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APPLYING CHILL DAYS MODEL IN PHENOLOGICAL OBSERVATIONS OF *FAGUS SYLVATICA* L. IN NATURAL FORESTS

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Abstract

Dormancy is a period when temperate species are not active. Their physiological processes are delayed until the appearance of stimuli interrupt the dormancy. This period is commonly separated in two stages. The first stage is a rest period, when the buds remain dormant due to growth-arresting physiological conditions and the second is a quiescent period when buds are waiting favourable environmental conditions to burst. The Chill Days Model is a sequential model that uses the accumulation of chill days to break the rest and accumulation of anti-chill days to overcome quiescence. Predicting the beginning of the growing season and the duration of cooling is important for the analysis of forest ecosystems. The Chill Days Model gives a good prediction of the bud burst. The site-specific temperature threshold for *Fagus sylvatica* L. with this model was established as 7.3 °C and chill requirements were defined as 124 chill days in Balkan Range.

Key words: bud burst models, dormancy, phenology.

Introduction

Common beech is widespread deciduous species in Europe. Spring phenologycal phases are the subject of many discussions and research (Donnely et al. 2006, Bertin 2008, Vitasse et al. 2009). There are many models for predicting the budburst of different species. Some of them use chilling units or chilling hours (Utah, North Carolina, Low chilling), other – the temperature above 5 °C for accumulation (Slavov and Kazandjiev 2006). The first group weighted the temperature for the effectiveness of breaking dormancy with different scales. The last one uses different temperature sums for predicting the phase of phenologycal development. All of these models do not give good or proper results.

The temperature and light are of the most popular factors which are studied for the impact on the phenology of trees (Donnely et al. 2006, Bertin 2008, Caffarra and Donnelly 2011, Menzel et al. 2011). There have been various attempts to predict the beginning of growing season mostly in this connection (Falusi and Calamassi 1990, Schaber and Badeck 2003, Jeong et al. 2013). The model that has been applied in this research gives very good results on fruit and deciduous trees in Italy: Kiwifruit (*Actinidia deliciosa* C.F. Liang & A.R. Ferguson), Wild cherry (*Prunus avium* L.), Common pear (*Pyrus* *communis* L.), Evergreen oak (*Quercus ilex* L.), Common aspen (*Populus tremula* L.) (Cesaraccio et al. 2004, Linkosalo et al. 2006, Kamali et al. 2007).

Chill Days Model is based on the idea that chilling accumulates to break rest and heating accumulates to overcome quiescence (Cesaraccio et al. 2004). The model uses degree day calculations to determine chill days (units for chilling) and anti-chill days (units for heating). The model was tested in Balkan Range on Common beech and site-specific temperature threshold and chill requirements were established.

Chill Day Model is described for predicting bud-burst based on accumulation of negative chill days during rest until reaching a chilling requirement and then accumulation of positive anti-chill days during quiescence until reaching zero, which corresponds to release of dormancy. Cooling factors range from 0 when the temperatures do not help to meet their cooling requirements to 1.0 when the temperature is most effective to meet the requirements.

Fig. 1. The sample plot.

Threshold temperatures are important because some temperatures contribute to the cooling requirements while others do not. High temperatures do not contribute to meet the cooling requirements and in most cases, below a lower temperature threshold (0 °C) are not considered effective for cooling.

Site Description and Plant Material

Chill Days Model (C_D) was applied to phenologycal observations made on *Fagus sylvatica* L. in Balkan Range, near Vitinya pass. The stand is dominated by Common beech, aged between 120 and 140 years, at an altitude of 950 m west, at 23°55´48" latitude and 42°55´39" longitude (Kolarov et al. 2002). The soil is Distric-Eutric Cambisols*,* (Fig. 1) (Kolarov et al. 2002, ICP-Forest Manual 2000).

The climate is one of the most important factors for phenology. Figure 2 shows that maximum and minimum temperatures are at the same range among the years at the sample plot. The minimum temperatures in April started exceeding 0 °C and maximum temperatures are round 13 °C at the same month. This is the time of buds burst and the time which is marked in the model. There is a pick in minimum temperatures in October which is observed every year. This is the time of the end of autumn colouration of leaves which is the part of calculations for the beginning of next vegetation season. In the model there are introduced minimum and

