).

From the descriptive statistics (Table 2), it can be seen that the standard deviation of *DBH* ranges from 9.73 at 1550 m asl to 12.55 at 1350 m asl. *SD* of tree height is similar and ranges from 2.39 to 3.50 at 1550 and 1350 m asl, respectively. Also, *SD* of crown length ranges from 3.51 to 4.64 at 1550 and 1350 m asl, respectively. *SD* of tree volume ranges from 0.88 at 1150 m asl to 1.29 at 1350 m asl. This shows that all structural elements have a larger standard deviation at 1350 m asl, and smaller at 1550 m asl. Moreover, the data for tree volume have a larger coefficient of variation ranging from 53.0 to 68.2%, but the data for tree height has a smaller coefficient of variation ranging from 10.9 to 15.5% at all altitudes. This phenomenon shows that trees are more variable in terms of volume and less variable in terms of tree height.

Equations for the relation between *DBH* and *h* are:

$\Rightarrow$ 1150 m asl

$$h-1.3=\frac{DBH^2}{(-13.0305+1.4285\cdot DBH+0.0136\cdot DBH^2)}$$

$\Rightarrow$ 1350 m asl

$$h-1.3=\frac{DBH^2}{(-12.5701+1.3775\cdot DBH+0.0171\cdot DBH^2)}$$

$\Rightarrow$ 1550 m asl

$$h-1.3=\frac{DBH^2}{(-6.33768+1.00364\cdot DBH+0.02354\cdot DBH^2)}$$

Prodan's regression model for *H* has significance correlation index of 0.85, 0.80, 0.79 and *RMSE* of 6.55, 8.04, 6.18 for 1150 m, 1350 m and 1550 m, respectively.

