Acta Biol. Univ. Daugavp. 17 (2) 2017
ISSN 1407 - 8953

BIRCH TREE RESPONSE TO DIFFERENT ENVIRONMENTAL AND METEOROLOGICAL CONDITIONS IN LITHUANIA

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Araminienė V., Varnagirytė-Kabašinskienė I., Stakėnas V. 2017. Birch tree response to different environmental and meteorological conditions in Lithuania. *Acta Biol. Univ. Daugavp., 17 (2): 133 – 140.*

The objective of this study was to evaluate impact of meteorological factors (temperature and precipitation) and different soil humidity and fertility on crown defoliation and tree mortality of silver (*Betula pendula* Roth) and downy (*Betula pubescens* Ehrh.) birches in Lithuania. This study could provide a comprehensive view of more or less suitable sites for planting productive birch plantations.

The crown defoliation of birches was assessed annually starting from 1991 up to 2014 on the permanent observation plots of the Forest Monitoring Level I. For the data analysis, forest sites classification and actual meteorological data were used. The correlation analysis was used to find the relationships between temperature, precipitation and birch trees condition. The mean annual air temperature and amount of precipitation of the current and previous hydrological years were used. Aiming to find the relationship between the meteorological factors and birch defoliation in the forest sites with different soil humidity, a backwards elimination multiple regression model was used.

The study findings showed that lower defoliation of silver birch was found for the birches growing in more humid sites and for downy birches on the dryer sites. The highest birch mortality was found in normally moistured and permanently overmoistured forest sites. The correlation between meteorological factors and birch crown defoliation was not strong, except some cases for the birches growing in the forest sites with normal humidity.

Key words: birch species, defoliation, forest sites, mortality, precipitation, temperature.

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INTRODUCTION

Recently, more attention has been focused on the changing environment followed by direct and indirect plant responses, both globally and locally. The climatic changes could induce changes in the forest sites, including soil moisture and fertility, and, consistently, the vegetation growth and resistance could be affected.

Under non drastic impact of climatic changes, variations in soil humidity could be observed. We raised the hypothesis that the gradient of the natural environmental conditions, especially site humidity and fertility, at a local scale could be applied as a basis for this case study. Several authors examined the impact of forest site on tree biomass production (DeLucia et al. 2007; Goulden et al. 2011). Interactions between forest site and tree growth were discussed for individual tree species, for instance, a case of Norway spruce was analysed by Stakenas and Žemaitis (2014).

Generally, forests growing on soils with low-nutrient pools due to the weathering, leaching, and low mineralisation rates should have lower potential for tree growth. On the contrary, trees growing on more fertile soils should have higher diameter followed by increased biomass production. Earlier studies had not confirmed significant impact of climate zone, forest type or stand age on biomass production efficiency. However, Vicca et al. (2012) indicated that biomass was affected by nutrient availability.

As different forest sites with varying soil humidity and fertility have an impact on tree health, this should act as precondition factor for tree growth as well. Defoliation change, being one of tree health indices that reflects site specifics (soil fertility, moisture) and climatic fluctuations is not necessarily equivalent to the damage intensity and could be considered as an indicator of tree plastic equilibrium in a certain environment (Pollastrini et al. 2016). The crown defoliation correlates with the effects of environmental stress and climate change (Van Leeuwen et al. 2000; Bussotti et al. 2015).

Silver (*Betula pendula* Roth) and downy birch (*B. pubescens* Ehrh.) are birch species commercially important both for European and Lithuanian forestry sector. Being the most abundant species compared to other deciduous tree species, birches are widely distributed and grow naturally on peatlands, poorly drained soils, and the sites of different fertility. However, studies comparing the birch species growth and health conditions on different forest sites are still rare. The identification of the most optimal forest sites for the productive and sustainable birch plantations would improve the theoretical knowledge and could give a more reasonable links to the future forest management adaptations.

The aim of this study was to assess the growth, crown defoliation and mortality of silver and downy birch growing in the forest sites with different fertility and humidity.

MATERIAL AND METHODS

The study area is described as temperate forests of central Europe, which cover the whole territory of Lithuania. The climate of the country is described as typical oceanic to continental mild climate with warm, dry summers and fairly severe winters. The mean annual temperature ranges from 6.5º C to 7.1°C near the Baltic Sea up to 5.5°C in North-eastern part, and the mean annual precipitation is 630 mm. The total forest land area covers 34% of the Lithuanian territory with the dominant coniferous species (56%) and softwood deciduous forests (40%). Among deciduous trees, birch species cover the largest area.

