IECF 2020
The 1st International Electronic Conference on Forests
Forests for a Better Future: Sustainability, Innovation, Interdisciplinarity
15–30 NOVEMBER 2020 | ONLINE

Models to estimate the bark volume for *Larix* sp. in Poland

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Introduction

Bark is an important residues or/and by product of timber harvest, especially for mechanised systems (e.g. CTL with harvesters).

In Central Europe, timber is usually sold with the bark, however the customer pays for the volume of merchantable timber estimated under the bark.

Thus, it is important to know how much volume is assigned to bark. Such knowledge is essential for precise forest management.

Objectives

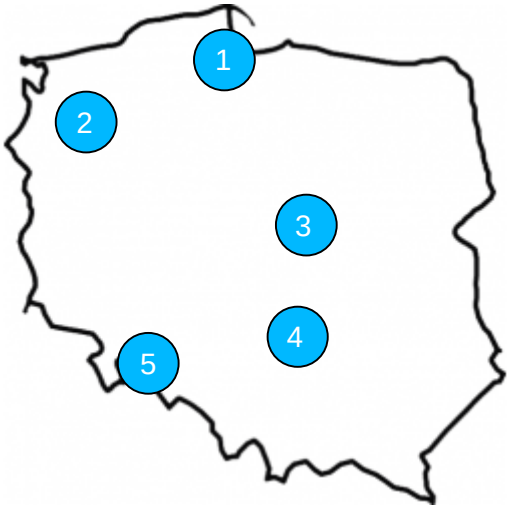
- analyse variability of bark volume and bark volume fraction for *Larix* sp. in Poland

- develop models to estimate the investigated parameters with regard to the basic dendrometric attributes

Material & methods

5 locations in various parts of Poland:

- N – Dobrzany & Kolbudy
- C – Rogów
- S – Pińczów & Prudnik



1 – Kolbudy, 2 – Dobrzany, 3 – Rogów,
4 – Pińczów, 5 - Prudnik

4 age classes (total range 19-127 years):

- II – < 40 years
- III – 40-60 years
- IV – 60-80 years
- V – >80 years

3 site types:

- E – eutrophic
- M – mesotrophic
- O – oligotrophic (upland and mountain sites, Pruchnik location)

62 study plots

Material & methods

9-10 trees per study plot – 599 individuals in total

section-wise over-bark volume and bark thickness measurements

analysed parameters:

- bark volume (bV)
- bark volume fraction (%bV) – share of bark volume in total volume of a tree

dendrometric variables:

- breast height diameter (d)
- height (h)
- total tree volume (V)

Kain et al. *Forests*, 2020

Material & methods – variability

Shapiro-Wilk test to assess normality of bV and %bV distribution

Kruskal-Wallis test to assess the impact of

- location,
- site type,
- age class

on the analysed bark parameters

Pearson correlation to evaluate the relationship between

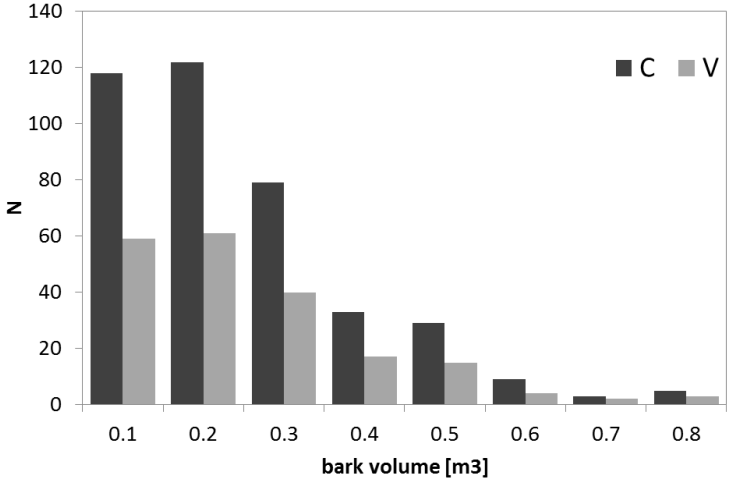
- breast height diameter,
- height,
- total tree volume,

and the analysed bark parameters

Material & methods - modelling

We split our data into calibration (C, $^2/_3$ of records) and validation (V, $^1/_3$ of records) sets based on the bark volume distribution

Obtained sets did not differ significantly in terms of analysed dendrometric parameters (Mann-Whitney test)



	C	V	z	p
age [yrs]	57.2	57.7	0.61	0.540
d [cm]	29.8	30.0	0.23	0.816
h [m]	26.9	27.2	0.82	0.414
V [m3]	1.073	1.100	0.39	0.696
Vk [m3]	0.197	0.201	0.26	0.794
%Vk [%]	18.8	18.7	0.32	0.749

Material & methods - modelling

Applied models included:

- $\hat{y} = a+b \cdot x$
- $\hat{y} = a \cdot x^{b}+c$
- $\hat{y} = a \cdot (exp^{x} \cdot b)+c$
- $\hat{y} = a \cdot x/(b+x)$
- $\hat{y} = a/(1+b \cdot exp^{-c \cdot x})$
- $\hat{y} = a \cdot exp^{(b \cdot exp^{c \cdot x})}$

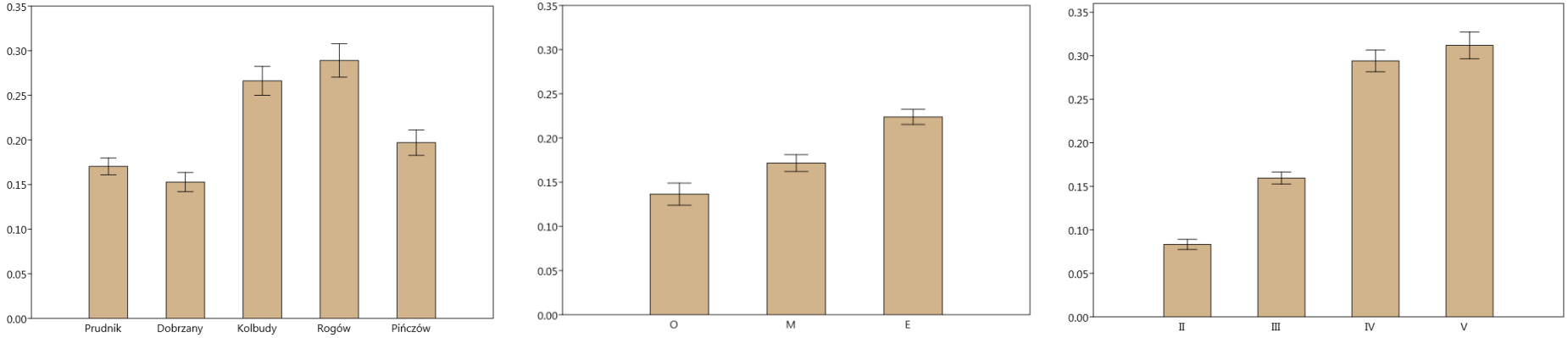
Model selection was based on AIC and R^2 for calibration dataset

Best models were verified using R^2 and residuals RMSE for validation dataset

Results – bark volume variability

Larch bark volume ranged from 0.0048 to 0.7984 m^3, with mean value amounting to 0.1985 m^3 (± 0.006 SE)

It varied significantly with regard to the analysed location ($p < 0.001$), site type ($p < 0.001$) and age class ($p < 0.001$)

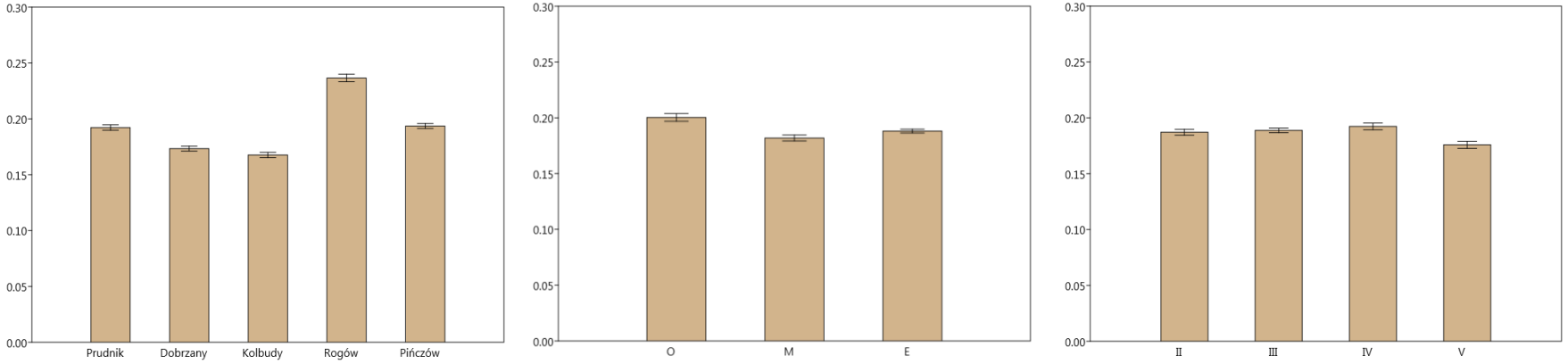


Bark volume [m^3] for investigated locations (left), site types (centre) and age classes (right)

Results – bark volume fraction variability

Fraction of bark volume in total volume of analysed larches ranged from 0.104 to 0.294, with mean value amounting to 0.188 (± 0.001 SE)

It varied significantly with regard to the analysed location ($p < 0.001$), site type ($p < 0.001$) and age class ($p = 0.003$)



Bark volume fraction in total volume of a tree for investigated locations (left), site types (centre) and age classes (right)