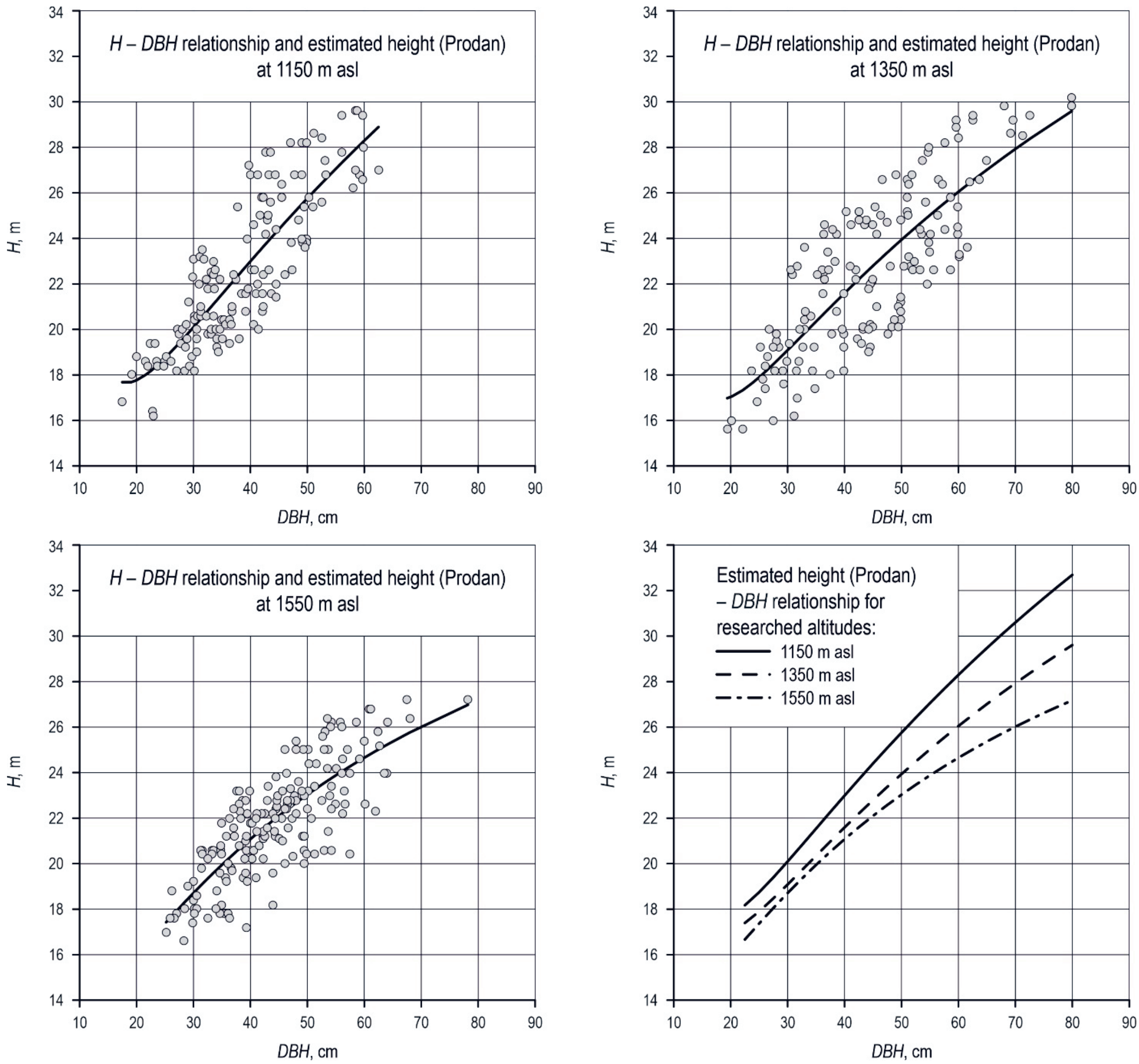

Fig. 2 Relation between diameter at breast height and real height and Prodan's regression model

Equations for the relationship between *DBH* and *L* are:

⇒ 1150 m asl

$$L = 3.7316 - 0.0071 \cdot DBH + 0.0037 \cdot DBH^2$$

⇒ 1350 m asl

$$L = 2.4078 - 0.0473 \cdot DBH + 0.0027 \cdot DBH^2$$

⇒ 1550 m asl

$$L = 0.4532 - 0.1513 \cdot DBH + 0.0011 \cdot DBH^2$$

The polynomial regression model for the relation between *DBH* and *L* has a correlation of 0.80, 0.81, 0.69, and *RMSE* of 8.31, 10.40, and 10.77 for 1150 m, 1350 m, and 1550 m, respectively.

Equations for the relation between *DBH* and *V* are:

1150 m asl $V = 0.00017 \cdot DBH^{2.43218}$

1350 m asl $V = 0.00017 \cdot DBH^{2.41444}$

1550 m asl $V = 0.00019 \cdot DBH^{2.39267}$

Table 3 Analysis of variance with a single factor of *H*, *L* and *V*

ANOVA of tree height (*H*)						
Source of Variation	*SS*	*df*	*MS*	*F*	*P*-value	F_{crit}
Between Groups	63.15	2	31.57	3.407	0.03396	3.015
Within Groups	4430.27	478	9.27	–	–	–
Total	4493.41	480	–	–	–	–
ANOVA of crown length (*L*)						
Source of Variation	*SS*	*df*	*MS*	*F*	*P*-value	F_{crit}
Between Groups	100.12	2	50.06	3.223	0.04071	3.015
Within Groups	7424.56	478	15.53	–	–	–
Total	7524.68	480	–	–	–	–
ANOVA of tree volume (*V*)						
Source of Variation	*SS*	*df*	*MS*	*F*	*P*-value	F_{crit}
Between Groups	19.86	2	9.93	9.276	0.000112	3.015
Within Groups	511.59	478	1.07	–	–	–
Total	531.44	480	–	–	–	–

The power regression model for *DBH* and *V* has a significant correlation of 0.99 for all elevations and *RMSE* of 1.08, 1.48, and 0.75 for 1150 m, 1350 m, and 1550 m asl, respectively.

The differences between average data at different elevations can be confirmed with ANOVA (Table 3) with a significance of $p<0.05$ and *F* of 3.4 for *H*, the significance of $p<0.05$ and *F* 3.2 for *L* data and $p<0.05$ and *F* of 9.2 for the value of *V*. Also, the data of *V* have higher differences between data at different elevations due to a higher *F* value regarding *F* critical value. Finally, *H* shows a better regression model at a lower elevation, the tree has a longer crown length at lower elevation and the volume of trees is also lower at lower elevation.

