JOURNAL OF FOREST SCIENCE, *62*, 2016 (10): 441–451

doi: 10.17221/77/2016-JFS

# Below-canopy and topsoil temperatures in young Norway spruce and Carpathian birch stands compared to gaps in the mountains

**O. Špulák, D. Kacálek**

*Forestry and Game Management Research Institute, Jíloviště-Strnady, Opočno Research Station, Opočno, Czech Republic*

**ABSTRACT**: Reduced air pollution load has allowed to use commercially oriented forestry in the Central European mountains since the 1990s. The goal is, however, to restore species- and age-diversified stable stands that are expected to cope with uncertain changes of the harsh mountain climate. The microclimate of current young forest stands can impact on growth and performance of underplanted seedlings. In the present study, aboveground (+10 cm), surface (0 cm) and belowground (–10 cm) temperatures were compared under Norway spruce and Carpathian birch canopies. Measurements were performed in 22-year-old Norway spruce and Carpathian birch stands and replicated three times. These measurements were compared with three adjacent gaps dominated by herbal vegetation. Temperatures were measured automatically during the growing periods 2011 and 2012. The research was conducted on Norway spruce on an acidic Spodosol forest site in the summit part of the Jizerské hory Mts., Czech Republic. Data were analysed using the Horn procedure of pivot measures. The highest variability of aboveground and soil surface temperatures was observed within the gaps during a spring time. The temperatures beneath the leafless birch were close to those within the gaps, whereas in the period of leaved trees the temperature extremes were reduced similarly like under the spruce stand canopy compared to the gaps. The differences between the plots were the smallest at the end of growing seasons.

**Keywords**: air; soil; below-canopy climate; microclimate; stand environment

Intensive removal of air-polluted declining spruce forests increased the area of forest clearings along the Czech-German and Czech-Polish borders in the 1980s. The decreased air-pollution load (Fenger 2009; Lomský et al. 2012; Vašát et al. 2015; Crippa et al. 2016) has improved growth conditions in the Central-European mountains since the 1990s. This change has helped foresters to practice the Norway spruce (*Picea abies* (Linnaeus) H. Karsten) oriented forestry again. The renewal efforts have led to restoration of less diversified stands again. The long-term goal, however, is to restore tree species- and age-diversified mixed stands that are expected to cope with uncertain changes of harsh mountain climate. Among many ways to achieve this goal, the restoration of pioneer broadleaves would be a beneficial measure.

In addition to Norway spruce, other tree species were planted to provide demanded services of the forest in the formerly air-polluted mountains. Among them, silver birch (*Betula pendula* Roth) was also used extensively in the Krušné hory Mts. and in the Jizerské hory Mts. However, it was found to be an unsuitable tree species in the mountain conditions due to suffering from a site-based decline (Bäucker, Eisenhauer 2001; Šrámek et al. 2008). Then the forestry research focused also on Carpathian birch (*Betula carpatica* Waldstein & Kitaibel ex Willdenow) and white birch (*Betula pubescens* Ehrhart) that are native pioneer tree

---

Supported by Ministry of Agriculture of the Czech Republic, Resolution RO0116 (reference number 10462/2016-MZE-17011), and Project No. QJ1230330.

species on mountain sites; they can grow also near the tree line. Many studies dealing with the birches in European conditions (e.g. El Kateb et al. 2004; Portsmuth, Niinemets 2006; Repola 2008; Balcar et al. 2010; Hynynen et al. 2010; Špulák et al. 2011; Ešnerová et al. 2012, 2013; Reid et al. 2014) were published. Carpathian and white birch are supposed to meet the mountain-site requirements; thus these two species can help us diversify the tree species composition of new forests.

Site microclimate conditions are affected by woody vegetation present on the site as overlying canopies modify intensity and quality of solar radiation [e.g. light composition of shortwave and longwave radiation (Geiger 1950; Webster et al. 2016)]. Also canopy openness plays a crucial role in stand ecology dynamics (e.g. Prévost, Raymond 2012). One of the most important features of the microclimate is temperature. The studies of forest microclimate were conducted mostly in mature or premature forest stands whereas young stands were analysed very rarely. Different impacts of conifers and broadleaves on ground microclimate parameters have been found obvious (Nihlgård 1969; Balcar et al. 2010; Chávez, Macdonald 2010). That impact depends also on forest stand density (Leikola, Pylkkö 1969). There were also studies comparing both, i.e. open and closed-canopy conditions (Rich et al. 2015). Different below-canopy conditions affect also snowpack properties and its duration (Bartoš et al. 2009; Dickerson-Lange et al. 2015). Knowledge of the microclimate below young canopies of different tree species can help to understand their potential for diversification of the growing conditions. This can be also important for future application of underplantings.

This study is focused on effects of the young spruce and birch canopies on aboveground air, surface and subsurface temperatures compared to the gap in 2011 and 2012 growing seasons. The study addresses a research question: How do young spruce sub-canopy temperature conditions differ from birch ones on the same site? We hypothesized that a difference in temperature conditions below the tree species can originate mostly in the development of foliage.

## MATERIAL AND METHODS

**Study site**. The study site is situated within the Jizerka experimental plot, in the Jizerské hory Mts. (GPS 50°49'34''N, 15°21'19''E) on the summit part of a moderate southwestern slope (< 2%) at the altitude of 980 m a.s.l. It is Norway spruce on acidic Spodosols (*Piceetum acidophilum*) according to the Czech forest site classification system (Viewegh et al. 2003); potential natural vegetation is *Calamagrostio villosae-Piceetum* (Neuhäuslová et al. 1997). In addition to Norway spruce, individually mixed tree species such as European beech, silver fir and rowan share the natural species composition (ÚHÚL 1999). Average annual air temperature is 5.0°C, average sum of precipitation totals 1,135 mm (Balcar et al. 2012a, b). At the beginning of the 1990s, various tree species were planted there to investigate both their health and performance within the experimental site (Balcar, Podrázský 1994). Almost all the tree species plantations already closed their canopies at the beginning of the study. Both Norway spruce and Carpathian birch treatments used in this study were planted in 1993.

