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An attempt to assess the correlation between lengthwise growth of the main shoot in 24-year old scots pines (*Pinus sylvestris* L) and the growth of lateral branches

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SUAMMARY

The most common species of tree in Polish forests is the Scots pine (*Pinus sylvestris* **L)**. In this paper we are interested in the finding of correlations between the lengths of the main shoot and lateral branches of the fifth whorl and correlation of these lengths with the bio-social position of the tree in the stand. These calculations can help to assess increments of the main shoot of living trees on the base lateral branches. The research was conducted on 25 sample trees coming from a 24-year-old Scots pine stand. Measurements included 5-year increments in length of the main shoot and all live, properly developed lateral branches of the fifth whorl. Lateral branches were measured with regard to the direction of their position on the tree in relation to the cardinal points of the compass. It is clear that the sample size is very small, but this is the first attempt to assess such dependence. Analysis of Pearson's linear correlation coefficients, multivariate regression analysis and polynomial regression analysis were applied in order to determine these dependences. Moreover, in order to remove from the model independent variables having a slight influence on variation of increment in height (the dependent variable), the backward multiple regression elimination method was used. After carrying out the calculations we were able to conclude that the increments in length of the main shoot were dependent on increments in length lateral branches growing on the tree in the westward direction.

Key words: backward elimination, correlation, lateral branches, linear regression, main shoot, multiple regression, Scots pine (*Pinus sylvestris* L).

1. Introduction

Each year annual shoots develop from buds formed in the previous vegetation season. Depending on the species they develop from the terminal bud (in coniferous and some deciduous species) or most frequently from the highest lateral bud (in most deciduous species). The length of the annual shoot, grown in the vegetation season and lignified, does not change, which makes it possible to determine its length at any given time. The length of the annual shoot is a variable trait. It depends not only on the weather conditions during growth (in the vegetation year), but also to a considerable degree on the weather in the previous year. This pertains especially to the months of July–September, since at that time of the previous year buds are formed and reserve substances are accumulated, which to a considerable degree will be used in the next year for shoot length increment (Assmann 1968). The crown, its size, shape and structure affect the course of tree growth.

Scots pine (*Pinus sylvestris* **L)** is a tree species with the monopodial type of growth. The main shoot develops from the terminal bud and constitutes an extension of the tree axis (Tomanek 1997, Bruchwald et al. 2005). Lateral branches, forming the branching of the tree, grow in whorls. Their number is usually 5 and decreases with age. Growth in length results to a greater or lesser degree in the elongation of individual shoots, which leads to crown formation. In practice measurements are usually limited to the determination of growth and increment in height of the tree by determination of the lengthwise growth of its principal axis.

The crown plays a major role in tree productivity. The size of the tree crown influences the growth and increment of the tree. The crown consists of branches and foliage. The location and distribution of branches and foliage determine the shape of the crown. Many researchers have examined the architecture of tree crowns (Mäkelä at al. 2001, Mäkinen 1999, Mäkinen at al. 1998, Mäkinen at al. 2003, Rautiainen at al. 2005), while others have concentrated on crown biomass (Hoffmann at al. 2002, Lehtonen 2005 and Lehtonen et al 2004). The Scots pine crown biomass is a criterion for wood quality (Pazdrowski 1994). Moreover crown size is one of the elements of the bio-social position of a tree in the stand. Social variation of trees results from competition for light and living space. Kraft has distinguished social classes of trees, which combined the social position of the tree in the stand with the degree of crown formation. This makes it possible to group trees into classes with uniform growth energy (Kraft 1988, after Assmann 1968).

Traits of the crown are also indicators of stand damage. Such parameters as the length and shape of shoots, the type of top and branching are used to determine the state of health of pines (Niehaus 1989, Dmyterko 1994, Wójcik at al. 2001). This criterion, next to defoliation, is one of the elements applied in the method used to determine forest damage zones (Instrukcja 2003).

The aim of this study was to attempt to assess the correlation between the length of the main shoot and lateral branches of the fifth whorl, as well as assessment of the correlation of these traits with the bio-social position of the tree in the stand. Moreover the dependence between lengthwise growth of the main shoot and lateral branches was estimated. Analyses were conducted on 25 mean sample trees coming from a 24-year-old pine stand. The research may contribute to determining the length increment of living trees on the basis of lateral branch length. These main shoot increments can be measured only for cut down trees.

