BRIEF REPORT

Bud Break and Intra-Annual Height Growth Dynamics of Saplings and Pole-Stage Trees of Scots Pine: Case Study for a Boreal Forest in Northern Finland

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Seo, J.-W., Aalto, T., Jalkanen, R., Eckstein, D., Schmitt, U. and Fromm, J. 2012. Bud break and intra-annual height growth dynamics of saplings and pole-stage trees of Scots pine: case study for a boreal forest in northern Finland. *Baltic Forestry* 18(1): 144–149.

Abstract

The timing of phenophases of trees has increasingly been used as bio-indicator for climate change. Many studies, however, did not sufficiently consider an influence of tree age. According to our exploratory study, the phenophases at the tops of saplings and of pole-stage trees of Scots pine growing in an open canopy boreal forest coincided with each other in a given year but differed between years (2008 and 2009). In 2008, bud break and the onset and end of height growth of saplings/pole-stage trees occurred at the same time, *viz.* at the end of May, beginning of June and mid-July, respectively. In 2009, bud break and onset of height growth occurred mid-May and end of May, respectively, whereas the end of height growth was the same as in 2008 (mid-July). This finding indicates the possibility of transferring observations made on easily accessible saplings to hardly accessible adult trees. This transferability may open up new ways to better understand growth processes of adult trees.

Key words: *Pinus sylvestris*, young vs. old trees, phenophases, Wilcoxon rank test

Introduction

The timing of the onset and cessation of tree growth in boreal forests is strongly related to the extreme growing conditions in the far north (Sarvas 1972, Häkkinen et al. 1995, Salminen and Jalkanen 2007, Seo et al. 2008). This is the reason why boreal trees are highly qualified as bio-indicators for climate change (Menzel et al. 2006, Linkosalo et al. 2008, Pudas et al. 2008, Rossi et al. 2008).

Bud break is the first visual phenophase after winter dormancy. Thereafter, shoot growth, formation of needles and flowers and, with some offset over time, radial growth follow (Lieth 1974, Lachaud 1989, Kramer and Kozlowski 1979). This fixed annual cycle is coordinated by phytohormones and modified by environmental influences (Larcher 2003) such as temperature or CO_2 content in the ambient air (Kilpeläinen et al. 2006, Slaney et al. 2007, Pokorný et al. 2010).

The extreme growing conditions for trees at high latitudes, especially in spring, lead to a chronological sequence of phenological events (e.g., Linkosalo 2000, Salminen and Jalkanen 2007) which does not allow much variation between individuals. Nevertheless, xylogenesis of trees (Rossi et al. 2008), as well as their response to climate (Linderholm and Linderholm 2004) and their strategy of carbon allocation, either into growth, storage or reproduction (Genet et al. 2010), are age-dependent.

Tree phenology during the growing season can be taken as a natural proxy to indicate climate change (e.g., Salminen and Jalkanen 2005, Slaney et al. 2007).

Although our understanding of the interlinked activity between different organs and meristems of trees has been improving (e.g., Ruttink et al. 2007, Salminen and Jalkanen 2007, Rossi et al. 2008, Fromm 2010), the relationship between the externally visible phenological cycle and the internally proceeding activities has not been sufficiently studied yet (e.g., Jayawickrama et al. 1998, Seo et al. 2010).

In an earlier study, we already linked the timing of intra-annual radial growth of pole-stage trees with intra-annual height growth of saplings (Seo et al. 2010). These results have shown that such linkage may be affected by many other parameters.

The aim of the current study was to compare the timing of bud break, onset and end of height growth of Scots pine saplings and pole-stage trees growing at the same site in a boreal forest in Finland and to check if these phenophases occurred statistically at the time for both age groups. With this case study we will check if observations on saplings can be transferred to pole-stage trees whose canopies are less easily accessible.

Material and methods

The study site is located near Rovaniemi (66°22' N; 26°43' E; 150 m a.s.l.) at the Arctic Circle in the northern boreal zone in Finland approx. 300 km south from the northern distribution limit of Scots pine (Fig. 1). The forest vegetation, following Cajander (1949), is of the *Empetrum-Vaccinium* type. The stand is exclusively composed of even-aged, 45-year old Scots pine, born naturally from local seed, with a density of 2000 stems per ha on a dry site.

