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# A variety of transpiration in the young spruce stands with different thinning management

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*Abstract:* Managing the spruce forest growing beyond its favourable conditions is trading between water consumption and increasing biomass. We examined tree transpiration in four stands with different thinning intensities in a 40-year-old spruce forest in South Moravia. Tree transpiration was significantly higher under moderate and heavy intensity compared to low intensity and control plots. Tree transpiration differed also among trees of different sizes within the treatments and also between the treatments. The stem increment was visibly increasing with the intensity of treatment, particularly for suppressed trees. The findings show an ecological tree response two years after the thinning.

*Key Words:* Norway spruce, tree size, water consumption, sap flow, biomass production, thinning treatment

## INTRODUCTION

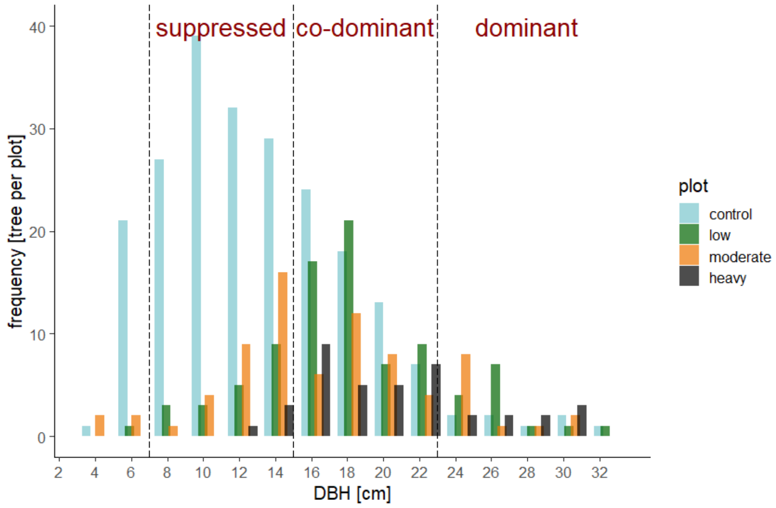
The increasing frequency, intensity and duration of a period with extreme weather conditions have already led to a decrease in forest productivity (Allen et al. 2015). This emphasises a need for silvicultural approaches for existing forest stands that have not reached economic maturity, suitable short-term adaptation strategies to achieve a higher forest resistance and resilience to extreme climatic events (Brang et al. 2014, Lasch et al. 2002). Moreover, still prevailing spruce forest growing beyond its ecological suitable conditions is more vulnerable in terms of water deficit conditions, which is increasing with climate change (Brázdil et al. 2015). Hence, the essential assumption for an examination of the future of spruce-dominated forestry is the estimation of spruce water demand. The thinning is suggested as an approach to climate adaptation in the short term and has a positive impact of thinning on the growth performance of trees during drought. This has been shown in several studies from America (D'Amato et al. 2013, Hsiao 1973), Israel (Tsamir et al. 2019) and Europe (Elkin et al. 2015, Nilsen and Strand 2008). However, a response of trees to any sudden long-lasting conditions varies with a taxonomic class (conifer or broadleaved), species' potential to occupy newly available growing space, thinning intensities, time since the last thinning and stand age (Elkin et al. 2015), not to mention the meteorological conditions. In this study, we evaluated the response of tree and stand transpiration and diameter increment to the thinning treatments of different intensities.

## MATERIAL AND METHODS

### Study site description

The study site is located close to Rájec–Němčice (49°26'37"N, 16°41'47"E) at an altitude of 625 m.a.s.l. The mean annual temperature from May until September in 2020 was 17 °C (long-term annual average is 7.8 °C) and the amount of precipitation over the same period was 495 mm (long-term average annual sum is 679 mm). It is 40 years old Norway spruce managed forest. The study area was divided into four equally large plots, of an area of 625 $m^2$ and lastly managed in spring 2018 with three thinning intensity treatments from below (low, moderate, heavy) and a control plot without thinning treatment (Table 1). The distribution of all trees' diameter in breast height (1.3 m, further DBH) varied between thinning intensities especially considering suppressed trees (Figure 1).

