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Evaluation of silver birch diameter increment model based on data of the Czech National Forest Inventory

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Abstract: In the Czech Republic, the silver birch (*Betula pendula* Roth.) is considered as a pioneer and a soil preparing tree species. It occurs mainly on clearcutting areas after disturbances. The aim of this study was to fit breast height diameter increment model for birch with respect to tree age, share of birch trees and forest site type (ecological series – ES and forest vegetation zones – FVZ). We used data of both cycles of National Forest Inventory of the Czech Republic. We evaluated production potential of this species. We tested Korf and Michailoff increment models in variant of nonlinear least squares model (NLS) and nonlinear mixed effects model (NLME). Michailoff models performed better. We found seven statistically significant and practically applicable models. The greatest influence on increment of diameter at breast height have forest vegetation zone and ecological series whereas the influence of the share of birch in forest stand is smaller. The highest absolute values of diameter increment were on gleyed or enriched with water sites in the fourth forest vegetation zone.

Keywords: growth conditions; Korf function; Michailoff function; share of birch trees; stand production

The use of silver birch as a pioneer, soil preparing and stabilizing tree species has been recently on the rise. In the conditions of the Czech Republic and central Europe, it naturally occurs on large clearcuttings caused by disturbances in previous allochthonous spruce stands. Clearcutting areas are often caused by a combination of biotic and abiotic factors (recently drought as a primary factor and bark beetle, wood-destroying fungi or wind as a secondary factor (Martiník et al. 2017b). It is desirable for these large clearcutting areas not to remain without forest cover for a long time, because irreversible and accelerated mineralization of the humus occurs. This is associated with, for example, a significant reduction of the water retention function of the soil. Tree regeneration is the first step to slow down the adverse processes on large deforested areas and alleviate extreme climatic conditions, as well as to improve soil

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conditions for target tree species. Birch regeneration proceeds either artificially or, if possible, naturally. Target tree species are planted (most often by underplanting) with a time lag (10 to 40 years) after birch. The birch trees usually remain there until the target trees are secured.

Silver birch is a pan-European tree species, which began to return to the territory of the Czech Republic during the ice age with gradual warming. Birch is a light demanding species, which is characterized by its pioneering strategies (it is r-strategist). Its typical feature is rapid occupation of the most habitats (with an exception of flooded areas) over long distances by wind-transferable seeds. The natural area of silver birch extends from the Pyrenees to the Arctic Circle in Europe and further eastwards to Siberia. In the Czech Republic, it occurs from the lowlands to the mountains, with the exception of floodplain forests.

Apart from these, it does not like alkaline soils (Úradníček, Maděra 2001). Due to its light demands, it inhabits southern and southeastern expositions, which can often be drier, but it also grows in habitats of moist and shady edges of forest stands. Birch tolerates frosts very well. Medium-moist sandy-clay soils can be considered the most suitable for birch growth (Válek 1977). From the forestry point of view, silver birch, in the conditions of the Czech Republic, is considered as a pioneer tree species, which serves primarily as a basic soil improving and stabilizing tree species. The Decree of the Ministry of Agriculture 298/2018 Coll. considers birch as a suitable soil improving and stabilizing tree species in several management sets (Pagan 1999; Kula 2011). Fertility in solitary standing birches begins very early, at the age of 10 years, and in birches growing in canopy fertility begins between the ages of 20 and 30 years. It usually bears seeds every year and the wind spreads seeds over long distances – it is an anemochoric species (Úradníček, Maděra 2001).

The use of silver birch varies across the European continent. In the Czech Republic, birch is widely used especially for regeneration of clearcutting areas after disturbances (Kula 2011). For example, Martiník et al. (2017b) state that birch is suitable for spontaneous natural regeneration on calamity clearcuttings after allochthonous spruce stands in Central and Western Europe. This is in accordance with findings of Špulák et al. (2014). In contrast, in northern and eastern Europe, birch is an important commercial tree species (Uri et al. 2012). In the light of potential broad use of birch in large clearcuts, exploration of its production potential seems to be perspective. The rotation of birch on clearcuts after disturbances may be prolonged and enhance, in addition to non-production functions, the production. This is common in northern and eastern Europe.

