

Original Research

# Biomass Structure and Morphometric Parameters for Non-Destructive Biomass Estimation of Common Forest Underbrush Species in Lithuania

Mindaugas Škëma\*, Virgilijus Mikšys, Marius Aleinikovas,  
Benas Šilinskas, Iveta Varnagirytė-Kabašinskiė

Institute of Forestry, Lithuanian Research Centre for Agriculture and Forestry,  
Liepų str. 1, Girionys, LT-53101, Kaunas District, Lithuania

Received: 16 March 2017

Accepted: 15 June 2017

## Abstract

A study was conducted to construct functions for aboveground biomass of different components (leaves, stems, and branches) of hazel (*Corylus avellana* L.), rowan (*Sorbus aucuparia* L.), and alder buckthorn (*Frangula alnus* L.) growing naturally under the stand canopy. The functions were designed to calculate the potential amount of biofuel produced from underbrush species in Lithuanian forests. Biomass production of common underbrush species was estimated in seven stands located in southwestern Lithuania. The ages of the stands varied from 55-70 to 80-100 years. The biomass relationships with morphometric parameters were determined, including stem diameter at 1.3 m and 0.3 m above ground level, stem height, and crown length. The study findings showed that biomass relationships for underbrush species were not comparable to the same relationships for canopy trees. As the biomass changes for canopy trees are mostly caused by competition, and the growth of underbrush species depends more on the light regime. Therefore, stem diameter (D) rather than stem height (H) should be better used for estimating total aboveground biomass of underbrush.

**Keywords:** allometric equations, underbrush species, aboveground biomass, stem diameter, stem height

## Introduction

Estimating woody species biomass could be important for carbon sequestration and cycling in forest ecosystems. A common database of forest biomass measurements from Europe would sustain harmonization

of carbon accounting methods [1]. For quantifying carbon sequestration, shrub biomass and growth rate have been modelled in different regions [2-3].

Recently, the biomass of canopy trees harvested during thinning and final felling and short rotation forestry for energy purposes is expanding [4]. Furthermore, the biomass derived from underbrush or woody underbrush left after stem harvesting could play an important role for biofuel potential in Lithuania. Underbrush harvest would

\*e-mail: skeminis@yahoo.com

also provide forest owners with additional revenue and could facilitate replanting.

Generally, underbrush is defined as shrubs or small trees growing under the tree canopy. An initial hypothesis of this study could be that allometric development of underbrush species differ from that of canopy trees. However, less attention has been paid to biomass estimates of underbrush compared to canopy trees – especially in mixed forests, where tree competition is more intensive [5-6].

In Lithuanian forest stands, the most common underbrush species are common hazel (*Corylus avellana* L.), rowan (*Sorbus aucuparia* L.), and alder buckthorn (*Frangula alnus* L.). The mentioned species naturally grow as underbrush in deciduous or mixed forests, but individual plants could also be found along riverbanks and in parks, farms, or gardens. The underbrush individuals never reach canopy level in certain conditions. In the forest stands the mean height of rowan and alder buckthorn trees amounts to about 1.2 m, while hazel underbrush is slightly higher and reaches 1.8 m. The average amount of underbrush amounts to 8,600-8,900 stems ha<sup>-1</sup> in Lithuanian forests. The main part is registered in deciduous forests, and also in cut areas and forest gaps. The lowest amount is found in coniferous stands [7].

According to the assessment of sustainability, precise estimates of forest biomass could be valued as an essential precondition for forest management [8]. The selection criterion of both model canopy and underbrush trees is one of the most relevant issues for determining different aboveground biomass components (foliage mass, stem, and branches) in different studies [2, 9-14]. Methodologically, more significant data of dry biomass could be obtained when biomass sampling is conducted from the middle until the end of the vegetation period [15].

For evaluating total aboveground tree biomass or biomass of different tree components we used various stem and crown parameters, including stem diameter at breast height (D), height (H), and crown length [16-22]. Sometimes, stem volume index  $D^2H$  is used [23-25]. Several studies show that biomass of canopy trees and their different components (foliage, branches, stem, crown) is relatively closely correlated with morphometric parameters [26-27].

In a study carried out in Botswana, total tree fresh mass of 14 tree species, as a regression between mass and stem basal area at 5-10 cm above ground level, was estimated. A single regression curve was calculated because the curve satisfactorily described the relationship between stem basal area and fresh mass for most trees [28-29]. A strong correlation between hazelnut biomass and stem height and diameter at the stem base was found in Slovenia [30]. According to data obtained in Niepołomice Forest in Poland, species composition of the stand was not the factor mostly affecting underbrush biomass [31].