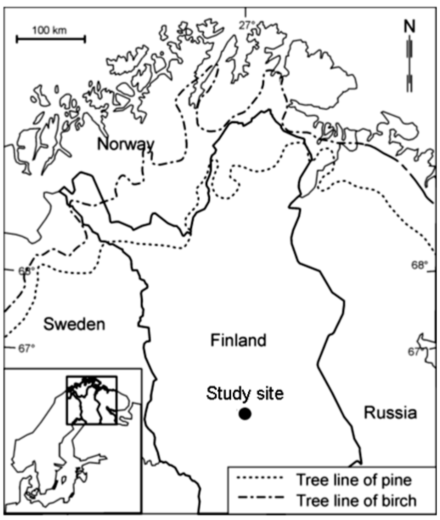

Figure 1. Study site at the Arctic Circle; the tree lines for pine and birch are drawn according to Varmalo et al. (2004)

Ten saplings and five pole-stage trees of Scots pine (*Pinus sylvestris* L.) (Tab. 1) were selected to monitor and compare their phenological development and intra-annual height growth dynamics. The mean, maximum and minimum daily temperatures were collected by a data logger (Tinytag Ultra by Gemini Data Loggers/UK) installed at the site.

Table 1. Data on the sample trees of Scots pine (saplings and pole-stage trees)

	No. of trees		Height (m)*		DBH (cm)*		Age (yrs)	
Year	2008	2009	2008	2009	2008	2009	2008	2009
Saplings	10	9	1.9	2.0	2.0	2.0	14	15
Pole-stage trees	5	5	10.3	10.3	11.5	15.3	40	43
Site	Latitude		Longitude		Altitude		Vegetation type	
Vanttauskoski Rovaniemi	66°22'N		26°28'N		150 m a.s.l.		*Empetrum-Vaccinium*	

*average value

Three phenological phases, i.e., bud break and onset and end of height growth, were monitored weekly from beginning of May to the end of August in 2008 and 2009. Bud break was considered to be accomplished when bud elongation reached or exceeded 1 mm in relation to the reference value directly measured on winter buds; onset and cessation of height growth were appointed when 5 and 95%, respectively, of the total annual shoot elongation were achieved (Salminen and Jalkanen 2007). The monitoring was carried out with the same saplings for two years, 2008 and 2009; however, due to damage by reindeer, one sapling had to be removed from the 2009 monitoring set. To help measuring leader-shoot length of the saplings to the nearest millimetre, a pin was inserted permanently through the previous annual shoot of the main stem as a reference point (Fig. 2a).

For the pole-stage trees, the phenological stages of each tree were photographed from a 6.3 m high, experimental tower (Fig. 2b below, c, d). Current and previous-year shoots were photographed weekly (eve-

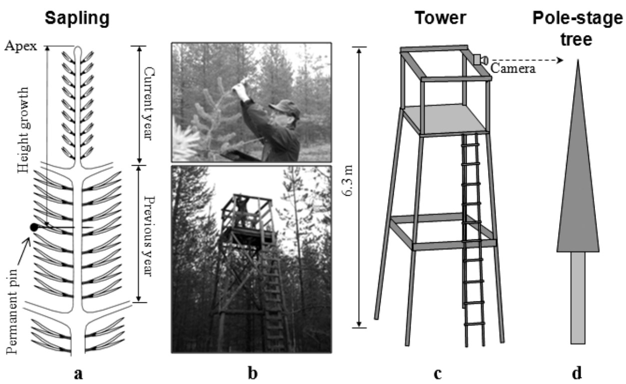

Figure 2. Monitoring of intra-annual height growth of saplings (a, top of b) and of pole-stage trees (bottom of b and c, d)

ry Monday) in both years by a permanently attached camera with the same magnification throughout the summer. After felling of the sample trees, the length of the current year's shoots were directly measured, and the previous-year shoot length was used as a reference for the developing length of the current-year's shoot. As these trees had to be cut in September 2008, new trees of the same dominant class and of approximately the same age, height and DBH were chosen for 2009. All trees were located at a distance of 4 to 20 m from the tower.

A Wilcoxon rank test was applied to check the differences between the phenological phases of the two age groups within the same year and between the two monitoring years. This test does not require normally distributed data.

Results

In 2008 and 2009, the intra-annual height-growth dynamics of the saplings and pole-stage trees were highly similar to each other (Fig. 3). The simple correlations between the average values of 10 saplings and of 5 adult trees were 0.66 ($p = 0.076$) (2008) and 0.98 ($p < 0.001$) (2009). This synchrony appears to be driven by temperature (Tab. 2) even if the significance of most correlations is slightly below the 95% confidence level.