**Treatment design and temperature monitoring**. To monitor aboveground air (+10 cm), surface (0 cm) and below-ground (–10 cm) temperatures, three replications (plots) were established in 18-year-old Norway spruce (spruce treatment; stand density 3,800 trees per hectare, mean tree height 4.5 m) and Carpathian birch of the same age (birch treatment; stand density 4,200 trees per hectare, mean tree height 3.5 m). These were compared with three grass-dominated [*Calamagrostis villosa* (Chaix) J.F. Gmelin, height of 0.4 m, dry mass about 200 $g \cdot m^{-2}$] gaps (gap treatment). Ground vegetation under tree canopies was dominated by *C. villosa* and *Vaccinium myrtillus* Linnaeus. The tree-covered and gap plots were 10 × 10 m sized each.

The air and soil temperatures were monitored using six (five in the open gaps) randomly distributed vertical TMS 1 loggers (TOMST Ltd., Prague, Czech Republic) within every replication (plot). Each logger is equipped with three temperature sensors. The sensors recorded temperature directly at the following positions: (*i*) below ground (at a soil depth of 10 cm), (*ii*) soil surface (0 cm), (*iii*) air temperature near ground (at 10 cm above ground surface). The data were recorded every 15 min. The loggers were uninstalled during the dormant season and reinstalled again in the early spring of 2012. The randomly placed loggers in three times replicated treatments were established to collect representative data.

Overall information on weather conditions (mean daily air temperature, daily sum of radiation 200 cm a.g.l. and daily sum of precipitation) is based on an automatic meteorological station placed ca 100 m nearby the experimental site. Snow cover was present usually between November and April (Balcar et al. 2012a, b). The two periods were monitored from May 1st to October 31st in 2011 and from May 15th to October 31st in 2012. Both periods roughly represent a growing season.

**Data analysis**. Using the methods of exploratory analysis, the data that were incorrect due to technical problems were omitted. Means and variances of temperature in individual terms and treatments were computed using Horn's Quantile Based Method (Horn et al. 1998). This robust method is based on order statistics and it is appropriate for datasets with a low amount of numbers ($4 \le n \le 20$). Mean value in every measuring term (15 min) was computed as pivot halfsum (PL), the 95% confidence interval of the mean was expressed by pivotal statistics (Meloun et al. 2001). $L_{95\%}$, $H_{95\%}$ and $R_{95\%}$ denote lower limit, upper limit of the confidence interval and their difference (range), respectively.

Daily mean of temperatures of each replication (plot) was computed as an average of pivot halfsums of all terms in the day and confidence interval was expressed by averages of $L_{95\%}$, and $H_{95\%}$. A similar procedure was used to obtain daily mean values for treatments. To describe trends minimally influenced by daily variation weekly statistics are presented.

The temperatures in the gap were chosen as a reference. Differences in the temperature characteristics (weekly mean temperature, weekly average minima and temperature amplitudes) of appropriate sensors between gap and tree-covered treatments were computed and compared. The negative values of differences indicate higher temperatures compared to gap treatment, the positive values indicate lower temperatures than in the gap and zero values denote the same temperatures in both the sub-canopies and gap conditions.

The statistical analysis of the data was computed in the R statistical environment (Version 3.1.3, 2015). The comparison of two samples was made using the $F$-test and $t$-test; multiple samples were compared by the one-way ANOVA with Tukey's test for multiple comparisons (normality and homogeneity of the data). To improve normality the Box-Cox transformation (Box, Cox 1964) was applied. If the data still showed heteroscedasticity ($R_{95\%}$ data), Welch's ANOVA (Welch 1951) with Games-Howell test (Games, Howell 1976) was used with package stats (Version 3.1.3, 2015) and "userfriendlyscience" (Version 0.4-0, 2015). Gap-spruce and gap-birch differences in daily minimum temperatures, which were considered measures of temperature stresses which act on daily basis, were compared by the paired $t$-test.

The Kruskal-Wallis non-parametrical test and Nemenyi post-hoc test (package PMCMR, Version 4.1, 2016) were used in the case of abnormal and/or non-homogeneous data. The significance level was $\alpha = 0.05$.

## RESULTS

### Course of weather

In both monitored periods of 2011 and 2012, average daily temperature was 10.7°C (Fig. 1). Due to intensive precipitation, particularly from 20th to 22nd of July, the 2011 season was significantly richer in precipitation than the next year. Average daily radiation sum of both seasons was similar (315.8 $W \cdot m^{-2}$ in 2011 and 317.5 $W \cdot m^{-2}$ in 2012).

Average daily temperatures below zero occurred at the beginning and at the end of the monitored season 2011 (Fig. 1). The precipitation events were rich and balanced over the investigated period; extremes contributed to the higher sum of precipitation during the second half of July 2011 compared to the following year (899 mm between May and October in 2011; 588 mm between May and October 2012).

Compared to the period of 2011, considerably higher temperatures occurred at the beginning of the second growing period (2012); the first frost occurred at the end of October. Despite this, average temperature of the monitored period did not increase. There was no precipitation during the second half of May in 2012 (Fig. 1).

### Average temperatures

Both investigated periods exhibited the highest average air and soil temperatures (PL) in the gap while the lowest ones occurred under the spruce stand. The differences in particular positions (ground air, soil surface, subsurface) were mostly up to 0.5°C. The average daily gap temperatures were significantly higher compared to the spruce stand (Table 1). The greatest variability in ground air temperatures was manifested on daily temperature amplitudes in the gap. The mean daily temperature amplitudes of particular measurement layers differed significantly except for soil temperatures under spruce and birch (both years) and

