

## The influence of slope exposure and altitude on the height of trees in the stands of the Carpathian beech forest *Dentario glandulosae-Fagetum* in the lower montane zone in the Bieszczady National Park

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**Abstract:** *The influence of slope exposure and altitude on the height of trees in the stands of the Carpathian beech forest *Dentario glandulosae-Fagetum* in the lower montane zone in the Bieszczady National Park.* The aim of the study was to investigate the influence of slope exposure and elevation above sea level on the average height of trees in the stands of the Carpathian beech forest *Dentario Glandulosae-Fagetum* in the lower montane zone of the Bieszczady National Park. The research material consisted of measurements made as part of a grid of permanent research plots of the Bieszczady National Park with a size of 4 ares, arranged in a grid of squares with a spacing of 500 x 500 m. Using a two-factor analysis of variance, the average height of beech trees in two height zones (600-800 and 800-1000 m above sea level) and at two slope exposures (north and south) were compared. The influence of the interaction between the two factors was also studied. The height of beech stands was mainly determined by the altitude and the interaction between the exposure of the slope and the altitude. It was not found that the exposure of the slope significantly differentiated the average heights of beech trees in the lower montane zone in the Bieszczady National Park.

*Key words:* European beech, aspect slope, altitude, Bieszczady National Park, solid beechwood

### INTRODUCTION

The most widespread plant complex in the Bieszczady National Park (BdPN) is the Carpathian beech *Dentario glandulosae-Fagetum* (Kucharzyk, Sugiero 2008). This complex forms beech and fir stands with admixtures of such species as spruce and sycamore (Matuszkiewicz 2007). Due to the diversity of habitat conditions, 5 subtypes of *Dentario glandulosae-Fagetum* occurring in the BdPN are distinguished: the most widespread typical subcomponent of Carpathian beech *Dentario glandulosae-Fagetum typicum*; the wet subcomponent with bear's garlic *Dentario glandulosae-Fagetum allietosum ursini*; the moist subcomponent with perennial menstruum *Dentario glandulosae-Fagetum lunarietosum*; the herbaceous subcomponent *Dentario glandulosae-Fagetum athyrietosum distentifoliae*; and the grassy-sedge subcomponent *Dentario glandulosae-Fagetum festucetosum drymejae* (Winnicki, Zemanek 2014).

In the Carpathians, *Dentario glandulosae-Fagetum* achieves optimal conditions in the lower montane zone. The Bieszczady beech forests are classified in the Eastern Carpathian variety (Dzwonko 1986). The area occupied by beech, the main species of this plant complex, is 17,894 hectares, which is about 76% of the forest area of the Park (Kucharzyk, Przybylska 2016). Beech growing in this plant community reaches its largest size, due to the optimal conditions for its growth. In lower mountain locations it can reach heights of up to 40 m (Dzwonko 1990, Jaworski, Zarzycki 1983).

In the Bieszczady National Park, beech occurs on average up to an altitude of 1150 m above sea level, reaching a maximum of about 1270 m above sea level on Mala and Wielka Rawka peaks (Jasiewicz 1965). The area of solid beech stands in the Bieszczady National Park increases with altitude, while in species-diverse beech forests the admixture of spruce and fir decreases and the proportion of sycamore increases (Kucharzyk, Przybylska 1997). As altitude increases, tree growth conditions also change. This results into a decrease in: average yield, maximum dimensions and breast height basal area, while the density of trees increases (Kucharzyk 1996, Przybylska, Kucharzyk 2003).

Tree height is an important element describing the forest space, stand structure and growth rate. Height growth proceeds differently in different tree species. It depends on weather conditions, habitat, growth space, nurturing of the stand. Tree height is also influenced by the way the stand is regenerated, too much shading by the parent stand causes slow early growth of the tree (Borowski 1974, Assmann 1968). The magnitude of this feature in mountain stands can be further conditioned by altitude and slope exposure. The influence of orographic factors especially in mountain stands has always been of interest to many researchers.

The issue of the influence of altitude on the height of beech in the Żywiec Beskid was dealt with, among others, by Socha and team (2014). The height of spruce trees in the altitudinal gradient was described by Orzeł and his team (1999) and the height of fir in the stands of the Low Beskid was studied by, among others, Bruchwald and his team (2015).