Table 3. Wilcoxon rank test to compare the phenological phases of Scots pine (saplings and pole-stage trees) during the two study years, 2008 and 2009; *p*-values in bold mean significance at the 95% confidence level; BB = bud break, H_O = onset of height growth, H_E = end of height growth

	Saplings			Pole-stage trees		
Phenology	BB	H_O	H_E	BB	H_O	H_E
Chi-square	12.452	16.443	0.250	8.334	7.868	1.476
p-value	**0.001**	**0.001**	0.618	**0.004**	**0.005**	0.114

Phenophases of saplings

In the saplings, bud break occurred in 2008 at the end of the third week of May (May 19), and in 2009 approx. 7 days earlier in the middle of the second week of May (May 12) (Fig. 4). The next phenophase, onset of height growth, followed around 14 and 12 days later in 2008 and 2009, respectively. The onset of both phenophases occurred at statistically highly different dates in 2008 and 2009 (June 3 and May 24, respectively) (Tab. 3). However, height growth stopped in 2008 and 2009 at around the same time in the first half of July ($p = 0.618$). Accordingly, in 2008 and 2009 the average duration from bud break up to the end of height growth was 53 and 64 days, and from onset of height growth up to its end 39 and 51 days, respectively.

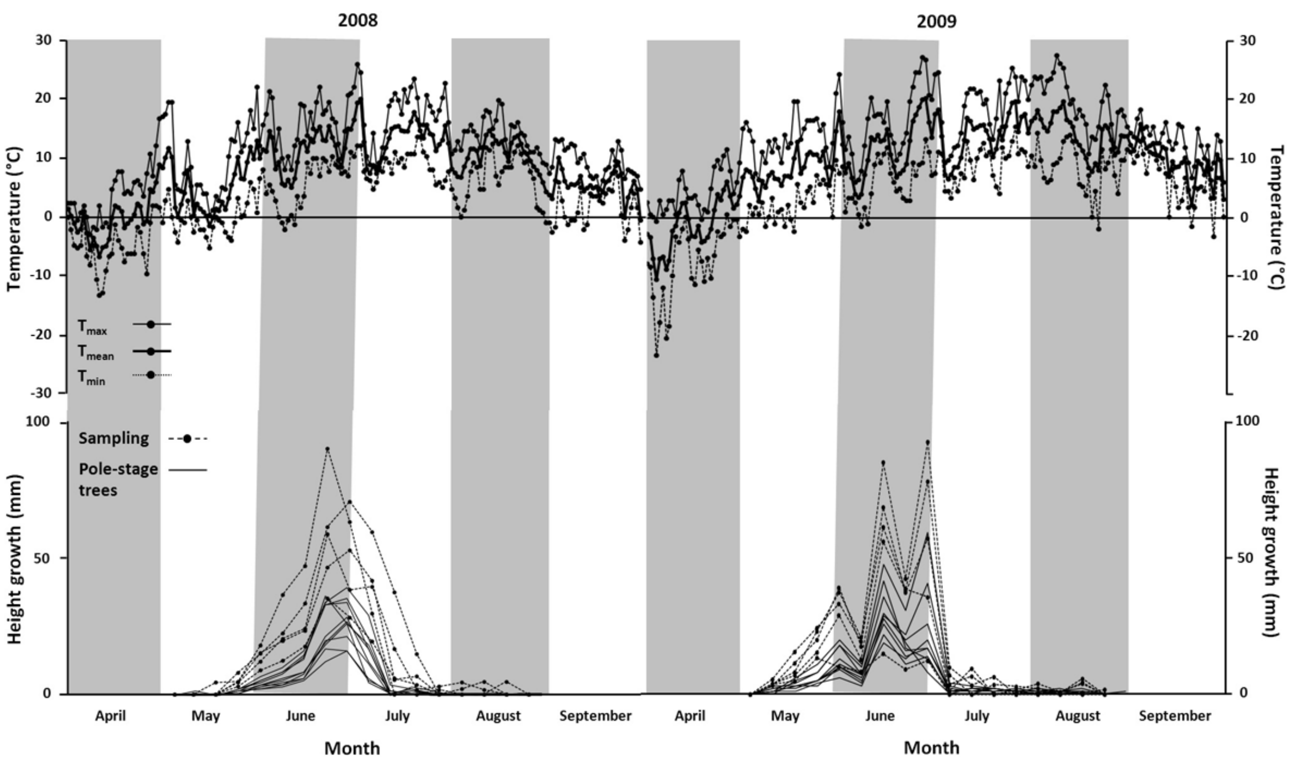

Figure 3. Daily temperature and intra-annual height-growth dynamics of the saplings and pole-stage trees from April to September 2008 and 2009; T_{max}, T_{mean}, T_{min} = daily maximum, mean and minimum temperature

Phenophases of pole-stage trees

In the pole-stage trees, bud break in 2008 was observed in the third and forth week of May (May 19 and 26) and in 2009 in the second week of May (May 11) (Fig. 4). The onset of height growth followed approx. one week later each year. The difference between 2008 and 2009 was highly significant for both phenophases (Tab. 3). In contrast, height growth in 2008 and 2009 ended during the first three weeks of July (Fig. 4), that means, statitically at the same time (p = 0.114) (Tab. 3). Accordingly, in 2008 and 2009 the average duration from bud break up to the end of height growth was 52 and 60 days, and from onset of height growth up to its end 43 and 52 days, respectively.