The aim of silviculture of birch in preparatory and substitute forest stands is to create a stand skeleton from high quality birch trees and at the same time to support target tree species. Target tree species in these stands can be naturally regenerated or can be artificially introduced into these stands 10 to 20 years after their establishment. At this stage, silvicultural interventions could be assessed as positive, directed to the main canopy level (Slodičák, Novák 2008). Although birch is a light demanding tree species, it is also able to regenerate naturally under mature spruce canopy and thus it can be prepared for a faster occupation of emerging clearcuttings in allochthonous spruce stands (Huth, Wagner 2006). Martiník et al. (2017b) also mention this phenomenon in their work. They add that such decaying spruce stands are already heavily stressed by armillaria fungus.

The production potential and growth patterns of pioneer tree species are conditioned by their bionomic strategy (Míchal 1994). Height increment of silver birch usually culminates between the ages of 10 and 20 years (Černý, Pařez 1998). Around the age of 50 years, pioneer trees begin to show declining vitality and at about 100 years of age they begin to die out (Hynynen et al. 2010). Černý and Pařez (1998) mention faster culmination of height and volume increment of pioneer tree species compared to climax ones (spruce, beech). According to Hynynen et al. (2010) in Central Europe there is an earlier culmination of increment compared to northern Europe. According to Kula (2011), birch stands produce valuable commercial wood since the age of 20 years. Hein et al. (2009) add that the optimal age for the value production of silver birch in the conditions of Germany (which can be considered similar to the conditions of the Czech Republic) should not exceed 50 years. Diameter increment is mainly influenced by tree bionomy, site conditions, social status in the stand, climatic conditions, and also biotic and abiotic factors. The diameter increment of silver birch is fast in youth and after that culminates soon (Drápela, Zach 1995).

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Table 1. Basic characteristics of silver birch calculated from the 1st cycle of National Forest Inventory (NFI) and periodic annual increment calculated from both NFI cycles

Variable	Mean value	Standard deviation	Minimum value	Maximum value
Diameter at breast height (cm)	22.01	8.49	7.00	60.80
Total tree height (m)	18.56	5.18	5.60	37.10
Stem volume (m^3)	0.388	0.396	0.009	3.345
Tree age (years)	57.3	20.3	16.0	134.0
Periodic annual increment ($mm \cdot year^{-1}$)	3.03	2.48	–1.93	18.82

The production of forest ecosystems is indirectly affected by their stability (Míchal 1994). For forestry purposes, Stolina et al. (1985) described the stability as resistance potential, which includes mechanical stability and biocentric functional stability, e.g. effect on soil, nutrient chains, etc. (Míchal 1992). The effect of stability may consist in the positive influence of pioneer tree species on the soil or climate and thus contribute to the growth of target tree species (Podrázský 1992). Martiník et al. (2017a) describe the improvement of soil properties and soil chemistry under 15 to 20 years old birch stands compared to spruce stands. Another important step in the future to mitigate climate change is the use of natural processes and thus pioneer tree trees (Mrkva 2009). In the stands of silver birch, the riskiest factor is the disruption of mechanical stability by snow (mainly wet snow), which often damages crowded stands and stands from 10 to 20 meters of their heigh (Nykänen et al. 1997; Martiník et al. 2017b)).

The aim of this study is to evaluate the production potential expressed by diameter at breast height increment of silver birch in relation to the investigated factors (age of the tree, ecological series, share of birch trees in the forest stand and forest vegetation zone). Results should support decision process under what conditions silver birch can also be recommended as a production tree species. Another aim is to evaluate the suitability of different models for modelling the diameter at breast height increment of silver birch.