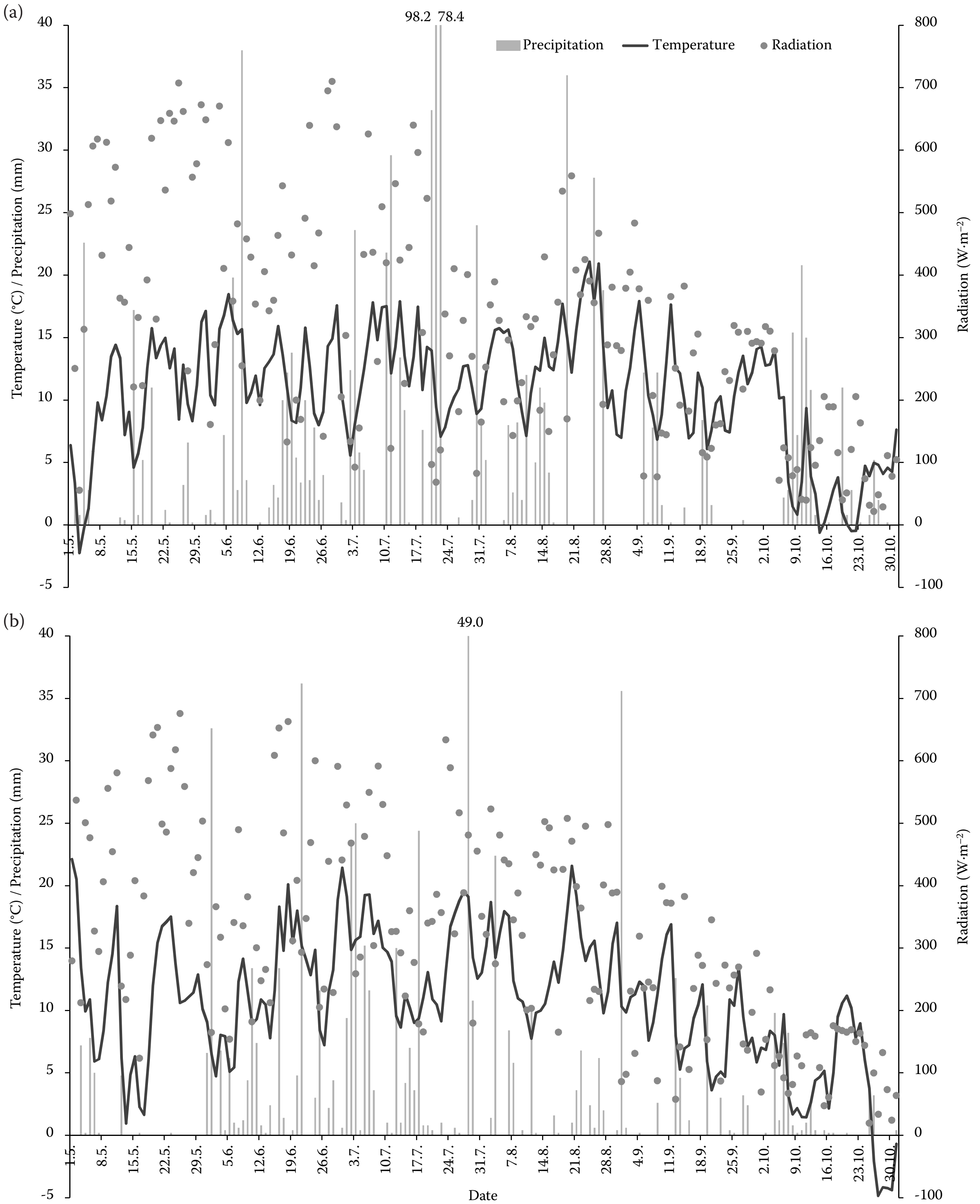


Fig. 1. Mean daily air temperature and daily sum of radiation 200 cm a.g.l. and daily sum of precipitation in 2011 (a) and 2012 (b)

surface temperatures in the gap and under spruce in 2012 (Table 2).

One-week average ground air (+10 cm) temperatures under birch were closer to the ground air temperatures in the gap at the beginning of the growing season. Afterwards the temperatures were lower with a maximum difference of 1.5°C in June-end and July-beginning in both years of interest (Fig. 2). The differences diminished towards the end of the growing season and the average birch temperatures were higher compared to the gap ones at the very end of the growing season. Spruce ground air (+10 cm) temperatures were lower compared to the gap ones during the whole measure-

Table 1. Mean temperatures of the observed 2011 and 2012 growing periods

| Year | Layer | PL | | | | | | $R_{95\%}$ | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | gap | | birch | | spruce | | gap | | birch | | spruce | |
| | | mean | SD | mean | SD | mean | SD | mean | SD | mean | SD | mean | SD |
| 2011 | +10 cm | 11.5 | 5.1 | 11.1 | 4.6 | 10.3 | 4.3 | 4.1 | 2.1 | 3.3 | 1.5 | 2.1 | 0.9 |
| | 0 cm | 11.1 | 3.3 | 10.5 | 3.2 | 10.0 | 3.1 | 3.3 | 1.2 | 2.5 | 1.3 | 1.9 | 0.6 |
| | –10 cm | 10.3 | 2.2 | 10.1 | 2.2 | 9.6 | 2.4 | 1.3 | 0.4 | 2.0 | 0.4 | 1.3 | 0.4 |
| 2012 | +10 cm | 11.7 | 5.4 | 11.4 | 4.8 | 10.4 | 4.5 | 3.9 | 2.2 | 2.8 | 0.7 | 1.9 | 0.9 |
| | 0 cm | 11.3 | 3.0 | 10.7 | 2.7 | 10.2 | 2.9 | 2.0 | 0.8 | 1.9 | 0.5 | 2.1 | 0.7 |
| | –10 cm | 10.7 | 2.2 | 10.1 | 2.1 | 9.8 | 2.2 | 1.3 | 0.4 | 1.1 | 0.3 | 1.3 | 0.3 |

PL – average pivot halfsum, $R_{95\%}$ – average range of 95% confidence intervals, SD – standard deviation

Table 2. Probability of significant differences in mean temperatures of the observed 2011 and 2012 growing periods, for average pivot halfsums (PL) ANOVA and Tukey's test were used, for average range of 95% confidence intervals ($R_{95\%}$) Welch's ANOVA and Games-Howell test for data heteroscedasticity were used

| Year | Layer | PL | | | | $R_{95\%}$ | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | ANOVA | Tukey's test | | | Welch's ANOVA | Games-Howell test | | |
| | | | gap-birch | gap-spruce | birch-spruce | | gap-birch | gap-spruce | birch-spruce |
| 2011 | +10 cm | **0.013** | 0.439 | **0.01** | 0.201 | **< 0.001** | **< 0.001** | **0.022** | **< 0.001** |
| | 0 cm | **0.002** | 0.155 | **0.001** | 0.21 | **< 0.001** | **< 0.001** | **< 0.001** | **< 0.001** |
| | –10 cm | **0.008** | 0.576 | **0.007** | 0.102 | **< 0.001** | **< 0.001** | **< 0.001** | 0.958 |
| 2012 | +10 cm | **0.047** | 0.867 | **0.049** | 0.155 | **< 0.001** | **< 0.001** | **0.002** | **< 0.001** |
| | 0 cm | **< 0.001** | 0.124 | **< 0.001** | 0.126 | **0.003** | **0.005** | 0.996 | **0.017** |
| | –10 cm | **0.002** | 0.067 | **0.001** | 0.414 | **< 0.001** | **< 0.001** | **< 0.001** | 0.419 |