2. Experimental material

The experimental material consisted of the results of measurements of 25 mean sample trees growing in a 24-year old pine stand. Mean sample trees were selected following the methodology developed by Draudt. Their social class was determined prior to felling. Measurements included 5-year increments in length of the main shoot (*pg*) and all live, properly developed lateral branches of the fifth whorl (counted from the top). The increment of the main shoot is the increment in height of a tree (Zh_5). Lateral branches were measured with regard to the direction of their position on the tree in relation to the cardinal points of the compass. There were between one and six properly developed lateral branches growing in the fifth whorl. It should be explained why the fifth whorl was considered: this is because in a forest the trees grow upwards and the lower lateral branches wither. In this paper the 5-year height increments were investigated and the fifth whorl consists exactly of the five annual increments.

The cardinal points of the compass from which lateral branches were growing in the largest numbers were east (branches denoted *gbE*) and west (*gbW*). A total of 18 trees have such lateral branches. North (*gbN*) lateral branches were present on 15 trees, and south (*gbS*) lateral branches on 11. The intermediate directions were represented by a lower number of shoots, ranging from 7 to the south-east, through 5 to the south-west, 4 to the north-east, to 3 to the north-west. Due to the low frequency of lateral branches in the intermediate directions, the analyses included only the length of shoots growing in the four primary directions and the means calculated for all lateral branches of the fifth whorl growing in a given tree. In relation to Kraft's classes, logistic transformation into a continuous trait was applied (Snell 1964). It should be pointed out that this sample is very small and all results obtained should be verified for larger samples of trees.

3. Methods

Prior to the calculations, the discrete trait – Kraft's class – was transformed into a continuous trait using Snell's method. This is a logistic method in which there are k categories and m treatments. The points x_j are defined in such a way that the range (x_{j-1}, x_j) corresponds to the s_j categories (j=0,1…,k), moreover the continuous distribution function of random variable with logistic distribution is

$$P_i(x_j) = \frac{1}{1+e^{-(a_i+x_j)}} \qquad \text{where } i = 1,2\ldots, m;\ j = 0,1\ldots, k$$

with mean - a_i and variance $\pi^2/3$. The values corresponding to the points x_j are calculated using the maximum likelihood method. The iteration procedure for calculating the points x_j is obtained. For the data used in this paper the weighted mean from the number of trees in individual classes (with Kraft's classes being weights) was assumed as the starting point for the iteration procedure; at the same time this mean was the middle transformed class.

Next the Pearson's linear correlation coefficients were calculated for the analyzed dependencies between the increment in the height of the tree and lateral branches, and also between bio-social class of tree position in the stand and shoot increment. In turn, multivariate regression analysis and polynomial regression analysis were applied in order to determine the dependence of 5-year increments of the main shoots on increments in lateral branches (taking into consideration the cardinal points of the compass) and Kraft's bio-social classes. In order to remove from the model independent variables having a slight effect on variation of increment in height (the dependent variable), variables were eliminated using the backward elimination method (Seber at al. 2003, Draper at al. 1973). Necessary calculations were performed using an Excel spreadsheet and the SAS software package at a significance level of 0.05.

4. Results and Discussions

To begin with the liner correlations between the analyzed traits were calculated; these dependences are given in Table 1. Most of the symbols used in this table are written in the paragraph titled Experimental Material, moreover the mean of all lateral branches will be named *gb*. The sign ** represents significance at a level of 0.01, and * represents significance at a level of 0.05. After analyzing these linear dependencies it turned out that increments of lateral branches growing in the westerly (*gbW*) and easterly (*gbE*) directions and the mean of increments in all directions (*gb*) were correlated most strongly with increments of the main shoot. The correlation with Kraft's classes is significant for all primary directions and for the mean of lateral branches and the increment of the main shoot.

Table 1. Correlation coefficients between the length of the main shoot and the length of lateral branches and Kraft's class

Trait	Kraft's class	Length of lateral branches of the fifth whorl in the following directions				Mean length of lateral branches (*gb*)
		gbE	*gbN*	*gbW*	*gbS*	
Zh_5	-0.776**	0.663**	0.498*	0.783**	0.371	0.748**
Kraft's class	1	-0.772**	-0.538**	-0.715**	-0.529**	-0.731**

** correlation coefficients significant with probability $p < 0.01$, * correlation coefficients significant with probability $0.01 < p < 0.05$

In turn a multiple linear regression was calculated between increments in height of the main shoot (Zh_5) and four independent variables (lateral branches: the easterly and westerly directions *gbE* and *gbW*, the mean of lateral branches from all directions *gb*, Kraft's classes). In the analyzed sample there were 12 trees having lateral branches of the fifth whorl in both the easterly (*gbS*) and westerly (*gbW*) directions. It was decided to reject the other two directions (*gbE, gbN*), since they were too poorly correlated with the main shoot. Moreover, only 3 trees had shoots growing in all four primary directions. This was too few for the analysis. The analysis of variance for the general hypothesis on multiple regressions is shown in Table 2. The coefficient of determination for this model was 0.55.