Residual analysis and normal probability plot show that all calculations are reasonable and regression models are valid. Residual analysis of *H* and *L* calculations has circular dispersion meaning that errors are dispersed at all stems, and only volume data residuals are concentrated at lower volumes.

4. Discussion

Firstly, in pure forests, the impact of climate on tree growth depends only on the conditions of the habitat and the growing possibilities of the species itself. In mountain forests, climate change impacts are complex, as there can be strong differences in climate conditions in a small elevation zone. Therefore, differences appeared in forest structures of the research stands of Macedonian pine. First of all, the total density of stands has different numbers of stems at different elevations – a lower number of stems at lower elevation (1150 m asl), but a higher number of stems at higher elevation (1550 m asl). This is a result of better conditions of habitats, i.e. since there is a big competition of trees, the number is lower. At a higher elevation, the competition of trees is lower and therefore the number of trees is higher.

Secondly, the quadratic mean *DBH* differs depending on the elevation. Consequently, the stands at lower elevations (1150 m asl) have lower *DBH* than the stands at higher elevations (1550 m asl). This fact is connected with the number of trees per hectare and the height of trees. Thus, at higher elevations, the density of trees is smaller than the density at lower elevations, and therefore trees have more free area, more available sunlight, and can grow freely without the need to grow in height to get the sunlight, and as a result, they grow in diameter. The case in lower stands is quite the opposite.

The different data of Loray *H* at different elevations is also evident. An especially great difference has been