Comparison of the phenophases between saplings and pole-stage trees

The chronological differences of the three phenophases, bud break, onset and end of height growth, between the saplings and pole-stage trees in both study years varied from 1 to 5 days (Fig. 4) but they were not significant at the confidence level of 95%. Hence, there is no difference between the chronological development of both age classes regarding bud break as well as onset and end of height growth.

Discussion

The phenological cycle of height growth of both saplings and pole-stage trees of Scots pine near the Arctic Circle in Finland started earlier in 2009 than in 2008; this is clearly due to above-average May temperature in 2009 (8.6°C) as compared with 2008 (4.9°C). According to previous studies with saplings at the same site in the years 2001–2003 (Salminen and Jalkanen 2007, Seo et al. 2010), bud break occurred between April 30 and May 11 and height growth started between May 14 and 20, varying in dependence on the prevailing temperature. Although Menzel (2000) has reported that the phenophases have been starting increasingly earlier since 1959, bud break and the onset of height growth in 2008 and 2009 occurred later than during the years 2001 to 2003. Considering that the timing of the phenophases of trees growing at high latitudes is highly positively correlated with temperature (e.g., Linkosalo 2000, Salminen and Jalkanen 2007), below-average temperature in April 2008 and 2009 (–0.5 and –1.3°C, respectively) presumably has delayed bud break (April temperature in 2001, 2002 and 2003

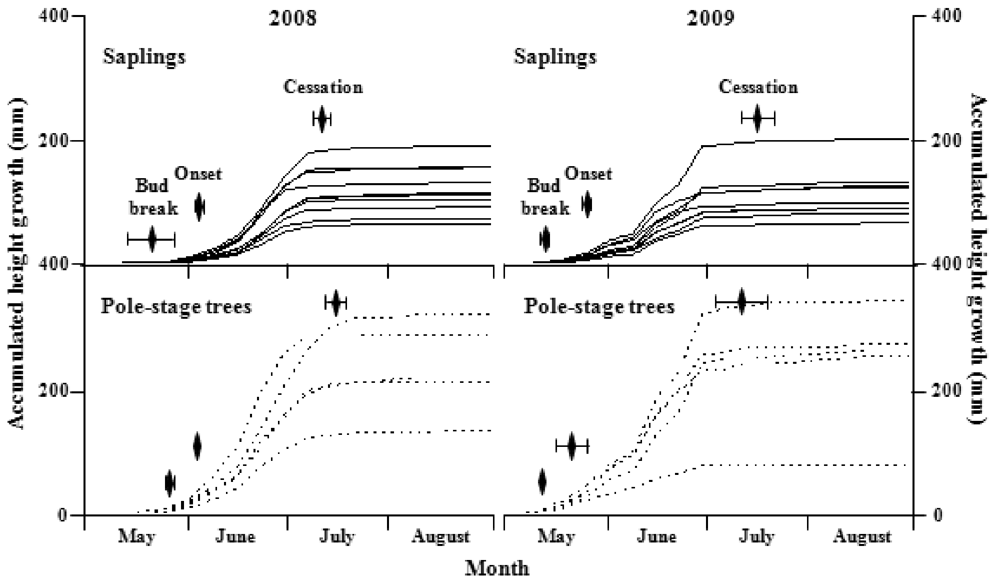

Figure 4. Bud break and cumulative height growth of the saplings and pole-stage trees in 2008 and 2009; diamond: average over all trees, horizontal bars: standard deviations

was –0.1, +2.0 and –1.2°C, respectively). The later onset of height growth in 2008, as compared to 2001, 2002 and 2003, may be due to low May temperature (4.9°C) (May temperature in 2001, 2002 and 2003 was 5.2, 8.1 and 7.1°C, respectively).