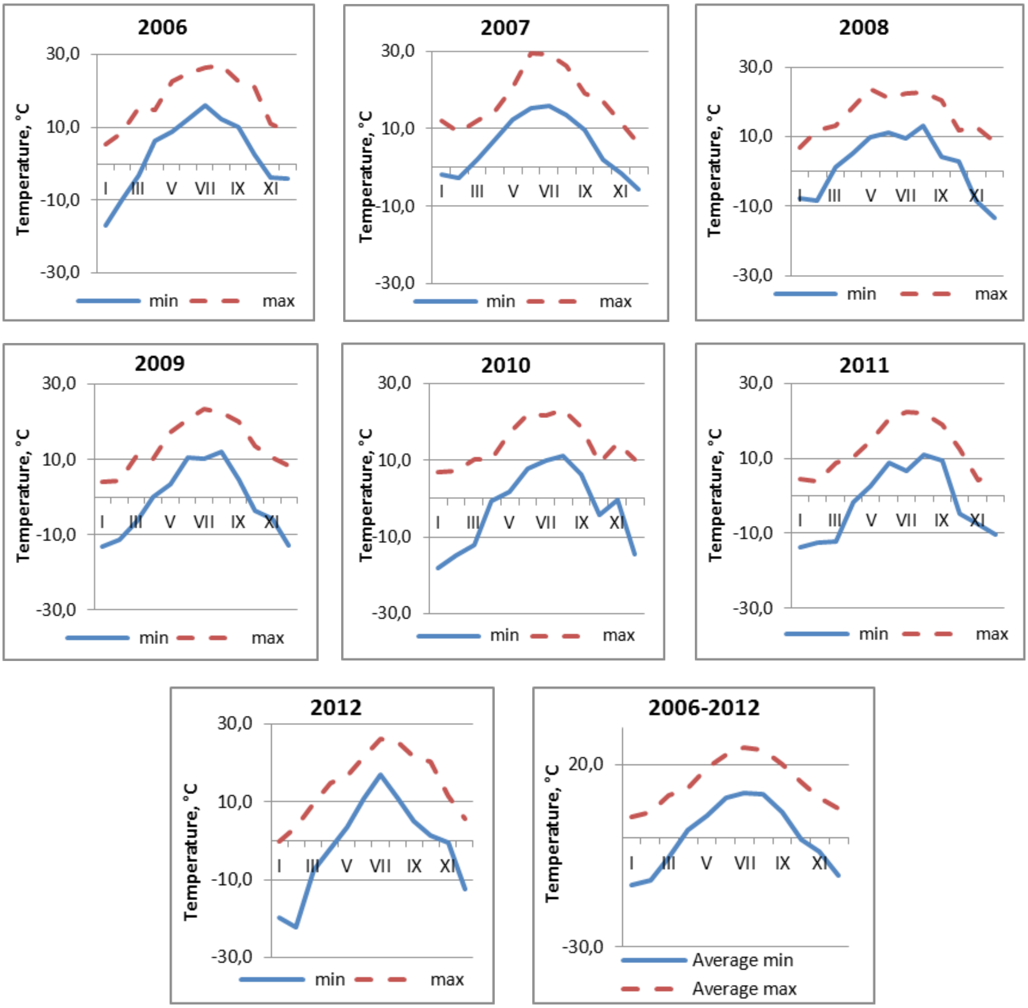

Fig. 2. Maximum and minimum air temperature for the period 2006–2012.
Note: Abscissae of all graphics are inflicted months of the years.

maximum daily temperatures for the period. The plot is situated in temperate forest vegetation zone (Georgiev 1991).

Methods

Chill days (C_D) Model is a sequential model that uses the accumulation of chill days (C_d) to break the rest and accumulation of anti-chill days (C_a) to overcoming quiescence. Negative C_d values are accumulated until they reach a pre-selected value that is identified as the chilling requirement (C_R). The chilling requirement is met on the day when $\sum C_d \leq C_{R,}$ which corresponds to breaking rest. On the following day, the model begins to add anti-chill days on each day starting at C_R, until $C_R + \sum C_a \geq 0$ at the predicted bud-burst. The chill days and anti-chill days both depend on the selection of a temperature threshold (T_C) and C_R, so these parameters are iterated to find the combination that best predicts the bud-burst dates. Chill days and anti-chill days are calculated from daily maximum (T_x) and minimum (T_n) temperature data and T_C. For calculating C_d and C_a, there are five possible cases that depend on the relationship between T_x and T_n relative to T_C and 0 °C (Table 1 according to Cesaraccio et al. 2004).

The accuracy of bud-burst estimation was evaluated by comparing observed and predicted days of chilling.

Results and Discussion

Start, end and duration of cooling periods during the reference period were calculated by using the model of Chill Days (Cesaraccio et al. 2004). The values are recorded in DOY (day of year). They are based on the entered values of temperature in the model. There were no observations during 2010 and that is shown on Figure 3 as a line.

Table 1. Chill days (C_d) and anti-chill days (C_a) equations for the five cases that relate the maximum (T_x) and minimum (T_n) temperature to the threshold temperatures T_c and 0 °C.

