Chilling and forcing requirements to budburst for early and late – flushing tree species

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Abstract

Most of the temperate tree species has to fulfill chilling requirement during fall and early winter in order to start budburst in spring. Many researchers warn that some species might not attain their chilling requirements in a changing climate conditions. Our aim in this study was to detect the dates when chilling requirements are attained for different tree species and to evaluate tradeoffs between chilling and forcing. We collected dormant twigs in the cold period of the year 2015 – 2016 from the wild in Schoodic Peninsula of Acadia National Park, Maine, USA. Our results showed that early–flushing species (*Betula papyrifera, Alnus glutinosa*) has very low chilling requirements whereas late–flushing species (*Picea mariana, Abies balsamea*) has much higher chilling requirements. The transition from endodormancy to ecodormancy for the early–flushing species appeared in the middle of November and for late–flushing species in the second part of December. For the all investigated tree species non–linear and in all cases strong relationship was detected between accumulated thermal time and chilling.

Keywords: chilling, forcing, dormancy, budburst

1. Introduction

In the temperate ecosystems temperature is considered as a main driver of spring phenology *(*Jeong *et al.*, 2011; Wielgolaski *et al.*, 2011; *Chmielewski,* Rötzer, 2002*)*. Increased temperature in the late winter and early spring determines earlier occurrence of spring phenophases *(*Menzel, 2002*)*. The impact of increased temperature on plant phenology is well established and well documented. In the last decades spring phenology (budburst, leaf out, flowering) has advanced by 7 – 28 days depending on the region (Cleland *et al.*, 2007; Schaber, Badec, 2005; Ahas *et al.*, 2006; Chmielewski, Rotzer, 2001). The highest advancement is detected in northern regions where temperature in cold period of the year is increasing much higher as compared with southern regions.

As global temperature has dramatically increased, beginning of growing season continues to advance in many temperate zones (Jeong *et al.*, 2011). However, it is crucial to understand the dual role of temperature for trees seasonal development. Before the accumulation of thermal time in spring, most of temperate trees species has to fulfill its chilling requirements in late autumn and early winter in order to release winter dormancy. Some scientists warns that in a warming climate, some species might not meet their chilling requirements and therefore spring phenophases might delay instead of advancing (Yu *et al.*, 2010; Legave *et al.*, 1982). This is a crucial question for phenological modelling. Researchers provide controversial results about fitness of different phenological models and this topic is still under debate (Matzneller *et al.*, 2014; Blümel, Chmielewski, 2012). Most researchers agree that phenological models require more biological meaning but dormancy of the tress is still poorly understood.

It has been suggested to combine experimental and historical data in order to provide more accurate projections of trees phenophases (Wolkowich *et al.*, 2012) and some investigation has been already done (Chmielewski, Götz, 2016). Many of the parameters in phenological models must be optimized by using phenological data. In one stage thermal time models at least two or three parameters must be optimized. Experimental data can provide some beneficial information about trees transition from endodormancy to ecodormancy and this fixed date could be used in order to improve one stage models.

The aim of this study is to detect the date of the transition from endodormancy to ecodormancy for different trees species and investigate when chilling requirements are attained. The other goal is to define relationship between chilling and forcing for different tree species and determine forcing requirements.

2. Methods

The collection of dormant twigs was held in the cold period of the year 2015-2016. Four different trees species were chosen: early–flushing *Betula papyrifera* and *Alnus glutinosa* and late–flushing *Picea mariana* and *Abies balsamea*. The twigs were gathered from the wild surroundings the Schoodic Education and Research Center Campus on the Schoodic Peninsula of Acadia National Park, Maine, USA (44.37°N, 68.12°W°). The twig collection began immediately after leaf falling in autumn. The first date of collection was 10th of November in 2015 and the last date was 25th of March in 2016. We have chosen three trees of the same plant species growing away

from each other and cut one twig from each tree weekly. It was collected a total of 12 twigs per week and a total of 216 twigs during the entire time of experiment.

The twigs were cut at the length of about 20 – 30 cm and were kept dry during collection in the field. The twigs were brought into the laboratory at Schoodic Institute, where the base of each one was re-cut underwater and placed into containers with 250 ml of tap water. The twigs of each species were randomly split into groups of 4 and each group were randomly placed in one of two light sources fitted with full spectrum lights (Hydrofarm FLCDG125D Fluorowing Compact Fluorescent System, Full daylight spectrum 125 watt compact fluorescent grow bulb). The photoperiod was regulated automatically with timer and plants were exposed to 14 h of daylight which is typical for April in this area. The twigs were kept in laboratory with a mean constant temperature of 18 ^{O}C. The humidity and temperature in the laboratory was observed by HOBO.