MATERIAL AND METHODS

The data were obtained from the Forest Management Institute Brandýs nad Labem, data administrator of the National Forest Inventory (NFI). For the project itself, NFI data from both previous cycles (NFI1 and NFI2) were used in order to calculate the increments. Only data of the silver birch trees were processed. Both tree level and inventory plot level approach were used. At the tree level, diameter at breast height, total height and age of the tree were collected. The inventory plot level included data on the habitat – forest vegetation zone, edaphic category (EC), forest site complex (FSC), as well as data on altitude and share of birch trees in the inventory plot (in the forest stand).

Data of 4,361 trees were used for analysis on 1 379 inventory plots of the NFI network. The basic tree characteristics from the first cycle of NFI are given in the Table 1. Due to the small number of trees, individuals from the 6th to 10th forest vegetation zones and also individuals in extreme and peat ecological series were excluded from the analysis. However, this restriction does not fundamentally limit the aim of this study, as it can be assumed that the production function of birch is not primary in the above-mentioned sites. At these sites, birch plays the role of soil improving and stabilizing tree species as well as cover species.

Data analysis. To select the most suitable increment model, nonlinear increment functions according to Korf (1939) (Equation 1):

$$i_{d_i} = ae^{\left(\frac{k}{(1-n)*t_i^{(n-1)}}\right)} k/t_i^{\,n} \tag{1}$$

and according to Michailoff (1943) were tested (Equation 2):

$$i_{d_i} = ae^{\left(-\frac{k}{t_i}\right)} k/t_i^{\,2} \tag{2}$$

where:

i_{di} – periodic annual increment of diameter at breast height of a tree *i*;

a, k, n – model parameters;

t – age of a tree *i*.

The selection of the most suitable function was made on the basis of goodness of fit criteria

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(Akaike's information criterion – AIC, Akaike (1973), mean of residuals, residual standard deviation, root mean square error – RMSE) and also on the basis of practical applicability and complexity of respective model. The model itself was built in two variants. First as a global model using the nonlinear least squares method (NLS model) and then also as a nonlinear mixed effects model – (NLME model) (Lindstrom, Bates 1990), which will have global validity, but thanks to its calibration on plot level, the quality of the model will be close to the local models (e.g. level of forest stand).

Since this is a increment model, the main relationship is that between the diameter increment and the age of the individual tree. To model the diameter increment function, the periodic annual increment was calculated from the NFI data based on the relationship (Equation 3):

$$i_{d_i} = (d_{i_t} - d_{i_{t-n}})/n \qquad (3)$$

where:

I_{di} – periodic annual increment of diameter at breast height of a tree *i*;

d_{it} – diameter at breast height of a tree *i* from the 2nd cycle of NFI;

d_{it-n} – diameter at breast height of a tree *i* from the 1st cycle of NFI;

n – time period between both cycles of NFI at a level of tree *i*.

The following explanatory variables were also tested within the diameter increment model: forest vegetation zone, ecological series and share of birch trees in the forest stand. The ecological series was used instead of the variable edaphic category. The ecological series combines similar edaphic categories. An overview of the forest site complexes of the Czech Republic, which is given in Annex No. 4 to Decree 298/2018 of the Collection (Ministry of Agriculture 2018), was used to include individual edaphic categories in ecological series. The variable ecological series therefore has fewer levels than the edaphic category, which results in easier detection of the influence of different forest site conditions and also easier interpretation of the resulting model. The influence of share of birch trees in the forest stand was evaluated by estimating the parameter *a* of increment functions using a partial linear model (Equation 4).

$$a = a_0 + a_1\, SBT \qquad (4)$$

where:

a – parameter of increment function;

a_0, a_1 – parameters of partial linear model;

SBT – share of birch trees in the forest stand.

The influence of diameter at breast height of a tree and total height of the tree were not tested, because these variables are usually strongly dependent on the age of the tree and thus their addition to the model would cause multicollinearity issue.

The resulting model should therefore provide detailed information on the increment of silver birch diameter based on easily accessible data either from field measurements or, for example, from forest management plan data. Since the resulting model must contain a time factor (individual tree age), it should also be possible to predict the future development of birch stands (through the diameter increment), the importance of which is now on the rise. Data were analysed in R software (R Core Team 2019) at significance level $\alpha = 0.05$.