A case-study approach was chosen to evaluate tree defoliation and tree mortality of two most common birch species silver birch and downy birch growing on the forest sites with different fertility and humidity. The data used for this analytical study was collected under the Forest Monitoring Level I, being a part of ICP-Forests program (International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests, ICP Forests programme, www.icp-forests.net). The crown defoliation of birch trees was assessed annually starting from 1991 up to 2014 on the permanent observation plots. These plots were established on the national and transnational grids. The defoliation assessment was done annually in the period from August till the middle of September. The total number of assessed birch trees during the 25-year period was about 22 thousand units. Defoliation was defined as birch leaf loss in the crown, compared with a reference tree. To assess the health of forests, crown defoliation was assessed in 5% steps following ICP Forest manual (Eichhorn et al. 2010).

The growth-independent birch mortality was calculated as a percent of dead trees from all annually assessed trees for the period from 1991 to 2014. For the data comparison, Lithuanian forest sites classification described by Vaičys et al. (2006) was used. Over the forested land, forest sites with normal moisture (N-sites) comprised about 43 percent; temporarily overmoisted (L-sites) – near 34 percent; the sites with permanently overmoisted soils (U-sites) – 5.5 percent and peatland soils (P-sites) – 8.3 percent (Stakenas, Žemaitis 2014). Differences among all assessed tree characteristics, including age and density were insignificant.

For data statistical analysis, the normality of the variables was checked by Lilliefors and Kolmogorov-Smirnov tests. As the normality hypothesis was rejected, the Kruskal-Wallis analysis of variance (ANOVA) test was used. Statistical analyses were conducted using the software Statistica 7.0, and a level of significance of $\alpha = 0.05$ was chosen in all cases. To identify the relationships between temperature, precipitation and defoliation of birch species the correlation analysis was done. The relationship between meteorological factors and birch defoliation in the sites with different humidity was checked by a backwards elimination multiple regression model.

RESULTS

Birch health response to site fertility and humidity

During the estimated 1991–2014-years period, the mean crown defoliation of silver birch and *B. pubescens* did not significantly depend on site humidity, and varied within the range of 18.67 and 24.97% (Fig. 1).

The crown defoliation of silver birch did not significantly depend on the site humidity. However, slightly higher

defoliation of silver birch was found in normally moistured (N-sites) and temporarily overmoisted (L-sites) forest sites. Contrary to silver birch, evidently higher mean defoliation of downy birch was recorded in the peatland soils (P-sites).

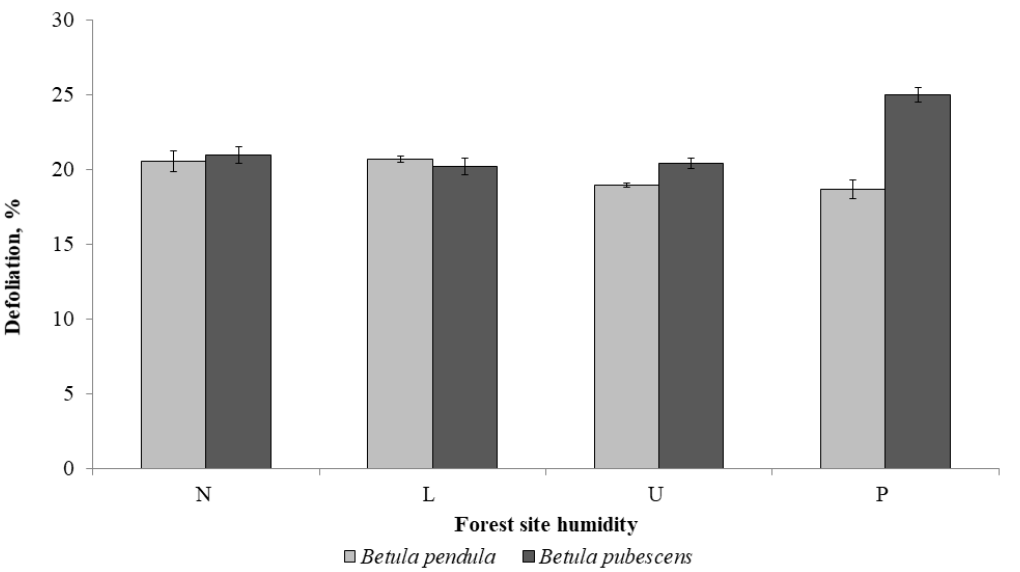

Fig. 1. Defoliation (%) of silver and downy birches growing in the sites of different humidity. Values are given as the mean±SE.

