ECOSYSTEMS: ECOLOGY AND DYNAMICS, 2022, Vol. 6, No. 2, P. 164-181

DYNAMICS OF ECOSYSTEMS AND THEIR COMPONENTS

UDC 574.24

HOW DOES ELEVATION ABOVE SEA LEVEL AFFECT THE MORPHOMETRIC GROWTH OF PINUS NIGRA IN MONTENEGRO

© 2022. S.O. Korol*, T.O. Korol, E.I. Golubeva****

**University of Vienna*
Austria, 1090, Wien, Spitalgasse 2, Hof 8. E-mail: sok.archive@gmail.com
***M.V. Lomonosov Moscow State University*
Russia, 119991, Moscow, GSP-1, Leninskie Gory
E-mail: tatiana@korol.ru, egolubeva@gmail.com

Received April 11, 2022. Revised April 20, 2022. Accepted May 1, 2022.

Montenegro belongs to the Mediterranean climate zone, but due to the presence of high mountain ranges on a fairly limited territory, there is a multitude of microclimatic varieties: in the coastal part there is a zone of pronounced Mediterranean climate; in the flatland part of the country the climate is a changed Mediterranean; in mountainous areas – a zone of severe mountain climate with cold long winters. In the diversity of the flora of this region, an important place is occupied by the Black Pine (*Pinus nigra*), which grows both in the mountainous parts and in the valleys and, according to some versions, gave the country its name. It is of interest to analyze the variability of the morphometric parameters of this plant species depending on the growing conditions.

This study is based on the establishment of a field practice in biogeography in the summer of 2021, held in Montenegro. The aim of the work was to determine the dependence of modification changes in Black Pine on the height of growth above sea level according to the following indicators: tree height, crown diameter, trunk diameter, and needle length. Measurements of adult representatives of *Pinus nigra* were taken at 8 recorded sites located at different heights above sea level, starting from the minimum coastal line of the sea (12.5 m) to the maximum growth height of *Pinus nigra* in Montenegro (1270.1 m) in the mountains. At each point, 10 mature trees were selected, visually reflecting the most common morphometric indicators for each selected high-altitude plateau with uniform growing conditions (flat surface, slope orientation, central part of the tree mass, forest stand density).

The results of measurements and statistical analysis established a significant negative correlation between height above sea level and morphometric growth rates of *Pinus nigra*.

Keywords: Montenegro, *Pinus nigra*, Black pine, vegetation of Montenegro, flora of Montenegro, habitats of Black pine, habitats of *Pinus nigra*, altitudinal zonality, modification variability of *Pinus nigra*.

DOI: 10.24412/2542-2006-2022-2-164-181

EDN: QWBKDZ

Montenegro’s flora is one of the most diverse, compared to most temperate-to-subtropical regions in the world; the mountains of the inland of the country are largely dominated by coniferous or mixed forest. Among them grows the *Pinus nigra*[1], the European black pine, which is the focus of this investigation; commonly it is found in forests most often including species such as the Norwegian spruce, *Picea abies*, the silver fir, *Abies alba*, the Aleppo pine, *Pinus halepensis*, the Bosnian pine, *Pinus leucodermis*, and the Heldreich pine, *Pinus heldreichii* (Discover Montenegro …, 2020). *Pinus nigra* is characterized by its height, reaching to a maximum of 50m in some areas and usually growing as a single trunk, with ascending branches that form a broad

[1] The Latin names of species are given according to Plantarium (2022).

conical crown, with thick and fissured dark-grey bark on matured trees, and the needles with length 8-16cm long (The Gymnosperm Database, 2020).

The focus of this investigation is the effect of altitude above sea level on four factors of the growth of the *Pinus nigra*: the tree height, the crown diameter, the trunk circumference, and the needle length. N.L. Kazakova and I.S. Antonova (2015) investigated the impact of ecological conditions, including altitude of the habitat on the growth of the Araucaria Araucana. The results of this and other alike investigations suggest the existence of a dependence of tree growth on the altitude above sea level; the similarity in methodology furthermore asserts the validity of my conclusions.

The study of Ya. Lazarevic et al. (2017) on Dothistroma Needle Blight on High Altitude Pine Forests in Montenegro mentions the European black pine in Montenegro, at heights 820 to 1450 meters above sea level, among *Querculus*, *Carinatum*, *Betulus* and *Picea* communities. The European black pine is a common fast-growing conifer found across Europe and Asia Minor in primarily mountainous regions. In Montenegro, located on the Adriatic coast of the Balkans, it is common to areas both in the mountains and adjacent to the sea, though mostly found in abundance in coniferous forests on mountain slopes (Pinus Nigra in Europe …, 2016).

Materials and Methods

Hypothesis. H1: There is an overall correlation between the elevation above sea level and growth of tree height, trunk circumference, crown diameter, and needle length of the *Pinus nigra*. H0: The elevation above sea level has no effect on the growth of the *Pinus nigra*.

Background Knowledge. The growth of the *Pinus nigra* as well as of surrounding vegetation in general may highly vary at different altitudes. The vegetation is comparably richer and more diverse in the mountains than the vegetation in the plains due to the greater variety of soil and climatic conditions in the mountains. *Pinus nigra* can grow on different substrates and bedrock, such as limestone, dolomite, and serpentine-peridotite (Vidakovic, 1991). The optimal altitudinal range for the European black pine is between 800 to 1500m above sea level (Fetic, 2015.)

The exposition and elevation of the slope determines the radiation level, the distribution of snow during the winter, and wind speed (Yergina et al., 2012). On the slopes of different expositions, regular changes in air and soil temperature, and the degree of soil warming are observed. The influence of these indices is reflected in the composition of vegetation, which, in its turn, affects the nature of vegetation, the flora composition, the development dynamics and general plant morphology (Volkov, Volkova, 2009).

Temperature is the determining factor in the set of plant species and diversity on slopes at different elevations. Fluctuations in the temperature gradient over heights on slopes of different exposure and under different conditions are quite large.

The kind of vegetation surrounding the *Pinus nigra* thus influences its root system and subsequently other growth factors such as the tree height, width, direction of trunk and branch growth and shape of the crown. Considering that different elevations on mountain slopes are claimed by different ecosystems, the morphometric parameters of the black pine may vary.

Variables. Independent variable: elevation above sea level (metres).

Dependent variables: 1) tree height (metres), 2) trunk circumference (metres), 3) tree crown diameter (metres), 4) pine needle length (centimetres).

All measurements are taken from trees growing on the *identical side of the mountain slope*: the south-west slope, which is facing the sea. On average, the temperature drop, with an increase in absolute altitude up to 100m, is mostly uniform and equal to 0.5°C for every 100m, but on northern slopes the temperature drop is generally slower than on the southern slopes. Thus, the conditions are kept uniform throughout the investigation, as only one side of the mountain slope is being used continuously for the collection of the data.

The *ecological succession* in each area in which the measurements of the black pines are taken is primary. Since ecological succession affects both species diversity as well as, potentially, age of the trees growing in a certain area, it is crucial to only take measurements of trees growing in alike ecological successions. This ensures that the surrounding species for the black pine are uniform and that there is a larger ratio of mature trees to young trees.

All points from which tree measurements are taken are *located on flat ground*, though on different points of elevation up the mountain slope. Difference in slope and consecutively soil composition may influence the direction of growth and the system of the trees' roots, which may affect other factors including tree height and distribution of the crown and branches.

All measurements were taken of *mature trees*, minimising the possibility for inaccuracy as a result of misjudging the young age of the trees for a trend in growth.

The *measuring tools* are kept the same throughout the investigation. The same measuring tape is consistently used, with measurements rounded off to the nearest tenth of a meter (in the case of pine needle measurements: to the nearest tenth of a centimeter). The mobile application for measuring tree height, "Object Height", is consistently used as well as used by the same individual, to avoid deviations which might be caused by a difference in height of the measurer. Analogically, the same process accounts for measuring the elevation above sea level. The mobile device with the app "Altimeter" was placed on flat ground at the base of the tree.