RESULTS

From all possible combinations of individual explanatory variables, four NLS models and three NLME models were fitted, which were statistically significant and practically applicable. Goodness of fit criteria of these seven model are given in the Table 2. From the values of these criteria is evident that the diameter at breast height increment of silver birch is influenced by its age, forest vegetation zones, ecological series and share of birch trees in the forest stand. The more accurate models are those where the Michailoff function is used. For the NLS model type, it was not even possible to fit a model using the Korf function.

If we compare the NLS and NLME model with the same explanatory variables and using the same increment function, we find that the NLME model provides a lower mean value of residuals and also lower variability of residuals. From the point of view of a practical comparison, we can state, the accuracy of the resulting four NLS models (according to Michailoff) is similar. However, those models that have one more independent variable (FVZ, ES or share birch trees in the forest stand) always fitted slightly better. From the final NLS models listed below, any of them can be recommended for practical use, with the decisive factor being whether the information about the forest site

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Table 2. Goodness of fit criteria of final diameter increment models of silver birch

Function	Model	Explanatory variable	Mean value of residuals	Residual standard deviation	RMSE	AIC
Michailoff	NLS	TA	0.0461	2.2410	2.2413	7042.96
		TA, FVZ	0.0343	2.2197	2.7306	6958.75
		TA, ES	0.0479	2.2145	2.8109	6939.23
		TA, SBT	0.0447	2.2393	2.2395	7020.92
Michailoff	NLME	TA	0.0368	1.5792	1.5794	3990.35
		TA, FVZ	0.0368	1.5796	1.5799	3993.08
Korf	NLME	TA	0.1254	1.6383	1.6429	4336.06

RMSE – root mean square error; AIC – Akaike´s information criterion; NLS – nonlinear least squares model; NLME – nonlinear mixed effects model; TA – tree age; FVZ – forest vegetation zone; ES – ecological series; SBT – share of birch trees in the forest stand

(FVZ and ES) and about share of birch trees in the forest stand is available at the given locality. For the resulting NLME models according to Michailoff, the values of all goodness of fit criteria are almost identical, so they can be evaluated from the quality point of view as practically the same. When using the NLME model, it is not necessary to know site information about FVZ, because this information will not increase the final model quality.

Estimated parameters of NLS models (according to explanatory variable) and of the best NLME model are shown in the Table 3. Fitted curves of NLS diameter increment of silver birch related to share of birch trees in the forest stand are in the Figure 1. In the Figures 2 and 3 are fitted curves of NLS diameter increment of silver birch related to ecological series and forest vegetation zones respectively. The results show that effect of share of birch trees in the forest stand is negative, it means that with increasing share of birch trees in the forest stand the diameter increment is decreased.

From the Figure 1 is evident that this effect is very small (in the time of increment culmination is difference 0.5 mm·year^{-1}). Bigger differences are connected with the effect of ecological series. The Figure 2 shows that at sites characterized by ecological series with higher amount of nutrients (nutrient-rich and enriched with humus) are smaller absolute values of diameter increment (and increment is culminated lately) than at sites characterized by ecological series with higher amount of water (gleyed and enriched with water).

Absolute values of diameter increment are higher and their culmination is faster on acidic sites compared with nutrient rich and enriched with humus sites (Figure 2). A significant effect of forest vegetation zones on the values of diameter increment can be observed too (Figure 3). Curves of diameter increment model from first to fourth forest vegetation zone are similar. The differences are only in the absolute values of increment in the time of culmination, where the increment connected with fourth FVZ is the highest and connected with the first FVZ is the smallest. The absolute values of silver birch diameter increment are smaller at sites from fifth FVZ, but only to the age of 40 years. From this time is the curve of diameter increment similar with curves from first to fourth FVZ. Significantly smaller diameter increment is at azonal forest sites with dominant Scots pine (*Pinus sylvestris* L.).