Table 1. Percent of damaged birches from all assessed trees in the sites of different humidity and fertility during the period of 1991–2015. Values are given as the mean±SE

Site fertility index*	Site humidity index			
	N *(normal moisture)*	L *(temporary overmoistured)*	U *(permanently overmoistured)*	P *(peatland)*
	Percent of damaged silver birches			
a *(very oligotrophic)*	4.26 (n=2)	-	0	25.00 (n=4)
b *(oligotrophic)*	16.44 (n=274)	17.80 (n=115)	12.50 (n=8)	0
c *(mesoeutrophic)*	15.45 (n=453)	14.77 (n=514)	6.25 (n=96)	0
d *(eutrophic)*	16.96 (n=153)	16.97 (n=556)	5.15 (n=194)	17.65 (n=51)
f *(very eutrophic)*	21.60 (n=62)	20.89 (n=324)	33.33 (n=3)	0
Mean	**16.18 (n=944)**	**16.85 (n=1509)**	**6.00 (n=301)**	**8.40 (n=55)**
	Percent of damaged downy birches			
a *(very oligotrophic)*	25.00 (n=2)	0	0	0
b *(oligotrophic)*	27.60 (n=61)	33.93 (n=38)	0	5.54 (n=202)
c *(mesoeutrophic)*	16.13 (n=85)	13.86 (n=125)	9.62 (n=312)	24.55 (n=277)
d *(eutrophic)*	10.34 (n=9)	13.56 (n=93)	26.76 (n=142)	10.68 (n=103)
f *(very eutrophic)*	9.09 (n=2)	17.29 (n=23)	0	0
Mean	**18.38 (n=159)**	**15.22 (n=279)**	**14.91 (n=454)**	**17.55 (n=582)**

* Site fertility and humidity indexes are shown according to the Lithuanian forest sites classification.

Table 2. Coefficients of correlation between the defoliation of silver and downy birches and average monthly temperature and precipitation

	Silver birches					***Downy birches***				
	Site humidity index									
Periods	**All**	**N**	**L**	**U**	**P**	**All**	**N**	**L**	**U**	**P**
T_IV	0.0680 p=0.758	0.1034 p=0.639	-0.0583 p=0.792	-0.0776 p=0.725	-0.1725 p=0.431	-0.1935 p=0.376	0.115 p=0.601	-0.0892 p=0.686	-0.2796 p=0.196	-0.1883 p=0.390
T_V	-0.1156 p=0.599	0.0279 p=0.899	-0.2527 p=0.245	-0.1301 p=0.554	0.1154 p=0.600	0.3187 p=0.138	0.2196 p=0.314	0.1737 p=0.428	0.2085 p=0.340	0.1174 p=0.594
T_VI	-0.1418 p=0.519	-0.0822 p=0.709	-0.0468 p=0.832	0.2056 p=0.347	0,0038 p=,986	-0,1168 p=,596	-0,0611 p=,782	-0,1155 p=,600	0,0463 p=,834	0,1097 p=,618
T_VII	0,1296 p=,556	0,1083 p=,623	0,0921 p=,676	-0,0029 p=,990	0.2416 p=0.267	0.2965 p=0.170	0.0867 p=0.694	0.0767 p=0.728	0.3416 p=0.111	0.3683 p=0.084
P_IV	0.0685 p=0.768	0.3349 p=0.138	0.0613 p=0.792	0.1139 p=0.623	-0.1812 p=0.432	-0.0025 p=0.991	0.2253 p=0.326	-0.1311 p=0.571	-0.1425 p=0.538	0.0518 p=0.824
P_V	0.1340 p=0.563	-0.0588 p=0.800	0.3003 p=0.186	0.1833 p=0.426	0.1378 p=0.551	-0.0005 p=0.998	0.0807 p=0.728	-0.0644 p=0.782	-0.1096 p=0.636	0.1588 p=0.492
P_VI	0.2626 p=0.250	-0.2167 p=0.345	0.0817 p=0.725	-0.0034 p=0.988	0.4273 p=0.053	0.3661 p=0.103	0.0906 p=0.696	0.2858 p=0.209	0.3571 p=0.112	0.1081 p=0.641
P_VII	0.1063 p=0.647	-0.1570 p=0.497	-0.0052 p=0.982	0.0234 p=0.920	0.2845 p=0.211	0.3745 p=0.094	0.1842 p=0.424	0.3437 p=0.127	0.1842 p=0.424	0.0665 p=0.775

Table 3. Coefficients of stepwise multiple regression of defoliation and meteorological factors (1991–2015)