in bold – differences at the significance level α = 0.05

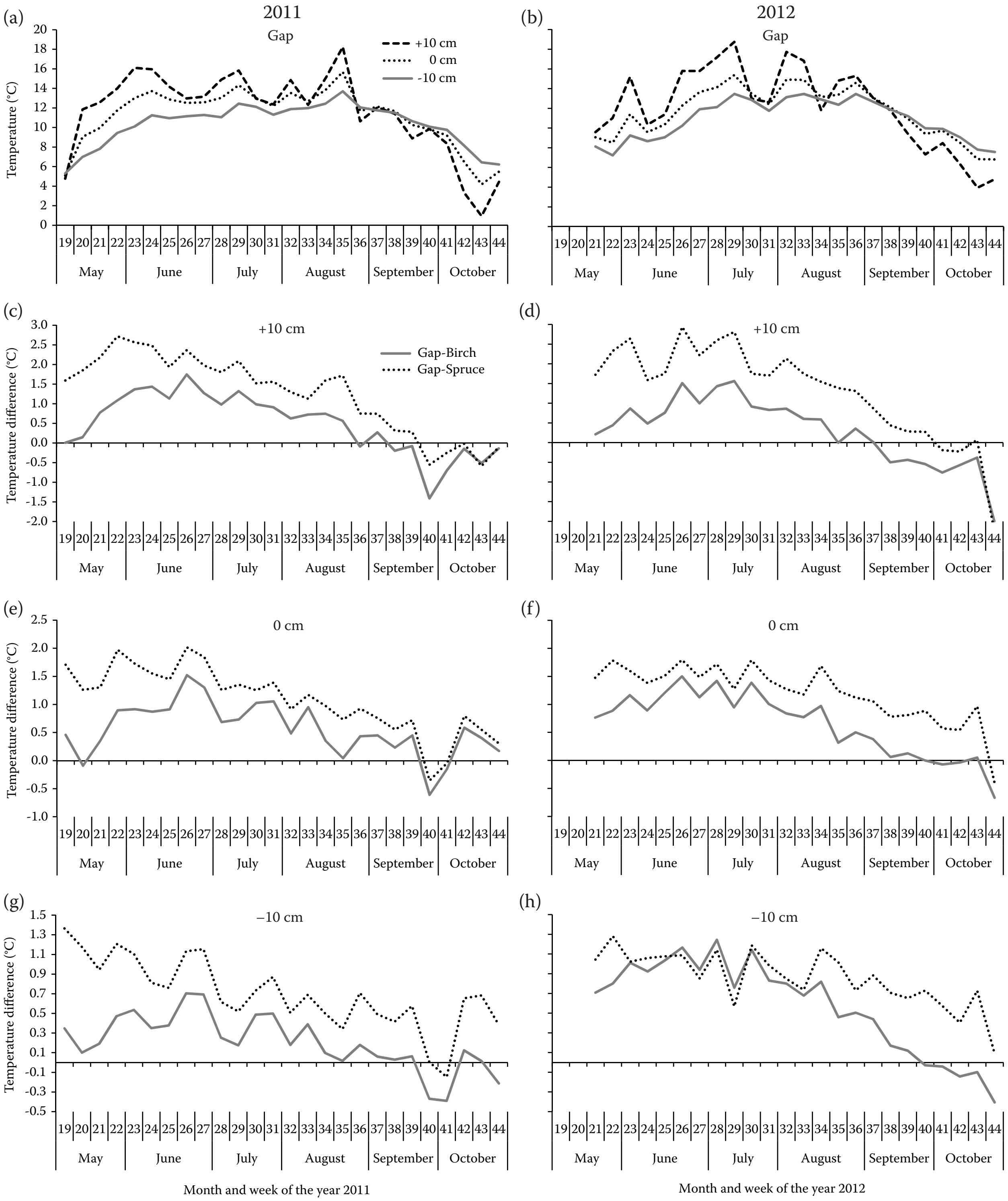
ment period. In 2011 and 2012, the greatest differences occurred in May and at the June-July turn, respectively. At the end of October 2011, spruce temperatures were comparable to gap ones. During the frost period in October 2012 (Fig. 1), the one-week average spruce temperatures were 2°C higher than in the gap. In both periods, one-week averages under spruce were significantly lower compared to birch at the beginning of the growing season and in August (Fig. 2) more significant differences were found in 2011.

One-week average surface (0 cm) temperatures were related to the ground air ones in both years. As for summer temperatures, birch temperature was up to 1.5°C lower and spruce temperature was up to 2°C (2011) lower compared to the gap in at the June-July turn (Fig. 2). The averages of spruce stand were significantly lower compared to birch ones till the start of June and around August in both years.

Also one-week average subsurface (–10 cm) soil temperatures partially differed in the two years of interest. In 2011, the birch temperature was up to 0.7°C lower compared to the gap while being higher compared to spruce. Next year, both birch and spruce were comparable during June and July exhibiting a higher difference (up to 1.2°C) compared to the gap. In both years, the greatest spruce vs. gap difference was found at the beginning of May while birch vs. gap exhibited it when June turned to July (Fig. 2). In 2011, average subsoil temperatures under spruce were significantly lower than those under birch in almost the whole period, next year the differences were confirmed at the beginning and from August onwards.