Apparatus. We used a 3-meter measuring tape roller, measuring to three decimal places for meters: 1) "Altimeter" mobile app, 2) "Object Height" mobile app; measures height through angle of elevation, trigonometric ratios, 3) "Ruler" mobile app; the "level" function measures the incline of the slope.

Methodology. Measuring growth parameters of a *Pinus nigra* tree are as follows.

1. Two people are needed for taking the measurements.
2. Find a black pine that grows on level ground. For that, use the "Ruler" mobile app and the "level" function.
3. Measure the altitude above sea level using the "Altimeter" mobile app by placing the device on the ground at the base of the tree.
4. Measure the height of the tree using the "Object Height" app. Enter your height into the app and hold the device at eye level when measuring for the most accurate results. Record in the data table with one decimal place.
5. Use the measuring tape roller to measure the circumference of the tree trunk at eye level. Record in the data table with one decimal place.
6. Using the measuring tape roller, find the radius of the tree crown by measuring the distance from the tree trunk to the edge of the tree crown. Multiply by 2 to get the tree crown diameter. Record in the data table with one decimal place.
7. Using the measuring tape roller, measure the length of 5 pine needles from under the pine tree. Record in the data table with one decimal place.
8. Repeat the process for a total of 10 trees at one altitude point.
9. Repeat for a total of 8 locations.

Data analysis process. Microsoft Excel was used for all data analysis.

Average values are calculated for every location, meaning for every 10 trees at the same altitude point. Averages of altitude, tree height, trunk circumference, crown diameter and needle length for each point are calculated using Microsoft Excel.

Correlation is calculated for altitude above sea level and each of the four factors: tree height, trunk circumference, crown diameter and needle length. This is done using the correlation formula in Microsoft Excel.

Trend line and R^2 are calculated using Microsoft Excel directly from the scatter plots for each growth factor of the *Pinus nigra*.

Standard deviation is calculated using the formula for general standard deviation in Microsoft Excel; it is then mapped onto the graphs of average values for each growth factor of the *Pinus nigra*. For the raw data see Table 1.

Table 1. Raw data from the general data base.

Point	No.	Above sea level (m)	Tree height (m)	Trunk circumference (m)	Crown diameter (m)	Crown radius (m)	Needle length (cm)					Average needle length (cm)
P. 1: Gradski park	1	12.5	12.5	2.1	11.6	5.8	9.8	14.5	11.2	10.2	9.1	11.0
	2	12.6	13.7	1.7	7.0	3.5	13.3	8.6	13.7	9.7	10.1	11.1
	3	12.8	18.6	2.2	5.6	2.8	9.4	12.3	7.4	7.8	14.2	10.2
	4	13.0	13.8	1.8	11.4	5.7	13.1	10.5	9.5	10.0	11.0	10.8
	5	16.0	14.3	2.1	8.2	4.1	14.4	11.0	12.3	12.1	9.7	11.9
	6	15.7	16.6	1.4	8.4	4.2	12.0	15.5	13.0	13.4	14.4	13.7
	7	12.9	18.9	1.8	7.8	3.9	9.2	9.5	9.7	12.6	12.1	10.6
	8	13.1	19.6	1.9	12.4	6.2	7.6	8.9	13.7	10.9	10.1	10.2
	9	13.8	17.0	2.0	7.4	3.7	8.6	7.9	12.8	14.6	13.5	11.5
	10	15.4	12.8	1.5	8.8	4.4	9.1	15.6	14.2	7.8	11.0	11.5
P. 2: Vrmac	11	474.4	9.5	2.3	6.4	3.2	19.0	16.6	16.9	15.9	14.1	16.5
	12	474.5	9.1	1.9	6.0	3.0	13.9	18.6	19.0	20.0	16.8	17.7
	13	476.2	13.1	1.5	6.2	3.1	23.1	20.4	18.2	19.2	19.8	20.1
	14	472.5	10.0	1.8	6.6	3.3	15.9	16.5	17.5	16.8	19.9	17.3
	15	475.3	15.2	1.4	4.8	2.4	18.5	19.2	21.9	17.2	16.3	18.6
	16	475.8	14.0	1.7	6.2	3.1	16.7	19.4	17.6	17.4	18.0	17.8
	17	466.9	12.6	1.8	5.8	2.9	16.8	20.9	19.5	18.1	19.2	18.9
	18	474.2	13.9	2.0	5.6	2.8	17.8	18.4	18.9	19.2	16.7	18.2
	19	475.1	14.2	1.5	4.6	2.3	16.1	14.9	18.0	16.0	17.4	16.5
	20	476.0	13.4	2.2	6.8	3.4	19.4	20.5	21.0	17.8	18.2	19.4
P. 3: Gorazda	21	382.2	9.7	2.2	8.2	4.1	15.5	16.0	19.1	17.2	16.9	16.9
	22	376.2	13.1	2.3	6.8	3.4	15.2	18.6	14.9	15.5	19.0	16.6
	23	375.9	7.2	1.5	8.0	4.0	16.2	16.7	15.0	16.7	17.3	16.4
	24	371.5	7.0	1.6	5.0	2.5	17.5	18.0	16.4	19.1	18.7	17.9
	25	371.6	8.6	1.6	7.4	3.7	14.8	17.1	15.1	18.9	17.6	16.7
	26	380.7	7.7	1.7	5.8	2.9	15.9	16.3	16.7	19.0	14.9	16.6
	27	382.0	9.1	1.9	6.8	3.4	15.0	15.8	18.6	19.3	19.0	17.5
	28	377.9	9.5	2.1	7.0	3.5	18.8	17.5	15.2	17.4	17.0	17.2
	29	377.2	12.0	2.0	4.4	2.2	16.7	16.0	19.0	14.8	15.2	16.3
	30	370.8	7.6	1.8	7.0	3.5	15.9	15.2	18.5	18.0	17.4	17.0
P. 4	31	955.0	11.9	1.6	5.2	2.6	14.0	14.1	13.5	15.2	14.5	14.3
	32	954.7	12.7	1.7	5.4	2.7	12.5	12.7	14.5	14.0	13.9	13.5
	33	958.0	18.3	1.2	3.8	1.9	14.2	13.0	14.7	14.9	13.5	14.1

Continuation of Table 1.