Table 2. Analysis of variance for multiple regression (independent variable: gbW, gbE, gb, Kraft's classes).

Source	*Df*	*SS*	*MS*	F_{calc}	*p- value*
Model	4	0.9078	0.2270	3.05	0.0941
Error	7	0.5202	0.0743		
Total	11	1.4280			

Since the *p*-value was greater than 0.05, thus is no basis to refute the general hypothesis, i.e. all regression coefficients simultaneously are not different from zero. Verification of elementary hypotheses shows that the individual regression coefficients do not differ significantly from zero. Thus it turns out that none of the analyzed traits (independent variables) improves the model more markedly in relation to the variation which is explained by the other traits.

In order to exclude from the model the least significant traits (explaining the lowest percentage of variation of the dependent trait) the analysis of backward elimination regression was used. Table 3 presents the analysis of variance for the model obtained after the stepwise procedure was stopped. Only one independent variable *gbW* remained in the model.

Table 3. Analysis of variance for the reduced model (independent variable: gbW).

Source	*df*	*SS*	*MS*	F_{calc}	*p- value*
Model	1	0.7735	0.7735	11.82	0.0064**
Error	10	0.6545	0.0655		
Total	11	1.4280			

This model is significant because $p < 0.05$ (the coefficient of determination is 0.54). This model is the following

$$Zh_5 = 0.53(GbW) + 2.11 \tag{1}$$

Estimates of regression coefficients and their significance are given below (Table 4). Both regression coefficients are significant.

Table 4. Estimates of regression coefficients for the reduced model.

Variable	Estimate of parameter	Standard error	F_{calc}	*p- value*
β_0	2.11	0.27	59.03	<0.0001**
β_1 (*gbW*)	0.53	0.15	11.82	0.0064**

It is clear that after elimination of traits an ordinary linear regression is obtained, in which the increment in height of the main shoot may be determined using the increment of the lateral shoot of the fifth whorl growing in the westerly direction (*gbW*). However, the coefficient of determination in the model defined by the stepwise method (0.54) is lower than the coefficient (0.61) determined from the linear dependence of these two traits. These results from the different numbers of observations used to estimate the regression coefficients. In multiple regression it was possible to use only 12 observations, whereas in a simple linear regression determined for two variables 18 observations were used (i.e. the total of lateral branches growing in the westerly direction). Thus the model of linear regression established directly for the dependence of increment of the main shoot on lateral branches growing in the westerly direction is a better fit to the data. Such a model takes the following form

$$Zh_5 = 0.70 * GbW + 1.73 \qquad (2)$$

Both regression coefficients in this model are significantly different from zero at the assumed level of significance.

In the successive steps the analysis of polynomial multiple quadratic regression was applied for the set of the four above-mentioned independent traits. Since $p > 0.05$ there is no ground to reject the general hypothesis. After the application of backward elimination regression in the model there remained only one variable, gbW^2. The analysis of variance is given in Table 5. This model is significant (not all regression coefficients are zero at the same time).

Table 5. Analysis of variance for reduced model of polynomial multiple regression (independent variable: gbW2).

Source	*df*	*SS*	*MS*	F_{calc}	*p- value*
Model	1	0.8095	0.8095	13.9	0.0047**
Error	10	0.6185	0.0619		
Total	11	1.4280			

The model is the following

$$Zh_5 = 0.15 * (GbW)^2 + 2.54 \tag{3}$$

Table 6 presents respective estimates of regression coefficients and their significance (the coefficient of determination is 0.57).

Table 6. Estimates of regression coefficients in a reduced model of polynomial multiple regression.

