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DEFOLIATION EFFECTS ON THE BIRCH GROWTH: LITHUANIAN CASE STUDY

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The impact of defoliation was estimated in Lithuanian birch experiment where one-year-old silver birch (*Betula pendula* Roth) seedlings were damaged by 25, 50 and 75% defoliations in 2014. The birch growth and biomass were monitored during a two-month period. The study findings showed that induced defoliations decreased birch growth. At the end of the experiment, the 75% defoliation significantly reduced the total dry mass of birch saplings but not the total productivity or cumulative dry mass. The dry mass of leaves was reduced almost twice in the 75% defoliated seedlings while the total production became close to the control level and showed even increase trend.

The 75% defoliation by 12% reduced the main-stem diameter and by 1.4 times root dry mass. The response of other defoliation treatments was not as much significant. The defoliated birch seedlings fully compensated for the removal of leaf and all aboveground biomass in two months post-defoliation. However, total dry mass of birch seedlings remained reduced.

Additionally, based on the forest monitoring data in Lithuania, we tested and asserted the idea that tree radial increment decreased by 20% when the defoliation increased by 10% in mature stands. The results showed that birch radial increment decreased almost by 50% following the defoliation increase from 10 to 20%. However, only weak dependence between the defoliation and increment were further obtained.

Key words: *Betula pendula*, artificial defoliation, growth compensation, radial increment.

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INTRODUCTION

In recent years, there has been an increasing interest in climate change induced consequences on various indices of forest stands. Nevertheless, basic forest health and growth parameters, including their interdependencies, further remain not less important. Combining the mentioned parameters with climate change impact, as abiotic factor, the research based on the changes of forest growth and stand condition is becoming even more relevant both at regional level and in a wider context.

Some of the most important frequently analyzed parameters are defoliation and tree increment (height and radial increment), changes in biomass of different above- and below-ground tree compartments and biomass allocation and, occasionally, photosynthetic parameters may also be measured.

Defoliation, caused by various environmental factors, reduces the photosynthetic area and decrease leaf area per tree. Consequently, many growth indices may change, including photosynthetic activity, height growth, biomass and growth rates (Mattson et al. 2004, Schat & Blossey 2005, Huttunen et al. 2007). The negative effect of defoliation on growth rate or final biomass is usually proportional to the removal of fresh biomass while it could be even positive (McNaughton 1983). This scenario is known as compensatory regrowth because the defoliated plants partially or fully compensate for the removal of biomass (Belsky 1986, McNaughton 1986, Oesterheld 1992, Anten & Ackerly 2001, Eissenstat & Duncan 1992, Ferraro & Oesterheld 2002).

Several studies have documented the different consequences of defoliation for relative biomass allocation (McNaughton 1986, Evans 1991, Holland et al. 1996, Anttonen et al. 2002, Zhao et al. 2008, Stevens et al. 2008). The changes in the above- and below-ground biomass allocation were recorded by Markkola et al. (2004). Shoot growth is favoured at the expense of root growth (Oesterheld 1992).

Several studies have been addressed to the presumption stating that impact of different defoliation to tree growth (increment) is statistically significant (Soderberg 1991, Juknys & Jancys 1998, Juknys 2004). The radial growth of forest trees may be influenced by many factors, including defoliation. Especially significant effect could be detected in a case of prolonged defoliation. However, the effects of severe and prolonged defoliation cannot be separated from the effects of other factors (Mott et al. 1957). The response of defoliation on tree growth depends on tree species and individual tree resistance. For example, the previous year's defoliation could have a positive influence on radial increment, very low increment may be unrelated to defoliation or it could have no clear relationship (Muzika & Liebhold 1999).

A number of authors have reported that clear decrease of tree increment starts when defoliation exceeds 20-30% (Schweingruber 1985; Braker & Gaggen 1987; Soderberg 1991) or more than 40-50% (Frantz et al. 1986, Petraš 1993). For example, Kontic & Winkler-Seifert (1987) found that decrease of tree increment in the polluted sites starts before the crown defoliation can be fixed. Similar studies conducted in Scots pine stands have shown that despite relatively week correlation between defoliation and increment, the statistically significant relations could be found (Juknys & Jancys 1998)

The dependence of radial increment on crown defoliation is expressed by a logistic curve. In 2004, Juknys divided several stages of the above-mentioned interrelations: radial increment decreases relatively slowly when defoliation increases up to 20-25%; the increase of defoliation leads to the higher increment losses; in higher than 70-80% defoliation does not result in a fast decrease of radial increment.