Point	No.	Above sea level (m)	Tree height (m)	Trunk circumference (m)	Crown diameter (m)	Crown radius (m)	Needle length (cm)					Average needle length (cm)
P. 4: Turn to Njegus	34	957.5	11.2	1.1	2.2	1.1	13.2	13.0	12.6	12.9	14.2	13.2
	35	960.1	14.3	1.0	2.0	1.0	12.6	11.9	13.0	12.5	12.7	12.5
	36	953.3	16.9	1.2	2.6	1.3	13.9	12.9	13.5	12.7	12.6	13.1
	37	956.1	18.0	1.3	2.6	1.3	12.1	15.0	13.4	13.0	14.3	13.6
	38	955.4	20.1	1.1	2.4	1.2	13.4	14.9	14.7	12.5	15.0	14.1
	39	955.4	17.6	1.2	1.8	0.9	13.6	14.0	13.2	12.9	13.0	13.3
	40	967.0	19.1	1.1	2.0	1.0	12.2	13.7	13.4	12.1	12.5	12.8
P. 5: Road to Lovcen	41	1120.8	16.8	0.7	2.4	1.2	11.2	12.0	11.9	13.3	14.0	12.5
	42	1126.0	14.7	1.1	2.0	1.0	14.0	12.8	11.4	11.2	11.9	12.3
	43	1118.3	18.0	0.8	3.6	1.8	12.5	13.6	12.3	12.5	13.4	12.9
	44	1119.0	17.2	0.9	1.8	0.9	11.5	11.5	11.6	13.0	11.1	11.7
	45	1123.2	17.6	0.9	2.4	1.2	11.0	11.0	13.7	12.4	12.6	12.1
	46	1123.3	15.9	1.0	3.2	1.6	13.7	11.9	13.3	13.5	13.0	13.1
	47	1123.7	16.4	0.9	2.4	1.2	13.5	12.9	11.3	12.1	13.6	12.7
	48	1129.1	15.7	0.6	1.6	0.8	13.1	12.4	10.9	13.7	10.5	12.1
	49	1126.5	18.5	1.2	2.0	1.0	13.4	11.2	13.4	12.2	11.0	12.2
	50	1120.5	17.8	0.8	2.2	1.1	11.3	13.1	12.6	12.8	11.9	12.3
P. 6: Plavi Horizonti	51	14.6	17.2	1.8	7.0	3.5	11.1	13.0	11.5	12.5	14.2	12.5
	52	11.9	16.4	1.4	5.6	2.8	10.8	11.3	12.0	13.5	11.5	11.8
	53	15.6	17.7	2.0	7.6	3.8	14.0	10.5	11.2	14.2	13.4	12.7
	54	10.2	14.5	1.4	6.6	3.3	11.2	11.7	10.8	13.6	13.9	12.2
	55	11.4	18.2	2.4	8.2	4.1	10.6	12.9	13.4	11.3	11.3	11.9
	56	11.8	17.0	1.8	5.4	2.7	12.4	14.7	14.2	10.5	12.6	12.9
	57	16.3	16.7	1.9	5.8	2.9	11.8	13.9	13.1	10.9	12.0	12.3
	58	16.7	16.2	1.5	6.8	3.4	10.2	14.3	11.0	12.2	14.5	12.4
	59	12.4	13.4	1.6	6.0	3.0	11.1	13.9	11.7	14.2	11.5	12.5
	60	12.9	18.0	2.1	9.0	4.5	13.5	11.1	10.8	12.5	13.0	12.2
P. 7: Lovcen	61	1554.1	3.4	1.0	4.6	2.3	8.9	7.5	9.3	8.7	9.8	8.8
	62	1557.6	4.0	0.9	5.8	2.9	7.0	8.4	11.6	10.9	9.3	9.4
	63	1555.6	3.8	0.8	4.4	2.2	6.9	7.2	5.6	20.3	9.0	9.8
	64	1553.2	3.7	0.8	5.4	2.7	5.8	6.7	9.9	10.8	8.7	8.4
	65	1553.7	4.1	1.1	5.0	2.5	6.4	10.2	5.7	6.9	7.4	7.3
	66	1556.0	3.5	0.7	6.0	3.0	9.2	6.2	7.5	8.3	10.4	8.3
	67	1555.7	3.7	0.8	5.0	2.5	6.8	5.8	10.5	9.8	7.0	8.0
	68	1554.8	3.2	1.0	5.6	2.8	9.4	10.5	6.6	5.5	8.9	8.2
	69	1555.2	3.9	0.9	4.6	2.3	7.7	9.3	10.9	8.7	6.8	8.7

Continuation of Table 1.

Point	No.	Above sea level (m)	Tree height (m)	Trunk circumference (m)	Crown diameter (m)	Crown radius (m)	Needle length (cm)					Average needle length (cm)
P. 7	70	1552.9	3.8	0.8	4.8	2.4	10.1	7.3	8.7	6.9	8.6	8.3
P. 8: Ivanovo Korito	71	1270.2	14.9	1.5	4.2	2.1	12.2	11.6	12.0	11.8	14.8	12.5
	72	1270.1	16.2	1.8	5.2	2.6	14.0	13.1	11.6	14.5	14.5	13.5
	73	1271.6	18.4	1.7	4.8	2.4	13.0	11.2	10.6	11.9	12.5	11.8
	74	1272.1	19.6	1.5	2.8	1.4	13.6	11.0	12.1	13.0	12.6	12.5
	75	1272.4	17.7	1.2	3.4	1.7	14.5	13.7	11.7	12.3	12.0	12.8
	76	1271.9	17.9	1.9	4.4	2.2	14.0	12.1	13.8	12.0	11.4	12.7
	77	1273.0	15.8	1.6	4.0	2.0	13.8	12.2	13.1	10.9	14.4	12.9
	78	1272.5	18.2	2.0	3.0	1.5	11.7	13.0	14.2	11.5	12.3	12.5
	79	1270.3	19.1	1.8	3.8	1.9	11.9	11.6	13.7	12.8	13.3	12.7
	80	1270.1	17.0	1.7	5.0	2.5	12.0	14.3	11.3	12.2	12.6	12.5

The relatively large sample size as well as clustering measurements into 8 distinct points on the mountain slope allowed to maximise, to the extent available in the conditions of the Internal Assessment, the validity of the collected data. Measuring 10 trees at each point of elevation allowed me then to find averages, which make analysis easier in terms of its visualisation and its graphic representation. A total of 80 samples is a substantial number which implies the reliability of the results derived from the data analysis.

The controlled variables were extensive in number and were adhered to and kept uniform throughout the whole investigation. All black pine trees used as samples for measurement were found growing in predominantly *Pinus nigra* composed forests, and all elevation points of measurement were, though located at different positions up the mountain slope, all on relatively flat ground. The effort to sustain the controlled variables is most certainly a strength of this investigation, as it minimised, to the extent possible, the chance of inaccuracy which may occur because of unaccounted for conditions.

Systematic error is potentially the largest weakness of this investigation: tree height, a crucial growth factor, was, due to my limited access to higher-level technology, possible to measure only through the use of a mobile application. The application, though fairly accurate (a control test conducted prior to data collection proved the application to accurately determine the height of a 1.6m object 8 out of 10 times) for shorter objects, showed on occasion a large calculation error when it came to the tallest trees. The reason for this inconsistency is the limited ability of the phone camera to capture the needed object, and of the application's ability to determine the degree to which the device was lifted.

Limited resources also present a weakness, as I had no devices for determining other factors such as the soil composition, the humidity, the wind speed, etc. Given those limitations, the collected data may possibly be affected by the unaccounted-for factors, such as the ones mentioned above. The resulting incompleteness of analysis due to these technical boundaries may have thus affected the conclusion drawn from it (Table 2). Other factors that should have been considered as controlled variables include distance from water source, soil type, and wind patterns.

Results and Discussion

The graph of Figure 1 is the scatter plot of all measured tree heights; the data is clustered into 8 areas of 10 trees per area, corresponding to the 8 chosen altitude points (out of which two were at similar altitudes, hence the lack of distinction between the two clusters). The calculated coefficients of determination (R^2) and correlation ($r = -0.28$) have low values, but their mathematical certainty is high enough ($r - \alpha = 0.05$), which proves there is a trend (the latter is determined by the significant coefficient of correlation r with its values on the module equal or higher than 0.2-0.3) or a valid negative relationship between the altitude above sea level and the height of a tree.

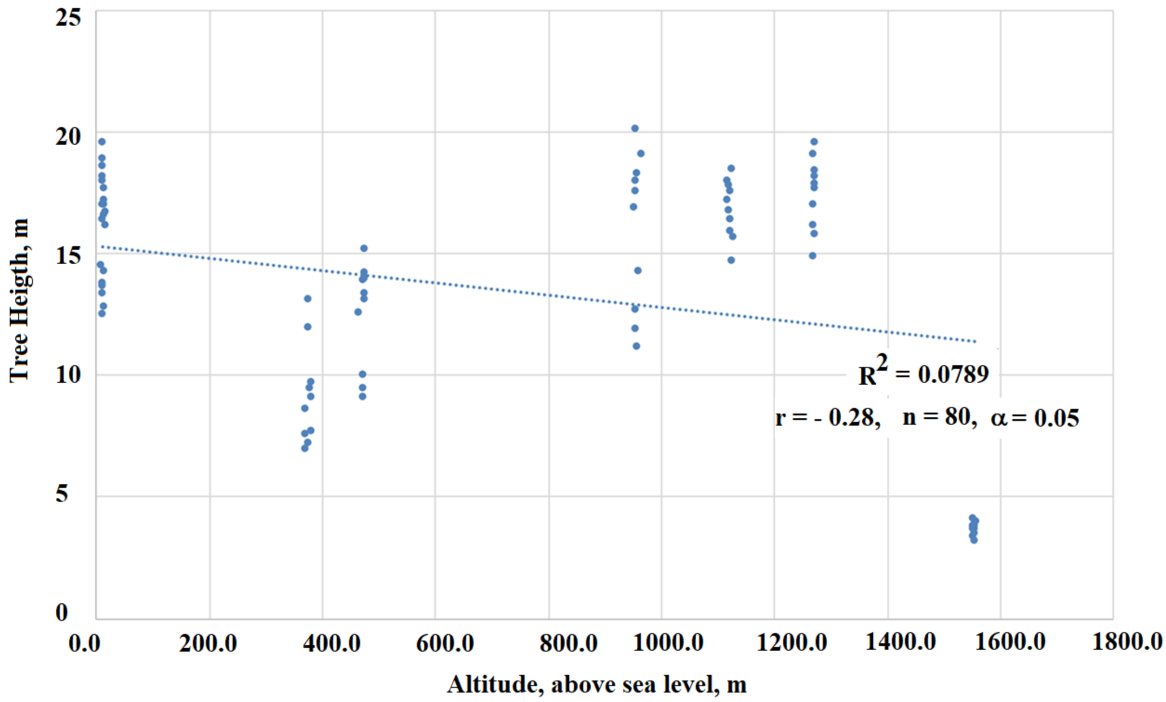

Fig. 1. Effect of altitude (meters above sea level) on tree height.