Earlier findings indicated that the number of small trees and shrubs in underbrush significantly decreases

with the increase of stand age [32-33]. The changes of underbrush density and species composition are recorded under the National Forest Inventory. On the other hand, the assessment of forest felling does not include evaluation of underbrush biomass in Lithuania.

Up until now, too little attention has been paid to underbrush biomass assessment and to the peculiarities of the relationship between underbrush biomass and morphometric parameters. This indicates a need to create best-fit parameters for estimating aboveground biomass of underbrush. It is still unclear what parameters best-fit for canopy trees could fit underbrush species. This paper investigates the biomass allocation of hazel (*Corylus avellana* L.), rowan (*Sorbus aucuparia* L.), and alder buckthorn (*Frangula alnus* L.) underbrush, and biomass relationships with morphometric parameters: stem diameter at different heights aboveground, stem height, and the complex index  $D^2H$ .

## Materials and Methods

The research site was located in Dubrava Experimental and Training Forest Enterprise (54°51' N, 24°03' E) in southwestern Lithuania. In the study area, the yearly mean temperature is 6.5°C and yearly mean precipitation is 686 mm. Six experimental plots were selected in the Norway spruce stands with admixture of deciduous species, and one plot was set up in Scots pine stands. In the experimental sites, the soil type was *Luvisol* in the Norway spruce stand and *Arenosol* in the Scots pine stand. The selection scheme for each studied species was designed according to the amount of dominant underbrush.

Fieldwork was conducted in August-September 2009 and 2010. Sample plots of 15 by 20 m were established for determining morphometric parameters and underbrush stem sampling. Diameters at 0.3 and 1.3 meters above ground level were measured for all stems within the plot (1,684 stems total).

The potential hazel (*Corylus avellana* L.), rowan (*Sorbus aucuparia* L.), and alder buckthorn (*Frangula alnus* L.) underbrush were selected for biomass assessment. No fewer than 30 model underbrush stems were chosen within each plot. Selection of model stems was conducted to encompass the diameter range from each plot, i.e., taking the stems from the lowest to highest diameter groups within each plot. The procedure was applied following the idea that measuring a higher number of stems in the plot does not give higher data accuracy and does not compensate for the time-input [34-35]. The model stems were cut down at 0.1 m distance from the stem base.

The following morphometric parameters were measured: stem height, stem diameter at 0.3 and 1.3 m heights, and crown length. The fresh biomass of different components (branches, stems, and leaves) was assessed. In total, 92 hazel stems and 63 stems each for rowan

Table 1. Main characteristics of sampled plots.

Plot No.	Undergrowth species	Species composition*	Stand age (years)	Stocking level	Forest site
1	Hazel ( <i>Corylus avellana</i> L.)	8E1A1B	107	0.9	Nc
2		6E2A2B	82	0.8	Nc
3		5A4E1P	92	0.7	Nc
4	Rowan ( <i>Sorbus aucuparia</i> L.)	8E1A1B	100	0.9	Nc
5		7E3B	90	0.8	Lc
6	Alder buckthorn ( <i>Frangula alnus</i> L.)	10P	70	0.7	Lc
7		5E2B2J1D	55	0.8	Lc

\*E – *Picea abies* (L.) H. Karst., A – *Quercus robur* L., B – *Betula pubescens* Ehrh., P – *Pinus sylvestris* L., J – *Alnus glutinosa* (L.) Gaertn., D – *Populus tremula* L.

\*\* Nc – mineral mesoeutrophic soils of normal moisture, Lc – mesoeutrophic temporary overmoistured soils

and buckthorn were measured. The main characteristics of the sampled underbrush are given in Table 1.

The moisture content of underbrush biomass was first estimated. The branches were removed from the stems, all leaves were removed from the branches, and these components were weighed separately. Stem, branch, and foliage samples of 0.5 kg were taken, weighed, and put into clean paper bags. The samples were dried at 105°C for 24 hours until constant weight for determining dry biomass and the dried samples were weighed. Under the same environmental conditions, the average moisture of stems amounted to about 45-48% for hazel, rowan, and buckhorn (data not shown). Higher moisture contents of 52-53% and 63-64% were found for the branches and leaves, respectively.