### Minimum temperatures at 10 cm

Minimum aboveground temperatures were higher under both tree species compared to the gap over the investigated period. At both the beginning and the end of growing periods, we found the higher minimum temperature under spruce compared to birch. As for weekly average, the maximum difference between the treatments was more than 2°C. The difference between birch and spruce dimin-



| Period | Position | Month | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | May | | | | June | | | | | July | | | |
| | | week number | | | | | | | | | | | | |
| | | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| 2011 | +10 cm | **0.012** | < | 0.219 | < | **0.021** | 0.159 | 0.211 | 0.156 | 0.289 | 0.113 | 0.222 | 0.327 | 0.234 |
| | 0 cm | < | < | < | < | **0.002** | < | **0.054** | **0.033** | **0.045** | **0.003** | 0.102 | 0.520 | **0.012** |
| | −10 cm | < | < | < | < | < | < | < | < | < | **0.003** | **0.047** | **0.179** | < |
| 2012 | +10 cm | | | **0.006** | < | **0.003** | 0.079 | **0.029** | **0.005** | **0.040** | **0.005** | **0.005** | **0.020** | **0.002** |
| | 0 cm | | | < | **0.022** | **0.001** | 0.081 | 0.132 | 0.173 | 0.096 | 0.192 | **0.002** | 0.072 | **0.038** |
| | −10 cm | | | < | 0.880 | **0.001** | 0.469 | 0.302 | 0.528 | 0.176 | 0.059 | 0.416 | 0.186 | 0.739 |

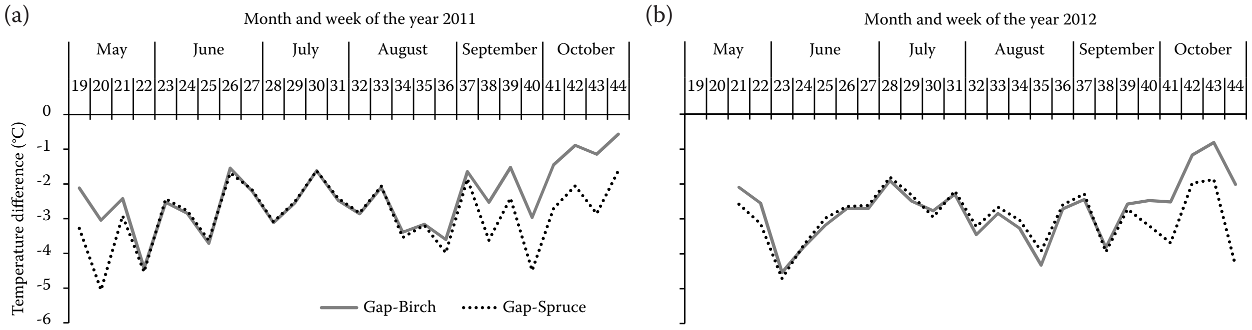
| Period | Position | Month | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | August | | | | | September | | | | October | | | |
| | | week number | | | | | | | | | | | | |
| | | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 |
| 2011 | +10 cm | **0.003** | **0.029** | **0.035** | < | **0.032** | **0.030** | 0.286 | 0.325 | **0.031** | 0.421 | 0.700 | 0.855 | 0.908 |
| | 0 cm | **0.003** | 0.238 | **0.008** | < | **0.038** | 0.214 | **0.024** | 0.121 | 0.185 | 0.829 | 0.366 | 0.541 | 0.288 |
| | −10 cm | < | **0.008** | < | **0.002** | < | < | < | < | < | 0.224 | **0.002** | < | < |
| 2012 | +10 cm | **0.015** | **0.008** | < | **0.002** | **0.003** | **0.002** | **0.003** | < | 0.055 | 0.351 | **0.034** | 0.744 | 0.252 |
| | 0 cm | < | < | < | **0.001** | < | < | **0.002** | < | < | **0.009** | < | 0.535 | 0.081 |
| | −10 cm | 0.109 | < | < | **0.007** | < | < | < | < | < | < | < | **0.041** | **0.015** |

Fig. 2. Weekly mean temperatures in the gap (a, b) and differences in the weekly mean of above- (+10 cm) (c, d), soil surface (0 cm) (e, f) and below-ground (−10 cm) (g, h) temperatures between gap and below-canopy treatments in 2011 and 2012. The table depicts the probability of statistically significant differences in weekly mean temperatures for birch vs. gap and spruce vs. gap in individual weeks (*t*-test), in bold – differences at the significance level α = 0.05, < denotes $P < 0.001$. Note: Negative differences indicate higher absolute temperatures under canopies, while positive differences indicate higher absolute temperatures in gaps (e.g. at 10 cm a.g.l. in the 40th week of 2011: weekly mean temperature in birch is 1.4°C higher than in the gap)

ished after development of birch leaves and ground vegetation at the end of May (Fig. 3). Leaf-fall in September and senescence of ground vegetation approximated the birch minimum aboveground temperature closer to the gap. In both years, daily minima under birch were significantly lower than under spruce in May and from the half of September to the end of the observed period. In 2012, the differences were also significant between the end of July and the beginning of August (Fig. 3).

### Temperature amplitudes at 10 cm

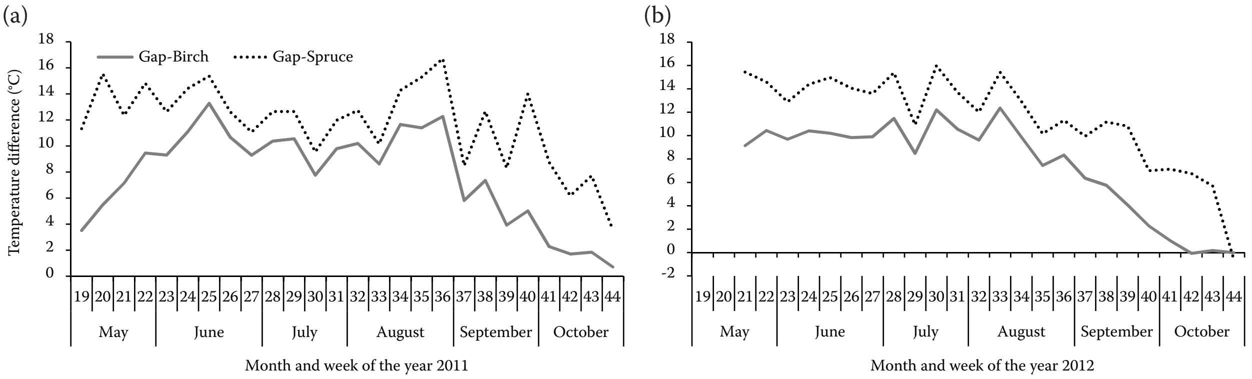
The greatest temperature amplitudes were found in the gap, the smallest amplitudes were under



| Period | Month | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | May | | | | June | | | | | July | | | |
| | week number | | | | | | | | | | | | |
| | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| 2011 | 0.113 | **0.001** | **0.012** | 0.112 | 0.152 | 0.152 | 0.084 | 0.361 | 0.469 | 0.507 | **0.010** | 0.978 | 0.298 |
| 2012 | | | **0.040** | 0.176 | 0.457 | **0.001** | 0.714 | 0.459 | 0.195 | **0.045** | 0.260 | **0.042** | **0.006** |

| Period | Month | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | August | | | | | September | | | | October | | | |
| | week number | | | | | | | | | | | | |
| | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 |
| 2011 | 0.570 | 0.394 | 0.065 | 0.664 | **0.002** | 0.146 | **0.001** | **0.025** | < | **0.009** | **0.041** | **0.009** | **0.039** |
| 2012 | **0.047** | **0.002** | < | 0.085 | 0.056 | 0.063 | 0.247 | **0.001** | **0.002** | **0.040** | **0.036** | < | 0.924 |