Figure 2 shows the relationship between two dependencies, according to the values from Table 2: a) distribution of the model points by their altitude (Figure 2, dotted line), and b) distribution of trees height on them (Figure 2, solid line). The figure shows a positive relationship from Gorazda to Ivanovo Korito, with outliers at both ends of the spectrum of measured altitude values. The standard deviation is lowest for Lovcen, meaning that the trees were mostly uniform in height; the standard deviation is highest for Crossroad Njegusi, showing a greater dispersion in terms of tree heights.

Figure 3 is a scatter plot of all measured tree trunk circumferences; the data is clustered into 7 areas of 10 trees per area, corresponding to the 8 chosen altitude points (out of which two were at similar altitudes, hence the lack of distinction between the two clusters). This figure shows a maximally valid noticeable[2] negative correlation relationship ($r = -0.68$, $\alpha = 0.001$) between the trunk circumference and altitude above sea level.

Figure 4 shows a distribution of the model points by their altitude (Fig. 4, dotted line) in comparison with the trucks circumference dependence on the altitude on the corresponding plots

[2] The valid coefficients of correlation were valued according to Chaddock-Snedecor scale: 0.1-0.3 – weak, 0.4-0.5 – moderate, 0.6-0.7 – noticeable, 0.8-0.9 – close, 0.91-0.99 – strong.

(Fig. 4, solid line). There is a spike at Ivanovo Korito, however excluding it the relationship is negative. The standard deviation is generally larger for the first 4 altitude points, suggesting a greater dispersion of values and tree sizes at lower altitudes than at higher altitudes.

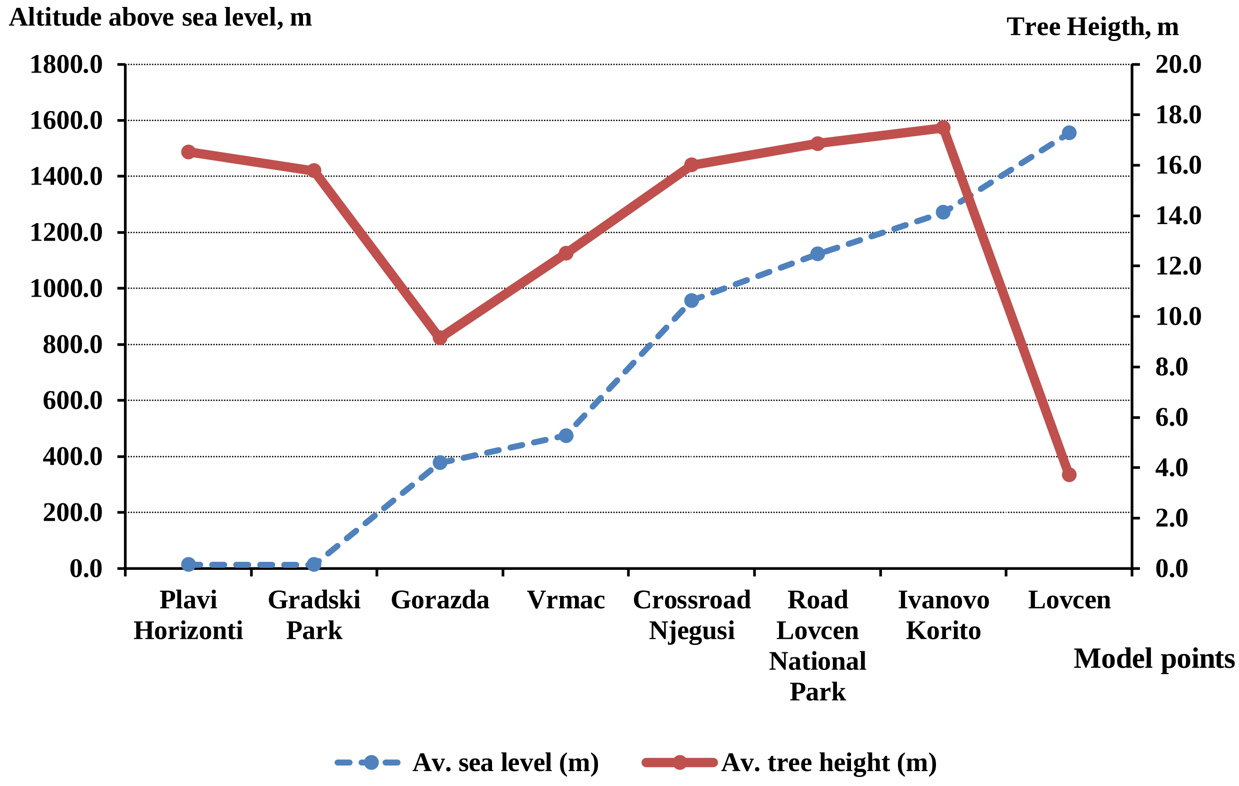

Fig. 2. Correlation between a) the distribution of model points according to their altitude (dotted line) and b) the distribution of the trees height on them (solid line).

Table 2. Average of measured parameters for each model point.

Points	Average altitude above sea level (m)	Average tree height (m)	Average trunk circumference (m)	Average crown diameter (m)	Average needle length (cm)
Plavi Horizonti	13.4	16.5	1.8	6.8	12.3
Gradski Park	13.8	15.8	1.9	8.9	11.3
Gorazda	376.6	9.2	1.9	6.6	16.9
Vrmac	474.1	12.5	1.8	5.9	18.1
Crossroad Njegusi	957.3	16.0	1.3	3.0	13.4
Road Lovcen National Park	1123.0	16.9	0.9	2.4	12.4
Ivanovo Korito	1271.4	17.5	1.7	4.1	12.6
Lovcen	1554.9	3.7	0.9	5.1	8.5

