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## Budburst dynamics of Norway spruce seedlings (*Picea abies* Karst.) – selection for late spring frosts resistance

Branislav Cvjetković<sup>1</sup>✉, Milan Mataruga<sup>1</sup>, Vanja Daničić<sup>1</sup>, Mirjana Šijačić-Nikolić<sup>2</sup>

<sup>1</sup>University of Banja Luka, Faculty of Forestry, Banja Luka, Republic of Srpska, Bosnia and Herzegovina

<sup>2</sup>University of Belgrade, Faculty of Forestry, Belgrade, Republic of Serbia

✉ [branislav.cvjetkovic@sf.unibl.org](mailto:branislav.cvjetkovic@sf.unibl.org)

### Abstract

Norway spruce is one of the most commonly used species for new forest planting in Europe. It is planted in a large number of habitats, often without following the previous results in the success of afforestation. In order to improve Norway spruce afforestation, open field tests were established in which developmental phenophases are monitored. The use of planting material of different provenances, which had not previously been tested for habitat conditions, was often the cause of the decline of newly planted forests. Early budburst of Norway spruce causes losses due to the freezing of terminal buds. Norway spruce testing for different habitat conditions in Bosnia and Herzegovina (B&H) was conducted at two ecologically different localities: Srebrenica (eastern part of B&H) and Drinić (western part of B&H). During 3 years, the budburst on the seedlings originating from 6 populations (Han Pijesak 1, Han Pijesak 2, Foča, Olovo, Kneževo and Potoci) was monitored. The budburst dynamics was monitored in 2013, 2015 and 2016 and it was recorded for each seedling in two progeny tests. Seedlings from the Kneževo population budburst the earliest. The seedlings would start budburst on different days of the year, depending partly on the temperature sums and their origin. The earliest budburst was recorded in 2013 (119<sup>th</sup> day of the year in Srebrenica and 121<sup>st</sup> day of the year in Drinić). During 2015 and 2016, the budburst started later (125<sup>th</sup> day in Srebrenica and 129<sup>th</sup> day in Drinić). Temperature cumulants indicate that a smaller sum of temperatures was required for the budburst in the Srebrenica test than in the Drinić test. However, the temperature sums did not clearly indicate the budburst pattern because they were different for each observed year, but the populations ranking was almost the same. This indicates the influence of some other variables on the budburst. The knowing of the data on the budburst dynamics are a prerequisite for a successful selection of starting populations from which planting material is produced and new forests are later planted. Population Kneževo had the earliest budburst but population Han Pijesak 2 had the latest budburst.

### Keywords

Norway spruce; Budburst; Progeny tests

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## 1 Introduction

Planting new forests requires the application of knowledge acquired through short-term and long-term field testing. Afforestation and reforestation in Europe and the world require the use of planting material adapted to climate change with the highest possible wood production and with minimal risks. Early budburst and late budset raises the probability of damage caused by late spring and early autumn frosts respectively (Heide 1985). Late frosts are one of the common reasons for unsuccessful afforestation causing severe damage on seedlings or seedlings decay.

Norway spruce is considered to be one of the species with the longest cultivation history (Skrøppa 2003). The total area under spruce forests in Europe is estimated to be greater than 30 million hectares (Jansson et al. 2013). The species, based on the latest genecological tests from Switzerland, is considered to be an adaptive specialist. This means that the influence of the external environment has a significant impact on the survival and physiological functions (Cvjetković et al. 2015a; Frank et al. 2017) due to its sensitivity to the change of ecological factors. It should be considered when transferring it to other habitats and the dynamics of growth can be very different (Jansone et al. 2020). A positive correlation between frost damage and early budburst for many European Norway spruce provenances has been found (Lundströmer et al. 2020). Due to climate change, budburst starts earlier than before (Lange et al. 2016; Allen et al. 2018; Liu et al. 2018). It is believed that the budburst will begin 10 days earlier in the period 2051-2080 compared to 1971-2000 (Olsson et al. 2017) when late spring frosts could be a more common problem due to earlier budburst.

In general, plants have a survival mechanism that allows them to “sense” and adapt to adverse environmental influences and to reproduce successfully (Howe et al. 2003; Rohde et al. 2011; Azeez and Sane 2015). Species with a longer period of bud dormancy avoid damage caused by late spring frosts at the cost of a shorter period of growth (Leinonen and Häinninen 2002; Häinninen and Tanino 2011; Basler and Körner 2012; Basler and Körner 2014). Bud dormancy is a variable and at the same time polygenic adaptive trait (Frewen et al. 2000; Rohde and Bhalerao 2007). It allows plants to survive in times of dehydration and stress caused by low temperatures by stopping their growth and development.