The main objectives of this study were (I) to investigate the effects of different artificial defoliation regimes on some growth indices of one-year old silver birch seedlings and (II) to analyse the potential changes of tree radial increment in relation to different defoliation levels in naturally growing mature silver birch stands.

MATERIAL AND METHODS

Experimental study. An experiment of the effect of artificial defoliation on silver birch (*Betula pendula* Roth) seedling was conducted in southwestern Lithuania in the vegetation season of 2014. One-year-old silver birch seedlings of equal size and origin were planted into individual 3 litres plastic pots filled with the soil substrate just before the beginning of vegetation season (beginning of April 2014). Artificial 25, 50 and

75% defoliation were conducted using scissors in the middle of June. Non-defoliated control seedlings were also prepared. Each of four treatments included 20 seedlings.

The following parameters were measured: the individual height of birch seedlings one and five weeks, also 2 months post-defoliation; the diameter of air-dried main stems at a 2 cm distance above the stump base was measured for individual seedling using an electronic digital calliper; aboveground biomass was sampled 2 months post-defoliation. The leaves, living and dead shoots, branches, stems and roots were sampled separately for the determination of each compartment and total dry mass. The collected samples were oven-dried to a constant weight at 60ºC. The harvested roots were first rinsed of soil.

Analytical study. The study of the possible impact of defoliation on birch increment was based on the data from two permanent observation plots in Lithuania. The first plot included 37% of over 70-year-old birch trees growing in a drained oligotrophic peatland. The second plot included 78% of 50-year-old birch trees growing on temporarily overmoistured oligotrophic soils. We analysed the correlation of different defoliation regimes with tree growth in diameter.

Data and statistical analyses

The total aboveground biomass of each tree was calculated by the summation of the mass of dried shoots, branches and leaves, in grams. The total biomass of each tree was calculated by the summation of the aboveground and belowground biomass, in grams. Leaf, aboveground and total production or cumulative dry mass were calculated by summing the dry mass at harvest plus the leaf mass removed in the defoliation events.

According the Lilliefors and Kolmogorov-Smirnov tests, we rejected the data normality hypothesis for all observed variables with a 0.05 significance level. Then, the Kruskal-Wallis analysis of variance (ANOVA) test was used to ascertain the significant differences in dry mass between the different treatments (four groups: control, 25, 50 and 75% defoliations). The means are presented with the standard error of the mean (±SE). Statistical analyses conducted using the software Statistica 7.0, and a level of significance of $\alpha = 0.05$ was chosen.

