EVALUATION OF BARK VOLUME OF FOUR TREE SPECIES IN LATVIA

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Abstract
The objective of this study is to elaborate the mathematical model describing the bark proportion (BP) in stems of Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* [L.] Karst), silver birch (*Betula pendula* Roth.) and aspen (*Populus tremula* L.), as well as to analyze the vertical variation of the BP for the aforementioned species. The study material consists of data of 372 sample trees sampled in three regions of Latvia – Western (Kurzeme), Eastern (Latgale) and North-eastern (Vidzeme) during the years 2011 – 2014. The BP for each tree was calculated as a difference between the under-bark and over-bark stem volume. In this study, we compared the performance of three power regression models in predicting of BP using breast height diameter (DBH), tree height (H) and total volume (TV) as independent variables. The best fit to data was achieved by using tree height for the prediction of BP. Our results confirm that the highest proportion of the bark is at the upper part of the stem (relative height 95%) for all trees species. Pine stems have a lower BP of up to 30% relative height comparing to other species, while the spruce has the lowest bark percentage at the stem base relative to other tested species There were no significant differences found in BP among the stands from different regions for all studied species, indicating no need for derivation of separate equations for each region and ascertaining the possibility of use of the average BP values for the whole country.
Key words: bark proportion, bark volume, Scots pine, Norway spruce, silver birch, common aspen.

Introduction

The necessity of the assessment of forest stand, individual tree and its components' biomass has been highlighted internationally during the last decades since the mitigation of climate change became a highest priority worldwide. The Kyoto Protocol determines that carbon pools in forest above – and below – ground biomass and other carbon sources should be reported by countries which have ratified this protocol. According to the general guidelines defined by Intergovernmental Panel on Climate Change, the carbon is calculated by multiplying the dry biomass by 0.5 default value, which is based on a very overall assumption about carbon content in wood biomass (Good practice guidance for land use …, 2003). In fact, the carbon concentration is different among tree species and tree components, particularly in stem wood and bark (Chauhan et al., 2009). Elaboration of the mathematical functions for calculation of the bark proportion in the total stemwood volume will provide the possibility to improve the accuracy of the national reporting of the carbon balance.

Besides the improvement of national reporting of carbon stock, the reliable methods for calculation of bark content are demanded for the estimation of under-bark volume of roundwood assortments and the bark content of energy wood. The ratio of bark and wood is among qualities influencing the heating value of biomass feedstock (Kenney et al., 1990). The influence of bark content on energy wood quality becomes particularly important in harvesting of small dimensions trees (Adler, 2007). In a two-year poplar short-rotation coppice bark proportion in the extracted whole-stem biomass ranged from 33.9–31.4% in small dimensions stems to 15.1–12.5% in largest stems, depending on their moisture content (Guidi et al., 2008).

The average heating value of bark from the coniferous species is about 7% higher than the average of the deciduous species (Corder, 1976) indicating that bark content is increasing the calorific value of the energy wood. However, a potential problem of using bark in the heating is that the bark of many wood species has higher ash contents than the stem wood (Passialis et al., 2008). High ash content also tends to lower the heating value (Corder, 1976). In Sweden, the estimation of tree ash content showed that the ash content of Scots pine (*Pinus sylvestris* L.) stem with bark is clearly under the limit (0.7%), as well as in almost all cases of silver birch (*Betula pendula* Roth.) (Lestander et al., 2012). Authors found that Norway spruce (*Picea abies* [L.] Karst) stems seem to be problematic for producing pellets of the highest quality because of their high bark ash content (the average ash content in spruce bark is 3.27%, for pine bark – 1.97%, for birch bark – 2.20%) and relatively high bark percentages. The average ash content in pine, spruce and birch stem wood is 0.35%, 0.36% and 0.32%, respectively. Wood ash is a by-product of wood burning, causing problems when making a deposition on heat transfer surfaces in boilers and on internal surfaces in gasifiers (Misra et al., 1993).

The bark can comprise a remarkable amount of the total stem volume and its relative proportion of total stem volume is depending on trees species, tree diameter, tree height and bark thickness (Wehenkel et al., 2012). Bark can reach from 6 to 20% of the total volume of the stems (Heath et al., 2009; Cellini et al., 2012; Wehenkel et al., 2012). Bark thickness is also affected by the climatic zone, stem form, site quality, tree age and other aspects (Laasasenaho et al., 2005; Sonmez et al., 2007; Cellini et al., 2012). R. Li and A.R. Weiskittel (2011) emphasize the importance of the tree bark that plays a critical role in the life of a tree when it is standing, while the harvested bark can be used as a source of energy or mulching, as well as applied in the production of some special products like in the pharmacy.

Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* [L.] Karst), silver birch (*Betula pendula* Roth.) and aspen (*Populus tremula* L.) are economically most important tree species in Latvia. According to data from the National Forest Inventory, in 2014 these four tree species covered 81.3% of the total forest area and 85.8% of the total forest volume (http://www.csb.gov.lv/en/dati/koku-sugas-latvijas-mezos-30236.html). The proportion of the bark and bark thickness has been studied previously in Latvia. The existing average bark volume values for tree species in Latvia are very general disregarding the tree age while the available equations for calculation of the bark proportions are applicable only for the estimation of under-bark volume of roundwood assortments (Līpiņš and Liepa, 2007) and cannot be used in calculation of bark proportion of standing trees. Bark thickness of spruce and pine depending on the vertical location in the stem has been studied by A. Drēska et al. (2002), however, the authors have not provided the mathematical equation for predicting the bark thickness. Z. Sarmulis et al. (2005) recommended to use the fourth-degree polynomial equation for predicting the bark thickness for spruce. The study material of the aforementioned research is based on sample trees obtained only on pre-matured and matured spruce stands restricting the use of model for prediction of bark thickness of young trees.

Several studies have been carried out abroad on the bark thickness modelling (Laasasenaho et al., 2005; Li and Weiskittel, 2011; Cellini et al., 2012). The proportion of bark biomass for pine, spruce and birch has been studied previously in Sweden (Lestander et al., 2012). For further studies authors suggested to clarify the information about the ash content in different tree parts, especially in bark biomass and to investigate the variation of bark structure along the stem. C. Wehenkel et al. (2012) estimated bark volumes for 16 native tree species in Mexico and recommend using power regression models to evaluate the proportion of bark in tree stems.

The objective of this study is to elaborate the mathematical model describing the proportion of bark volume in the stems of Scots pine, Norway spruce, silver birch and aspen, as well as to analyze the vertical variation of the bark proportion for the aforementioned species.

Materials and Methods

The study material consists of 27 Norway spruce, 34 Scots pine, 35 silver birch, and 28 common aspen stands. These stands are located mainly on mineral and drained soils representing a largest part of forest stand types in Latvia and covering all age classes starting from young stands to matured forest. The selected stands were located in three regions of Latvia – Western (Kurzeme), Eastern (Latgale) and North-eastern (Vidzeme), representing different climatic regions and tree populations. The temporary plots were laid in all selected stands placing them subjectively in the spots most accurately representing the whole stands. All the sample plots were circular plots with an area of 500 m^2. In each of the established sample plots three sample trees representing the range of dimensions of the dominant stand were felled down. The measurements for all tree species were based on data of 372 sample trees carried out during the years 2011 – 2014 (Table 1).

The sample trees were felled and the stem length was measured with the measuring tape. Felling height (stump height) was defined to be 1% of the tree height being measured before the felling. The stems were cross-cut into 1 m or 2 m sections towards the top depending on the stem length (1 m sections for stems with a length below 20 m, 2 m sections for stems with length over 20 m). The bark thickness was measured at the end of each section to the nearest millimetre using a metric tape at two perpendicular directions. The measurements were made also at the stump height, 1.3 m height and at the midpoint of the first section.

Table 1

Sample tree characteristics by tree species

	Scots pine			Norway spruce			Silver birch			Common aspen		
	DBH, cm	L, m	T, year	DBH, cm	L, m	T, year	DBH, cm	L, m	T, year	DBH, cm	L, m	T, year
Mean	19.0	17.3	54.0	17.5	16.6	41.0	14.7	18.1	35.0	13.8	16.6	23.0
Std	9.4	9.2	39.1	9.0	8.9	26.9	7.5	8.1	23.6	8.3	8.5	18.2
Min	1.5	1.9	6.0	2.3	2.8	9.0	2.7	4.8	8.0	2.7	3.7	5.0
Max	45.2	34.5	141.0	36.3	30.8	97.0	37.1	32.3	92.0	34.0	29.9	76.0

DBH = mean diameter at breast height, L = stem length, T = stand age.