To evaluate the relationship between underbrush biomass components and morphometric parameters and to construct the functions for underbrush biomass evaluation, we tested a non-linear regression model using D, H, and D<sup>2</sup>H, and together D and H as independent variables. The following function was applied:

$$Y = a_0 \times P_1^{a_1} \times P_2^{a_2} \times \dots,$$

...where Y is biomass component (leaf biomass, branches biomass, etc.); a<sub>0</sub>, a<sub>1</sub>, a<sub>2</sub>, etc. are coefficients; and P<sub>1</sub>, P<sub>2</sub>, etc. are stem parameters (D, H, D<sup>2</sup>H).

The coefficient of determination (R<sup>2</sup>) was used to evaluate the fitness of the models. The best models were then used on biomass data from the sample stems to present equations describing the relationship between the biomass components and morphometric parameters D and H.

A regression analyses was used for the statistical relationship between different variables. Statistical analyses were conducted using the software Statistica 7.0, and a level of significance of  $\alpha = 0.05$  was chosen in all cases.

## Results and Discussion

Various biomass distribution models, as a good tool for improving the pre-harvest estimates of harvested volume, could also be important for the underbrush species [37]. When the underbrush study was conducted, the results showed that stem biomass made the biggest relative contribution to total aboveground biomass, amounting to 68, 73, and 66% for the underbrush hazel (*Corylus avellana* L.), rowan (*Sorbus aucuparia* L.), and alder buckthorn (*Frangula alnus* L.) stems, respectively (Table 2). Differences of the relative contribution were not significant among different underbrush species ( $P > 0.05$ ).

A number of studies demonstrated that hazel leaf biomass amounted from 10-12% [32] to about 17% [30] from total aboveground biomass. The data of hazel stem biomass were comparable to a study carried out in the northern United States, where stems comprised 49-55% from total aboveground biomass [30].

Relatively similar biomass contributions of various components were obtained for canopy trees. Both for deciduous and coniferous tree species, mean stem biomass accounted for 75-80% from total aboveground biomass, foliage biomass amounted to about 4-8%, living branches to 14-20%, and dead branches to less than 3% [38]. The study also indicated that stem-to-foliage mass ratio ranged from 1.93 (alder buckthorn) to 2.69 (rowan),

Table 2. Mean dry biomass of different components of the various undergrowth species  $\pm$  SE, percent from total aboveground biomass.

Biomass component	<i>Corylus avellana</i> L.	<i>Sorbus aucuparia</i> L.	<i>Frangula alnus</i> L.
	Mean dry biomass, percent from total aboveground biomass		
Stem	68.2 $\pm$ 2.1	72.9 $\pm$ 2.9	65.9 $\pm$ 2.8
Branches	20.5 $\pm$ 1.2	18.9 $\pm$ 1.5	24.5 $\pm$ 1.4
Leaves	11.3 $\pm$ 0.8	8.2 $\pm$ 1.0	9.6 $\pm$ 0.9