Fig. 3. Differences in weekly average minimum of above-ground (+10 cm) temperatures in the gap and under both tree species in 2011 (a) and 2012 (b). See the note to Fig. 2. The table depicts the probability of significant differences in weekly mean temperatures for birch vs. gap and spruce vs. gap in individual weeks (paired *t*-test), in bold – differences at the significance level α = 0.05, < denotes $P < 0.001$



| Period | Month | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | May | | | | June | | | | | July | | | |
| | week number | | | | | | | | | | | | |
| | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| 2011 | **0.010** | < | **0.017** | **0.005** | 0.156 | **0.037** | 0.254 | 0.284 | 0.588 | 0.535 | 0.378 | 0.648 | 0.440 |
| 2012 | | | < | 0.555 | 0.109 | **0.007** | **0.004** | **0.003** | **0.009** | **0.001** | 0.212 | **0.007** | < |

| Period | Month | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | August | | | | | September | | | | October | | | |
| | week number | | | | | | | | | | | | |
| | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 |
| 2011 | 0.337 | 0.316 | **0.023** | **0.013** | < | 0.279 | < | **0.026** | < | **0.010** | 0.054 | **0.010** | **0.046** |
| 2012 | **0.042** | **0.013** | **0.012** | 0.275 | 0.078 | 0.207 | **0.003** | < | 0.368 | < | < | **0.012** | **0.032** |

Fig. 4. Differences in one-week averages of daily above-ground (+10 cm) temperature amplitudes (max minus min) in the gap and under both tree species in 2011 (a) and 2012 (b). See the note to Fig. 2. The table depicts the probability of significant differences in daily temperature amplitudes for birch vs. gap and spruce vs. gap in individual weeks (*t*-test), in bold – differences at the significance level $\alpha = 0.05$, < denotes $P < 0.001$

spruce. At the beginning and the end of growing seasons, the amplitudes of birch were similar to the gap ones. Summer (June to September) birch amplitudes were closer to spruce, in 2011 significantly (Fig. 4).

## DISCUSSION

Forest canopies differ in many features depending on tree species, stand age, density and structure (Parker 1995; Augusto et al. 2015). Development of the canopy affects stand environments in terms of hydrological cycling (Natkhin et al. 2012), local climates (Renaud, Rebetez 2009; von Arx et al. 2012) and nutrient cycling (Ranger et al. 1997; Yanai et al. 1999; Rothe, Binkley 2001; Prescott 2002) having impacts on growth conditions of the forest. This is particularly important for forest management on summits of the Central European mountains that are "islands" of boreal conditions within temperate landscapes. In the Czech Republic, these mountain conditions of Norway spruce and dwarf pine forest vegetation zones – the 8th and 9th in the Czech forest site classification system (Viewegh et al. 2003), are the harshest forested sites together with specific conditions of frost pockets regarding the frequency of minimum temperatures, snow cover duration and cold air retention on the site. To restore a needed species composition, coniferous canopy can mitigate partially the impact of frost events occurring over the growing season. For example Balcar et al. (2010) proved that an evergreen coniferous woody species such as mountain and/or bog pine could nurse the other crop tree species to cope with conditions in a frost hollow. For instance Dy and Payette (2007) documented that the reduced frequency of freezing temperature events supported a massive black spruce establishment in frost hollows over ten years. On the other hand, Drobyshev and Nihlgård (2000) found that the Norway spruce saplings grew better in larger gaps than in smaller ones and under canopy in Russian southern taiga conditions.

It is known that the actual temperature of forest canopies can deviate from ambient atmospheric conditions (Leuzinger, Koerner 2007). Canopy elements cool more quickly than the canopy air space during transition between radiative gain (day) and radiative loss (night) regimes (Froelich at al. 2011; Rich et al. 2015). Winkel et al. (2009) considered canopy height, leaf area index and sky cloudiness being the most important factors for the sheltering effect development. In our study, both tree species of the same age differ obviously in the type of canopy: dense crowns covering efficiently the soil surface are typical of spruce; unlike the spruce, birch develops new foliage every year. The lowest average temperatures were under denser spruce canopy. As for minimum aboveground temperatures, the tree cover increased the air temperature compared to the gap. These findings are in accordance with Renaud and Rebetez (2009), who found also higher below-canopy minimum temperatures in premature stands during summer (especially in conifers) compared to open conditions.

The difference between young spruce and young birch stands was attributable to seasonal changes in deciduous birch canopy. Both birch and gap ground air temperatures were close at the beginning of the growing season and the differences between the treatments diminished towards the end of the growing season. Similarly to Renaud and Rebetez (2009), we found the sheltering effect depending on dominant tree species. Young evergreen conifer spruce moderated temperature amplitudes more than birch which showed temperature amplitudes similar to those in the gap at the beginning of the growing season. In summer, below-birch temperature amplitudes became closer to below-spruce ones. For instance, this was also demonstrated on the leaf area index development in a deciduous stand by Savoy and Mackay (2015).

The effect of the gap on the temperature pattern is highly dependent on gap site and surrounding forest parameters (Carlson 1997; Latif, Blackburn 2010), as well as on the slope aspect which is related to the length of shadows and illumination of the soil surface (Čihal, Jurča 1961; Souček 2015). The size of gaps in our experiment was more than twice larger than the height of the surrounding young tree stand and the slope was minimum, therefore the effect of shading was small.