Type of regresion, *n*	Linear regression model	F	p	R2 tdj.
Df(BK)	Df=16.82+0.42*TVpr.+0,04*KXIIpr.-0,48*TXpr.	8,56	<0,001	0,51
Df(BP)	Df=12,10+0,90*TIXpr.+0,72TXIpr.+0,05KVIIpr.-0,91TXpr.	9,42	<0,001	0,60
Df(BK_N)	Df=47,12-0,06*KXIpr.-0,87*TVIpr.-1,34*TXpr.	12,26	<0,001	0,61
Df(BK_L)	Df=10,03+0,63*TVpr.-0,22*TIIpr.+0,04*KV	4,83	<0,011	0,33
Df(BK_UP)	Df=20-0,08*KIII-0,41*TIpr.	5,73	<0,010	0,29
Df(BP_N)	Df=37,66-1,71*TXpr.-0,09*KIpr.	4,93	<0,018	0,25
Df(BP_L)	Df=20,39+0,48*KXpr-0,52*TXpr	4,94	<0,017	0,26
Df(BP_UP)	Df=2,03+1,01*TVII+1,00*TXIIpr.+0,72*TXIpr.-0,83*TIII+0,03*KVIIpr.	9,39	<0,0002	0,66

D - average defoliation (%), H- number of healthy trees (%), T - temperature (°C) (where number express month or period), P - amount of precipitation (mm) (where number express month or period), pr - previous hydrological year.

The highest, more than 20%, number of damaged silver birch trees was observed in very fertile (very eutrophic) forest sites with normally moistured and temporary overmoistured soils (Table 1). On the contrary, the highest number (almost one third of all assessed trees) of damaged downy birch trees was found in relatively poor forest sites.

The correlation analysis showed no significant relationship between average air temperature and precipitation of the individual months from April to July and crown defoliation of birches (Table 2). These results differed much from the results obtained in a Norway spruce case, which showed statistically significant relationships for July air temperature and spruce defoliation (Stakenas, Zemaitis 2014). However, correlation between the crown defoliation of silver birch and air temperature showed tendency of higher mean air temperature of July and higher crown defoliation. The same correlation was found for silver birch trees growing in the sites with normal moisture, also temporarily overmoistured forest sites and peatland soils. Silver birch defoliation decreased when the amount of precipitation in July was higher. This tendency differed than Silver birch growth in normally moistured, temporarily overmoisted forest sites.

The study results showed that crown defoliation of downy birch decreased when mean air temperature of July was higher. Similar tendency was found in the forest sites of all humidity indices. The amount of precipitation in July was affected downy birch crown defoliation in the same way like air temperature.

The regression analysis showed that about 51% cases of silver birch defoliation were caused by meteorological conditions (air temperature and precipitation) (Table 3). Moreover, these conditions explain about 60% of downy birch defoliation cases.

With increasing habitat humidity, the regression model becomes less significant for silver birch. However, tendency for downy birch was totally different and the regression model significantly increased for the peatland soils.

Birch trees mortality in Lithuania

During the 1991–2015-year period, the highest percent of dead silver and downy birch trees was recorded in the permanently overmoistured forest sites. The annual mortality rate of silver birch was by 58% higher than downy birch in this forest site (Table 4). No clear dependence

Table 4. Mean annual birch mortality (%) in the forest sites of diferent humidity during period of 1991-2015

Site humidity index	*Silver and downy birches*	*Silver birch*	*Downy birch*
	Mean annual mortality, %		
N *(normal moisture)*	1.4	1.4	1.5
L *(temporary overmoistured)*	0.8	0.8	1.1
U *(permanently overmoistured)*	1.5	1.9	1.2
P *(peatland)*	0.9	1.1	0.9

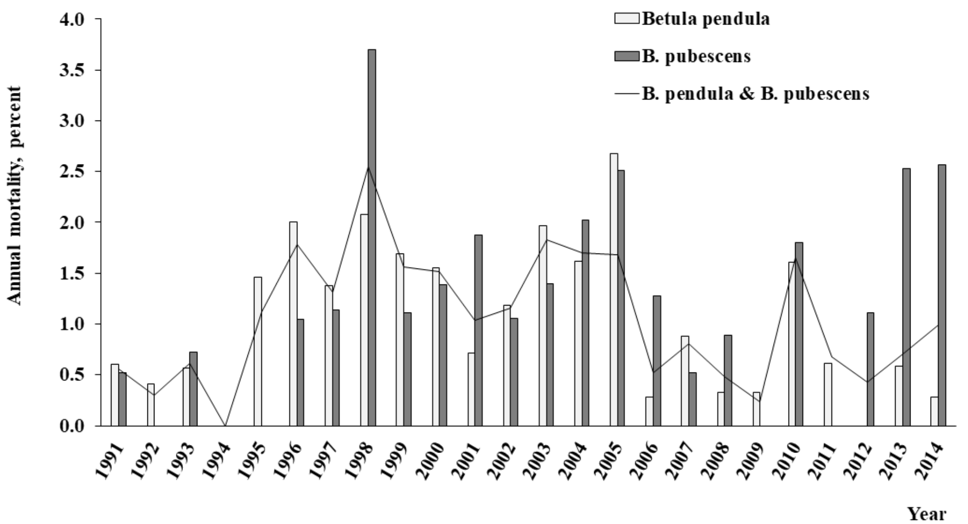

Fig 2. Changes in birch tree mortality (%) during the period of 1991-2014 (Forest monitoring data).