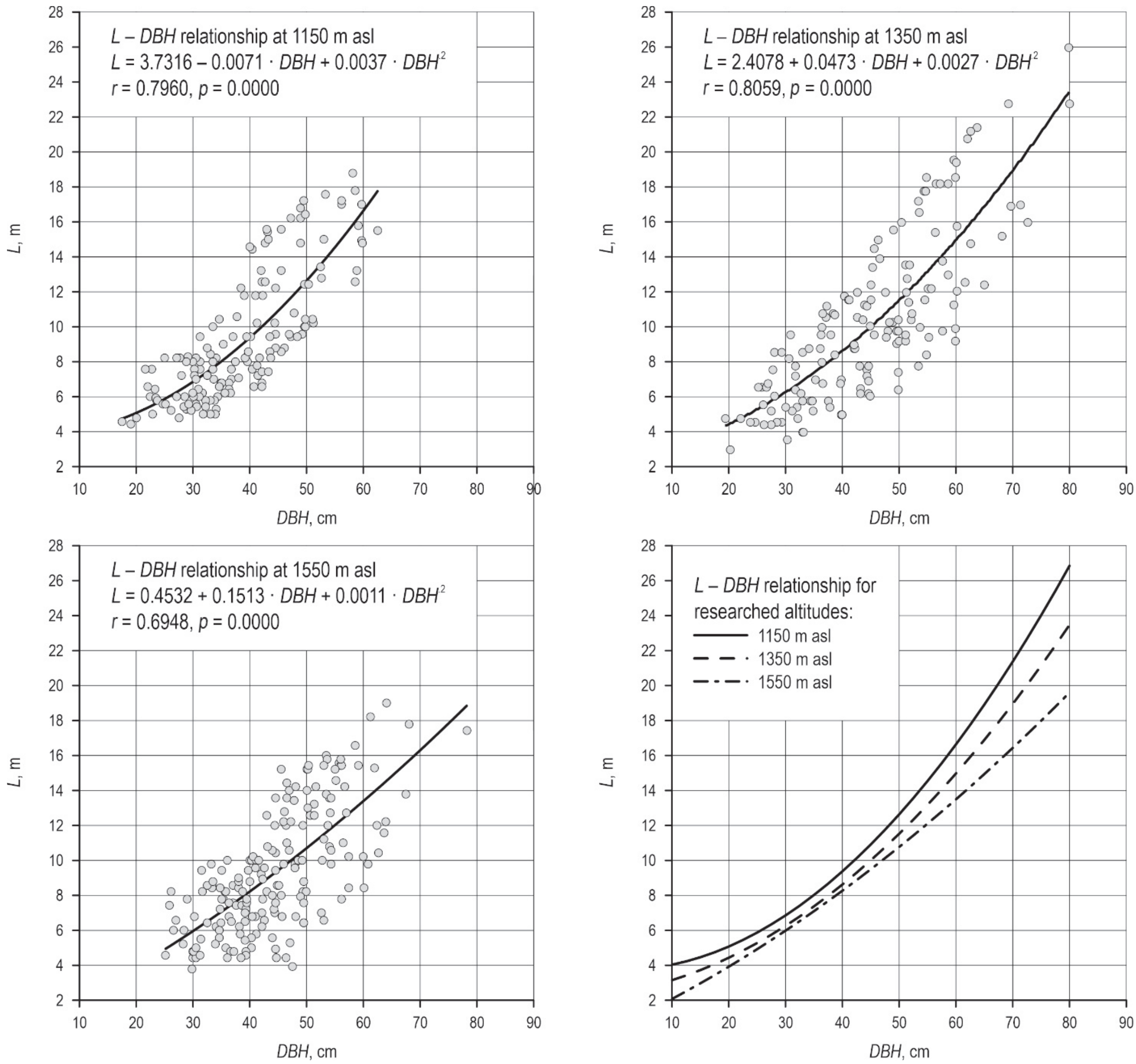

Fig. 3 Relation between diameter at breast height and crown length

observed between stands at 1350 m and 1550 m asl. Here, it can be said that Macedonian pine trees have higher stem at lower elevation, while trees at high elevation have smaller height. This statement is also confirmed by Bachmann et al. (2015) about the Macedonian pine plantations in Germany. This phenomenon is a result of lower density at the stands of 1550 m asl. because trees do not have real competition and stay lower. Crown length is longer in stands at 1350 m asl than in stands at 1550 m asl. Consequently, the crown ratio points out a bigger percent at mid-elevation (1350 m asl) and a lower percent at higher elevation (1550 m asl). This fact is directly connected with tree height, i.e. taller trees have longer crowns and the other way round. The lower tree height at high elevation and longer crown also at high elevation has been approved by Popovski (1953), who states that at high elevation, the crown of Macedonian pine trees is long to the base of the tree.

Stands at mid-elevation (1350 m asl) have a larger volume of trees, while stands at 1150 m asl. have a lower volume. As a statistical element, the volume of trees is certainly affected by altitude, but since the average diameter and average height are the largest in