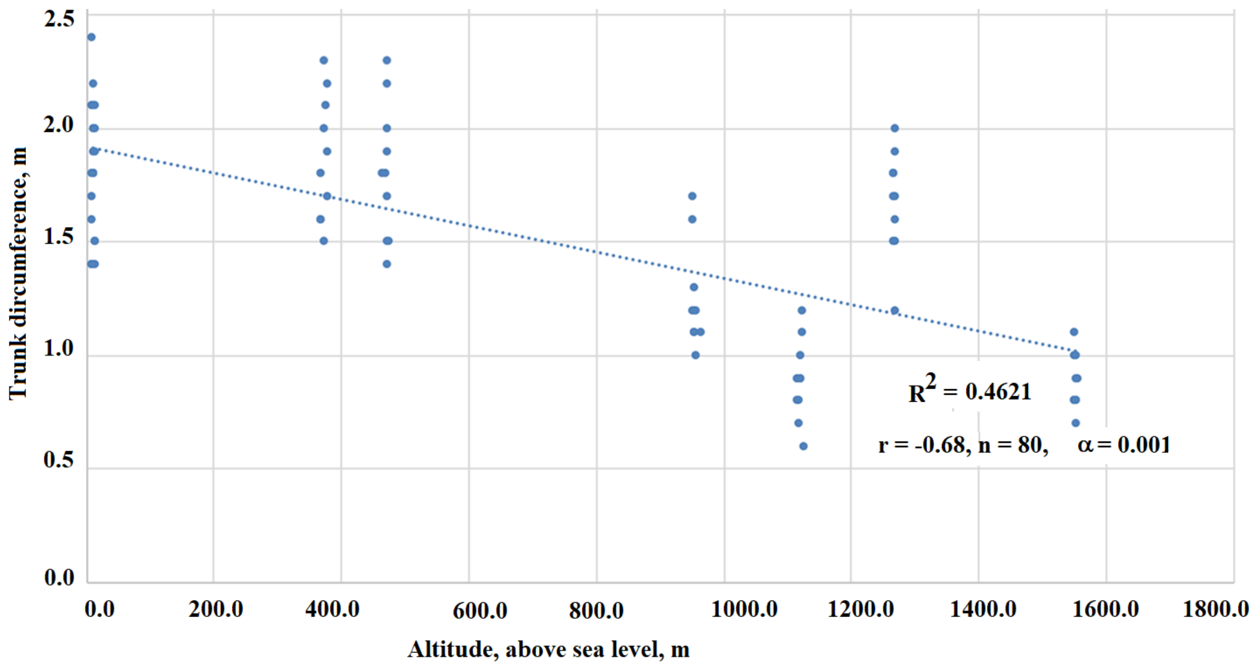

Fig. 3. Effect of altitude (meters above sea level) on trunk circumference.

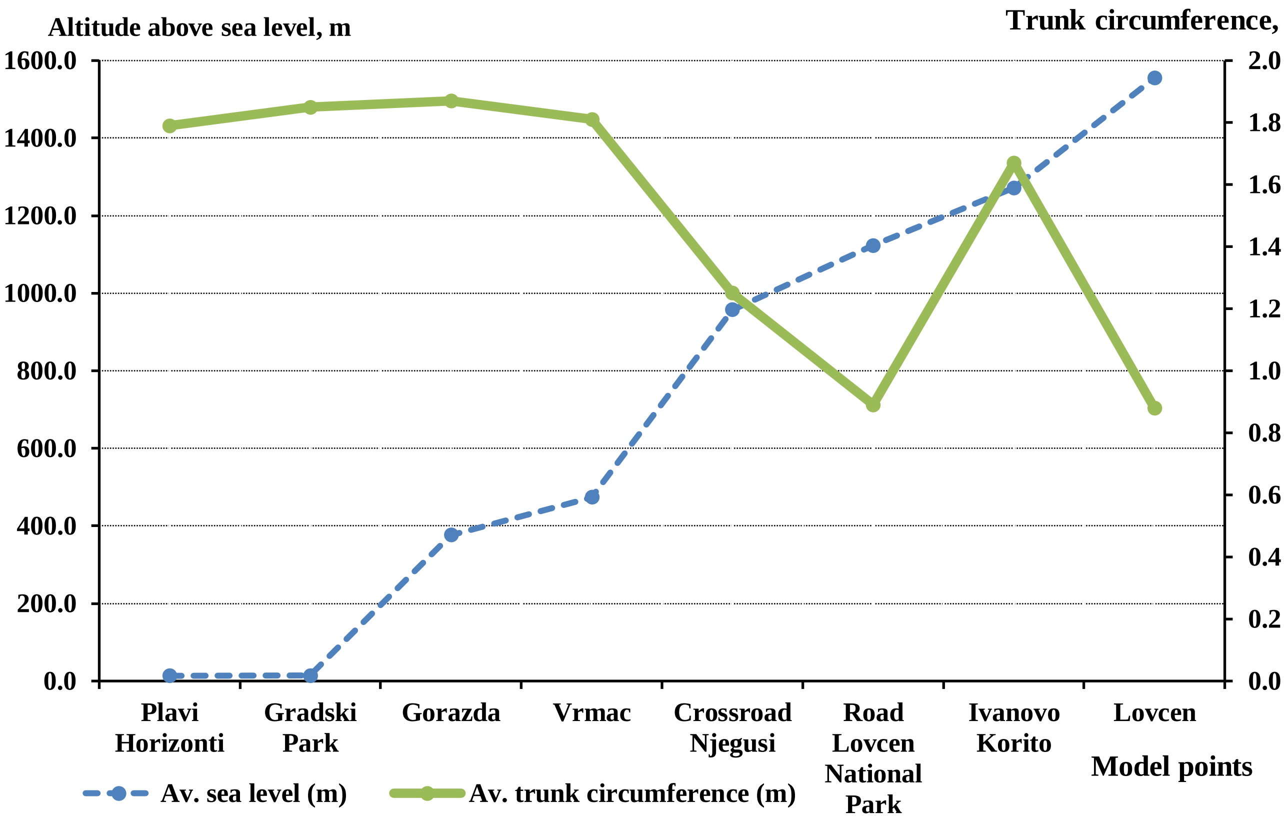

Fig. 4. Correlation between a) the distribution of model points according to their altitude (dotted line) and b) the distribution of the average trunk circumference on them depending on the altitude (solid line).

Figure 5 shows all measured crown diameters. The data is clustered into 7 areas of 10 trees per area, corresponding to the 8 chosen altitude points (out of which two were at similar altitudes, hence the lack of distinction between the two clusters). The moderately high coefficients of determination (R^2 = 0.4429) and correlation (r = -0.67) have the highest significance there (α = 0.001). Therefore, a noticeable (according to Chaddock-Snedecor scale) negative correlation dependence between the crown diameter and altitude above sea level was revealed there with a 99.9% validity.

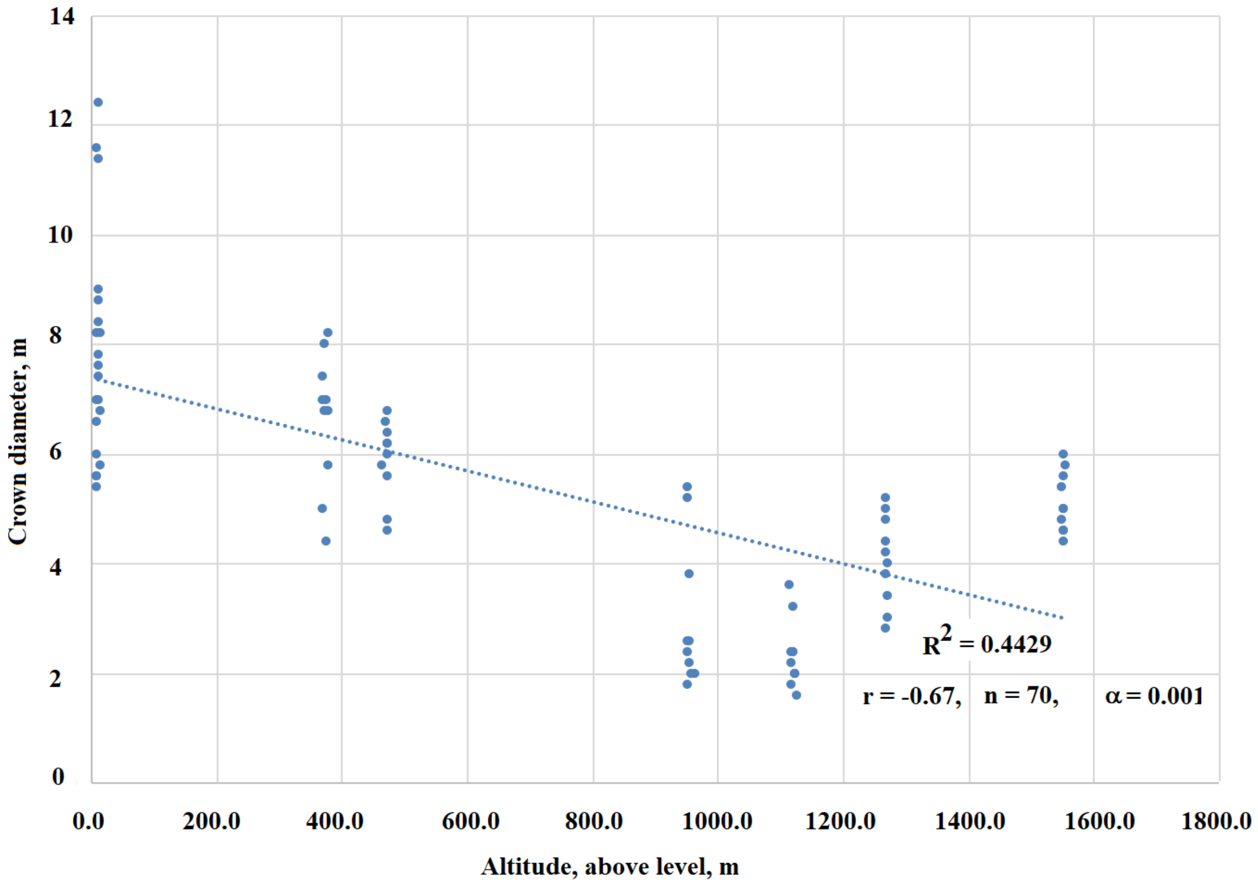

Fig. 5. Effect of altitude (meters above sea level) on crown diameter.