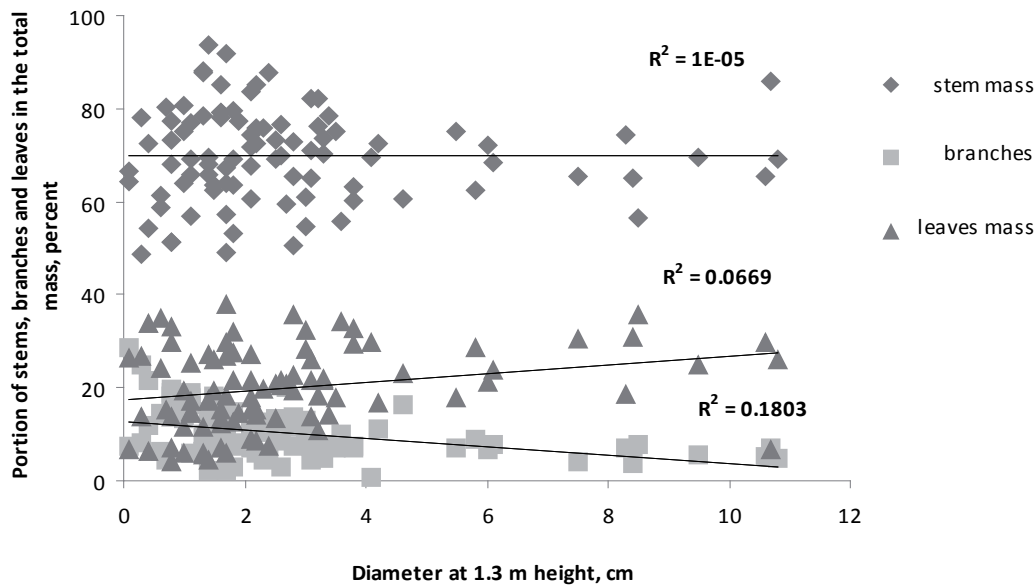


Fig. 1. Dependence of the portion of hazel stems, branches, and leaves on diameter at 1.3 m height.

but mean values of the ratio did not differ significantly among different underbrush species.

The results obtained from this study showed that the portions of stems, branches, and leaves in total underbrush stem biomass did not significantly depend on morphometric parameters. Analyzing the data of hazel underbrush components, regression analysis of biomass percentage of components with stem diameter at 1.3 m height was performed (Fig. 1). There was no relationship between stem diameter and the biomass portion of stems, branches, and leaves. The portion of hazel and rowan branches increased insignificantly with increasing diameter, while that of leaves decreased. The portion of both leaves and branches of buckthorn remained stable with increasing diameter (data not shown).

These results differ from the results obtained from aboveground biomass studies of canopy trees. For the canopy trees, with increasing tree age and morphometric parameters, biomass is mostly accumulated in the stems of trees; thus the stem biomass of older and larger trees as well as of older stands is considerably greater than that of young trees and stands [38]. However, these peculiarities are not characteristic for the biomass of underbrush species, i.e., hazels, rowans, and buckthorns. This result may be explained by the fact that underbrush species grow under limited light, i.e., the amount of light is a more limiting factor than competition among the individuals. Such conditions almost eliminate gradual self-cleaning from branches, and all components of underbrush develop more proportionally.

Prediction equations are used worldwide to estimate the amount of biomass at the tree, stand, and landscape levels. The resulting non-linear regression functions for total aboveground biomass of underbrush, as a function of tree dimensional parameters  $D_{1.3}$  and  $D_{1.3}^2H$ , showed  $R^2$  values ranging from 0.932 to 0.987 ( $p \leq 0.001$  for rowan and alder buckthorn,  $p \leq 0.03$  for hazel; Table 3).

Relatively high coefficients of determination were ascertained between the total mass of hazel, rowan, and buckthorn underbrush and stem diameters at 0.3 m height:  $R^2$  values ranged between 0.912 and 0.988 ( $p \leq 0.001$  for rowan and buckthorn,  $p \leq 0.04$  for hazel; Table 3). The parameter  $D_{0.3}$  was tested to check whether more accurate shrub stem diameter values would increase the reliability of indicators. However, our findings confirmed that despite slightly higher  $R^2$  values obtained for  $D_{0.3}$ , no significant differences from  $D_{1.3}$  were determined.

In the case of hazel, the most appropriate predictable parameters were  $D_{1.3}$  and  $D_{1.3}^2H$  both for stems and crown biomass components (branches and leaves), giving  $R^2$  values of 0.973, 0.786-0.800, and 0.926-0.931, respectively (Table 4).

The parameters  $D$  and  $D_{1.3}^2H$  were the best predictors for estimating total aboveground and stem biomass of rowan, giving  $R^2$  values ranging from 0.96 to 0.99 ( $p = 0.001$ ; data not shown). The  $R^2$  values were to some extent lower, ranging from 0.88 to 0.95, for estimations of leaf and branch biomass.

Compared to hazel and rowan, similar results were obtained for alder buckthorn biomass estimations. The coefficients of determination were highest for the equations with  $D$  ( $R^2$  was 0.93-0.98) and  $D^2H$  ( $R^2$  was close to 0.99). It was a proper parameter for the stem biomass evaluation (data not shown).

For all studied underbrush species, the relationships as a function of height ( $H$ ) showed lower coefficient of determination, ranging from 0.597 to 0.973, compared with the relationships as a function of other independent variables. The equations for branch and leaf biomass had a weaker relationship than those for stem biomass.

Comparable results were obtained when the biomass of canopy trees was studied. Mikšys et al. [38] found a weaker relationship of tree height or crown parameters to tree biomass compared to stem diameter. Subsequently, the

Table 3. Relationships of total biomass of hazel, rowan, and Alder buckthorn to their morphometric parameters.