Bark thickness values were determined by averaging the two measurements.

The bark volume for each tree was calculated as the difference between the under-bark and over-bark stem volume and expressed as a percentage. Stem volume with and without bark was calculated using cone formula for top section of the tree and using truncated cone formula for the rest of stem sections summing the obtained volumes of each separate section. The vertical variation of the bark proportion was calculated as the ratio of cross sectional basal area with and without bark.

The power regression models proposed by C. Wehenkel et al. (2012) were chosen to determine the relationship between the dependent variable and specific tree characteristics as independent variables. The general forms of the models are as follows:

$$BP = \beta_1 \times DBH^{\beta 2} \quad (1)$$

$$BP = \beta_1 \times H^{\beta 2} \quad (2)$$

$$BP = \beta_1 \times TV^{\beta 2} \quad (3)$$

Where BP is the bark proportion, DBH is breast height diameter, H is tree height and TV is the total volume of tree stem with bark. β_1 and β_2 are the coefficients.

The DBH and H are easily measurable variables and also used in the forest inventory, but TV is possible to calculate from the two previous variables using the tree stem volume equations. Statistic evaluation of the models was made by R^2 which reflects the total variability that is explained by the model and RMSE – root mean square error which measures the precision of the estimates. The best fit of regression is indicated by smaller RMSE value. The RMSE is calculated using the following equation:

$$RMSE = \sqrt{\frac{\Sigma(y_i - \hat{y}_i)^2}{n}} \quad (4)$$

Where y_i and $\hat{y}_i$ are observed and predicted values of BP for *i*th tree and *n* is the total number of BP observations for the particular tree species.

The influence of different tree growing regions on BP was assessed using covariance analysis marking growing region as fixed factor, but DBH and H separately as covariants. Regression, correlation, covariance analyses and descriptive statistics were carried out with the SPSS Statistics 20.0 statistical software package.

Results and Discussion

The vertical variation of BP is the combined effect between bark thickness and stem diameter at examined height. For all studied tree species the bark was thickest at the base of the tree that is reflecting as the higher BP values. In the middle part of the stem, which is usually utilized for roundwood production, the BP is rather constant, thereafter sharply increasing towards the top part of the tree. This indicates that energy wood produced form logging residues mainly consisting from branches and tree tops has a tendency to have a bigger bark content. Disregarding the particular bark percentage values, the general form of bark curves at different tree size is similar for all tree species (Fig. 1).

The general tendency is that BP is decreasing from the base towards the middle part of the stem. However, the lower-most values of BP for every particular tree species are reached at different height. For Scots pine the smallest BP is in the middle of the stem at 50% relative height while for Norway spruce, silver birch and common aspen the smallest BP is in the lowest third of the stem at 20 – 30% relative height (Table 2). Similar results are reported by J. Laasasenaho et al. (2005) who stated that the lowest proportion of bark for Norway spruce in Finland is detected at 20% relative tree height. The vertical variation of pine and spruce bark thickness along the stem in Latvia has been studied by A. Drēska et al. (2002). In the study it was reported that at 20% relative height the bark of Scots pine becomes thinner than that for Norway spruce while at the base of tree the bark of Scots pine

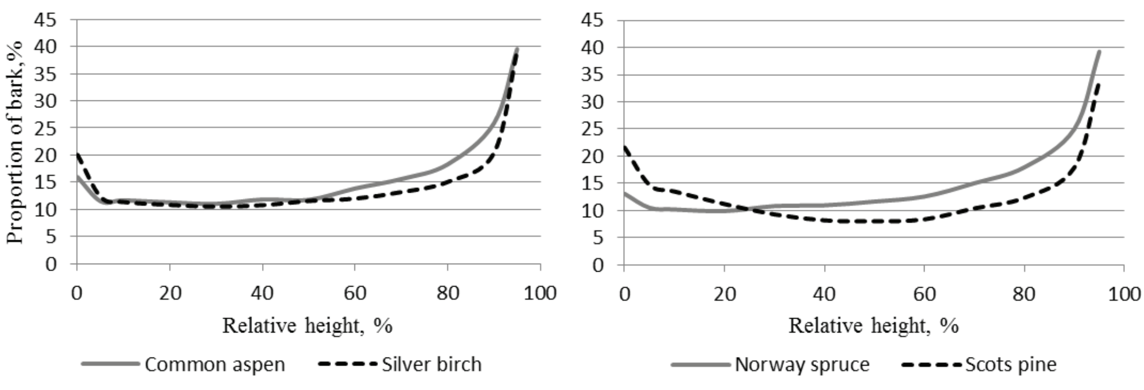

Figure 1. Average values of BP of stem basal area as a function of relative height.