DISCUSSION

Drápela and Zach (1995) describe diameter increment as fast in youth, which, however, reaches an early culmination and subsequently slows down. Our results are in accordance with this finding. We add that, in the conditions of the Czech Republic, the culmination of diameter increment of silver birch occurs between 16 to 35 years of age, depending on the tested factors.

On the contrary, Nieuwenhuis and Barrett (2002) claim that the downy birch diameter increment culminates between 5 and 20 years of age. However, they published these values for the Ireland. The fact that the diameter increment of silver birch is the highest at the age of 20 was confirmed by Niemistö (1994), who adds that the diameter increment depends on stand density and the highest increment values are achieved with 2 500 to 5 000 trees per

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Table 3. Estimated parameters of final diameter increment models of silver birch (Michailoff function)

Model	Explanatory variable	Parameter	Estimation	SE	*t*-value	*P*-value
NLS	TA	*a*	435.355	4.641	93.80	< 0.0001
		k	41.307	1.408	29.34	< 0.0001
NLS	TA, FVZ	*a* (FVZ 0)	365.826	16.502	22.17	< 0.0001
		a (FVZ 1)	410.394	24.493	16.76	< 0.0001
		a (FVZ 2)	446.586	17.598	25.38	< 0.0001
		a (FVZ 3)	449.471	10.849	41.43	< 0.0001
		a (FVZ 4)	455.219	12.455	36.55	< 0.0001
		a (FVZ 5)	441.232	22.203	22.25	< 0.0001
		k (FVZ 0)	49.519	6.676	7.42	< 0.0001
		k (FVZ 1)	42.334	6.406	6.61	< 0.0001
		k (FVZ 2)	45.086	5.732	7.865	< 0.0001
		k (FVZ 3)	46.133	3.200	14.42	< 0.0001
		k (FVZ 4)	44.040	3.616	12.18	< 0.0001
		k (FVZ 5)	51.022	2.823	18.07	< 0.0001
NLS	TA, ES	*a* (acidic)	414.264	7.632	54.28	< 0.0001
		a (nutrient-rich)	454.653	9.179	49.53	< 0.0001
		a (enriched with humus)	451.660	32.257	14.00	< 0.0001
		a (enriched with water)	545.365	23.149	23.56	< 0.0001
		a (gleyed)	485.809	15.191	31.98	< 0.0001
		a (wet)	342.589	20.923	16.373	< 0.0001
		k (acidic)	38.245	2.318	16.501	< 0.0001
		k (nutrient-rich)	48.815	2.439	20.02	< 0.0001
		k (enriched with humus)	63.990	7.357	8.70	< 0.0001
		k (enriched with water)	42.535	7.679	5.54	< 0.0001
		k (gleyed)	31.424	3.298	9.529	< 0.0001
		k (wet)	35.935	7.524	4.78	< 0.0001
NLS	TA, SBT	a_0	450.974	7.518	59.99	< 0.0001
		a_1	–0.410	0.155	–2.64	0,0084
		k	40.845	1.415	28.86	< 0.0001
NLME	TA	*a* (FP)	468.243	8.024	58.358	< 0.0001
		k FP)	47.722	1.860	25.661	< 0.0001
		a (SD RE)		218.501		
		RSD		1.736		

SE – standard error of parameters; NLS – nonlinear least squares model; NLME – nonlinear mixed effects model; TA – tree age; FVZ – forest vegetation zone; ES – ecological series; SBT – share of birch trees in the forest stand; a, a_0, a_1, k – model parameters; FP – fixed part of model parameters; SD RE – standard deviation of the random part of the parameter; RSD – residual standard deviation

hectare (in a 20 years old stand). The average annual diameter increment according to Hynynen et al. (2010) is 3 to 4 mm·year^{-1} in optimal conditions (northern Europe). However, in the Czech Republic, depending on the site conditions and in the age range of 15–40 years, it was found, that increment could be higher even up to 2.5 times. The high growth rate predetermines the silver birch to be used not only as a pioneer tree speies, but also as a short rotation tree species (Telenius 1999).