The aim of this study was to verify the hypothesis assuming the influence of altitude and slope exposure on the height of trees in stands of Carpathian beech forest of the lower montane zone. The rationale for the choice of this objective may be related to the fact that no information has been found in the literature on the average height of beech trees in the lower alpine forest in the Bieszczady Mountains and its relationship to the characteristics of mountain slopes.

## MATERIAL AND METHODS

The measurements were made in the Bieszczady National Park as part of a camp of the Forest Biometry Section of the Forestry Student's Scientific Association (Warsaw University of Life Sciences). Bieszczady National Park is located in southeastern Poland, in the Western Bieszczady Mountains, which are the westernmost part of the Eastern Carpathians. The BdPN is the largest park in the Polish mountains and the third largest national park in Poland. In 2021, 11% of the park's area was inscribed on the UNESCO World Heritage List. The list included primeval Carpathian beech forests (ICUN 2021). The objects of the study were strictly protected mature stands of Carpathian beech *Dentario Glandulosae-Fagetum*, which is the dominant plant community in the lower alpine forest of the Bieszczady Mountains (Michalik, Ryka 1996). The unusual arrangement of vegetation floors in the Bieszczady Mountains is not fully explained although it has been the subject of numerous studies (Kotula 1883, Zarzycki 1963, Dolecki 1971, Skiba 1995). For the purposes of this study, the lower regiel of the BdPN with Carpathian beech forest was divided into two altitudinal zones: 600-800 and 800-1000 meters above sea level.

Measurements were made within a grid of permanent study plots of the Bieszczady National Park, 4 acres in size, arranged in a grid of squares with a 500 x 500 m bond (Przybylska et al. 1996). Twenty-two plots were selected from a base of about 500 sample plots, which contained the *Dentario glandulosae-Fagetum* plant community, and the dominant species was common beech from age class IV upwards. The assumption was that the sample plots represented two elevation zones in the lower alpine: 600-800 and 800-1000 meters above sea level, and slopes with northern and southern exposures. Measurements on sample plots were made on the basis of the adopted methodology of the mathematical-statistical method of forest inventory (Rutkowski 1989, Przybylska 1993). In accordance with this method, a number of

tree characteristics and sample plots were measured, with tree height being used for the purposes of this study. The study included the height of beech trees in the first storey of the stand.

Using two-factor analysis of variance, the average height of beech trees in two elevation zones (600-800 and 800-1000 meters above sea level) and at two slope exposures (north and south) were compared. The effect of interaction between the two factors was also examined. The data met the assumptions of two-factor analysis of variance (normality of the distribution in each group, homogeneity of the variances of the compared groups). Statistical hypotheses were verified at a significance level of 0.05.