To assure proper water supply, the base of each stem were washed, re-cut underwater (1-1.5 cm) and water was changed every week. So we maintained the ability of the twigs to take up water and kept the stems tissues clean. Weekly twig evaluation and washing continued until budburst but no longer than 10 weeks following each collection date. Afterwards we discarded the remaining twigs.

We evaluated and recorded the development stage of twigs two times per week. The phenological stage of budburst was investigated in this research. Budburst of conifers and deciduous trees species is described as date when the protective scale coating is shed from the bud exposing tender new growth tissues of one or more flower buds or leaves. We considered that species met their chilling requirements when two of three (more than a half) twigs reacted to increased temperature in the laboratory and started to budburst.

Temperature data was retrieved from http://mesowest.utah.edu for the station named McFarland Hill in Acadia National Park (44.37°N, 68.26°W, 129 m elevation). Chilling days were calculated in the range of temperature from 0 to 5°C. Chilling days calculation started from 1st October and this date was chosen, because we wanted to involve the longer possible time influencing the tree. The end of the chilling calculation was twigs collection date. Thermal time was calculated as all temperatures above 5°C and started from the twigs collection date and lasted until budburst.

3. Results

The collection of the twigs started immediately after leaf falling in Acadia National Park in 2015 autumn. The first date of collection was 10 of November and no tree twig started developing its buds after first collection date even after being kept for two months in the laboratory. Whereas after the second and third collection *Betula papyrifera* and *Alnus glutinosa* started to budburst and showed its minimum chilling requirements which were met on 17 and 26 of November respectively (Figure 1). *Picea mariana*

and *Abies balsamea* showed much higher chilling requirements and first occurrence of budburst appeared after collection on 18th and 23rd of December respectively. As compared with deciduous trees an additional month spent outside was required for evergreens in order to fulfill minimal chilling requirements.
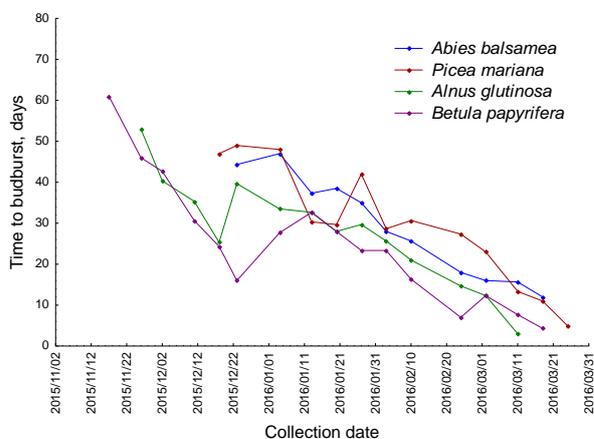

Figure 1. Dynamics of number of days to budburst at different timing of twigs collection

The need of the thermal time (days to spend in the laboratory) in order to occur for first budburst was higher for early–flushing species such as *Betula papyrifera* (61 day) and *Alnus glutinosa* (53 days). Whereas, late–flushing species had to spend 47 days for *Picea mariana* and 44 days for *Abies balsamea* until first budburst date. Evergreens burst its bud very late and have larger thermal time requirements to budburst than other deciduous tree species. Larger thermal time requirements for evergreens were detected during the whole period of the experiment when all species started their development (Figure 1).

Relationship between the thermal time and chilling days is presented in figure 2. Thermal time calculated as the sum of temperature above 5 ^{o}C from collection date to budburst. Amount of chilling calculated as number of days in the range of temperature between 0 and 5 ^{o}C from 1st of October until twigs collection date. Non–linear and in all cases strong relationship was detected between accumulated thermal time and chilling. These results indicate that the longer trees are exposed in chilling temperatures in the field the lower amount of forcing is required for all tree species in the laboratory.