Morphometric parameters*	Coefficient of determination (R <sup>2</sup> )	Coefficient	Estimate	Standard error	t-value	p-level
<i>Hazel Corylus avellana L.</i>						
H	0.783	a	0.002	0.002	1.276	0.205
		b	3.940	0.331	11.898	0.000
D <sub>1.3</sub>	0.938	a	0.068	0.022	3.099	0.002
		b	2.745	0.141	19.414	0.000
(D <sub>1.3</sub> ) <sup>2</sup> x H	0.932	a	0.012	0.005	2.170	0.032
		b	1.144	0.066	17.234	0.000
D <sub>1.3</sub> and H	0.938	a	0.054	0.034	1.580	0.117
		b	2.694	0.198	13.605	0.000
		c	0.147	0.361	0.409	0.683
D <sub>0.3</sub>	0.912	a	0.031	0.015	2.112	0.037
		b	2.931	0.197	14.815	0.000
<i>Rowan Sorbus aucuparia L.</i>						
H	0.910	a	0.001	0.001	1.671	0.099
		b	5.123	0.412	12.411	0.001
D <sub>1.3</sub>	0.969	a	0.164	0.014	11.196	0.001
		b	2.047	0.081	25.102	0.001
(D <sub>1.3</sub> ) <sup>2</sup> x H	0.975	a	0.063	0.007	8.484	0.001
		b	0.882	0.032	26.981	0.001
D <sub>1.3</sub> and H	0.975	a	0.042	0.014	2.871	0.005
		b	1.646	0.123	13.318	0.001
		c	1.237	0.305	4.041	0.001
D <sub>0.3</sub>	0.988	a	0.070	0.004	14.200	0.001
		b	2.303	0.052	44.087	0.001
<i>Alder buckthorn Frangula alnus L.</i>						
H	0.742	a	0.012	0.010	1.166	0.247
		b	3.166	0.540	5.863	0.000
D <sub>1.3</sub>	0.982	a	0.121	0.011	10.975	0.000
		b	2.480	0.065	38.088	0.000
(D <sub>1.3</sub> ) <sup>2</sup> x H	0.987	a	0.022	0.003	7.265	0.000
		b	1.183	0.031	37.517	0.000
D <sub>1.3</sub> and H	0.988	a	0.043	0.012	3.606	0.000
		b	2.408	0.062	38.323	0.000
		c	0.717	0.179	3.993	0.000
D <sub>0.3</sub>	0.985	a	0.123	0.010	11.830	0.000
		b	2.067	0.050	41.246	0.000

\*Note: H – stem height, m; D<sub>1.3</sub> – stem diameter at 1.3 m height cm; D<sub>0.3</sub> – stem diameter at 0.3 m height, cm; (D<sub>1.3</sub>)<sup>2</sup> x H – square stem diameter at 1.3 m height and stem height; D<sub>1.3</sub> and H – stem diameter at 1.3 m height and stem height.

data showed that there was no reasonable explanation for the use of both diameter (D) and height (H) because height parameter did not change the reliability of the equations. There are a number of important differences between the aboveground biomass assessment of underbrush and

canopy trees. For example, stem diameter (D), height (H), and  $D^2H$  index are often used for the canopy trees stem biomass functions, but they are less informative for estimating crown and leaf or needle biomass [38-39]. In general, when changes in stem diameter, stand age, or

Table 4. Relationships of different biomass components of hazel (*Corylus avellana* L.) to their morphometric parameters.