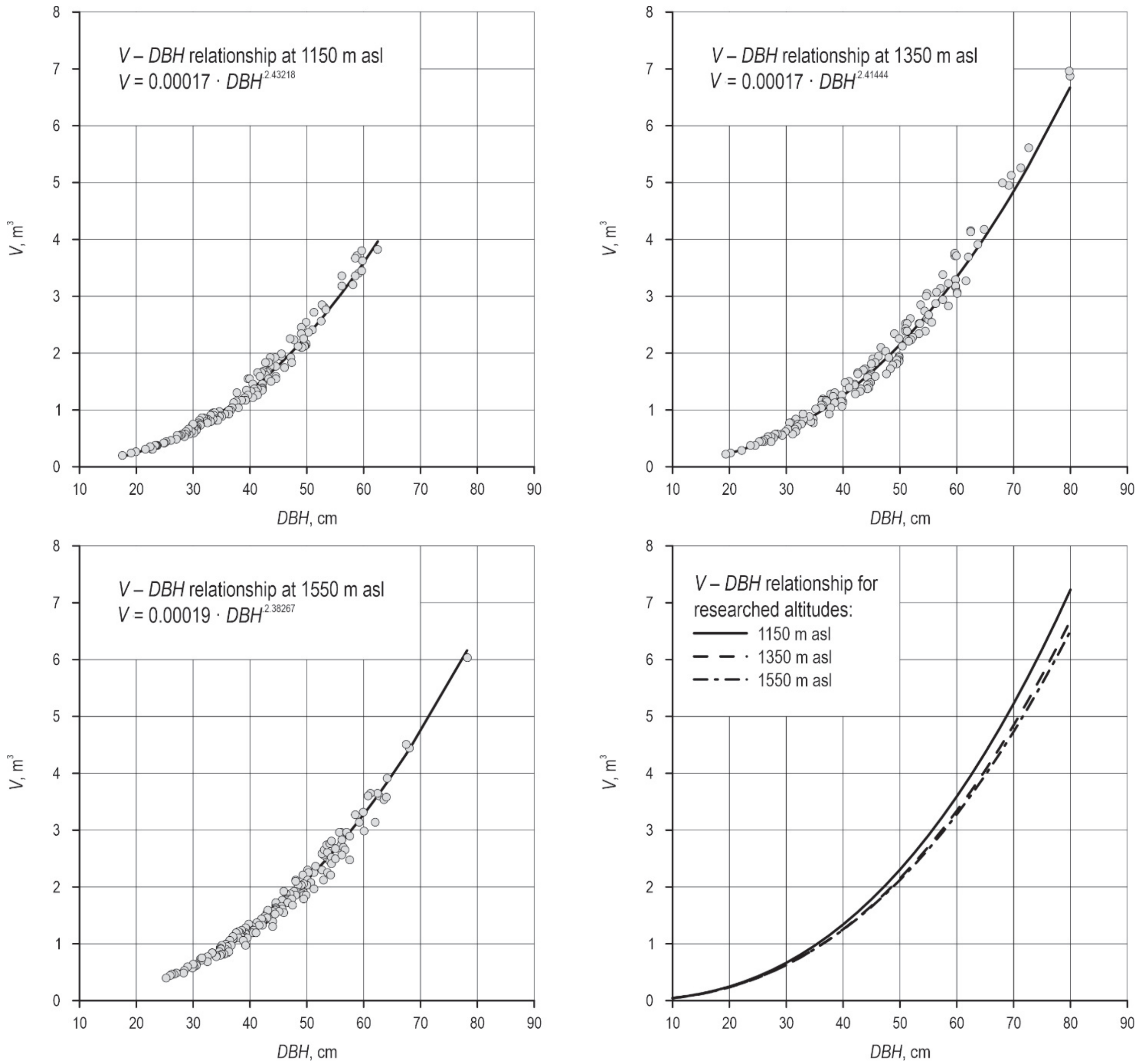

Fig. 4 Relation between diameter at breast height and tree volume

these stands, they also have a larger volume. From the residual analysis and normal probability plot, it can be seen that the predicted data have small differences against real data, and also that the sample data are random and normally positioned.

The impact of elevation is different for different species. Thus, changes in growth trend are not dependent on altitude for some species (Norway spruce), but European beech growth is altitude-dependent (Pretzsch et al. 2022a). In the case of Norway spruce and European beech, the growth was the highest at lower elevations and decreased with altitude, but during the last 200 years, the relationships turned to superior growth at higher altitudes (Pretzsch et al. 2020). Also, intra and inter specific growth synchrony in response to inter-annual fluctuations, as an indicator of tree species dependence on climate variability, can vary along the elevation gradient (del Río et al. 2021). In tropical montane forests, the decline of tree size with increasing elevation is an evident signal (Lieberman et al. 1996, Raich et al. 1997). The decrease in growth aligns with going from the lower, middle, and upper montane forests (Gentry et al. 1993), and the leaf area index also decreases with elevation from lowland to the upper