Figure 6 shows the distribution of points by the average crown diameter on them (solid line) in comparison with the distribution of the said points depending on the altitude (dotted line). This graph suggests, similarly to the graph of the dependence of tree height on elevation, a negative relationship from Gradski Park to Road to Lovcen National Park; the lowest and highest elevations are outliers to the general trend. The standard deviation is largest at Gradski Park, showing the greater diversity in crown diameter, and it is the smallest at Lovcen, analogously to standard deviation for tree height; this further supports the observation that the black pines at Lovcen are the most uniform in size.

Figure 7 shows all measured pine needle lengths. The data is clustered into 7 areas of 10 trees per area, corresponding to the 8 chosen altitude points (out of which two were at similar altitudes, hence the lack of distinction between the two clusters). Despite the low values of the coefficients of determination (R^2 = 0.0821) and correlation (r = -0.27), the sample size (n = 70) makes the correlation coefficient (α = 0.05) highly significant. Therefore, according to the determination of the trends presence, we have an established and absolutely valid negative relationship (although not a very high one, i.e. insignificant, according to Chaddock-Snedecor scale) between the needle length and the altitude above sea level.

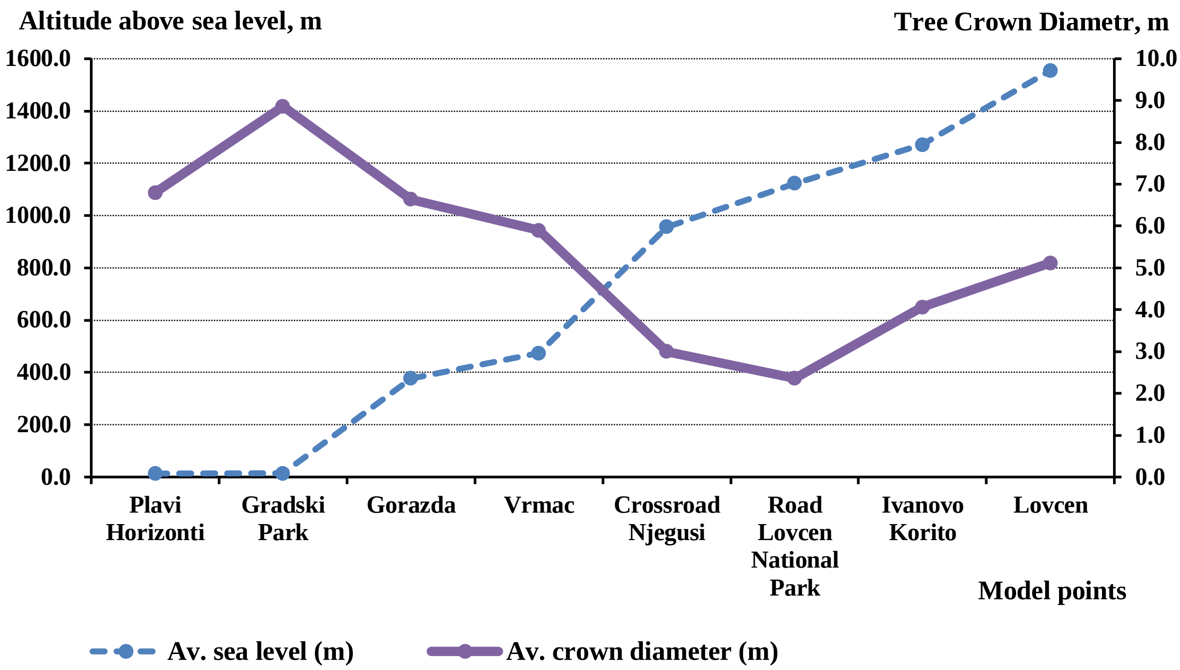

Fig. 6. Correlation between a) the distribution of model points according to their altitude (dotted line) and b) the distribution of the average crown diameter on them depending on the altitude (solid line).

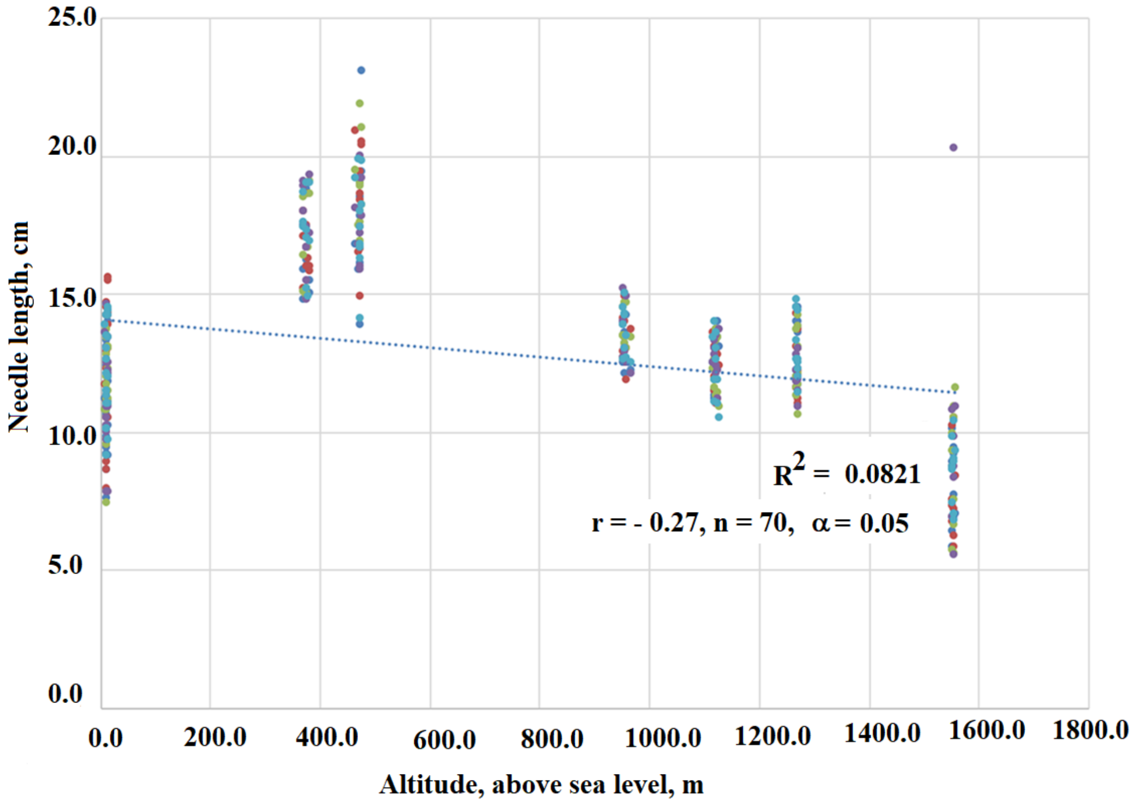

Fig. 7. Effect of altitude on needle length.

Figure 8 shows the relationship between distribution of the points by their altitude (dotted line) and dependence of average pine needle length on the altitude (solid line) on the corresponding points. There is an increase in needle length at Gorazda and Vrmac, however the general trend is still negative. The R^2 value is notably low for all altitude points, showing little dispersion or variety.