## CONCLUSIONS

The highest aboveground and soil surface temperature variability was observed in gaps. Spring temperatures beneath the leafless birch were closer to gaps. In the period of leaved trees, birch reduced temperature extremes similarly like the spruce did. The differences between treatments were smallest at the end of the growing period. The results indicate that young spruce as well as young birch stands reduce aboveground and soil surface temperature extremes and also reduce soil warming. Effect of birches on below-canopy temperatures is driven by development of leaves.

## Acknowledgement

The study site is a part of the experimental plantation established by Dr. V. Balcar.

## References

Augusto L., De Schrijver A., Vesterdal L., Smolander A., Prescott C., Ranger J. (2015): Influences of evergreen gymnosperm and deciduous angiosperm tree species on the functioning of temperate and boreal forests. Biological Reviews of the Cambridge Philosophical Society, 90: 444–466.

Balcar V., Podrázský V. (1994): Založení výsadbového pokusu v hřebenové partii Jizerských hor. Zprávy lesnického výzkumu, 39: 1–7.

Balcar V., Špulák O., Kacálek D. (2010): Tvorba druhové skladby horských lesů na lokalitách extrémně zatížených klimatickými stresy. Zprávy lesnického výzkumu, 55: 241–250.

Balcar V., Špulák O., Kacálek D., Kuneš I. (2012a): Klimatické podmínky na výzkumné ploše Jizerka – I. Srážky a půdní vlhkost. Zprávy lesnického výzkumu, 57: 74–81.

Balcar V., Špulák O., Kacálek D., Kuneš I. (2012b): Klimatické podmínky na výzkumné ploše Jizerka. II – teplota, vítr a sluneční svit. Zprávy lesnického výzkumu, 57: 160–172.

Bartoš J., Špulák O., Černohous L. (2009): Ukládání sněhu ve vztahu k dřevinám vysazeným na kalamitní holině v hřebenové partii horských poloh. Zprávy lesnického výzkumu, 54: 166–173.

Bäucker B., Eisenhauer D.R. (2001): Damage to common birch (*Betula pendula* Roth) in higher altitudes of the Ore Mts. (Erzgebirge). Journal of Forest Science, 47 (Special Issue): 156–163.

Box G.E.P., Cox D.R. (1964): An analysis of transformations. Journal of the Royal Statistical Society, Series B (Methodological), 26: 211–252.

Carlson D. (1997): Microclimate of clear-cut, forest interior, and small openings in trembling aspen forest. Agricultural and Forest Meteorology, 87: 313–329.

Chávez V., Macdonald S.E. (2010): The influence of canopy patch mosaics on understory plant community composition in boreal mixedwood forest. Forest Ecology and Management, 259: 1067–1075.

Čihal A., Jurča J. (1961): Příspěvek k otázce využívání údajů o délkách stínu a podzáření při obnovách lesních porostů. Sborník Vysoké školy zemědělské v Brně, Řada C: Spisy fakulty lesnické: 21–32.

Crippa M., Janssens-Maenhout G., Dentener F., Guizzardi D., Sindelarova K., Muntean M., Van Dingenen R., Granier C. (2016): Forty years of improvements in European air quality: Regional policy-industry interactions with global impacts. Atmospheric Chemistry and Physics, 16: 3825–3841.

Dickerson-Lange S.E., Lutz J.A., Martin K.A., Raleigh M.S., Gersonde R., Lundquist J.D. (2015): Evaluating observational methods to quantify snow duration under diverse forest canopies. Water Resources Research, 51: 1203–1224.

Drobyshev I., Nihlgård B. (2000): Growth response of spruce saplings in relation to climatic conditions along a gradient of gap size. Canadian Journal of Forest Research, 30: 930–938.

Dy G., Payette S. (2007): Frost hollows of the boreal forest as extreme environments for black spruce tree growth. Canadian Journal of Forest Research, 37: 492–504.

El Kateb H., Benabdellah B., Ammer C., Mosandl R. (2004): Reforestation with native tree species using site preparation techniques for the restoration of woodlands degraded by air pollution in the Erzgebirge, Germany. European Journal of Forest Research, 123: 117–126.

Ešnerová J., Karlík P., Zahradník D., Koňasová T., Stejskal J., Baláš M., Vítámvás J., Rašáková N., Stacho J., Kuthan J., Lukášová M., Kuneš I. (2012): Morfologická variabilita rodu bříza (*Betula* L.) v Krkonoších se zaměřením na tetraploidní zástupce. Zprávy lesnického výzkumu, 57: 112–125.

Ešnerová J., Vítámvás J., Koňasová T., Kolář F., Baláš M., Karlík P., Zahradník D., Křížová M., Stacho J., Rašáková N., Stejskal J., Kuneš I. (2013): Využití obrysové analýzy při sledování morfologické variability listů rodu bříza (*Betula* L.). Zprávy lesnického výzkumu, 58: 107–114.

Fenger J. (2009): Air pollution in the last 50 years – from local to global. Atmospheric Environment, 43: 13–22.

Froelich N.J., Grimmond C.S.B., Schmid H.P. (2011): Nocturnal cooling below a forest canopy: Model and evaluation. Agricultural and Forest Meteorology, 151: 957–968.

Games P.A., Howell J.F. (1976): Pairwise multiple comparison procedures with unequal n's and/or variances: A Monte Carlo study. Journal of Educational Statistics, 1: 113–125.

Geiger R. (1950): The Climate Near the Ground. Cambridge, Harvard University Press: 482.

Horn P.S., Pesce A.J., Copeland B.E. (1998): A robust approach to reference interval estimation and evaluation. Clinical Chemistry, 44: 622–631.

Hynynen J., Niemistö P., Viherä-Aarnio A., Brunner A., Hein S., Velling P. (2010): Silviculture of birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.) in northern Europe. Forestry, 83: 103–119.

Latif Z.A., Blackburn G.A. (2010): The effects of gap size on some microclimate variables during late summer and autumn in a temperate broadleaved deciduous forest. International Journal of Biometeorology, 54: 119–129.

Leikola M., Pylkkö P. (1969): Verhopuuston tiheyden vaikutus metsikön minimilämpötiloihin hallaöinä. Silva Fennica, 3: 20–32.

Leuzinger S., Koerner C. (2007): Tree species diversity affects canopy leaf temperatures in a mature temperate forest. Agricultural and Forest Meteorology, 146: 29–37.