*Figure 1 Distribution of the tree classes within the managed plots (625 m²)*




*Legend: DBH – diameter breast height (cm), suppressed trees: 7–14 cm in DBH, co-dominant trees: 15–23 cm in DBH, dominant trees: above 23 cm in DBH*

*Table 1 Characteristics of the spruce stand in the different treatments*

| Thinning intensity | Stand density [tree/ha] | Stand BA [m²/ha] | BA reduction [%] | Mean DBH ± SD [cm] | LAI [-] | Mean sap flow ± SD [kg/year/tree] | $T_{stand}$ [l/year/ha] |
|---|---|---|---|---|---|---|---|
| Control | 3504 | 3.506 | 0 | 13 ± 5.2 | 5 | 1139 ± 518 | 399 |
| Low | 1424 | 2.514 | 28 | 18 ± 5.1 | 4 | 1602 ± 902 | 228 |
| Moderate | 1216 | 1.914 | 45 | 17 ± 5.7 | 3 | 1686 ± 389 | 205 |
| Heavy | 624 | 1.358 | 61 | 20 ± 5.2 | 3 | 2145 ± 1106 | 134 |

*Legend: BA – basal area, SD – standard deviation, LAI – leaf area index, $T_{stand}$ – stand transpiration*

**Sap flow measurement**

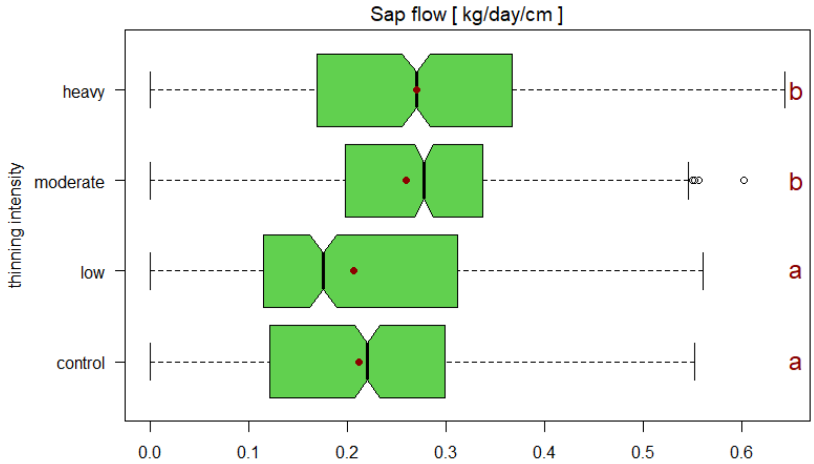
The water consumption was calculated based on the measurement of the tree transpiration by the sap flow modules EMS81 (EMS Brno, CZ), based on the tissue heat balance method from (Čermák et al. 2004). Data were measured in 2 minutes intervals, stored in 10 minutes averages and then aggregated to daily values. The growth increment was measured by band automatic dendrometers (DR 26, EMS Brno, CZ). We selected trees of similar diameter at breast height (DBH) in each plot in four DBH classes representing co-dominant and dominant trees (DBH18, DBH20, DBH23, DBH26). A software Mini32 (Environmental Measuring Systems s.r.o. Brno, CZ) was used for sap flow and dendrometers' data pre-processing. For data analysis, we used a selection of data of the main growing season, from 8 May 2020 until 30 September 2020, and excluded days with precipitation above 10 mm/day (moderate rain), according to the declining regression curve between sap flow and precipitation. For the statistical analysis were used the standardized sap flow data, expressed as mass flow from one centimetre of tree circumference [kg/day/cm]. Statistical analyses and graphs were conducted in R (R Core Team 2019). The sap flow of an average tree (calculated according to stand inventory data of DBH classes' distribution) was calculated for each plot to represent the stand density. The whole stand transpiration ($T_{stand}$) was calculated as the multiplication of the average tree sap flow and the number of trees in each treatment. As the assumptions to meet the requirement of homogeneity and normality were in most cases violated, we used the Kruskal-Wallis test and post hoc tests: Dunn's test for multiple groups means comparisons and the Median test for median comparison. Statistical significance for all analyses was set at $p \leq 0.05$ for $\alpha=0.05$.

## RESULTS AND DISCUSSION

### Effect of thinning on the tree and stand transpiration

The yearly transpiration of the single average tree increased by 41% in the low thinned plot, by 48% in the moderated, and by 88% in the heavily thinned in comparison with the average tree at the control plot (Table 1), which corresponds with the findings of Tsamir et al. (2019). The highest increase of tree sap flow was in a heavily thinned stand which is comparable with the results of Park et al. (2018) and McJannet and Vertessy (2001). In our study, an increased thinning intensity led to a reduction of total stand transpiration (Table 1), as also shown by Gebhardt et al. (2014) and Wang et al. (2019). Annual stand transpiration was reduced by 43% in the low thinned plot, by 49% in moderated and 66% in the heavy thinned plot compare to the control plot (Table 1). The proportional decrease of stand transpiration concerning the reduction of the basal area through thinning agreed with the findings of Morikawa et al. (1986) and Breda et al. (1995).