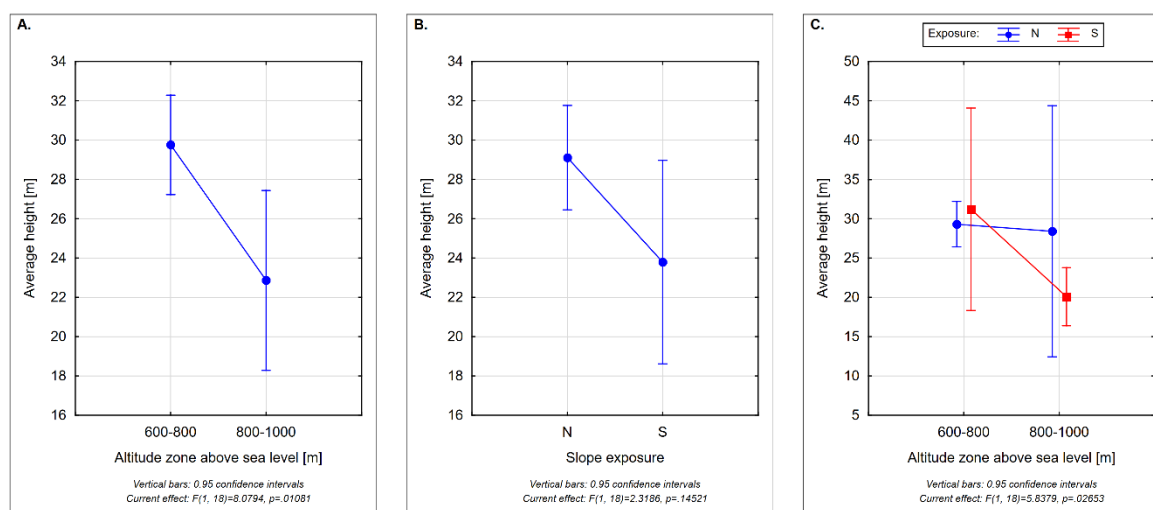
## RESULTS AND DISCUSSION

The first hypothesis tested was that of the effect of altitude on mean tree heights in the Carpathian beech forest. The analysis of variance conducted showed significant differences in the mean heights of beech trees in the 600-800 and 800-1000 meters above sea level zones, as evidenced by the test probability value of  $p = 0.0108$  (Fig. 1A). This allows us to claim that altitude differentiates the average height of trees in the Carpathian beech forest in the lower alpine of the Bieszczady National Park. Average tree heights turned out to be higher in the sample plots located in the 600-800 m altitude zone, where the average value was 29.76 m (Table 1). In the higher-lying stands (800-1000 m zone), the average heights of beech trees in the sample plots were significantly lower and their average value was 22.86 m. Plots located higher in the 800-1000 m zone were characterized by greater variability, as evidenced by the coefficient of variation with a value of 26.01% and a standard deviation of 5.95 m. The average tree heights in the plots located higher up had a greater right-hand asymmetry (skewness 0.80). Another factor studied was slope exposure. A two-factor analysis of variance showed that there were no significant differences in the average height of beech trees at both slope exposures ( $p = 0.145$ , Fig. 1B). This allows us to conclude that slope exposure does not significantly differentiate the mean height of trees in the Carpathian beech forest in the lower montane in the BdPN. Plots located on the southern exposure of the slope were characterized by greater variability, for which the coefficient of variation took the value of 28.29% (Table 1); the analogous measure of variability for plots located on the northern exposure of the slope took the value of 15.12%. The distributions of average tree heights on the two slope exposures differ in asymmetry, with the northern slope having a negative asymmetry (skewness -0.26) and the southern slope having a positive asymmetry (0.71).

The study also examined interactions between slope exposure and altitude. A two-factor analysis of variance showed a significant interaction effect of the two factors on tree height in the Carpathian beech forest ( $p = 0.026$ , Fig. 1C). The interactions indicate different relationships of the mean heights of beech trees located in the 600-800 and 800-100 zones depending on the slope exposure. On the southern slope, there is a large difference in the heights of beech trees between these zones: in the 600-800 m zone, the average height was 31.21 m, and in the 800-1000 m zone 20.08 m (Table 1). In contrast, on the northern slope, the heights of beech trees are similar; in the 600-800 m zone, the average height was 29.32 m, and in the 800-1000 m zone 28.42 m.

**Table 1.** Characteristics of average tree heights in circular plots in groups varying in slope exposure and altitude.

Group	Mean [m]	Minimum [m]	Maximum [m]	Standard deviation [m]	Coefficient of variation [%]	Skewness
Grouping factor: altitude zone						
600-800 m n.p.m.	29.76	21.72	37.55	4.18	14.05	0.05
800-1000 m n.p.m.	22.86	16.23	33.18	5.95	26.01	0.80
Grouping factor: slope exposure						
N	29.11	21.10	37.55	4.40	15.12	-0.26
S	23.79	16.23	35.00	6.73	28.29	0.71
Grouping factor: slope exposure for the altitude zone of 600-800 m above sea level						
N	29.32	21.72	37.55	4.05	13.82	0.27
S	31.21	25.31	35.00	5.18	16.59	-1.53
Grouping factor: slope exposure for the altitude zone of 800-1000 m above sea level						
N	28.42	21.10	33.18	6.43	22.64	-1.51
S	20.08	16.23	25.27	3.50	17.43	0.41



**Figure 1.** Results of two-factor analysis of variance for individual factors: A - altitude zone above sea level, B - slope exposure, C - interaction altitude zone above sea level vs. slope exposure.

## DISCUSSION

In the literature, one can find many studies focusing on the productivity of different tree species in an elevation gradient in mountain stands. However, the lack of research on the effect of altitude and slope exposure on the height of trees in stands of Carpathian beech *Dentario Glandulosae - Fagetum* in the lower alpine forest in the Bieszczady National Park became the rationale for the present study.