Cameron (1996) states that silver birch grows best in the site conditions that are sufficiently moist

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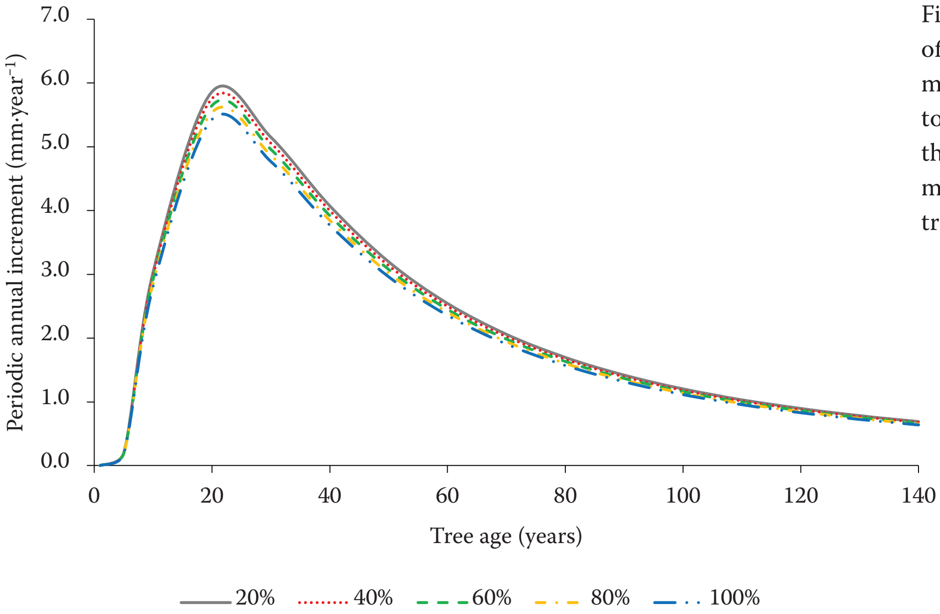

Figure 1. NLS model (Michailoff function) of diameter increment of silver birch as related to the share of birch trees in the forest stand (different lines mean different share of birch trees – in percentage)

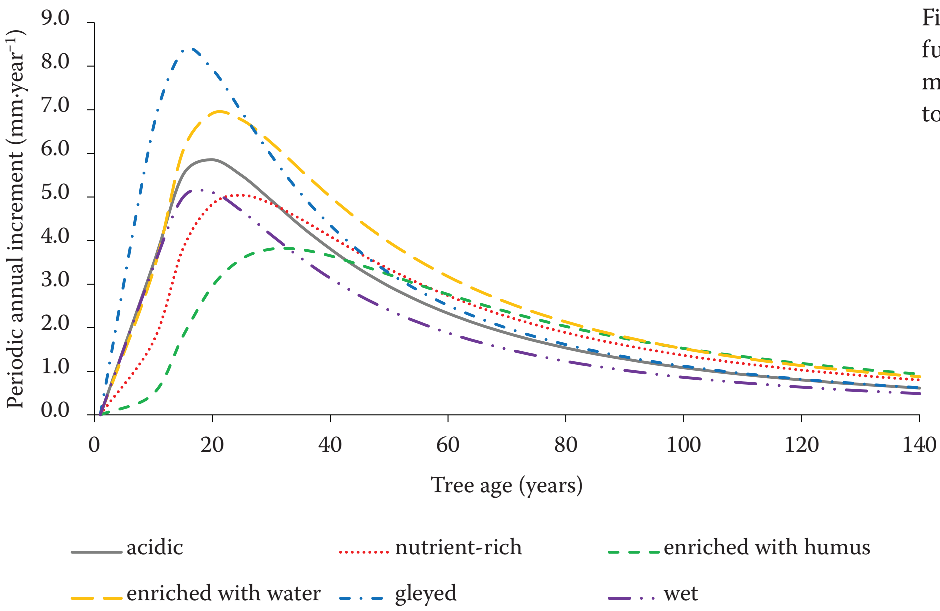

Figure 2. NLS model (Michailoff function) of diameter increment of silver birch as related to ecological series

but not waterlogged. This is also confirmed by our results, where the best increment was achieved by in sites enriched by water and gleyed. Niemistö (1995) also states this and draws attention to the unfavourable development of silver birch in waterlogged site conditions. The positive effect of precipitation and subsequent soil water content is also described by Zhang et al. (2017).