Height growth of saplings and pole-stage trees ended between July 11 and 14 in 2008 and July 10 and 14 in 2009 and hence later than between 2001 and 2003 (July 1, June 26 and July 7, respectively). Due to the varying timing of the phenophases, the growing season from bud break to the end of height growth of saplings/pole-stage trees in 2008 and 2009 (53/51 and 64/60 days, respectively) was shorter than in 2001–2003 (approx. 87 days) (Salminen and Jalkanen 2007, Seo et al. 2010). As the final shoot length of Scots pine is predetermined by temperature in the previous summer (Salminen and Jalkanen 2007), temperature of the early part of the current summer only affects the timing of the shoot expansion. This means that the warmer the current early summer, the less time is needed for the growing shoot to reach its final length. Further, the final shoot length can be reached in a shorter time if that previous summer has predetermined the shoot to become shorter than average. Independent on slight differences between seasons, the shortening day length from late June onwards determines that trees cannot grow in length anymore in late July or August.

The final annual shoots were longer in the pole-stage trees (23.7 cm) than in the saplings (11.6 cm). Based on the long-term age trend for height increment (Assmann 1961, Namkoong and Conkle 1976, Köster et al. 2008, Metslaid et al. 2011), height growth of the pole-stage trees is close to its culmination, having much better possibilities for photosynthesis to produce assimilates as compared to the saplings. Despite of the differences in the final shoot length between the saplings and pole-stage trees, intra-annual growth intensity was very well synchronized in the two groups. According to Salminen and Jalkanen (2007) and Seo et al. (2010), the intensity of intra-annual growth is determined by prevailing climate conditions.

According to previous studies, photosynthesis (Kull and Koppel 1987, Thomas and Winner 2002), carbon allocation (Genet et al. 2010), and the dependence of both processes on the prevailing growing conditions (Linderholm and Linderholm 2004, Rossi et al. 2008) depend on tree age. However, our monitoring data of bud break and height growth of saplings and pole-stage trees did not support such an age and/or size-dependent difference. Assuming that growing conditions are equal, we can conclude that the development of the shoot is dominantly determined by temperature. Therefore, if the sampling is carried out in an open canopy stand, such as at our sampling site, there is no difference in the phenology of bud break and height growth between saplings and pole-stage trees of Scots pine.

Accordingly, phenological observations made on saplings can be transferred to adult trees; and the phenological activities at the apex and in the lateral meristem are closely associated. It is, however, desirable that the data set of this exploratory study will be broadened to strengthen the reliability of the implications.

Acknowledgements

This study is conducted under the German Science Foundation (DFG) project no. FR 955/16-1. The work was partly supported by the Millennium (017008) EU project and German Science Foundation (DFG) project no. WI 2680/2-1. We want to thank Pekka Närhi for producing the height-increment data in field.

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РАСПУСКАНИЕ ПОЧЕК И ВНУТРИГОДОВАЯ ДИНАМИКА РОСТА В ВЫСОТУ ПОДРОСТА И ВЗРОСЛЫХ ДЕРЕВЬЕВ СОСНЫ ОБЫКНОВЕННОЙ (*PINUS SYLVESTRIS* L.): ИССЛЕДОВАНИЕ НА ПРИМЕРЕ БОРЕАЛЬНЫХ ЛЕСОВ СЕВЕРНОЙ ФИНЛЯНДИИ

Дж.-В. Со, Т. Аалто, Р. Ялканен, Д. Экштайн, У. Шмитт и Й. Фромм

Резюме

Смещения в датах наступления фенологических фаз деревьев все чаще используются как биоиндикатор изменения климата. Однако во многих исследованиях влияние возраста деревьев не учитывается в достаточной мере. В соответствии с нашими наблюдениями, у одиночных доминантных деревьев сосны обыкновенной, произрастающей в бореальных лесах северной Финляндии, фенологические фазы у подроста и у взрослых деревьев совпадают друг с другом в течение одного года, но различаются между годами (2008 и 2009). В 2008 году пробуждение почек, начало и конец роста в высоту у подроста и у взрослых деревьев, произошло одновременно, а именно в конце мая, в начале июня и в середине июля, соответственно. В 2009 году пробуждение почек и начало роста в высоту наступило в середине мая и в конце мая, соответственно, тогда как окончание прироста в высоту было таким же, как в 2008 году (в середине июля). Полученный результат указывает на возможность перенесения наблюдений, сделанных просто и доступно на подросте, на трудноосуществимые наблюдения над взрослыми деревьями. Этот перенос, возможно, позволит открыть новые пути к лучшему пониманию процессов роста взрослых деревьев.

Ключевые слова: *Pinus sylvestris*, сравнение молодых и старых деревьев, фенологические фазы, ранговый тест Вилкоксона