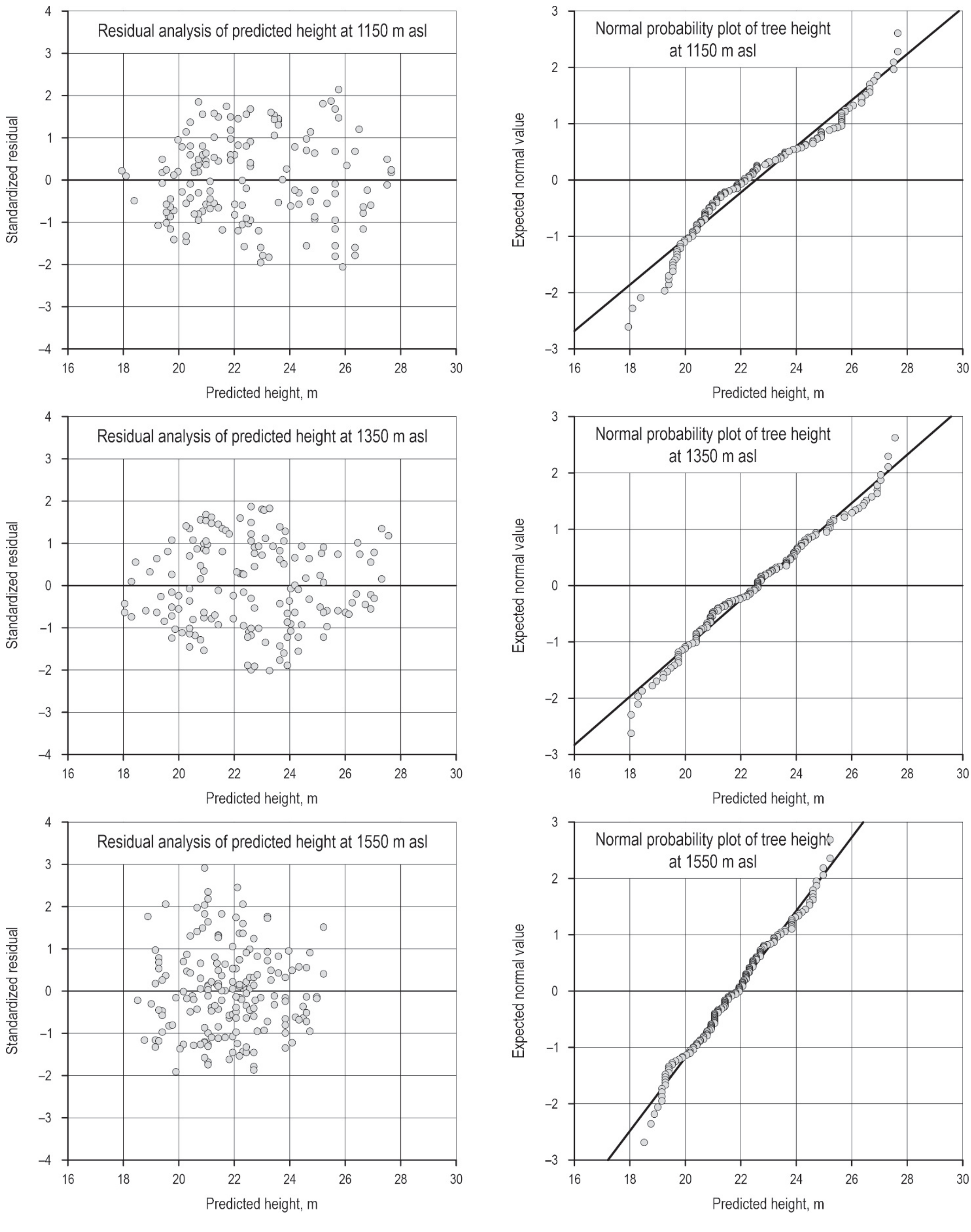

Fig. 5 Residuals and normal probability plot analysis of tree height

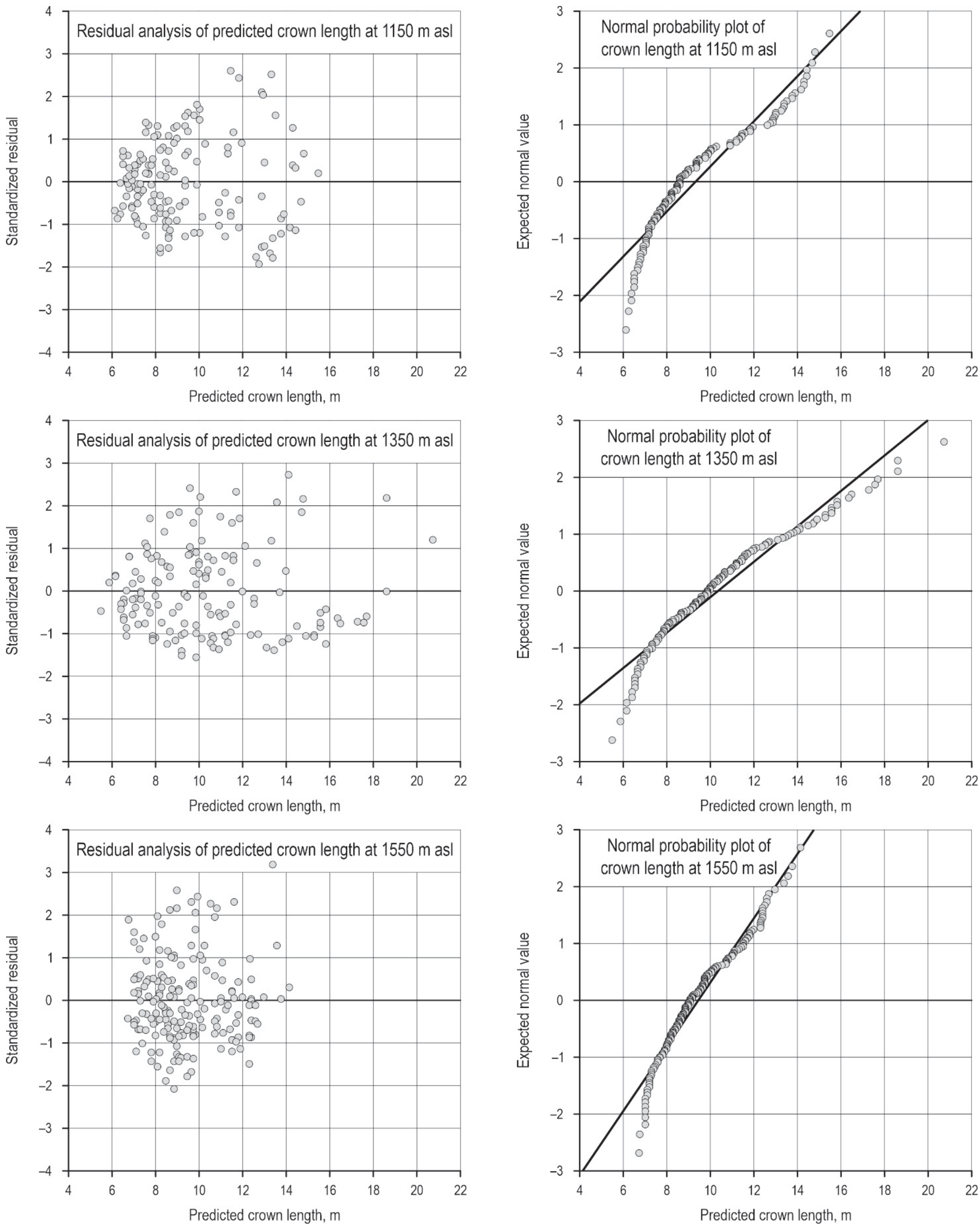

Fig. 6 Residuals and normal probability plot analysis of crown length

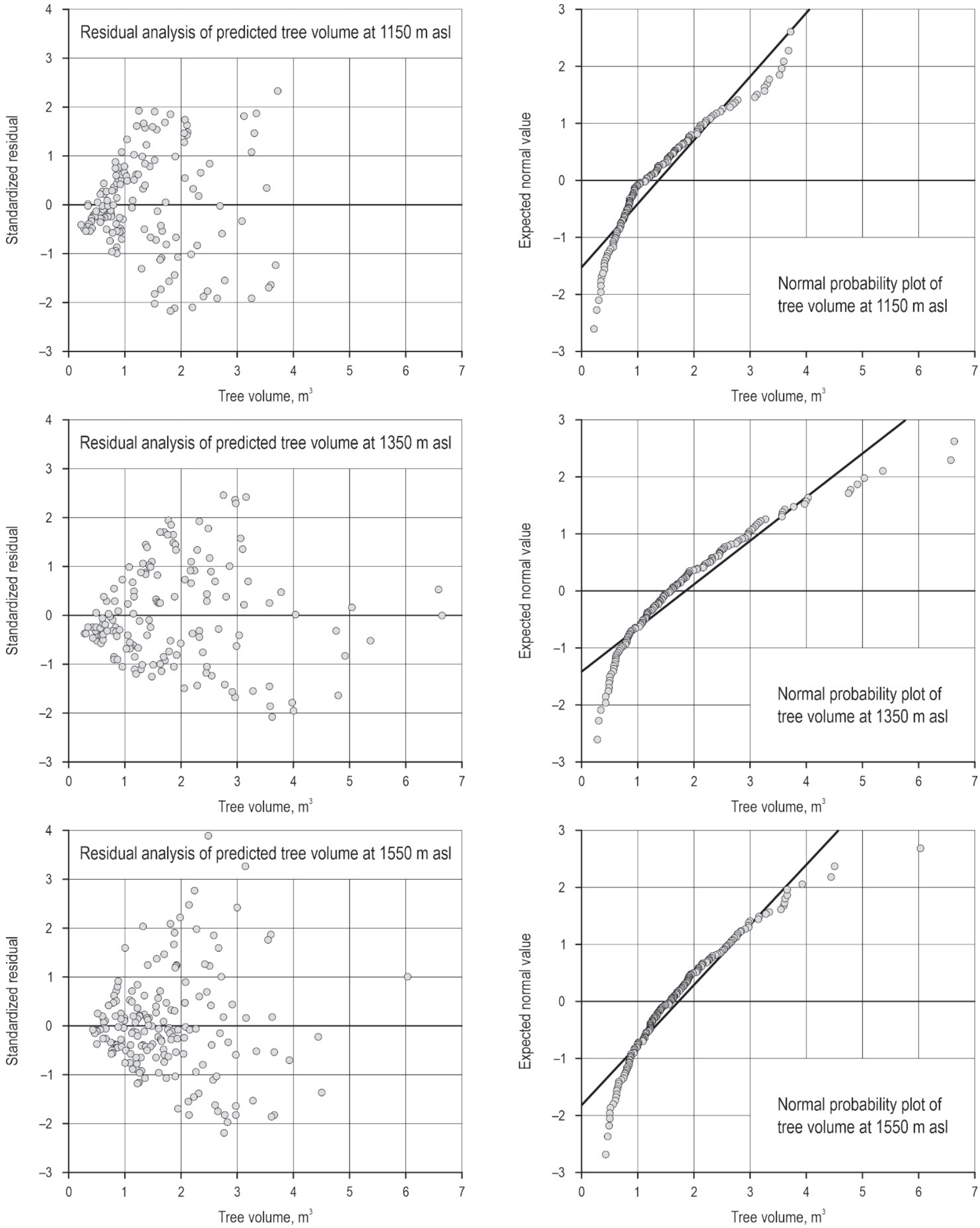

Fig. 7 Residuals and normal probability plot analysis of tree volume

montane forest (Kitayama and Aiba 2002). The causes of tree size reduction with elevation are closely linked to elevation changes in biomass, carbon allocation, and productivity of montane forests (Moser et al. 2008). The diameter growth of both pure spruce and silver fir is generally greater than that of *Pinus peuce* on the more fertile lower ground, but with increasing elevation, poorer soils and a more exposed, cooler climate, the vigour of the pine falls. At the forest limit, e.g. in