Betula papyrifera and *Alnus glutinosa* burst its buds very early and so has high thermal time requirements to budburst for the first time – on average 793 and 689 day ^{o}C accordingly. But thermal time decreased greatly with increased chilling (Figure 2). Chilling requirements for these species were extremely low and for *Betula papyrifera* reached only 11 days, for *Alnus glutinosa* – 13 days. *Picea mariana* and *Abies balsamea* whose chilling requirements are high burst their buds very late as compared with early–flushing species. For the first budburst *Picea mariana* was exposed for 24 days to chilling and for 26 days for *Abies balsamea*.
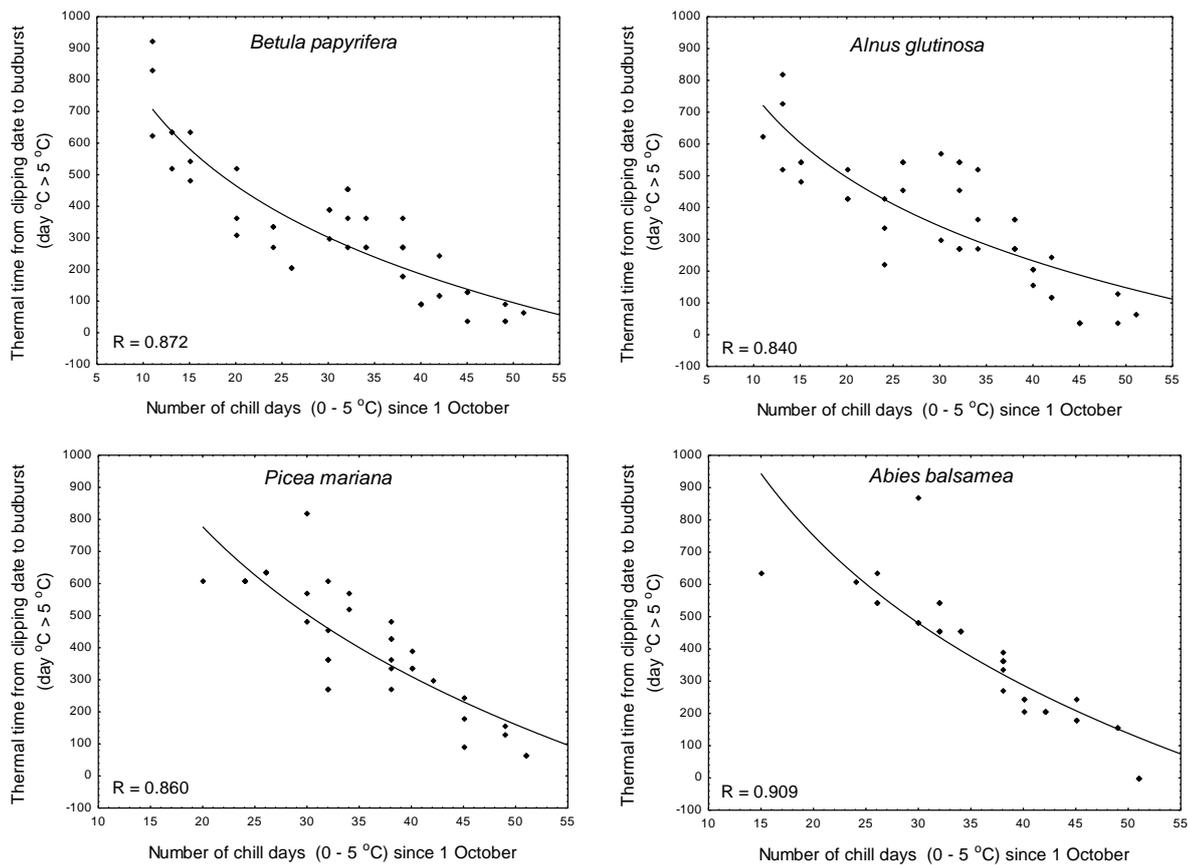
Figure 2. Relationship between the thermal times to budburst and the accumulated number of chill days for deciduous and evergreen tree species

These results enable to detect the date when chilling requirements are fulfilled for different tree species and allow the usage of that date for future projections of spring phenology in one–phase Thermal time models. As our results show, in the current climate in the Acadia National Park, the transition from endodormancy to ecodormancy of early–flushing species occurs in the second part of November, and for late–flushing species in the second part of December.

Discussion and conclusions

Early–flushing tree species have very low chilling but higher thermal time requirements for the first budburst. Whereas late–flushing species have approximately four weeks longer chilling requirements as compared with early–flushing species. This provides some insights that spring phenology of early–flushing species is mainly controlled by thermal time. Such results are consistent with some other investigation where tree species with non–obliged chilling budburst normally without chilling exposition (Harrington, Gould, 2015).

During the whole period of the experiment thermal time requirements were higher for late–flushing species even when chilling requirements were met. In a study conducted in England also showed that late species such as *Fagus sylvatica* have a large thermal time to budburst which increases greatly with a decrease in chilling (Murray *et al.*, 1989).

For the all investigated tree species non–linear and in all cases strong relationship was detected between accumulated thermal time and chilling. These results indicate that the longer trees are exposed in chilling temperatures in the field the lower amount of forcing is required for all tree species in the laboratory. Harrington and Gould (2015) also reported that well chilled plant require less forcing for budburst than plants which have received less chilling.