The average height of beech trees in the area of the Bieszczady National Park is mostly determined by the location of the stand above sea level. The average value of the height of trees in plots located at heights of 600-800 m above sea level was 29.76 m with a standard deviation of 4.18 m, while the corresponding values of these measures for beech trees from the 800-1000 m altitude zone are 22.86 m  $\pm$  5.95 m. The differences in the average heights of beech trees are statistically significant (at  $\alpha = 0.05$ ).

These results are consistent with Socha and team's (2014) research on the influence of elevation on the potential productivity of beech stands in the Żywiec Beskid. This study shows that altitude determines to the greatest extent ( $R^2 = 52.5\%$ ) the values of the site index, determined by a model describing the average height of stands of this species at a baseline age of 100 years. The values of the bonitation index of stands decrease with increasing elevation, more dynamically after exceeding 800 m above sea level. As the authors state, the reason for the decrease in the values of the site index with increasing elevation may be changing habitat conditions. As altitude increases, moisture and thermal conditions change, affecting the soil-forming processes, and the length of the growing season decreases. The length of the snow cover period and the length of the frost period also increase. The decrease in temperature observed in higher mountain locations and the significant increase in precipitation can adversely affect the growth of beech, a species that prefers warm and fresh habitats (Felbelmaier 1994 after Jaworski 2000). The effect of changes in growth conditions on the tree stand characteristics was also shown by many other researchers, including Regier (1968) and Neumann (1993).

Kucharzyk and Sugiero (2007), who studied the dynamics of beech stands in the Bieszczady National Park, showed a high homogeneity of stands in terms of age and breast height structure, as well as significant variation in terms of other tree stand characteristics along an altitude gradient. With elevation, the average yield and height of trees decrease, while density and breast height basal area increase. Similar conclusions were reached by Orzeł and his team (1999), who studied the effect of altitude on the productivity of spruce stands in the Western Beskids. In this work, it was shown that the location of a stand above sea level has a much greater inhibitory effect on height increment compared to tree diameter increment. The difference in the average height of stands located at 600 m above sea level and 1200 m above sea level was 48%. The negative effect of the location of the stand above sea level is clearly marked from an altitude of 800 meters above sea level.

Jaworski (2004) indicates that the most important factors affecting beech height growth are temperature and humidity. This is also confirmed by the work of several researchers: Biondi (1993), Peters, Poulson (1994) and Piovesan et al. (2005) who dealt with the height growth of beech stands located in mountainous regions. The results of their studies also indicate that thermal conditions play a major role, i.e. a longer frost period and a significant decrease in temperature with increasing altitude, resulting in weaker beech height growth. It is worth noting that studies conducted in European forests (Pretzsch 1996, Unthelm 1996, Socha et al. 2014), show that beech responds positively to climate change, which is associated with its preference for warm and fresh habitats.

An important aspect by which the study of beech trees in the Bieszczady National Park could be updated is the effect of altitude on the intensity of tree volume increment. This issue has been addressed by, among others, Orzeł and Maruszewski (2007) and Kucharzyk and Sugiero (2007).

The present study also examined the effect of slope exposure on average tree heights of Carpathian beech trees. The study showed that there was no statistically significant effect of this factor on average tree heights.

Przybylska and Kucharzyk (2016), characterizing the species compositions of Bieszczady beeches on the basis of the 2010 forest inventory, also found that beech showed no attachment to slope exposure. Similar regularities were observed by Socha and his team (2014), who report that slope exposure does not significantly differentiate the productivity of beech stands. This was explained by the structure of the root system of beech, which, unlike, for example, spruce, is not so exposed to drying of the topsoil, as can be observed in stands located on southern slopes.

Different results were obtained by Diaconu et al. (2015), who investigated the effects of slope exposure and silvicultural treatments on beech growth in Baden-Württemberg in southwestern Germany. The study showed a significant effect of slope exposure on the growth rate of beech trees, which turned out to be lower on slopes with southwestern exposures, where warmer and drier climatic conditions prevail. In a study of the effect of slope exposure on tree shape conducted in beech stands in the Carpathian Mountains in central Romania (Dutcă et al. 2022), it was observed that trees growing on northern slopes were characterized by significantly greater height at the same breast height.