Different habitat conditions dictate the time of budburst, and thus the reaction of plants in terms of a number of characteristics, including budburst. The features that characterize the annual growth cycle, especially the beginning of growth in spring and the end of growth, as well as the development of the resistance to damage caused by low temperatures, were found to show significant variability at provenance level (Kruttsch 1973; Skrøppa 1982; Beuker 1994; Hannerz 1994; Beuker

et al. 1998; Skrøppa et al. 2007; 2010). Norway spruce shows matching geographical patterns of the variation of budburst. The budburst dynamics depends on the latitude and longitude of seed sources in Norway spruce, which indicates the local adaptation of the populations to climatic conditions (Søgaard et al. 2008; Busov et al. 2015; Skrøppa and Steffenrem 2015).

The budburst dynamics can also be defined on a genetic basis (Johnsen et al. 2005; Yakovlev et al. 2006; 2008; 2014; 2017) and through epigenetic processes (Kvaalen and Johnsen 2008; Søgaard et al. 2009; Yakovlev et al. 2012; Aeresatad et al. 2014; Carneros et al. 2017; Solvin and Steffenrem 2019; Milesi et al. 2019).

The need to produce reproductive material resistant to environmental challenges, including late spring frosts, made the researchers test numerous Norway spruce populations in different environmental conditions through short-term and long-term tests. The task was to determine the correlations between the influence of the environment and the reaction of the offspring, and to constantly model the relationship "population x climatic conditions" in order to make recommendations for the safe transfer of forest reproductive material.

Norway spruce is considered to be sensitive to low temperatures, especially during the active period of growth: from the budburst to the end of the period of shoots elongation (Hannerz 1994; Hannerz et al. 1999). The selection of appropriate sources of reproductive material resistant to the appearance of late frosts is a challenge that is closely related to the time of budburst. Regarding this, various models have been developed to predict the timing of budburst and the risk of damage caused by late spring frosts (Leinonen and Hänninen 2002). Most often, the models related to the estimation of the budburst are related to the temperature sums. This model is applied in this research.

The investigation of the onset and budburst dynamics should be one of the important factors in choosing the starting population. Establishing forests with the planting material that has the optimal use of the growing season is a priority. In order to find such sources of starting material, it is necessary to test the planting material from different seed sources and to set up experiments on different locations.

## 2 Materials and methods

The dynamics of budburst was monitored in 2013, 2015 and 2016 in two progeny tests established in 2009 in different ecological conditions. Progeny tests are located in the east of Bosnia and Herzegovina (Srebrenica) and in the west (Drinić) (Table 1, Figure 1).

Table 1. Data on progeny tests.

Locality	Latitude	Longitude	Altitude [m]	Eco – vegetation area	Soil
Drinić	44° 31' 10"	16° 36' 04"	690	Inner Dinnarides	Calkomelanosol and luvisol
Srebrenica	44° 01' 34"	19° 25' 22"	1000	Transitional Iliri-Moesiac area	Distric cambisol

Six Norway spruce populations were tested: Han Pijesak 1, Han Pijesak 2, Foča, Potoci, Olovo and Kneževo. The geographical position and basic habitat characteristics of the populations which were tested are shown in Table 2 and Figure 1. In total, the

budburst was monitored on 1381 seedlings in Drinić and 1385 seedlings in Srebrenica. The total number of seedlings per populations on which the budburst was monitored is shown in Table 2, in the last two columns. The number of seedlings is different in each population due to the seedlings survival rate decline from the year of the progeny tests establishment (2009) to the years of budburst monitoring. In the period 2009-2013 there was no budburst monitoring. The dynamics of the budburst was recorded on dates given in Table 3.

Table 2. Starting populations data.

Locality	Latitude	Longitude	Altitude [m]	Number of seedlings per populat.	
				Srebrenica	Drinić
Han Pijesak 1	44° 08' 13"	18° 50' 01"	1000-1100	156	187
Han Pijesak 2	44° 02' 08"	19° 00' 11"	960-1040	94	139
Foča	43° 24' 58"	18° 52' 38"	1000-1126	347	304
Olovo	44° 07' 43"	18° 34' 54"	900-1000	258	268
Potoci	44° 28' 59"	17° 24' 45"	1010-1030	216	247
Kneževo	44° 23' 12"	16° 39' 39"	850-950	310	240

Table 3. Monitoring dates.

Year	Progeny test Srebrenica				Progeny test Drinić			
	I	II	III	IV	I	II	III	IV
2013.	Apr 24	May 4	May 8	-	May 2	May 5	May 15	-
2015.	May 7	May 11	May 16	May 21	May 9	May 13	May 19	May 24
2016.	May 8	May 13	May 19	May 25	May 10	May 16	May 21	May 26



Figure 1. Geographical position of native populations and progeny tests.