*Figure 2 Variation of the sap flow among thinning intensity*




*Legend: Different letters indicate significant differences in means of sap flow (red points) and notches in boxes show a 95% confidence interval for the median (black lines)*

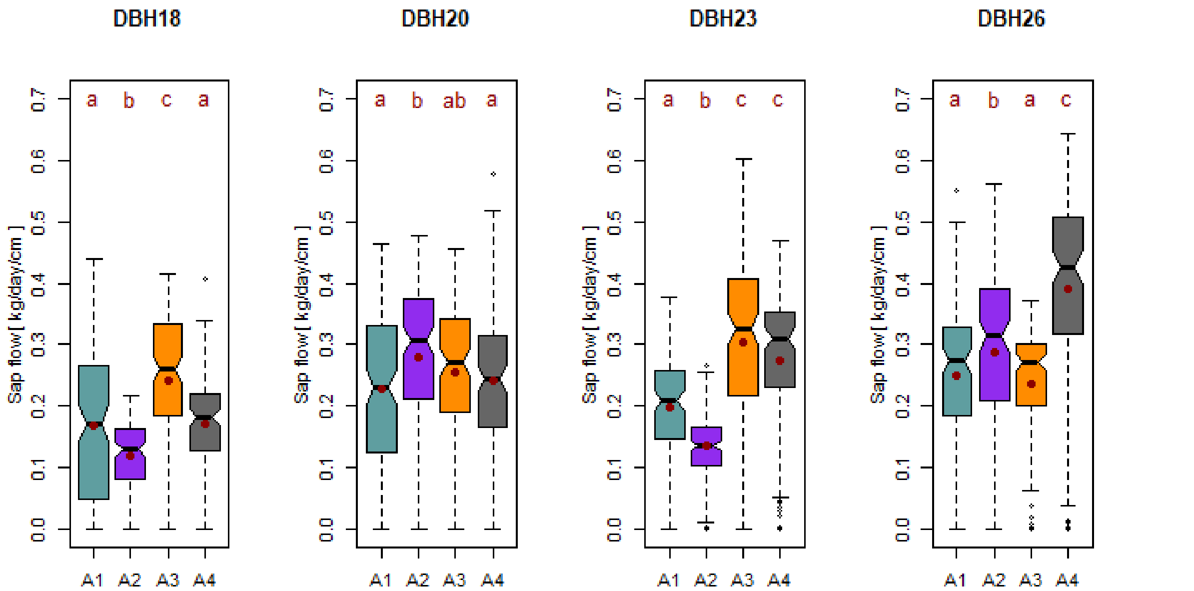
We were expecting an increase of sap flow with increasing tree size in each treatment in comparison to the un-thinned stand. According to the study of Lagergren et al. (2008), we were expecting higher transpiration within the same tree size range of DBH in heavy thinning compared to the control plot.

In our study sap flow differed significantly among treatments as well as among trees from the same DBH classes (from now on the number in the DBH class name corresponds to the mean DBH within class of 2 cm interval). The most contrasting mean transpiration was in heavy and moderate thinning intensity when compared to the control plot and low intensity thinning (Figure 2). The observed increase in tree sap flow after thinning can be related to various factors such as the increase in incoming radiation to the lower crown layers, increase in tree leaf area and higher soil water availability (Jiménez et al. 2008).

Comparing thinning intensity on selected DBH classes, we found that the heavy thinning had a significant effect on the sap flow of the dominant trees (DBH23 and DBH26) compared to the control (Figure 3). Despite the fact, that the mean tree transpiration of the control plot did not differ from low thinning (Figure 2), there was a significant effect of thinning when the separate DBH classes were considered. The most variance was among the trees in the DBH23 class, where all trees were different from the control (Figure 3).