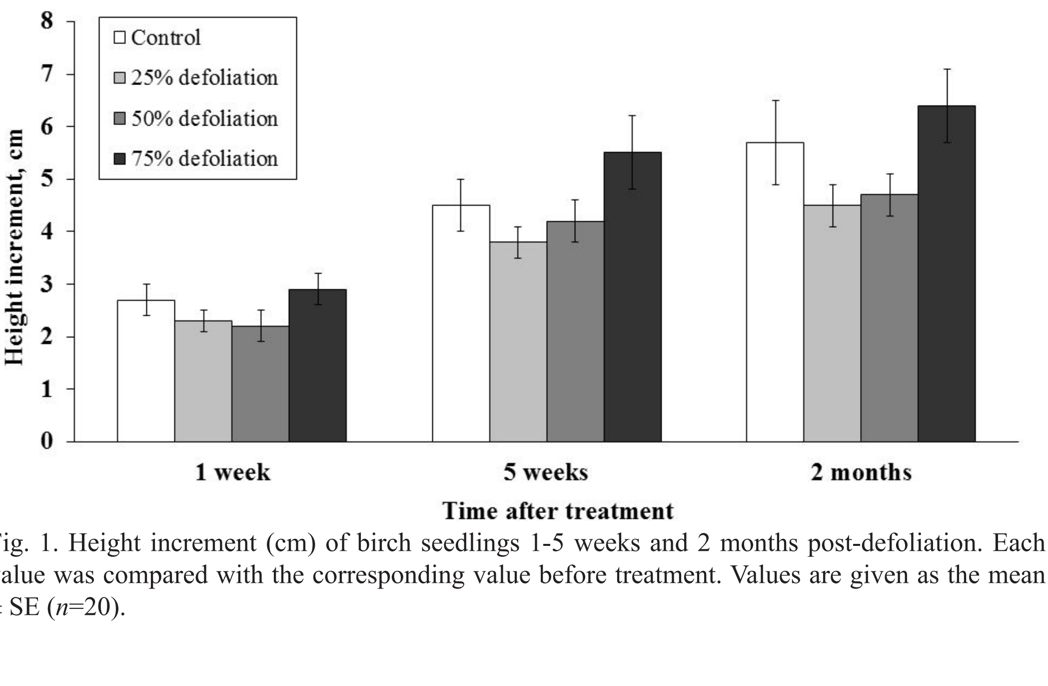

Fig. 1. Height increment (cm) of birch seedlings 1-5 weeks and 2 months post-defoliation. Each value was compared with the corresponding value before treatment. Values are given as the mean ± SE (*n*=20).

RESULTS AND DISCUSSION

Birch growth response to artificial defoliation simulations

The highest increment in height was determined in response to 75% defoliation. This tendency occurred just after the treatment and lasted for 2 months. The lower 25 and 50% defoliation intensities reduced the height increment compared to the control birch seedlings (Fig. 1). The lowest tested 25% defoliation about 1.0-1.3 cm decreased the mean height of birch seedlings compared with control seedlings.

Despite relatively low defoliation impact on the height growth, the impact on birch seedlings dry mass was more significant to compare with control. The dry mass of leaves, stems and roots of birch seedlings decreased in response to all tested defoliation levels. The strongest statistically significant decrease was caused by the 75% defoliation. Here, the dry mass of leaves 1.8 times and the dry mass of stems and roots 1.3-1.4 times decreased to compare with non-defoliated control two months after the defoliation event (Fig. 2A). Meanwhile, the defoliation levels of 25 and 50% had lower effect on the mentioned variables, i.e. leaf mass was by 1.4-1.5 times, stem and root masses were by