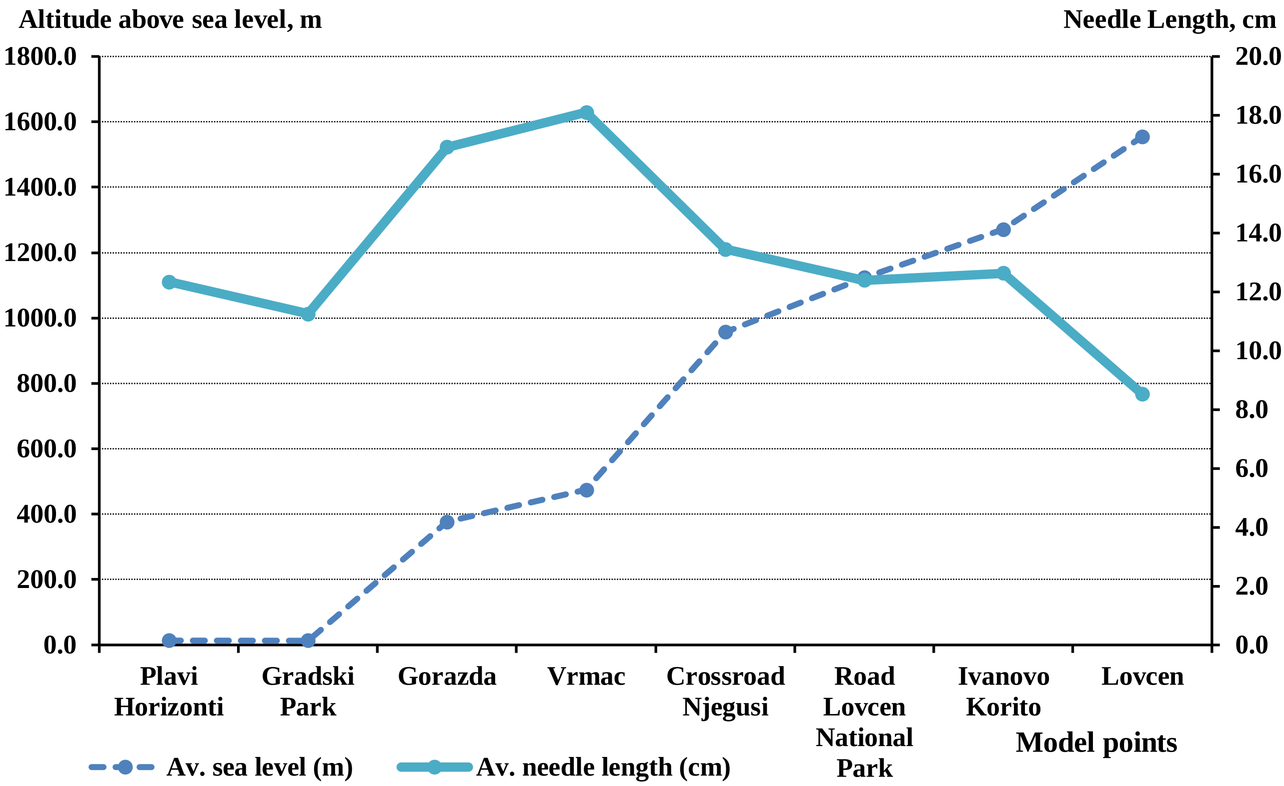

Fig. 8. Correlation between a) the distribution of model points according to their altitude (dotted line) and b) the distribution of the average pine needle length on them depending on the altitude (solid line).

Conclusions

Therefore, every calculated coefficient of correlation between the analysed parameters is of high mathematical significance from 95 to 99.9%. The coefficient of correlation allows us to infer whether the relationship between altitude and various growth factors of the *Pinus nigra* are substantial enough to be considered valid.

Calculations show that all growth factors had a negative valid correlation with the altitude above sea level. The coefficient of correlation ranged from ~ 0.27, which is an insignificant negative correlation, to ~ -0.68, which is noticeable, according to Chaddock-Snedecor scale. This means that, statistically, all growth factors have a distinct and proven negative correlation with the elevation above sea level.

From the results of the experiment, it can be concluded that elevation above sea level has a significant impact on the tree height, trunk circumference, crown diameter, and needle length of the *Pinus nigra*. Therefore, our null hypothesis is rejected, and the hypothesis H1 is taken for consideration. Though a correlation has been proven to exist between altitude and growth factors of the *Pinus nigra* (Table 3), hypothesis H1 is not correct, as the effect of the absolute altitude is not uniform for all measured factors.

Though the Statistical Analysis Table 3 shows a negative correlation of ~ -0.28 of tree height and altitude, further analysis of the processed data graph on the Figure 1 shows a strong positive correlation from point 3 (Photo 1) to point 7 (Photo 2), with the outliers being points 1 and 2 (Photo 3, 4) and point 8 (Photo 5), respectively. It can therefore be concluded that specific climatic factors influence most strongly the height of the *Pinus nigra* at the lowest and highest elevations. I hypothesize that it is the richer soil and the proximity to water caused the black pines at points Plavi Horizonti and Gradski Park to grow significantly in height. At the same time, I would expect the reason for the height of the black pines to drop to its minimum at the highest point 8 (Photo 5) to be the lower temperatures, the strong winds, and the snow in the winter.

Table 3. Correlations between altitude and measured growth factors.

Correlation parameters	**r**
Correlation of sea level and tree height	-0.28
Correlation of sea level and trunk circumference	-0.68
Correlation of sea level and crown diameter	-0.67
Correlation of sea level and needle length	-0.27

Photo 1. Gorazda, point 3.

The Statistical Analysis Table 3 reveals a negative correlation, against hypothesis H1, between altitude and trunk circumference of the *Pinus nigra*, with an outlier from the trend at point 7 (Photo 2). A presumed explanation for such is that the large trunk circumference coincides with the largest height of the black pines at Ivanovo Korito: as seen in the Photo 2, the trees grow on flatter larger space than trees at other mountainous points. The soil composition of the former is comparably different to the latter as well: there is richer and looser soil at Ivanovo Korito, while at other mountainous points (Photo 1, 5-8) the ground is made up largely of drier soil and rocks.

The correlation of altitude and crown diameter is ~ -0.67 (Table 3), however, similarly to the pattern of tree height, the processed data on the Figure 3 shows a discrepancy to the general trend at the lowest and highest two points. It can be speculated then that for Plavi Horizonti and Gradski Park it is the proximity to the sea and the lack of slope (flattest ground) that allowed for a broader crown; and for Ivanovo Korito and Lovcen it is the drop in temperature which causes a spreading of the crown.

Lastly, the processed data on the Figure 4 shows a generally negative correlation, though less steep, between altitude and needle length. A local rise seen between Gorazda and Vrmac coincides with a drop in tree height and can be potentially attributed to the specificity of the features of the slope of Vrmac mountain and the frequent winds from sea.

Photo 2. Ivanovo Korito, point 7.

Photo 3. Plavi Horizonti, point 1.

Despite the extensiveness of this study, there are a number of procedural modifications which could potentially increase the quality and viability of it. In order to increase the accuracy of the collected data, a different method of measuring height could have been used instead of the mobile application used for the purpose of this investigation. A more professional tool would not only have a lesser chance of miscalculation or technical malfunction but may also provide more precise measurements than the general tool that is the "Object Height" mobile application.

Photo 4. Gradski Park, point 2.

Photo 5. Lovcen Mountain, point 8.

Including more controlled variables would increase the quality and reliability of the data analysis. Factors such as soil composition, surrounding vegetation, and distance from water source are all factors which may influence the growth of the *Pinus nigra*. Therefore, to achieve the most accurate results possible, they would need to be taken into account.

Finding a way to tell the age of the pines would also increase the reliability of the investigation. One of the controlled variables was that all measured trees should be "mature trees", however with the limited resources it is difficult to tell, based only on the visual aspect, the age of the tree. Eliminating this issue would eliminate the degree of uncertainty that came with the analysis of the data as a result of lack of information about the individual tree.