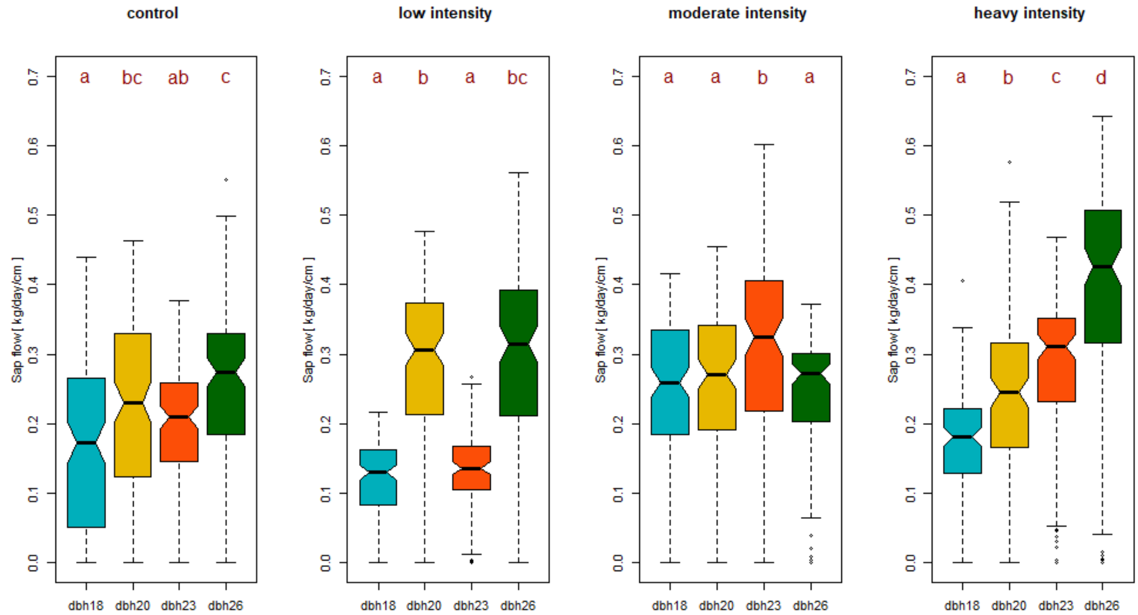
We were expecting sap flow to increase with the tree size according to Wang et al. (2019). The largest differences in sap fluxes were shown in heavy thinning among all tree DBH variations (Figure 4). Besides moderate intensity, the lowest tree and the largest (DBH26) are transpiring significantly different. With moderate treatment, all trees were transpired very similarly, except for the tree with DBH23.

*Figure 3 Tree sap flow response of various DBH classes to thinning management*




*Legend: Different letters indicate significant differences (α=0.05) in means of sap flow (red points). A1 – control, A2 – low intensity, A3 – moderate intensity, A4 – heavy intensity*

*Figure 4 Comparison of the tree sap flow among variance of large trees within plots*

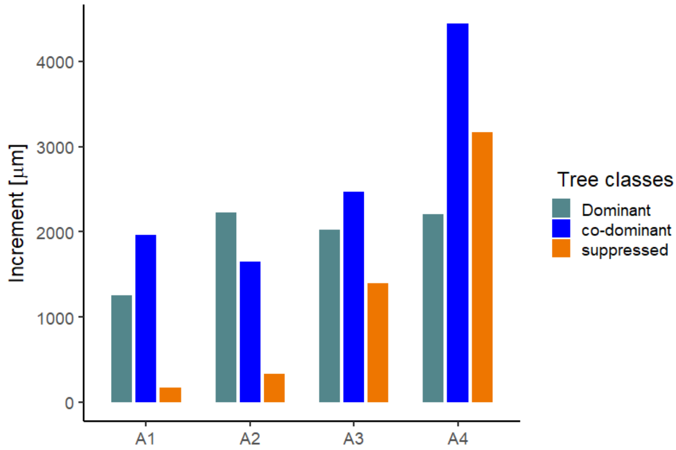



*Legend: Different letters indicate significant differences (α=0.05) in means of the tree sap flow. Boxplot shows variation for a single tree in time. The tree with DBH of 18 cm (blue), the tree with DBH of 20 cm (yellow), the tree with DBH of 23 cm (red), the tree with DBH of 26 cm (green)*

## Biomass

We did not find any statistically significant differences in increments among the plots nor the tree classes from averages of stem radial increment. Visually, the highest average radial stem increment was in the heavy thinning only for the suppressed and co-dominant trees (Figure 5), which is probably caused by an increase of the light availability for the crowns of the trees in lower social positions (Breda et al. 1995). A similar trend of increased diameter increment along with increased thinning intensity was found in other studies (Manrique-Alba et al. 2020). On the contrary, Breda et al. (1995) reported significantly higher stem circumference increment of dominant trees. The low thinning intensity supported the higher growth only of dominant trees. Our results generally agree with other studies showing that thinning can greatly increase tree radial growth while stand transpiration decreases due to the reduction of stand density (Wang et al. 2019).

*Figure 5 Average values of stem radial increment for the social status of the trees growing on plots with various thinning intensities*




*Legend: A1 – control, A2 – low intensity, A3 – moderate intensity, A4 – heavy intensity*

## CONCLUSION

The study confirmed the effect of thinning on the whole stand and mean tree transpiration. The results showed a significant effect of the heavy intensity thinning on tree transpiration for all measured tree DBH classes, where the tree transpiration increased in all thinning intensities compared to the control. On the other hand, the stand transpiration decreased in all thinning intensities. However, the transpiration of the dominant trees was primarily increased by the heavy thinning intensity, the stem increment was not affected so much. Contrarily, the effect of thinning on co-dominant trees sap flow was not consistent with diameter increment. Moreover, the highest stem radial increment was measured on the suppressed trees which could not be connected with the sap flow measurements. Given the limitation of sampling set and potential influence of other biometric and stand structural factors further studies are recommended.

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