	Morphometric parameters*	Coefficient of determination ( $R^2$ )	Coefficient	Estimate	Standard error	$t$ -value	$p$ -level
Leaves	H	0.821	a	0.0001	0.000	1.751	0.083
			b	3.491	0.243	14.322	0.000
	$D_{1.3}$	0.931	a	0.017	0.003	4.973	0.000
			b	2.038	0.090	22.518	0.000
	$D_{0.3}$	0.903	a	0.012	0.003	3.858	0.000
			b	2.073	0.111	18.643	0.000
	$(D_{1.3})^2 \times H$	0.926	a	0.006	0.001	3.748	0.000
			b	0.825	0.039	20.955	0.000
	$D_{1.3}$ and H	0.931	a	0.018	0.008	2.114	0.037
			b	2.051	0.183	11.201	0.000
			c	-0.028	0.334	-0.083	0.933
	Branches	H	0.597	a	0.0006	0.000	0.796
b				4.010	0.532	7.527	0.000
$D_{1.3}$		0.800	a	0.003	0.003	1.096	0.275
			b	3.506	0.392	8.934	0.000
$D_{0.3}$		0.778	a	0.0004	0.000	0.699	0.485
			b	4.193	0.584	7.170	0.000
$(D_{1.3})^2 \times H$		0.786	a	0.0002	0.000	0.720	0.473
			b	1.539	0.197	7.785	0.000
$D_{1.3}$ and H		0.800	a	0.007	0.011	0.621	0.535
			b	3.547	0.443	8.007	0.000
			c	-0.296	0.789	-0.375	0.708
Stem		H	0.973	a	0.001	0.001	1.600
	b			3.940	0.264	14.873	0.000
	$D_{1.3}$	0.973	a	0.065	0.012	5.420	0.000
			b	2.563	0.081	31.535	0.000
	$D_{0.3}$	0.949	a	0.034	0.010	3.263	0.001
			b	2.705	0.128	21.020	0.000
	$(D_{1.3})^2 \times H$	0.973	a	0.014	0.003	4.031	0.000
			b	1.060	0.035	29.506	0.000
	$D_{1.3}$ and H	0.975	a	0.029	0.010	2.723	0.007
			b	2.353	0.117	19.979	0.000
			c	0.534	0.215	2.486	0.014

\*Note: H – stem height, m;  $D_{1.3}$  – stem diameter at 1.3 m height cm;  $D_{0.3}$  – stem diameter at 0.3 m height, cm;  $(D_{1.3})^2 \times H$  – square stem diameter at 1.3 m height and stem height;  $D_{1.3}$  and H – stem diameter at 1.3 m height and stem height.

density occur, the values of crown biomass should vary considerably. For canopy trees with the same diameter, crown biomass portion decreases with increasing stand age [38].

Underbrush species grow under limited light conditions (under tree canopy layer), which could explain why their biomass relationships are not comparable to the same relationships for canopy trees. When discussing canopy trees, biomass changes are mostly caused by competition. However, the growth of underbrush species depends more on light regime than on competition [40-41]. Therefore, stem diameter (D) rather than stem height (H) would be better used for estimating total aboveground underbrush biomass. The underbrush stem diameter does not much relate to the growth restrictions compared to underbrush height.

We also tested equations in which crown length was included as an independent variable. In this case,  $R^2$  values were less than 0.45 for buckthorn, and less than 0.85 each for hazel and rowan ( $p < 0.05$ , data not shown).

The obtained theoretical implications of the certain link to practical applications still remain under discussion, since the available data of underbrush species from the Lithuanian National Forest Inventory mainly include underbrush height measurements. As this could be a limitation of using these equations, however, they could be used in practice when underbrush biomass resources should be evaluated in individual stands, as stem diameter measurements are less demanding than height measurements. The obtained equations are basically important for scientific studies, which require accurate underbrush biomass determination. This is also an important issue for future studies based on estimating carbon stocks stored in the underbrush.

## Conclusions

In this study, we presented a set of biomass equations for the common underbrush species hazel (*Corylus avellana* L.), rowan (*Sorbus aucuparia* L.), and alder buckthorn (*Frangula alnus* L.) in Lithuania. The results showed that biomass allocation (portions of stems, leaves, and branches) of hazel, rowan, and buckthorn remained stable throughout the range of sizes for the species. This structure differs from that obtained for the canopy trees, which is characterized by the stem biomass portion increase with tree size.

The highest  $R^2$  values were ascertained between total aboveground biomass and different underbrush components (stems, branches, leaves, and crown) with their stem diameters at 0.3 and 1.3 m heights ( $R^2$  0.77-0.98). Using the complex indicator  $D^2H$  instead of stem diameter,  $R^2$  values changed insignificantly.

When two independent variables (stem diameter and height) were used to assess underbrush biomass of hazels, rowans, and buckthorns,  $R^2$  values also changed insignificantly. These findings may help us understand

that the regularities of biomass changes for underbrush species are not comparable to the same relationships for canopy trees because the growth of underbrush species is more limited by light regime under the canopy than the competition.

## Acknowledgements

The research presented in this paper was from a long-term research program, "Sustainable forestry and global changes," implemented by the Lithuanian Research Centre for Agriculture and Forestry.

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