Table 2

Bark proportion as a percentage of stem basal area at different relative heights, %

Relative height, %	Scots pine		Norway spruce		Silver birch		Common aspen	
	mean*	range**	mean	range	mean	range	mean	range
1	21.6±0.6	9.5-40.6	13.1±0.6	4.6-30.0	20.1±0.6	9.7-36.5	16.0±0.5	7.9-29.8
5	14.7±0.5	8.3-37.6	10.5±0.4	4.5-30.9	12.3±0.7	6.5-31.5	11.5±0.4	6.6-25.8
10	13.5±0.4	4.8-34.4	10.2±0.3	5.1-24.8	11.4±0.2	3.8-26.0	11.7±0.2	5.1-23.1
20	11.2±0.6	2.5-32.4	9.9±0.5	5.5-31.8	10.8±0.2	6.5-23.7	11.3±0.4	6.1-23.7
30	9.3±0.6	1.7-36.0	10.8±0.5	5.3-30.2	10.5±0.2	5.8-19.5	11.0±0.4	5.3-24.3
40	8.2±0.5	2.7-27.3	11.0±0.4	5.2-26.5	10.8±0.2	6.5-20.3	11.8±0.4	5.8-24.4
50	8.0±0.5	3.0-26.5	11.6±0.5	5.5-35.4	11.6±0.2	5.6-22.1	11.8±0.3	6.9-26.5
60	8.4±0.5	2.9-30.6	12.6±0.5	6.1-29.6	12.0±0.2	5.6-24.7	13.9±0.4	7.9-26.5
70	10.4±0.7	2.9-37.9	15.0±0.6	6.3-32.8	13.2±0.3	7.7-31.8	15.6±0.5	7.6-30.6
80	12.3±0.8	3.6-53.4	18.0±0.8	5.4-49.0	15.1±0.4	8.1-36.0	18.3±0.6	7.9-40.8
90	17.9±0.9	5.1-50.2	25.0±1.0	8.0-59.5	20.4±0.5	9.8-43.8	25.9±0.9	9.1-49.0
95	33.8±1.7	10.5-67.3	39.3±2.2	8.9-64.0	39.2±1.8	19.0-88.9	39.5±1.6	23.4-71.0

***Average value of bark percentage ± SE; **minimum and maximum values.

is approximately two times thicker than for Norway spruce.

The vertical variation of the BP of studied deciduous trees is similar, showing the differences only in the upper part of the stem where the bark of the birch is slightly thinner than for aspen.

The average BP along the stem ranges from 8.0% to 39.5% depending on the tree species and relative height. Our results confirm that the greatest proportion of the bark is at the upper part of the stem (relative height 95%) for all trees species. Pine stems have a lower BP up to 30% relative height comparing to other species while the spruce has the lowest bark percentage at the stem base relatively to other tested species (Figure 1, Table 2).

The influence of geographic location of the studied stands on average BP of the stems was studied using covariance analysis excluding the effect of breast height diameter and tree height. We found no significant differences in BP among the stands from different regions that BP for all studied species ($p>0.05$) indicating no need for derivation of separate equations for each region and ascertaining the possibility of use of the average BP values for the whole country. These results are in consistency with those presented by L. Līpiņš and I. Liepa (2007). The effect of the climatic zones and forest type on bark thickness of spruce is studied in Finland (Laasasenaho et al., 2005). The study confirmed that the length of growing period is a very significant factor that affects the bark thickness – the bark is thicker in the northern parts of the country while the dependency of bark thickness on forest type was not found. The contradictory results of our study (no regional differences were found among the stands from different locations), can be explained by the small geographic variation of sampled stands all being close to 56th and 57th parallels.