On a broader scale, the research question might have been answered more sophisticatedly and accurately by including additional altitudinal points, not only could a more precise and truer trend line be drawn from the data; it may also reveal nuances to the patterns visible in this investigation, or to reveal the impact of more unique geographical features on the growth of the *Pinus nigra*. Overall, this adjustment would provide a fuller analysis of the Montenegrin landscape in general and the growth of the black pine within the whole country, or at least of the larger part of it.

Another major overhaul would be to choose only one growth factor, for instance the pine needle length, but have considerably more samples. These changes would make the research question and the following investigation narrower and clearer in focus, as well as increase the accuracy of the analysis results due to the larger number of samples.

Photo 6. Vrmac Mountain, point 4.

Photo 7. Crossroad Njegusi, point 5.

Photo 8. Road to the Lovcen National Park, point 6.

REFERENCES

1. Discover Montenegro: Flora. Discover Montenegro. 2020 [Available at www.discover-montenegro.com/flora (Date of Access 19/12/2021)].
2. *Enescu C.M., de Rigo D., Caudullo G., Durrant T.H.* 2016. *Pinus Nigra* in Europe: Distribution, Habitat, Usage and Threats // ResearchGate. P. 126-127.
3. EUFORGEN European Forest Genetic Resources Programme. *Pinus nigra*. 2003 [Available at www.euforgen.org/species/pinus-nigra/ (Date of Access 19/12/2021)].
4. *Fetic A.* 2015. Forests of Montenegro: Directorate for Forestry, Hunting and Wood Industry. Government of Montenegro: Ministry of Agriculture and Cultural Development. 25 p.
5. *Kazakova N.L., Antonova I.S.* 2015. Crown Shape of Araucaria Araucana K. Koch in Different Age States and Ecological Conditions of Natural Habitats // TvGU Herald. Series “Biology and Ecology”. Ser. 3. P. 135-153.
6. *Lazarevic J., Davydenko K., Millberg H.* 2017. Dothistroma Needle Blight on High Altitude Pine Forests in Montenegro // Lithuanian Research Centre for Agriculture and Forestry. P. 294-302.
7. Plantarium. 2022 [Available at https://www.plantarium.ru/page/view/item/44795.html (Date of Access 25/05/2022)].
8. The Gymnosperm Database. *Pinus nigra*. 2020 [Available at www.conifers.org/pi/Pinus_nigra.php (Date of Access 19/12/2021)].
9. *Vidakovic M.* 1991. Conifers: Morphology and Variation. Zagreb: Graficki zavod Hrvatske. 756 p.
10. *Volkov I.V., Volkova I.I.* 2009. The Analysis of Distribution of High-Mountainous Landscapes of Temperate and Subtropical Zones of Eurasia in the System of Mountain Zonality // Tomsk State Pedagogical University Bulletin. No. 11 (89). P. 161-167.

REFERENCES

1. Discover Montenegro: Flora. Discover Montenegro. 2020. Available at www.discover-montenegro.com/flora (Date of Access 19/12/2021).
2. Enescu CM, de Rigo D, Caudullo G, Durrant TH. Pinus Nigra in Europe: Distribution, Habitat, Usage and Threats. *ResearchGate.* 2016:126-127.
3. EUFORGEN European Forest Genetic Resources Programme. Pinus nigra. 2003. Available at www.euforgen.org/species/pinus-nigra/ (Date of Access 19/12/2021).
4. Fetic A. Forests of Montenegro: Directorate for Forestry, Hunting and Wood Industry. Government of Montenegro: Ministry of Agriculture and Cultural Development. 2015:25.
5. Kazakova NL, Antonova IS. Crown Shape of Araucaria Araucana K. Koch in Different Age States and Ecological Conditions of Natural Habitats. *TvGU Herald. Series “Biology and Ecology”.* 2015;3:135-153.
6. Lazarevic J, Davydenko K, Millberg H. Dothistroma Needle Blight on High Altitude Pine Forests in Montenegro. *Lithuanian Research Centre for Agriculture and Forestry.* 2017:294-302.
7. Plantarium. 2022. Available at https://www.plantarium.ru/page/view/item/44795.html (Date of Access 25/05/2022).
8. The Gymnosperm Database. Pinus nigra. 2020. Available at www.conifers.org/pi/Pinus_nigra.php (Date of Access 19/12/2021).
9. Vidakovic M. Conifers: Morphology and Variation. Zagreb: Graficki zavod Hrvatske, 1991:756.
10. Volkov IV, Volkova II. The Analysis of Distribution of High-Mountainous Landscapes of Temperate and Subtropical Zones of Eurasia in the System of Mountain Zonality. *Tomsk State Pedagogical University Bulletin.* 2009;11 (89):161-167.
11. Yergina E, Lysetskyi FN, Akulow VV, Repetska AI, Novikova YuA. Dendroclimatic Investigation of Conditions

11. *Yergina E.I., Lysetskyi F.N., Akulow V.V., Repetska A.I., Novikova Yu.A.* 2012. Dendroclimatic Investigation of Conditions of Growth of Crimean Pine or Pinus Pallasiana D. Don in the Foothern Crimea // Scientific Notes of V.I. Vernadsky Tavrichesky National University. Vol. 25. No. 2. P. 60-68.

of Growth of Crimean Pine or Pinus Pallasiana D. Don in the Foothern Crimea. *Scientific Notes of V.I. Vernadsky Tavrichesky National University.* 2012;25 (2):60-68.

УДК 574.24

ВЛИЯНИЕ ИЗМЕНЕНИЯ ВЫСОТЫ НАД УРОВНЕМ МОРЯ НА МОРФОМЕТРИЧЕСКУЮ ИЗМЕНЧИВОСТЬ СОСНЫ ЧЕРНОЙ В ЧЕРНОГОРИИ

© 2022 г. С.О. Король*, Т.О. Король, Е.И. Голубева****

**Венский университет*
Австрия, 1090, г. Вена, ул. Шпитальгассе, д. 2-8. E-mail: sok.archive@gmail.com
***Московский государственный университет им. М.В. Ломоносова*
Россия, 119991, г. Москва, Ленинские горы, д. 1
E-mail: tatiana@korol.ru, egolubeva@gmail.com

Поступила в редакцию 11.04.2022. После доработки 20.04.2022. Принята к публикации 01.05.2022.

Черногория относится к зоне средиземноморского климата, но благодаря наличию высоких горных массивов на достаточно ограниченной территории наблюдается большое разнообразие микроклиматических условий экотопа: в прибрежной части – зона ярко выраженного средиземноморского климата; в равнинной части страны климат континентальный; в горных районах – зона сурового горного климата с холодными длительными зимами. В разнообразии флоры этого региона важное место занимает сосна черная (*Pinus nigra Arnold*), произрастающая как горных частях, так и в долинных и, по некоторым версиям, давшая название стране. Нам представляется интересным анализ изменчивости морфометрических показателей данного вида растений в зависимости от условий его произрастания.

Данное исследование базируется на результатах полевой практики по биогеографии летом 2021 года, проведенной в Черногории. Целью работы являлось определение изменений морфометрических параметров сосны черной в зависимости от высоты произрастания над уровнем моря по следующим показателям: высота дерева, диаметр кроны, диаметр ствола, длина хвои. Были проведены замеры взрослых представителей *Pinus nigra* на 8 учетных площадках, расположенных на разных высотах над уровнем моря – от минимальной 12.5 м н.у.м. на береговой линии моря до максимальной – 1270.1 м н.у.м. в горах. В каждой точке было выбрано по 10 взрослых деревьев, визуально отражающих наиболее типичные морфометрические показатели для каждого выбранного высотного плато с однородными условиями произрастания (плоская поверхность, ориентация склона, центральная часть массива деревьев, плотность древостоя).

Результаты измерений и статистического анализа установили достоверную отрицательную корреляцию между высотой над уровнем моря и морфометрическими показателями роста *Pinus nigra*.

Ключевые слова: Черногория, *Pinus nigra*, сосна чёрная, растительность Черногории, места обитания сосны чёрной, высотная поясность, морфометрическая изменчивость сосны чёрной.

DOI: 10.24412/2542-2006-2022-2-164-181

EDN: QWBKDZ