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SHIFTS IN SPRUCE AND BEECH FLUSHING IN THE CONTEXT OF GLOBAL CLIMATE CHANGE

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Abstract

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Bud phenology and development of needle nitrogen content were monitored on Norway spruce (*Picea abies* [L.] Karst) and European beech (*Fagus sylvatica* [L.]) trees grown inside glass-domes for five years under ambient (385 μmol(CO_2) mol^{-1}) and elevated (700 μmol(CO_2) mol^{-1}) atmospheric CO_2 concentrations ([CO_2]). The spruce to beech ratio was 35:65 in both treatments. At the beginning of the experiment mean age of investigated trees was 5 years.
Elevated [CO_2] was responsible for premature growth of both spruce and beech buds in the E treatment (not significantly, by 3–7 days). Nevertheless the flushing of neither beech nor spruce was not significantly hastened in E treatment during the flushing within the 5 years. During the second half of flushing faster development of terminal beech buds comparing to spruce was found (Chi-square = 65, $p << 0.01$). While the trajectory of beech buds development proceeded in the line – terminal – apical – lateral, the development of apical and lateral buds in spruce was finished before finalization of terminal buds development. At the beginning of the growing season the lowest value of nitrogen in spruce needles from E treatment (mean ± standard deviation 1.20 ± 0.18 %) was found. This could be a reason of weak differences between A and E treatment in both tree species. Elevated [CO_2] acts as growth stimulator but the nitrogen insufficiency eliminates a positive effect of [CO_2]. As the global climate change express itself in many ways and relationship's consequences among plants and/or animals are hard to forecast.

elevated [CO_2], forest phenology, global climate change, needle nitrogen

Plant phenology studies the onset and duration of periodic vegetation cycles such as sprouting, foliage, flowering, fructification and leaf cast. Temperature is regarded to be an important environmental factor inducing bud flushing (Hannerz, 1999). Higher air CO_2 concentration, which rose from 316 ppm in 1956 to 394 ppm now, is associated with global temperature increase during previous 100 years of about 0.8 °C (IPCC 2007). Under elevated [CO_2] conditions, an acceleration of bud phenology (Repo *et al.*, 1996; Jach and Ceulemans, 1999) is reported, others studies showed a dilution response (Linkosalo, 2000), or no effects (Olszyk *et al.*, 1998; Roberntz, 1999; Kilpelainen *et al.*, 2006; Slaney *et al.*, 2007). Except flushing, climate change affects size of tree foliage and even changes the chemical composition (C/N ratio) of leaves – leaves contain less nitrogen and leaf-eating insects therefore have to consume more leaves to cover their nourishment needs (DeLucia *et al.*, 2008). Shifts in tree phenology may affect synchrony of insects and the reproduction of birds, and the time discrepancy between the gradation of caterpillars and the occurrence of birds can reduce bird population (Strode, 2003). Indeed, phenological changes are considered to be an early indicator of climate change due to their sensitivity to temperature changes (Chuine *et al.*, 2004).

Goal of this investigation was evaluate flushing of spruce and beech under elevated [CO_2] conditions and compare them with regard to needle/leaf needle nitrogen content in the course of five years. Possible consequences of phenological shifts on forest ecosystem are formulated.

Methodology

The long-term impact of elevated [CO_2] on the bud phenology of Norway spruce (*Picea abies* [L.] Karst.) and European beech (*Fagus sylvatica* [L.]) were investigated at the research site Bílý Kříž in the Beskydy Mts. (North-East part of the Czech Republic, 908 m a.s.l.). Since spring 2006 spruce trees were grown under two treatments inside the domes which differ in atmospheric [CO_2]: ambient (A, 385 μmol(CO_2) mol^{-1}) and elevated (E, A+385 μmol(CO_2) mol^{-1}). The equipment and environmental conditions – which were comparable in the both treatments and were the same as outside except the CO_2 – are described in Urban *et al.* (2001) in detail. In this locality, natural soil content of mineral nitrogen and available nitrogen forms are low throughout the whole soil profile (Formánek, 2000). The mean annual air temperature amounted to 6.8 °C and annual sum of precipitation amounts to 1 400 mm (last 10-years average).