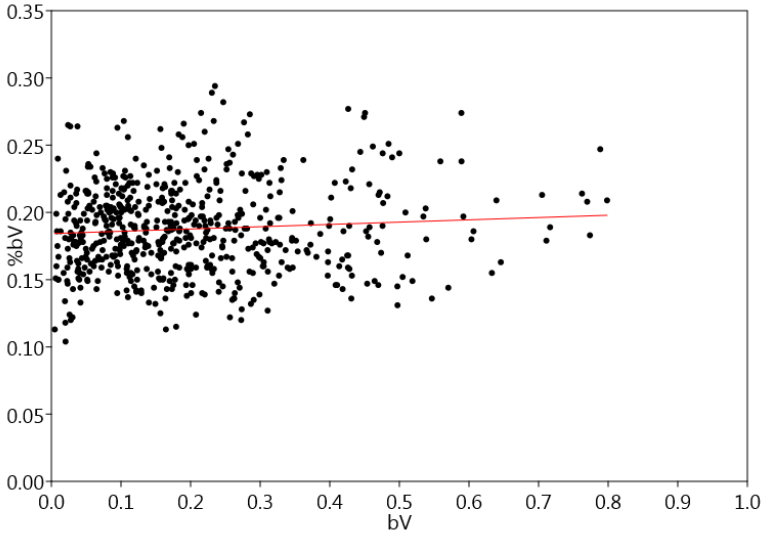
Results – relationships

Both bark volume and fraction of bark volume in total volume a tree were significantly dependent on breast height diameter (d), tree's height (h) and total volume (V). However for %bV this correlation is very weak.

Both features were however insignificantly correlated one to another (r = 0.077, p = 0.060)

		r	p
bV	d	0.939	<0.001
	h	0.781	<0.001
	V	0.956	<0.001
%bV	d	-0.106	<0.001
	h	-0.121	0.003
	V	-0.164	<0.001

almost lack of linear correlation,
perhaps non-linear fit will do?



Results – model calibration

AIC values for analysed models

	bV			%bV		
	d	h	V	d	h	V
$\hat{y} = a+b \cdot x$	5.08	7.29	4.81	4.46	4.46	4.45
$\hat{y} = a \cdot x^{b}+c$	6.85	8.93	6.81	6.49	6.49	6.48
$\hat{y} = a \cdot (exp^{x} \cdot b)+c$	6.87	8.92	6.84	6.49	6.49	6.48
$\hat{y} = a \cdot x/(b+x)$	5.11	7.05	4.78	4.46	4.46	4.46
$\hat{y} = a/(1+b \cdot exp^{-c \cdot x})$	6.90	8.94	6.99	6.48	6.48	6.48
$\hat{y} = a \cdot exp^{(b \cdot exp^{c \cdot x})}$	6.87	8.93	6.89	6.48	6.48	6.48

R^2 and RMSE for the best models

		bV			%bV		
		d	h	V	d	h	V
$\hat{y} = a+b \cdot x$	R2	0.880	0.631	0.912	0.008	0.007	0.022
	RMSE	0.0515	0.0905	0.0442	0.0328	0.0328	0.0326
$\hat{y} = a \cdot x/(b+x)$	R2	0.878	0.669	0.915	0.000	0.001	0.001
	RMSE	0.0521	0.0870	0.0435	0.0329	0.0329	0.0329

Results – model validation

R^2 and RMSE for the best models (validation data set) – bV only

		bV		
		d	**h**	**V**
$\hat{y} = a+b \cdot x$	R2	0.886	0.567	0.916
	RMSE	0.0511	0.0996	0.0440
$\hat{y} = a \cdot x/(b+x)$	R2	0.900	0.605	0.915
	RMSE	0.0478	0.0951	0.0442

Lack of normality and systematic bias of the residuals

		p (norm)	Mean	p (M=0)
$\hat{y} = a+b \cdot x$	d	<0.001	-0.001	0.341
	h	<0.001	0.008	<0.001
	V	<0.001	0.004	0.042
$\hat{y} = a \cdot x/(b+x)$	d	<0.001	0.006	0.001
	h	<0.001	0.001	0.041
	V	<0.001	0.002	0.070

Results – model performance

There is significant effect of location on the residuals of the applied models for bark volume determination.
Site type and age class seem to influence the estimates in smaller extent.

		Location	Site type	Age class
$\hat{y} = a+b \cdot x$	d	<0.001	0.613	0.236
	h	0.007	0.918	0.004
	V	<0.001	0.024	0.137
$\hat{y} = a \cdot x/(b+x)$	d	<0.001	0.363	<0.001
	h	0.005	0.649	0.768
	V	<0.001	0.046	0.232

Conclusions

- Both analysed bark parameters varied significantly with regard to location, site type and age class.
- Bark volume is strongly and significantly dependent on tree's breast height diameter, height and total volume (V). For bark volume fraction this correlation is also significant but very weak.
- The best results of bark volume estimation are achieved for model with total tree volume as independent variable. For the weak relationship with dendrometric parameters modelling o bark volume fraction seems to be pointless.
- Because of the strong effect of location it is recommended to elaborate locally-based models for bark volume estimation.

thanks for your attention!

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