All independent variables (DBH, H and TV) displayed a negative, statistically significant ($p<0.05$) correlation (correlation coefficients -0.73, -0.78 and -0.57, respectively) with the BP indicating that BP values decrease with the increase of the tree size. The

Table 3

Summary of fit statistics and parameter estimates of the model of BP estimated by the Equations 1-3

Species	Equation 1				Equation 2				Equation 3			
	R^2	RMSE	b_1^*	b_2^*	R^2	RMSE	β_1	β_2	R^2	RMSE	β_1	β_2
Scots pine	0.85	2.562	75.492	-0.654	0.90	2.075	57.943	-0.597	0.89	2.215	38.189	-0.227
Norway spruce	0.86	1.891	47.272	-0.516	0.89	1.691	47.051	-0.531	0.88	1.754	29.972	-0.194
Silver birch	0.51	2.153	25.502	-0.289	0.56	2.032	31.020	-0.335	0.53	2.097	20.194	-0.108
Common aspen	0.79	1.781	31.832	-0.385	0.80	1.740	39.671	-0.434	0.80	1.754	22.953	-0.141

* All parameters b_1 and β_2 are significant ($p<0.05$)

best fit to data was achieved by using Equation 2 for the prediction of BP (Table 3).

The tree height turned out to be the best predictor for the bark proportion explaining 56 – 90% of the variations depending on tree species. However, equations where the total volume and breast height diameter is used as predictors produced the R^2 values that are just slightly lower than for tree height – 2% and 5% respectively. In practice, the use of breast height diameter as the variable for prediction of BP is more convenient because it can be measured more precisely in the forest whereas the correct estimation of tree height is often more complicated and may produce substantial measurement errors. In respect to this, the use of Equation 1 can provide a more exact estimation of BP if the tree variables have to be obtained by direct measurements in the forests instead of using the forest monitoring data.

Discovering the residual plots for Equation 1, it is evident that the residuals are distributed evenly regarding the dimensions of the stems (Figure 2). The prediction ability of all models based on power equations produced good results; however, application of these equations might produce a slight underestimation of bark proportion of bigger dimensions silver birch stems. The examination of more sophisticated models for prediction of birch bark proportion can be proposed to produce more accurate results.

T.A. Lestander et al. (2012) in their study obtained BP from biomass functions constructed by L.G. Marklund (1988) and J. Repola (2008, 2009) that are widely used in Sweden and Finland. T.A. Lestander et al. (2012) found that the bark proportion predicted using J. Repola's function was significantly higher for pine than predicted using the L.G. Marklund's function, and the BP is decreasing with an increase of diameter of pine and spruce, but not of the birch. According to L.G. Marklund's function, for birch the smallest BP value is at 12.1 cm breast height diameter - increasing thereafter. However, this relationship is not confirmed by applying J. Repola's functions, in which case no certain minimum BP value is indicated. The proportion of bark and general bark curves obtained in our study for Scots pine, Norway spruce and Silver birch better corresponds to the variation of BP described by the model derived from Finnish biomass functions.

The greatest variation of BP is observed for silver birch that is indicated by the lowest R^2 values (Table 3). The high uncertainty in calculation of birch bark volume compared to that of spruce and pine is pointed out also by I. Liepa (2011). He explains this phenomenon by the peculiarities of the study data where the presence of two birch species (silver and pubescent birch) was possible. However, this explanation cannot be applied to our study where the measurements of exceptional silver birch stems were performed. The reason for the unexplained variation of BP for silver birch stems is not fully understood. One possible explanation for this variation is the different morphological forms of the silver birch. The formation of coarse bark at the base of the birch stems can be very divergent both for different populations of birches and within the same stand. Birch trees sometimes form very distinct ridges in the lowest 3 m sector of the stem while in some cases the matured silver birch stems maintain the thin smooth bark