In autumn 2005, the trees were planted with 2–3 year-old saplings of spruce and beech (mean tree height 77.1 ± 14.6 cm for beech and 46 ± 7 cm for spruce) in triangular spacing per treatment. Totally, there were 96 trees per treatment.

The methodology of Murray *et al.* (1994) was used to identify five phenological phases of the spring bud development (class: 0 – dormant bud, 1 – slight swelling, 2 – swollen bud, 3 – green needle/leaf clearly showing through the bud scales, and 4 – leaf/needle elongation).

On each tree, we observed identical terminal, lateral and apical buds. Minimally one time per year samples of five shoots/leaves from six trees for nitrogen content analysis were cut off. Needles/leaves were dried (48 h, 80 °C) and weighted (by model 1405 B MP8-1, Sartorius, Germany). Automatic elemental analyzer LECO CNS-2000 (LECO Corporation, St. Joseph, MI, USA) was used for nitrogen content analysis in the needles/leaves. Mixed needle/leaf samples with 200 mg of dry weight per tree were analyzed. Commercial standards (Sulfamethazine and Alfalfa) delivered by LECO corporation were used for the calibration procedure.

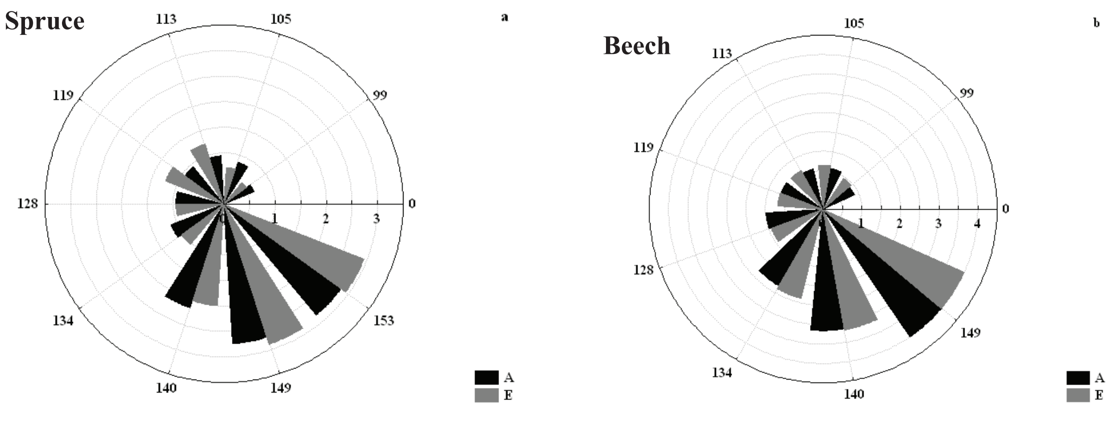
Statistical analysis

Mann-Whitney U test within Statistica software (StatSoft Inc., Tulsa, USA) was used for statistical analysis of data. Chi-square – test was used to test the significances of differences between the treatments for date-marked measurements. Study design can be characterized as pseudo-replication due to one dome per treatment (Hurlbert, 1984).