the Bunderitsa Valley of the Pirin Mts at the elevations just over 2200 m, the *Pinus peuce* does not have the form of most conifers, but retains its good stem and crown form, though with reduced height (Lines 1985). This is also similar with Macedonian pine stands in North Macedonia, where at high elevations (above 1550 m) the trees have good form but they are smaller than those in the stands at lower elevations. At the lower elevations, in the Pirin Mts near Banskothe, Scots pine probably grew rather faster than *Pinus peuce*, but with the increase in elevation, the Scots pine became more and more unhealthy with poorer needle retention and none survived at 1750 m (Lines 1985). Also, Krstanov (1970) states that absolute yield depends on on-site factors, and that high values of the structural elements are not expected from stands at a high elevation.

5. Conclusions

From the results of this work, it can be concluded that the elevation has an impact on the relationship between *DBH* and some structural elements (*H*, *L*, *V*) of Macedonian pine forest. The greatest impacts are visible in terms of average tree height and average crown length, and the least impact in terms of tree volume. The results also show that a lower elevation is better or more suitable for the Macedonian pine forest especially in terms of the average tree height, although this species is representative of the subalpine region. Finally, with the growing elevation, the structural elements get smaller, i.e. at higher elevations, the average tree height, tree crown, and volume are smaller than at lower elevations.

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