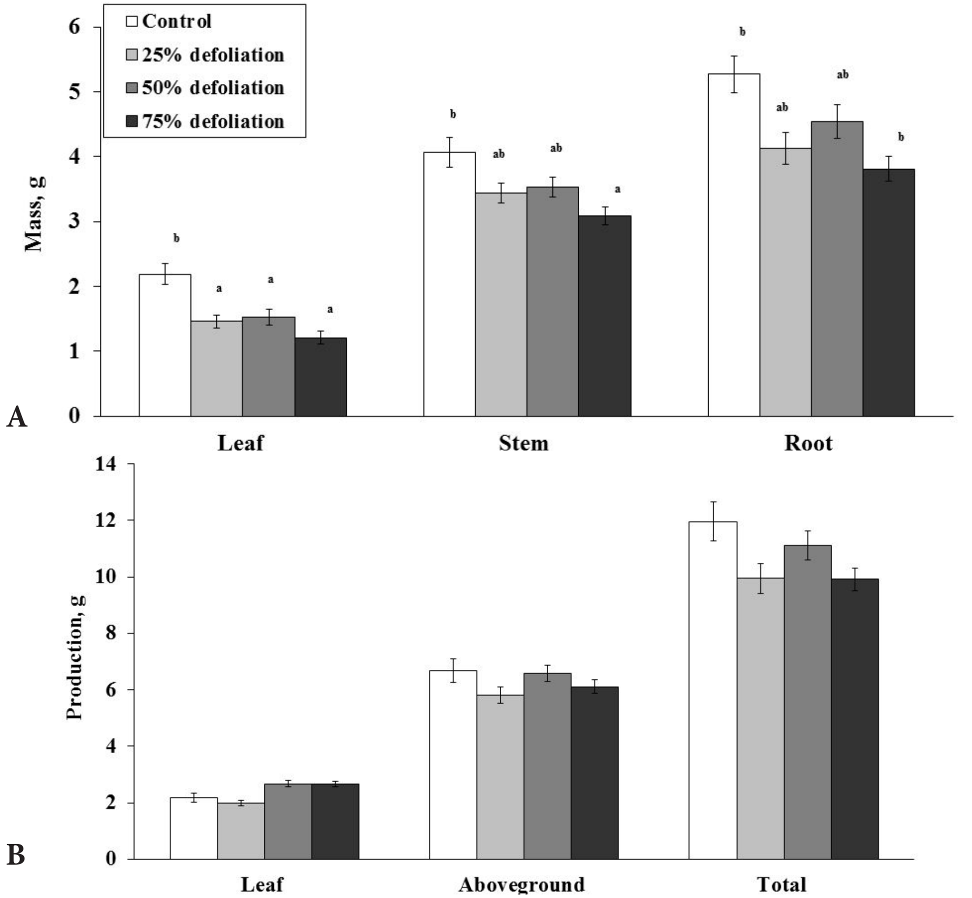

Fig. 2. Dry mass (g) of leaves, stems and roots (A) and leaf production (including leaf lost in defoliation), aboveground (leaf, stem and branches incl. leaf lost in defoliation) and total biomass (aboveground incl. leaf lost in defoliation and roots) (B) of *B. pendula* seedlings 2 months post-defoliation. Error bars show error of the mean. Statistically significant differences between treatments are indicated by different letters ($p<0.05$).

1.2-1.3 times lower of defoliated seedlings to compare with control (Fig. 2A).

Describing the aboveground and total above- plus belowground dry mass variables, the highest mass reduction to compare with control remained in the 75% defoliated seedlings (data not shown). The strongest defoliation event 1.4 times reduced the aboveground and total mass of birch seedlings, while 1.2-1.3 reductions were determined after the simulations of 25 and 50% defoliations.

Similarly to the response of aboveground dry mass, root dry mass also was significantly 1.4 times reduced in the 75% defoliated seedlings. Root dry mass in other defoliation treatments did not respond significantly.

Oppositely to the leaf dry mass changes (Fig. 2A), total production of leaves was even 1.2 times higher in the 50% and 75% defoliated seedlings than in the control (Fig. 2B). At harvest, the aboveground and total dry mass of the seedlings retained level of control.

The findings demonstrate that the main growth variables of defoliated birch seedlings grown under the same nutrient conditions most often showed the compensatory response in the case of total productivity. This study confirmed the findings from the earlier studies which fully compensate for the removal of biomass (Belsky 1986, Oesterheld & McNaughton 1988, Oesterheld 1992, Ferraro & Oesterheld 2002).

The highest significant effect of the only 75% defoliation and no significantly sound effect of other defoliation levels showed similar tendencies with the data presented by McGraw et al. (1990).

The loss of a 25, 50 and 75% of leaf mass did not inhibited the growth rate and damaged seedlings recovered similar dry masses to compare with control two months after the defoliation events. Reich et al. (1993) stated that plants defoliated by 75% only partially compensated biomass growth and recovered. In our case, the final leaf production showed fully compensation and this increase of cumulative dry mass, including leaf lost in defoliation, caused the compensation of all aboveground biomass but did not influence total dry mass of birch seedlings.

The 75% defoliation 12% reduced the main-stem diameter in 2 months after the defoliation event (Fig. 3). The 4-5% not statistically significant reductions of the main-stem diameter under the 25% and 50% defoliations were recorded.

Relatively rapid growth response of *B. pendula* seedlings under different defoliation levels was considered as a good finding if compared to other

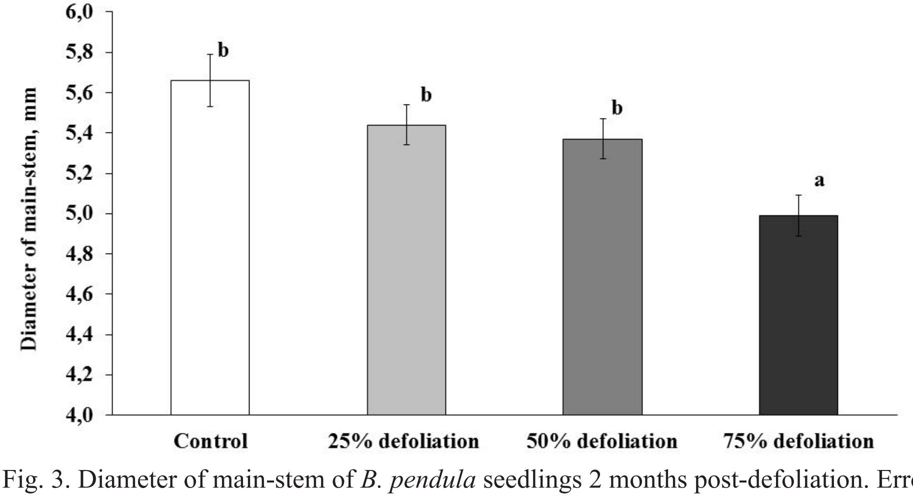

Fig. 3. Diameter of main-stem of *B. pendula* seedlings 2 months post-defoliation. Error bars show error of the mean. Statistically significant differences between treatments are indicated by different letters ($p<0.05$).

studies, which concluded the obtained changes after the longer period (Hoogesteger & Karlsson 1992).