It has been also determined that in the current climate in Acadia National Park the transition from endodormancy to ecodormancy for early–flushing species occurs in the second part of November, and for late–flushing species in the second part of December. This experiment enables to quantify the influence of main environmental drivers such as chilling and forcing and detect species-specific requirements.

Warming temperature of the cold period in the future might have reverse impact for late–flushing tree species which has higher chilling requirements as compared with early–flushing tree species with lower chilling requirements. Climate change has huge impact on trees phenology and some scientists warns that in some regions plants does not meet their chilling requirements and therefore later dates of start of vegetation season appears (Yu *et al.*, 2010; Luedeling *et al.*, 2011). Consequently it is crucial to understand species–specific response to climate change in order to forecast future changes in trees seasonal development. Such experiments are used to identify which species may benefit from a changing climate and which may decline or extinct.

Species–specific response to climate change has impact on trees interaction, their competition and distribution. It also causes mismatches between different interacting species

such as birds and trees which lead to the big changes of the whole ecosystem. Such experimental information can serve for researchers and environmental managers to improve phenological modeling, ecosystem processes and ecological interaction.

References

Ahas R. and Aasa A. (2006), The effect of climate change on the phenology of selected Estonian plant, bird and fish populations, *International Journal of Biometeorology*, 51, 17–26.

Blümel K. and Chmielewski F-M. (2012), Shortcomings of classical phenological forcing models and a way to overcome them, *Agricultural and Forest Meteorology*, 164, 10-19.

Chmielewski F-M. and Götz K-P. (2016), Performance of models for the beginning of sweet cherry blossom under current and changed climate conditions, *Agricultural and Forest Meteorology*, 218-219, 85-91.

Chmielewski F-M. and Rötzer T. (2001), Response of tree phenology to climate change across Europe, *Agricultural and Forest Meteorology,* 108(2), 101-112.

Chmielewski F-M. and Rötzer T. (2002), Annual and spatial variability of the beginning of growing season in Europe in relation to air temperature changes, *Climate Research*, 19, 257–264.

Cleland E. E., Chuine I., Menzel A., Mooney H.A. and Schwartz M.D. (2007), Shifting plant phenology in response to global change, *Trends in Ecology & Evolution*, 22, 357–365.

Harrington C.A. and Gould P. (2015), Tradeoffs between chilling and forcing in satisfying dormancy requirements for Pacific Northwest tree species, *Plant Science*, 6, 1-12.

Yu H., Luedeling E. and Xu J. (2010), Winter and spring warming result in delayed spring phenology on the Tibetan Plateau. *Proceedings of the National Academy of Sciences*, 107, 22151–22156.

Jeong S-J., Ho Ch-H., Gim H-J. and Brown M.E. (2011), Phenology shift at start vs. end of growing season in temperate vegetation over Northern Hemisphere for the period 1982-2008, *Global Change Biology*, 17, 2385-2399.

Legave J.M., Garcia M. and Marco F. (1982), Some descriptive aspects of drops process of flower buds or young flowers on apricot in south of France, *Acta Horticulturae*, 121, 75−83.

Luedeling E., Girvetz E.H., Semenov M.A., Brown P.H. (2011b), Climate change affects winter chill for temperate fruit and nut trees. *PLoS ONE*,6(5),20155,doi:10.1371/journal.pone.0020155.

Matzneller P., Blümel K. and Chmielewski F-M. (2014), Models for the beginning of sour cherry blossom, *International Journal of Biometeorology*, 58, 703-715.

Menzel A. (2002), Phenology: its importance to the global change community, *Climate Change*, 54, 379–385.

Murray M.B., Cannel G.R. and Smith R.I. (1989), Date of budburst of fifteen tree species in Britain following climatic warming. *Journal of Applied Ecology*, 26, 693-700.

Schaber J. and Badeck F-W. (2005), Plant phenology in Germany over the 20th century, *Regional Environmental Change,* 5, 37–46.

Wielgolaski F. E., Nordli O., Karlsen S. R. and O'Neil B. (2011), Plant phenological variation related to temperature in Norway during the period 1928 − 1977, *International Journal of Biometeorology*, 55, 819-830.

Wolkovich E.M., Cook B.I., Allen J.M., Crimmins T.M., Betancourt J.L., Travers S.E., Pau S., Regetz J., Davies T.J., Kraft N.J.B., Ault T.R., Bolmgren K., Mazer S.J., McCabe G.J., McGill B.J., Parmesan C., Salamin N., Schwartz M.D. and Cleland E.E., (2012), Warming experiments underpredict plant phenological responses to climate change, *Nature*, 485, 494–497.

Yu H., Luedeling E., Xu J. (2010), Winter and spring warming result in delayed spring phenology on the Tibetan Plateau. *National Academy of Science,* 107, 22151-22156.