Lomský B., Šrámek V., Novotný R. (2012): Changes in the air pollution load in the Jizera Mts.: Effects on the health status and mineral nutrition of the young Norway spruce stands. European Journal of Forest Research, 131: 757–771.

Meloun M., Hill M., Militký J., Kupka K. (2001): Analysis of large and small samples of biochemical and clinical data. Clinical Chemistry and Laboratory Medicine, 39: 53–61.

Natkhin M., Steidl J., Dietrich O., Dannowski R., Lischeid G. (2012): Differentiating between climate effects and forest growth dynamics effects on decreasing groundwater recharge in a lowland region in Northeast Germany. Journal of Hydrology, 448: 245–254.

Neuhäuslová Z., Moravec J., Chytrý M., Sádlo J., Rybníček K., Kolbek J., Jirásek J. (1997): Mapa potenciální přirozené vegetace České republiky. 1:500 000. Průhonice, Botanický ústav AV ČR.

Nihlgård B. (1969): Microclimate in a beech and a spruce forest – a comparative study from Kongalund, Scania, Sweden. Botaniska Notiser, 122: 333–352.

Parker G.G. (1995): Structure and microclimate in forest canopies. In: Lowman M.D., Nadkarni N.N. (eds): Forest Canopies. San Diego, Academic Press: 73–106.

Portsmuth A., Niinemets Ü. (2006): Interacting controls by light availability and nutrient supply on biomass allocation and growth of *Betula pendula* and *B. pubescens* seedlings. Forest Ecology and Management, 227: 122–134.

Prescott C.E. (2002): The influence of the forest canopy on nutrient cycling. Tree Physiology, 22: 1193–1200.

Prévost M., Raymond P. (2012): Effect of gap size, aspect and slope on available light and soil temperature after patch-selection cutting in yellow birch-conifer stands, Quebec, Canada. Forest Ecology and Management, 274: 210–221.

Ranger J., Marques R., Colin-Belgrand M. (1997): Nutrient dynamics during the development of a Douglas-fir (*Pseudotsuga menziesii* Mirb.) stand. Acta Oecologica, 18: 73–90.

Reid T.D., Spencer M., Huntley B., Hancock S., Essery R.L.H., Carle J., Holden R., Baxter R., Rutter N. (2014): Spatial quantification of leafless canopy structure in a boreal birch forest. Agricultural and Forest Meteorology, 188: 1–12.

Renaud V., Rebetez M. (2009): Comparison between open-site and below-canopy climatic conditions in Switzerland during the exceptionally hot summer of 2003. Agricultural and Forest Meteorology, 1495: 873–880.

Repola J. (2008): Biomass equations for birch in Finland. Silva Fennica, 42: 605–624.

Rich R.L., Stefanski A., Montgomery R.A., Hobbie S.E., Kimball B.A., Reich P.B. (2015): Design and performance of combined infrared canopy and belowground warming in the B4WarmED (Boreal Forest Warming at an Ecotone in Danger) experiment. Global Change Biology, 21: 2334–2348.

Rothe A., Binkley D. (2001): Nutritional interactions in mixed species forests: A synthesis. Canadian Journal of Forest Research, 31: 1855–1870.

Savoy P., Mackay D.S. (2015): Modeling the seasonal dynamics of leaf area index based on environmental constraints to canopy development. Agricultural and Forest Meteorology, 200: 46–56.

Souček J. (2015): Stanovení délky a průběhu stínu v maloplošných obnovních prvcích. Certifikovaná metodika. Lesnický průvodce 2/2015. Strnady, Výzkumný ústav lesního hospodářství a myslivosti: 22.

Špulák O., Balcar V., Kacálek D. (2011): Vliv mletého vápence v jamce na prosperitu výsadeb, fluorescenci chlorofylu a obsah živin v listech břízy karpatské a buku lesního. Zprávy lesnického výzkumu, 56 (Special Issue): 57–64.

Šrámek V., Slodičák M., Lomský B., Balcar V., Kulhavý J., Hadaš P., Pulkráb K., Šišák L., Pěnička L., Sloup M. (2008): The Ore Mountains: Will successive recovery of forests from lethal disease be successful? Mountain Research and Development, 28: 216–221.

ÚHÚL (1999): OPRL – Oblastní plán rozvoje lesů. Přírodní lesní oblast č. 21 – Jizerské hory a Ještěd. Jablonec nad Nisou, Ústav pro hospodářskou úpravu lesů Brandýs nad Labem: 247.

Vašát R., Pavlů L., Borůvka L., Tejnecký V., Nikodem A. (2015): Modelling the impact of acid deposition on forest soils in North Bohemian Mountains with two dynamic models: The Very Simple Dynamic Model (VSD) and the Model of Acidification of Groundwater in Catchments (MAGIC). Soil and Water Research, 10: 10–18.

Viewegh J., Kusbach A., Mikeska M. (2003): Czech forest ecosystem classification. Journal of Forest Science, 49: 85–93.

von Arx G., Dobbertin M., Rebetez M. (2012): Spatio-temporal effects of forest canopy on understory microclimate in a long-term experiment in Switzerland. Agricultural and Forest Meteorology, 166–167: 144–155.

Webster C., Rutter N., Zahner F., Jonas T. (2016): Measurement of incoming radiation below forest canopies: A comparison of different radiometer configurations. Journal of Hydrometeorology, 17: 853–864.

Welch B.L. (1951): On the comparison of several mean values: An alternative approach. Biometrika, 38: 330–336.

Winkel T., Lhomme J.P., Nina Laura J.P., Mamani Alcón C., del Castillo C., Rocheteau A. (2009): Assessing the protective effect of vertically heterogeneous canopies against radiative frost: The case of quinoa on the Andean Altiplano. Agricultural and Forest Meteorology, 149: 1759–1768.

Yanai R.D., Siccama T.G., Arthur M.A., Federer C.A., Friedland A.J. (1999): Accumulation and depletion of base cations in forest floors in the northeastern United States. Ecology, 80: 2774–2787.

Received for publication June 16, 2016
Accepted after corrections September 14, 2016

---

*Corresponding author*:

Ing. Ondřej Špulák, Ph.D., Forestry and Game Management Research Institute, Opočno Research Station, Na Olivě 550, 517 73 Opočno, Czech Republic; e-mail: spulak@vulhmop.cz