Birch growth response to naturally growing mature birch stands

The pilot study of the tree radial increment in relation to different defoliation levels in naturally growing mature silver birch stands showed that three stages of changes could be distinguished: stability with maximum increment in the healthiest birch stands; declining and stability with minimum increment in the birch stands of the worst condition (Fig. 4).

This episodic scheme partly corresponds to the findings of Juknys (2004) who found that the dependence of radial increment on crown defoliation is expressed by a logistic curve. Our data showed that mostly birch radial increment decreased until defoliation increased up to 25% and, consequently, the increase of defoliation leads to the higher increment losses. The radial increment of the birch trees of 25-30% defoliation level was by 2.8-3.1 times lower than the increment of the healthiest 5-10% defoliation level birch trees. This tendency is to some extent in agreement with Kramer (1986) and Huber (1987) findings which showed that each next 10% of defoliation relates to 20% decrease of the radial increment. However, the current study found the higher decrease of the increment following the increase of defoliation: radial increment decreased almost by 50% as a consequence of the defoliation increase from 10 to 20%. Despite this, not significant impact on the changes of increment starting 25-30% defoliation was further recorded.

CONCLUSIONS

No statistically significant changes in height growth of *B. pendula* seedlings were obtained at harvest, 2 months post-defoliation. The strongest 75%-defoliation by 24% and 12% reduced, respectively, the stem mass and main-stem diameter compared to the control.

The 50 and 75% defoliations did not inhibit the biomass growth of *B. pendula* seedlings and they recovered to the control level in 2 months, regardless of the defoliation intensity. The defoliated birch seedlings fully compensated for the removal of leaf biomass. The cumulative dry mass, including leaf lost in defoliation, caused the compensation of all aboveground biomass but did not influence total dry mass of birch seedlings.

The most significant response of defoliation on the radial increment was found when defoliation

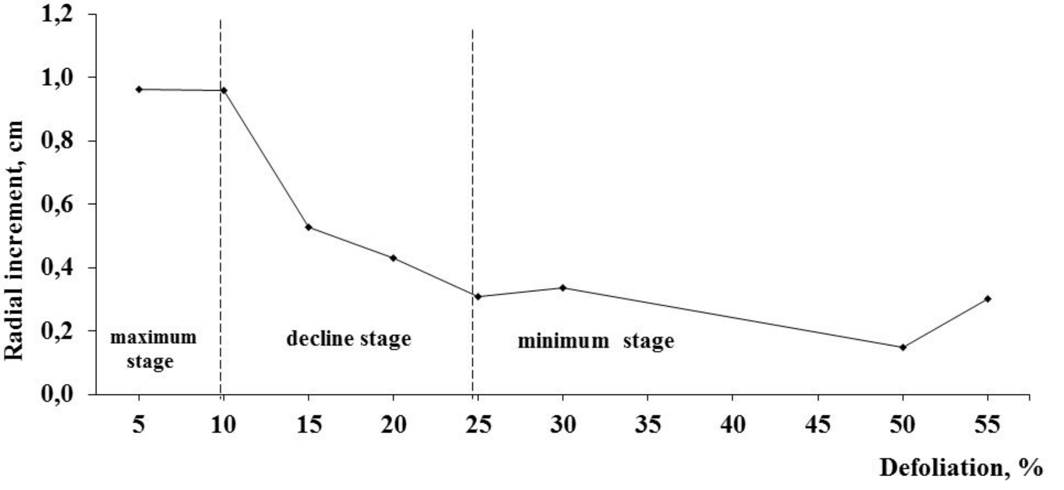

Fig. 4. Relation between radial increment changes and crown defoliation in older than 50-year old birch stands.

increased from 10 to 25%, but further the changes were not as much evident.

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