With reference to the above literature data, it is necessary to refer once again to the results obtained in this study. Although the differences in the average heights of trees in plots located on southern and northern slopes did not prove to be statistically significant, it should be noted that there were differences. The average height of trees on the southern slopes was 23.79 m and on the northern slopes 29.11 m. The lack of significance of the differences may be to some extent due to the relatively small sample size. Further clarification of this issue comes from the results of the interactions tested between height above sea level and slope exposure. These interactions turned out to be statistically significant at the significance level of 0.05. It turns out that the average heights of beech trees on northern slopes remain at a similar level (about 29 meters), while a large difference is marked on southern slopes. In the elevation zone of 600-800 meters above sea level, the average heights of beech trees on southern exposures are more than 31 meters, and in the zone of 800-1000 meters above sea level - about 20 meters. Assuming that we are dealing with homogeneous beech stands of the same age class (81-100 years old), the explanation for these differences may be greater differences in the growth conditions prevailing on southern slopes at different elevations above sea level.

Habitat fertility and climatic factors are considered to be the main tree growth conditions determining the productivity of stands (Socha et al. 1999). In mountainous conditions, variability in growth conditions can result from the different geological structure of individual mountain ranges, within which both the altitude of the stand above sea level and its exposure have a modifying effect. All this means that the measures characterizing the growth of trees, even of the same species, may differ from one range or mountain chain to another, even though other growth conditions remain *ceteris paribus*.

The study did not examine the effect of slope on average tree height, although many studies on this topic can be found in the literature. Examples include the work of Qingshang et al. (1998), who studied the effect of slope on the height of Manchurian ash (*Fraxinus mandhurica*), Manchurian walnut (*Juglans mandshrica*) and Amur cork tree (*Phellodendron amurense*) in northeastern China, or Saremi et al. (2014), who dealt with the effect of slope on the growth of pine plantations in different regions of Australia. It is worth including this theme in the study of beech in the Polish Carpathians.

The studies conducted in this paper showed a significant effect of altitude and the interaction between altitude and slope exposure on the average heights of Carpathian beech trees in the lower montane. They contribute to the study of the ecology of the Carpathian beech and the productivity of stands of this species in the Eastern Carpathians.

## CONCLUSIONS

- The average height of trees in stands of Carpathian beech *Dentario Glandulosae-Fagetum* turned out to be significantly higher in the zone of altitude 600-800 m. The higher altitude the average height of trees is lower. This is due to the change in growth conditions with the increase in elevation.
- Within the lower regiel, the exposure of the slope does not significantly differentiate the height of beech trees. The average height of stands located on northern slopes was

characterized by negative asymmetry, while on southern slopes by positive asymmetry.

- Interactions between height above sea level and slope exposure significantly differentiate the average height of trees. There are different relationships of the average heights of beech trees located in zones 600-800 and 800-1000 meters above sea level depending on the exposure of the slope. On northern slope exposures, average tree heights do not differ significantly in the elevation zone, while on southern slopes there are significant differences in tree heights depending on altitude.

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**Streszczenie:** *Wpływ ekspozycji stoku i wysokości nad poziomem morza na wysokość drzew w drzewostanach buczyny karpackiej Dentario Glandulosae - Fagetum w reglu dolnym na terenie Bieszczadzkiego Parku Narodowego.* Celem pracy było zbadanie wpływu ekspozycji stoku oraz wysokości nad poziomem morza na średnie wysokości drzew w drzewostanach buczyny karpackiej Dentario Glandulosae - Fagetum w reglu dolnym na terenie Bieszczadzkiego Parku Narodowego. Materiał badawczy stanowiły pomiary wykonane w ramach siatki stałych powierzchni badawczych Bieszczadzkiego Parku Narodowego o wielkości 4 arów, rozmieszczonych w siatce kwadratów o więźbie 500 x 500 m. Za pomocą dwuczynnikowej analizy wariancji porównano średnią wysokość buków w dwóch strefach wysokości (600-800 i 800-1000 m n.p.m.) oraz przy dwóch ekspozycjach stoku (północnym i południowym). Zbadano również wpływ interakcji między tymi dwoma czynnikami. Wysokość drzewostanów bukowych była determinowana głównie przez wysokość n.p.m. oraz interakcje między ekspozycją stoku a wysokością nad poziomem morza. Nie stwierdzono by ekspozycja stoku istotnie różnicowała średnie wysokości buków w reglu dolnym w Bieszczadzkim Parku Narodowym.

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