Abstract: The circumference increment assessment of Norway spruce focused on the effect of inter-tree competition in the mature spruce stand was made at the study site of Rájec (Drahanská vrchovina Highland) over a 5-year period. Data were collected from 49 trees, which were monitored continuously with mechanical band dendrometers from 2010 to 2014. The dependency of the circumference increment on competition index, diameter at breast height, Lang’s rain factor, mean temperature of various periods and sum of precipitation of various periods was evaluated. Climatic conditions of the study site are characterised with warm and wet summers and cold-dry winters. In 5 years average around 61% of the annual precipitation falls during growing season. There was highly significant correlation between relative increment and temperature \(p=2.324 \times 10^{-13}\) and significant correlation between relative increment and precipitation \(p=0.0439\). These results confirmed that inter-tree competition and diameter at breast height are sufficient variables for circumference increment estimation of unmeasured trees in the particular year. Coefficient of determination reached 0.25–0.63 for competition and 0.40–0.84 for tree diameter at breast height. The present investigation brings important results about tree growth and seasonal growth dynamics and its relation with competition and microclimatic conditions in mature spruce stand.

Key Words: dendrometers, seasonality, *Picea abies*, stem girth increment, competition

INTRODUCTION

Norway spruce (*Picea abies* (L.) Karst.) is one of the most important European tree species and also a tree species with the highest number of various health and growth problems which have appeared in the last decades (Rybníček et al. 2010). It is amongst the trees most strongly affected by forest dieback in Central Europe, which is generally attributed to industrial and automobile pollution (Eckenerwalder 2009).

The presence of distinct seasonal changes is the main prerequisite for trees forming growth rings. However, our knowledge concerning the timing of the various phases and the rate of wood formation is still far complete (Savidge et al. 2000, Chaffey 2002). The seasonality of an organism’s growth should be tuned to the annual cycle of resource availability (Muir et al. 1997). For many regions, the period of wood cells formation remains unknown, or the variation of growth rate during that period. The main reason for the gaps in our knowledge is the difficulty in measuring xylem formation at short intervals (Chaffey 2002).

In this study, we presented the investigation of seasonal growth dynamic of Norway spruce at the research site Rájec. Our objective was then to assess the progress of the stem radial increment focused on the effect of diameter, climate and inter-tree competition in a mature spruce forest located in an intensive research plot situated in Drahanská vrchovina Highland, which plays important role in international ecological monitoring infrastructure.
MATERIAL AND METHODS

The samples for the study were obtained at the study site of Rájec (Figure 1), about 30 km to the north of Brno (geographic coordinates N49°26'37", E16°41'48"). The study site is located in the natural forest area 30 Drahanská vrchovina Highland, forest vegetation zone 5 (fir–beech), representing about 2.7% of the Czech Republic area. This study site was established for long–term detailed experiments for various scientific issues. The bedrock consists of intrusive rock acid granodiorite of Brno Massive (Hruška 1980). The soil type was determined as unsaturated acidic brown forest soil (Klimo 1992), and it is modal oligotrophic Cambisol (Němeček et al. 2001). The site is situated at an altitude ranging between 620–630 m a.s.l. (Klimo 1992) and in a moderate climatic region (Quitt 1971). Mean annual air temperature at the study site is 7.1 °C and mean annual sum of precipitation 673 mm (Marková et al. 2015).

Increment as a dependent variable, and competition index, diameter at breast height, Lang’s rain factor (LRF), monthly temperatures and precipitations as independent variables for the study area were used to calculate the correlations of values of girth or circumference increments with climatic factors. Pearson’s correlation analysis, Regression analysis and Lang’s rain factor were performed to compare competition and stem increment. Meteorological measurements and dendrometer and circumference measurements were also performed. The seasonal variability was created in STATISTICA 10 application. Hegyi’s single tree competition index model was proposed to calculate the competition index.

Figure 1 Location of the study site of Rájec (the Drahanská vrchovina Highland)

RESULTS AND DISCUSSION

In this research a dendroclimatic investigation on Norway spruce from 2010 to 2014 (2009 was additionally included) was conducted. The number of trees (Figure 2) at the studied stand has decreased between 2010 and 2011 due to an intense cutting, as most trees have felt down because of the silvicultural management and/or severe climatic conditions.