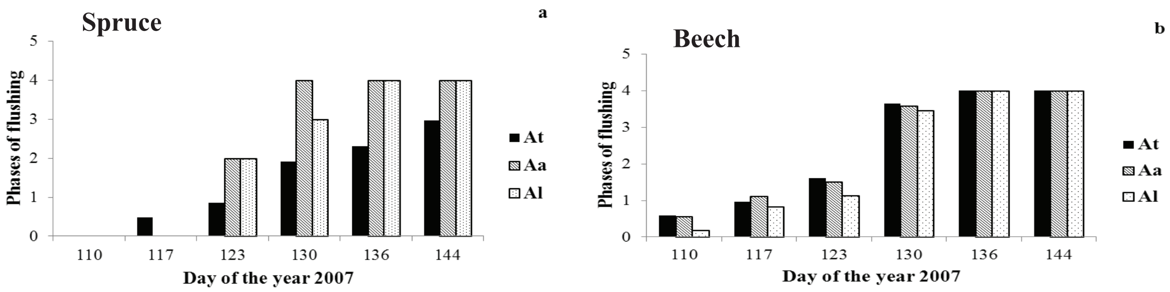
RESULTS AND DISCUSSION

The beginning of the growing season started within the first half of April (from 4th of April in 2008 and 20th of April in 2010). There was no significant difference in the start of flushing between the treatments as well as between spruce and beech although the development of trees in E treatment started by 3–5 days earlier compared to A treatment (Fig. 1).

According to our previous investigation with spruce (Pokorný *et. al*, 2010) statistically significant differences ($p << 0.01$) between A and E treatments were found. Nevertheless the spruce was older (16 years at the end of the investigation) and it grew in monoculture. In late bud development phases (the 3rd and the 4th phase) buds from E treatment developed significantly faster. The beginning of growing season is influenced more by elevated temperature than elevated [CO_2] which was confirmed by many authors (Repo *et al.*, 1996; Hanninen *et al.*, 2007; Slaney *et al.*, 2007). According to Dubrovský (2011) all observed climatological stations in the Czech Republic have shown a significant increase in the average annual temperatures in comparison to the long-term average as well as increase in the continuous length of hot season which can be attributed with a high probability to increasing [CO_2] via the mechanism



1: *Temporal development (day of the year on the circumference) of terminal buds for a) spruce and b) beech is showed by column size among concentric circles for five phases of flushing (centre – dormancy, and circles – phenological phases: 1 – slight swelling, 2 – swollen bud, 3 – green needle/leaf clearly showing through the bud scales, and 4 – leaf/needle elongation) during the growing seasons 2002. Ambient (A; 385 μmol(CO_2)mol^{-1}) and elevated atmospheric [CO_2] treatments (E; A+385 μmol(CO_2)mol^{-1}).*



2: *Temporal development during the selected year 2007 of terminal buds for spruce (a) and beech (b) is shown by column height for five phases of flushing (centre- dormancy, and circles –phenological phases: 1 – slight swelling, 2 – swollen bud, 3 – green needle/leaf clearly showing through the bud scales, and 4 – leaf/needle elongation). Ambient (A; 385 μmol(CO_2)mol^{-1}). Buds type: t – terminal, a – apical, l – lateral*

of enhanced greenhouse effect (IPCC, 2007). The development of beech buds (especially terminal) in E treatment was usually fully finished about 12 days sooner as compared to spruce.

Second half of bud development (usually beginning of May) was characterized by significant differences in flushing phase between spruce and beech. In both treatments, faster development of terminal beech buds compared to spruce was found (Chi-square = 65, $p << 0.01$). There was no steady development of apical and lateral buds in spruce compared to terminal one. 2nd or 3rd phase of spruce apical and lateral buds was usually omitted (Fig. 2).

Analogous to higher temperature, early flushing relates to high nitrogen concentration and a delay in bud break is expected at low nitrogen availability (Murray *et al.*, 1994; Bigras *et al.*, 2001). The long-term effect of elevated [CO_2] was responsible for the decrease of nitrogen content (Tab. I).

There were differences between A and E treatments in nitrogen content of spruce during the whole investigated period (from 2007 to 2011) and from July 2009 the differences become statistically significant ($p < 0.05$). At the beginning of flushing the lowest nitrogen content in spruce needles in E treatment was found (5 year mean ± standard deviation 1.20 ± 0.18 %). Thus at the beginning of the growing season the nitrogen content in E needles was permanently under critical level which was established as 1.3 % for the Norway spruce and European beech (Innes, 1993). Lower amount of nitrogen in E treatment leads to the lower amount of the Rubisco enzyme (Hrstka *et al.*, 2005) and decrease of carbon assimilation efficiency reported as the photosynthetic down-regulation. The decreasing nitrogen availability is expected to be responsible for non-significant differences in bud flushing between both treatments.