Variable	Estimate of parameter	Standard error	F_{calc}	*p- value*
β_0	2.54	0.15	288.52	<0.0001**
$\beta_1\ (gbW)^2$	0.15	0.04	13.09	0.0047**

As above, this model was obtained from only 12 observations, but for trait *gbW* we had 18 observations. The quadratic model was determined for all observations. Analysis of variance for the model of regression shows that all of the coefficients of regression are significant. The model takes the following form:

$$Zh_5 = 0.2 * GbW^2 + 2.31 \tag{4}$$

In this new model the coefficient of determination is 0.60 (slightly smaller than the coefficient obtained for the linear model). The model (4) is a better fit to the data than the model obtained using the backward elimination method (3)**.**

The results show clearly that the westerly direction has the greatest influence on increment in tree height. In order to decide whether it is advisable to determine the linear or quadratic function of the dependence, a subsequent analysis was performed using the backward elimination method, taking into consideration only the dependence of increment in height on direction *gbW* of lateral branches, when this variable was used for analysis in the first and second power. After this procedure the variable gbW^2 was removed from the model. Estimates of coefficients in the reduced model were identical as in model (2) and are significant. The coefficient of determination for the reduced model was 0.61.

In the end the analysis of residuals was considered. This analysis was done for the linear regression (2). The plots of residuals and studentized residuals versus predicted values exhibit no obvious patterns (Figure 1a, b). This means that linear regression provides a good fit to the data. It turns out that in the set of data are two outliers (Figure 1b). For these outliers the increments of main shoots were too small in relation to increments of lateral branches. Removing these two observations from the calculation did not improve the model.

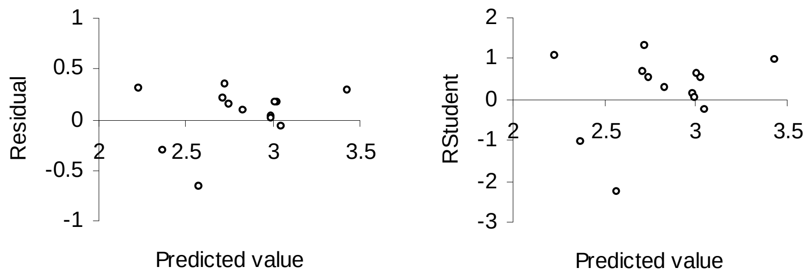

Figure 1. Residuals (a) and studentized residuals (b) versus predicted values.

The residual histogram (Figure 2a) is not clearly consistent with the assumption of Gaussian errors. Moreover the points on the plot of the dependent variable versus the predicted values lie along a 45-degree line, with a little deviation from a straight line (Figure 2b). However the residuals have the normal distribution at significance level 0.05, when the λ-Kolmogorov test was used. Moreover, in order to check the fit of the regression model a non-parametric test series was used (the hypothesis of randomness of residuals was tested). The analysis showed that the residuals are random, and consequently model (2) is a good enough fit.

It should be mentioned that this model was calculated using only 18 observations and it is too small to recognize formula (2) as appropriate for calculating main shoot increments. Thus future research is needed.

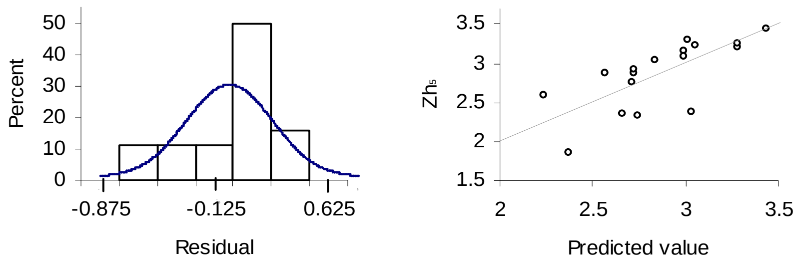

Figure 2. Residual histogram (a) and variable versus the predicted values lie along a 45 degree line (b)

5. Conclusions

It is found from the calculations that the length of the main shoot is significantly correlated with the length of lateral branches in directions *gbW* and *gbE*. Thus the 5-year increments of lateral branches growing in these directions may be used to predict the 5-year increment of the main shoot. However, backward elimination regression showed that only the westerly direction in the first power was significant. An adequate regression model for 24-year-old trees may be the model (2) obtained in the previous paragraph. This means that estimation of the 5-year increment of the main shoot will be best carried out on the basis of the 5-year increments of lateral branches of the fifth whorl growing in the westerly direction.

Moreover the analysis confirmed that all of increments (main shoot and branches) were significantly correlated with Kraft's classes. This means that the increments of 24-year Scots pines were closely connected with their social position.

This conclusion concerns only 24-year-old trees and it will should be confirmed in further research for other pine stands, using a larger sample if possible.

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