Figure 2 Number of trees per year at the study site of Rájec (Drahanská vrchovina Highland) in 2009–2014
The relative increment of the girth of the portion of stem in individual years (5-year increment is 100%) is shown on Figure 3. To see the effect of climatic conditions on stem girth increment there are shown only trees with recorded stem increment in whole 5-years’ period. Figure 4 describes the relative increment of the stem girth in the studied years 2010–2014; the confidence interval was very wide (for comparison year of 2011 with the highest value of confidence interval and year of 2013 with the lowest confidence interval). The year 2012 showed the second highest confidence interval. Trees increment in 2013 had significantly lower than in 2012 and 2014.

At each of the development stages, climatic factors manifest different degrees of impact.

**Figure 3 The relative stem increment in spruce stand at the study site of Rájec (Drahanská vrchovina Highland) in 2010–2014**

![Graph showing relative stem increment from 2010 to 2014.](image)

**Figure 4 The relative stem increment in spruce stand at the study site of Rájec (Drahanská vrchovina Highland) in 2010–2014**

![Graph showing relative stem increment from 2010 to 2014 with confidence intervals.](image)

The relative increment for any given year often integrates the effects of the previous and current year’s climate. There were tested 300 periods and combined all possible complex periods of the mean monthly air temperatures, and their correlations with stem increments, with the duration from one month up to January of the previous year to September of the current year, among which 25 best correlations of the girth or circumference increment with mean monthly air temperatures had positive highly statistical significant values. The period with the highest correlation of increment and mean monthly air temperature was from September of the previous year till September of the current year, i.e. the period of 13 months.

The growth of Norway spruce was statistically significantly affected only by precipitation in May of the previous year. In our case, the correlation was not good enough with precipitation to estimate the stem increment, as we had one result between significant and non-significant
(p = 0.0439). The second best correlation of the girth or circumference increment with precipitation is from July to September, either of the previous year was not statistically significant. The growth of Norway spruce was less statistically significantly affected by precipitation in September of the previous year and the precipitation in September of the current year.

CONCLUSION

The effect of climate, tree size (characterized with diameter at the breast height) and competition on variations in annual circumference increment of Norway spruce (Picea abies (L.) Karst.) trees were investigated in a mature spruce stand located at the study site of Rájec (Drahanská vrchovina Highland, the Czech Republic).

There were tested 300 periods of the mean monthly air temperatures, and their correlations with stem increments, with the duration from one month up to January of the previous year to September of the current year. All possible complex periods were combined. 25 best correlations of the girth or circumference increment with mean monthly air temperatures had positive highly statistical significant values. Variability of circumference increment differed according the size of the trees, competition index and the number of days in a given period. The high variability of circumference increment during the season might be due to physiological process resulting in stem saturation of water dynamics.

The microclimate at the study site is characterized by warm-wet summers and cold–dry winters. This study revealed that competition index and stem diameter at the breast height were good parameters for tree growth prediction; correlation was very good with air temperature [p < 0.01 (highly significant)], and it is possible to say that it is a good estimator in this case. The growth of Norway spruce was less statistically significantly affected only by sum of precipitation. Overall, there was highly significant correlation between air temperature and relative stem increment, and significant correlation between sum of precipitation and relative stem increment was confirmed.

It is obvious that unsuitable climatic conditions for spruce can lead to stem shrinkage during growing season. Here we assume that these responses are caused mostly by water storage deficit in stem and this leads to decreasing of the tree vitality.

This study provides new data revealing the basic growth processes of Norway spruce trees, and provides significant information to quantify the responses of tree growth to expected global warming. This approach provided a great opportunity to deepen our understanding and knowledge about the interactions of different environmental factors with the short-, medium- and long-term growth dynamics of one of the most important forest tree species.

Dendrometer traces should be compared with dynamics of xylem cell development to date onset of cambial activity and girth or circumference stem growth (i.e., extracted daily girth or circumference increments, cambial activity and enlargement of first tracheids). A comparison with cellular analyses can be useful to determine crucial phenological events such as cambial growth onset and ending and stem radius increment on the basis of dendrometer data, as both techniques will enable direct observation of the periodic process of cambial activity and tracheid differentiation (girth or circumference cell enlargement, secondary wall thickening, lignification and cell death) as suggested in some recent studies.

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REFERENCES