Number	Temperature cases	Chill Days	Anti-chill days
1	$0 \leq T_C \leq T_n \leq T_x$	$C_d = 0$	$C_a = T_M - T_C$
2	$0 \leq T_n \leq T_C < T_x$	$C_d = -\left[(T_M - T_n) - \left(\frac{T_x - T_C}{2}\right)\right]\left[(T_M - T_n) - \left(\frac{T_x - T_C}{2}\right)\right]$	$C_a = \frac{T_x - T_C T_x - T_C}{2 \quad 2}$
3	$0 \leq T_n \leq T_x \leq T_C$	$C_d = -(T_M - T_n)$	$C_a = 0$
4	$T_n < 0 < T_x \leq T_C$	$C_d = -\left(\frac{T_x}{T_x - T_n}\right)\left(\frac{T_x}{2}\right)\left(\frac{T_x}{T_x - T_n}\right)\left(\frac{T_x}{2}\right)$	$C_a = 0$
5	$T_n < 0 < T_C < T_x$	$C_d = -\left[\left(\frac{T_x}{T_x - T_n}\right)\left(\frac{T_x}{2}\right) - \left(\frac{T_x - T_C}{2}\right)\right]\left[\left(\frac{T_x}{T_x - T_n}\right)\left(\frac{T_x}{2}\right) - \left(\frac{T_x - T_C}{2}\right)\right]$	$C_a = \frac{T_x - T_C T_x - T_C}{2 \quad 2}$

Note: T_M is the mean daily temperature.

In order for the model to calculate the values for chilling requirements and temperature threshold, it is necessary to set start and end dates of the growing season. The starting date should be considered when 50 % of the organs are at observed stage. The selected dates correspond to full phenologycal stage. The observations are made by one and the same observer, once a week.

Figure 3 reports the dates of onset of cooling. The cooling begins with the completion of the growing season during the year and continues until the swelling of the buds begins, which marks the start of the next growing season. The period between two dates shows the time of buds' cooling in that particular year. These are the values of the graph, which have a negative meaning and almost in all years, reach

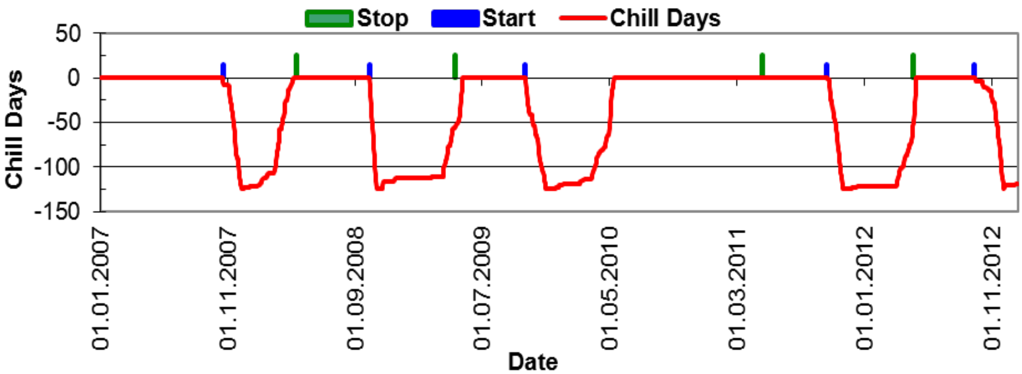

Fig. 3. Start and end dates of growing season.

Note: There were no observations in 2010.

up to 124. So are the days reported in the model for cooling as Chill Days. On Figure 3 is given the visible length of the days of cooling. The most extended period of detention of these values is in the range 21.10.2008 to 17.03.2009 and 9.11.2011 to 17.03.2012. The first date shows reaching cooling requirements, and the second one – beginning of accumulation of stimulating temperatures.

According to the applied model for Common beech were obtained 124 days required for cooling and 7.3 °C threshold temperature in Vitinya. It is possible to understand the difference between beginnings of the vegetation period in different altitudes, and different ages for the distinct species. With more analysis (of the researched species), it is possible to find the important meanings of the varied exposure at the same altitudes and diverse dates of beginning of the vegetation season.

The accuracy of the Model is evaluated with root mean square error between predicted and observed dates (RMSE = 12, where: RMSE is the smallest set mean square error between the observed and predicted values).

Chill Days Model predicted pretty good the days of leaf fall to the beginning of the leafing (Fig. 3). Cooling and warming of buds are the important periods of phenologycal development of beech trees. They are one of the most important external signals that determine the rate and intensity of bud burst.

The cooling factor as a function of the temperature could be developed and used to evaluate the effectiveness of cooling and the temperature at the exit from the dormancy.

Conclusions

The good performance of the Model may attribute to the fact, that it approximates the rest and quiescent of the rest by accounting the temperatures according to the phenologycal date, not according to the weather changes.

Chill Days Model can be tested on Common beech at different places and altitude to find the requirements of observed species, especially in cases with difficulties in establishment of the key factor of bud-burst. It will improve the accuracy of the model.

The advantage of this model is that beginning of foliage definition is necessary; it is bound by the previous growing season, which shows the plasticity of the species to changes in abiotic factors. This binds the beginning and end of the vegetation to the changes in temperature during the autumn, winter and spring.

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