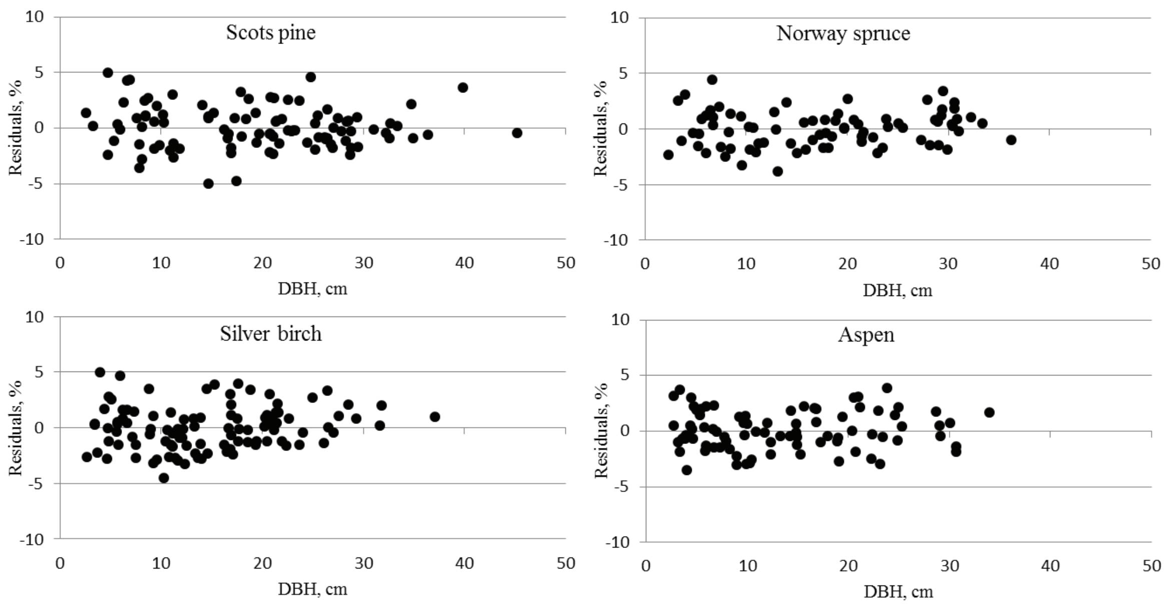

Figure 2. Residual plots (predicted – observed) of bark proportion depending on DBH using Equation (1).

Table 4

Average values of proportion of bark volume for studied tree species, %

DBH, cm	Scots pine	Norway spruce	Silver birch	Common aspen
5	26.9±1.3*	20.9±0.9	16.7±0.4	17.9±0.6
10	18.9±0.7	14.9±0.9	12.1±0.6	12.3±0.4
15	10.9±0.7	11.2±0.5	11.1±0.4	11.0±0.3
20	9.8±0.5	9.6±0.3	10.9±0.3	10.0±0.5
25	8.9±0.5	8.5±0.3	10.5±0.6	10.1±0.6
30	7.7±0.4	8.2±0.3	10.4±0.4	9.1±0.5

*Average BP values ± SE

(Līpiņš and Liepa, 2007). Bark variations of Scots pine have been studied by T. Jelonek et al. (2009). Based on other studies, the authors identified three forms of dead bark: scaly bark, ropy bark, and shell type bark, and distinguished different productivity among the morphological variety of pines.

The average BP values in stem obtained in our study revealed high within-species variation from 5.5 to 34.5% for pine, 6.6 to 28.3% for spruce, 7.9 to 21.5% for birch and 7.0 to 23.6% for aspen. Most of the variations can be explained by the effect of tree age or the size of the tree. At the breast height diameter 5 cm the pine, spruce birch and aspen bark proportion are respectively 26.9%, 20.9%, 16.7% and 17.9%, but if the breast height diameter is increased to 30 cm, then respectively 7.7%, 8.2%, 10.4% and 9.1% (Table 4).

The future studies are needed to increase the number of measured sample trees to clarify the population effect and influence of growing site on BP of the trees. To increase the predicting accuracy for the modelling of bark thickness at a certain height of the stem, the use of more sophisticated models including the effect of the tree age is recommended.

Conclusions

1. The best fit to data (R^2 is 0.90 for pine, 0.89 for spruce, 0.56 for birch, and 0.80 for aspen) was achieved by using tree height for the prediction of bark proportion (BP).
2. The highest proportion of the bark is at upper part of the stem (relative height 95%) for all trees species. Pine stems have a lower BP up to 30% relative height comparing to other species, while the spruce has the lowest bark percentage at the stem base relative to other tested species.
3. Study revealed a high within-species variation of average BP being 5.5 to 34.5% for pine, 6.6 to 28.3% for spruce, 7.9 to 21.5% for birch and 7.0 to 23.6% for aspen. Most of the BP variations can be explained by the effect of tree size – BP of small trees tends to be higher than for bigger dimension trees.
4. There are no significant differences found in BP among stands from different regions for all studied species indicating no need for derivation of separate equations for each region and ascertaining the possibility of use of the average BP values for a whole country.

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