Shifts in the tree phenology could influence a wide range of animals and their life activities and patterns. Shifts in the budding of trees may adversely affect insect gradation which will not correlate with the hatching of bird predators (Both, 2006). In a connection with higher annual average temperatures, it is necessary to envisage a higher quantity of insect pests that will outbreak more often and the damages could be worse (Kurz *et al.*, 2008). According to Curran (2008) there exists a direct relationship between temperature increase and the percentage of damaged leaves. At the same

I: *Variation of nitrogen content within beech and spruce current needles/leaves grown at ambient (A; 385 μmol(CO_2)mol^{-1}) and elevated atmospheric [CO_2] treatments (E; A+385 μmol(CO_2)mol^{-1}) during the years 2007–2011. The amount of needle/leaves nitrogen under the critical values of 1.3% is highlighted. STD – standard deviation.*

Date of measurement	A_beech		E_beech		A_spruce		E_spruce	
	mean	STD	mean	STD	mean	STD	mean	STD
July/2007	2.04	0.34	1.49	0.34	1.52	0.27	1.16	0.15
October/2007	1.58	0.24	1.28	0.42	1.91	0.24	1.78	0.20
July/2008	1.99	0.25	1.83	0.22	1.27	0.08	1.20	0.20
August/2008	2.13	0.28	2.15	0.34	1.77	0.17	1.59	0.26
September/2008	1.87	0.24	1.87	0.23	2.01	0.23	1.84	0.26
July/2009	2.24	0.28	2.18	0.26	1.47	0.13	1.14	0.16
Juny/2010	2.21	0.22	1.84	0.25	-	-	-	-
August/2010	2.48	0.23	2.03	0.22	1.54	0.13	1.23	0.21
September/2010	-	-	-	-	1.86	0.14	1.47	0.29
Juny/2011	2.50	0.35	1.85	0.26	-	-	-	-
August/2011	2.73	0.30	2.16	0.15	1.48	0.17	1.27	0.20
October/2011	-	-	-	-	1.81	0.23	1.41	0.26

time changes of environmental parameters alter faster than the actual adaptation of trees to the new conditions can cope with.

SUMMARY

Bud phenology was monitored on Norway spruce (Picea abies [L.] Karst) and European beech (Fagus sylvatica [L.]) trees grown under ambient (385 µmol(CO_2) mol^{-1}) and elevated (700 µmol(CO_2) mol^{-1}) atmospheric CO_2 concentrations ([CO_2]). The spruce and beech individuals were 5 years old and the spruce to beech ratio was 35:65 in both treatments. The trees were cultivated in glass domes for five years. Elevated [CO_2] was responsible for premature growth of both spruce and beech buds in the E treatment (not significantly, by 3–7 days). Compared to our expectations acceleration of the flushing was not significantly hastened in E treatment within the 5 years neither in beech nor in spruce. During the second half of flushing differences among spruce and beech phenological phases were found (Chi-square = 65, $p << 0.01$) and faster development of beech buds was recorded. While the trajectory of beech buds development proceeded in the line – terminal – apical – lateral, the development of apical and lateral buds in spruce was finished before finalization of terminal buds development. At the beginning of the growing season the lowest value of nitrogen in spruce needles from E treatment (mean ± standard deviation 1.20 ± 0.18%) was found. This could be a reason of weak differences between A and E treatment in both tree species. Elevated [CO_2] acts as growth stimulator but the nitrogen insufficiency eliminates a positive effect of [CO_2]. As the global climate change express itself in many ways and relationship's consequences among plants and/or animals are hard to forecast.

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