They add that the amount of water has greater effect on the increment than air temperature. We can see similar results in our work, where the influence of sites from the point of view of nutrient and water content has a greater variance of diameter increment than the influence of temperatures, which can be assessed according to the classification of individual sites into forest vegetation zones.

Forest vegetation zones are defined by climatic conditions (Viewegh et al. 2003), which include air temperature. The exception is forest vegetation zone 0 – azonal forest sites with dominant Scots pine, which is mainly dependent on soil properties (Viewegh et al. 2003). One of the main soil property

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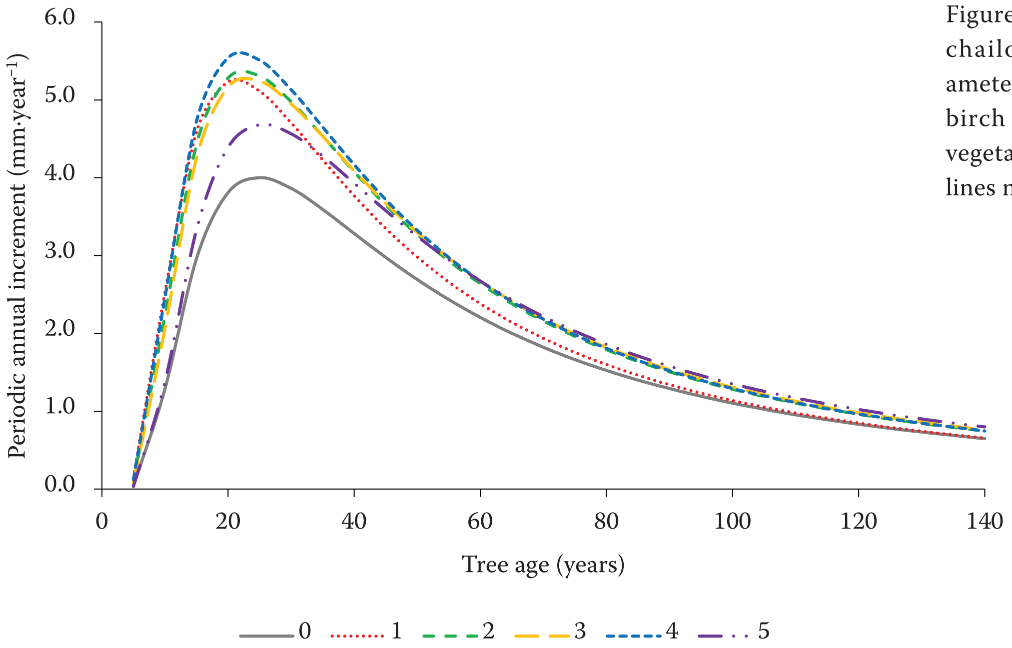

Figure 3. NLS model (Michailoff function) of diameter increment of silver birch as related to forest vegetation zones (different lines mean FVZ 0–5)

is amount of available water in soil profile. And the amount of available water in soil profile is important factor for growth of silver birch. We found that silver birch diameter increment is smaller at azonal forest vegetation zone than at other forest vegetation zones (FVZ 1–5). Hence we assume growth in near or at the ecological limits of silver birch at azonal forest vegetation zone frequently typical with sand and loamy sand (generally well drained) soil forming substrate (Mikeska et al. 2008).