was identified between the birch annual mortality rate and forest site humidity. The highest annual silver birch mortality was found in the sites with permanently overmoistured soils, for downy birch – in the sites of normal moisture.

The annual birch mortality higher than 1 percent was observed in the period from 1995 to 2005 (Fig. 2). A slight decrease trend of annual mortality was recorded about a decade ago. During the studied period the annual mortality rate of downy birch was by 1.2 times lower compared with the silver birch. However, the mortality rate for both birch species varied from year to year. In the recent years, the annual mortality started to increase for downy birch. For example, it exceeded the mortality of silver birch by several times in the period of 2012–2014.

DISCUSSION

Summarising the main findings, better crown condition or lower defoliation of silver birch trees was recorded in more humid sites. However, higher percent of downy birch trees with lower defoliation were obtained in the dryer sites. On the other hand, these results could be associated with large variability of assessed trees per each site.

Hytönen et al. (2013) studied the differences between silver and downy birches, growing on organic and mineral soils. The mentioned study showed that silver birch had a higher mean annual increment than downy birch on mineral soils but no significant differences between two species growing on organic soil were found. However, it remained unclear, whether birches growing on the nutrient rich sites are more or less resistant than those growing on the nutrient poor sites.

The increasing defoliation, as a response of various environmental changes, could exponentially increase tree mortality which often is referred as a key process in forest ecosystems (Ozolincius et al. 2005). The mentioned index – tree mortality – could also be used as a tool for the assessment of stand sustainability. Lorenz at al. (2000) concluded that the annual tree mortality rate of different tree species in Europe varied between 0.1 and 0.8%. The findings of our study indicated that the mortality rate of birched varied for year to year and differed among forest sites with different soil humidity. But, anyway, the annual birch mortality in Lithuania for the studied period was within the European range.

Hallinger et al. (2016) noted that key factors for birch mortality were tree height and wet soil. The mortality of birch increased with increasing tree height. We also predicted that silver and downy birches growing on non-typical forest sites would have higher defoliation and mortality rate. For example, Koski (1991) noted that birches growing on infertile sites form the stands of poor quality. The most important site characteristics for the vigorous growth of silver birch are adequate moisture and air content (Hynynen et al. 2010). The excessive moisture content in the soil leads to lack of oxygen, and this causes a negative impact on forest site productivity and birch growth. These results were explained in the previous studies, which concluded that about 98% of silver birch trees grow in the mature forest stands on the normally moistured soils, otherwise, lower birch percentage was found in the temporary overmoistured and peat soils (Bareika 2008).

The defoliation change, assigned as a tree health index reflecting site specifics and climatic fluctuations, cannot be referred as a key indicator for the evaluation of all species health reaction. Despite relatively good correlation between the crown defoliation and environmental changes (Van Leeuwen et al. 2000; Bussotti et al. 2015) in general case, some species respond in different way or much slightly than others. The slight dependence between the crown defoliation of birches and meteorological conditions reconfirms the silver and downy birches as flexible widely distributed species. Overall, this study strengthens the idea that to identify the most optimal forest sites for sustainable birch plantations, further research should be undertaken on longer-term and larger scale.

CONCLUSIONS

Lower defoliation of silver birch was recorded for the birch trees growing in more humid sites and for *B. pubescens* – growing in the dryer sites. The correlation analysis showed no significant relationship between average air temperature and precipitation of the individual months from April to July and crown defoliation on both silver and downy birches. Acting together, air temperature and precipitation influenced by 51% crown defoliation cases of silver birch and by 60% cases of downy birch. The highest birch mortality was found in the forest sites with normal moisture and also permanently overmoistured sites, i.e. no clear dependence between annual birch mortality and site humidity was found.

ACKNOWLEDGEMENT

The paper presents research findings obtained through the long-term research programme “Sustainable forestry and global changes” implemented by the Lithuanian Research Centre for Agriculture and Forestry.

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Received: 30.05.2017.
Accepted: 14.10.2017