However, the silver birch could grow at such sites in normal year, the evident ecovalence leads to stress during summer drought (caused by lack of available water) (Perala, Alm 1990; Sazonova et al. 2012) which results either in increased mortality or decreased increment values. The climatological events of last five years (mainly summer drought) (cf. Ďurský et al. 2006) exhibit for such species as silver birch escalation of stress (caused by lack of available water) when episodically exceeded ecological limits based on edaphic site properties. With regard to its diameter increment and yield, silver birch can be considered sufficiently eligible to become a commercial tree species (in case of forest site conditions which were tested in this study) as it is in northern Europe (Uri et al. 2012).

When using the NLME model, the practical possibility of model calibration is essential. In order to be able to calibrate the NLME model, it is necessary to have at least one value of the dependent variable available at a given level (in this case at the level of the inventory plot) – i.e. the tree diameter increment. This is not a problem with repeated measurements on the same plots. It is enough to measure the diameter of only one tree, then take the diameter from the previous inventory and calculate the tree diameter increment and use it for model calibration at the given plot. This variant is not possible with a single measurement.

The only way to calibrate the NLME increment model for such plot is to take the increment core sample and measure the increment for a required period. However, if this destructive method cannot be used, then it is not possible to calibrate the model. Then the marginal model (part of the NLME model with fixed part of the parameters only) or the local NLS model must be used. In such a case, the NLS model is used more often, which was recommended, for example, by Miguel et al. (2012).

This study was carried out to investigate the growth potential of silver birch due to changing climatic conditions and test silver birch. As a result of climate changes, an increase of temperature and an extension of the growing season can be expected, in particular an increase in the average temperature by 1–2 °C in summer and 2–3 °C in winter. This would result in higher primary production and increased carbon sequestration in forest ecosystems (Reich, Schlesinger 1992; Kirschbaum 1994). Higher temperatures can also accelerate decomposition of organic matter in the soil and thus increase the availability of nutrients in the

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soil (Melillo et al. 1993). In general, the concentration of atmospheric CO_2 increases with higher temperatures, which may be another guarantee of faster tree growth, but in this case the availability of water in forest stands is limiting (Kellomäki, Väisänen 1996). From these findings, it can be concluded that the silver birch can grow faster, and in terms of its ecological amplitude, we can expect less predisposition than in other tree species. This statement is opposed by Briceño et al. (2006) who reported that tree growth increased only slightly with increasing air temperature and confirmed that precipitation has become a limiting factor.

The results show the best possible combinations of tested factors for the growth and increment of silver birch. However, based on the information from our dataset we can confirm that silver birch occurs in the most of forest sites with different ecological conditions. According to this, we can say that silver birch is able to naturally regenerate most of the clearcutting areas caused by disturbances regardless of the ecological conditions of the forest site. We found similar results in the work of Kula (2011), who considers silver birch to be a suitable tree species for clearcutting areas caused by disturbances.

The occurrence of silver birch across site conditions and clearcutting areas caused by disturbances is also mentioned by Martiník et al. (2017b). The wide ecological amplitude, relatively low demands on nutrients and resistance of silver birch to direct sunlight (resistance to high temperatures in the middle of clearcutting areas) are undoubtedly important factors in solving the current calamity situation, where the tree regeneration of large overheated clearcutting areas becomes a very difficult task.

CONCLUSION

A total of four NLS and three NLME statistically significant and practically applicable models were compiled from the tested combinations of variables. The models show a clear influence of tree age, forest vegetation zone, ecological series and share of birch trees in the stand on the diameter increment.

Models that used the Michailoff function were evaluated as more accurate. Lower mean value of residuals and also residual variability were found in the NLME models.

All of the above NLS models can be recommended for practical use, with the decisive factor being whether there is information on the site (FVZ and ES) and on the share of birch in the stand. When using the NLME model, it is not necessary to know information about FVZ, because when implementing it, we will not achieve the expected refinement of the model. With increasing share of birch in the stand, its increment decreases. From a practical point of view, the most optimal habitats with regard to the diameter increment are gleyed and enriched with water sites in lower and middle altitudes.

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