The data were recorded in binary code: 0 for closed bud and 1 for budburst. The bud was considered as open (budburst) from the moment the winter sheath was started to be discarded and a new, green terminal bud starts to appear (Figures 2 and 3). To determine the time of budburst, Hannerz (1994) temperature sum methodology was applied. The methodology implies that the start of monitoring is performed from that ordinal day in the year on which the average daily temperature for 3 consecutive days exceeds 5°C. After that, the average daily temperatures are summed up by days and the beginning of budburst is monitored. The budburst rate was presented as a percentage of seedlings with budburst, in relation to the total number of seedlings per population in progeny tests.



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Figure 2. Closed bud.

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Figure 3. Budburst.

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The temperatures in the experiments were recorded by automatic meteorological stations PCE-FWS 20. Meteorological stations were set up in the immediate vicinity of the experiments at 100 m in Srebrenica and 2 km in the progeny test in Drinić. The data on temperature sums was calculated as a cumulant of average daily temperatures which were calculated according to the formula:

$$T = \frac{T_{7h} + T_{14h} + T_{21h} \cdot 2}{4}$$

where the following are:

$T_{7h}$  - temperature at 7 a.m.

$T_{14h}$  - temperature at 2 p.m.

$T_{21h}$  - temperature at 9 p.m.

The time of budburst was determined based on the intersection of the linear function describing the dynamics of budburst and the x-axis (ordinal number of days in the year). The linear function has been used as the simplest and the most comparable among the observed years and populations.

### 3 Results and discussion

#### 3.1 Temperature sums

Temperature sums are shown in Figures 4 and 5 for the Srebrenica and Drinić sites. In the progeny test Srebrenica, the initial day of monitoring the temperature sums was different for the observed years. The monitoring on temperature sums on the Srebrenica site was recorded starting from the 96<sup>th</sup> day (April 6<sup>th</sup>), in 2013, from the 95<sup>th</sup> day (April 5<sup>th</sup>) in 2015 and from the 32<sup>nd</sup> day (February 1<sup>st</sup> in 2016), (Figure 4).

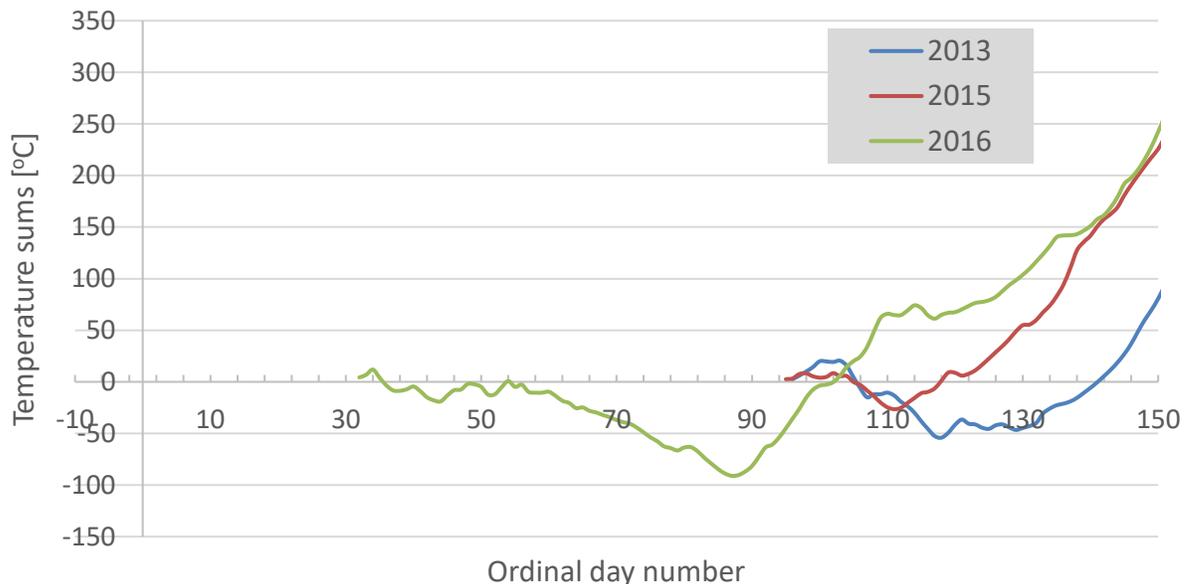


Figure 4. Temperature sums in progeny test Srebrenica in 2013, 2015 and 2016.

In the Drinić progeny test, monitoring the average daily temperatures began on the: 69<sup>th</sup> day (March 10<sup>th</sup>) in 2013, 110<sup>th</sup> day (April 20<sup>th</sup>) in 2015, and 9<sup>th</sup> day

(January 9<sup>th</sup>) in 2016 (Figure 5). Data about temperature sums are very variable depending on the geographic position and it can range for 150 days as it was recorded for some European countries (Hannerz, 1994).

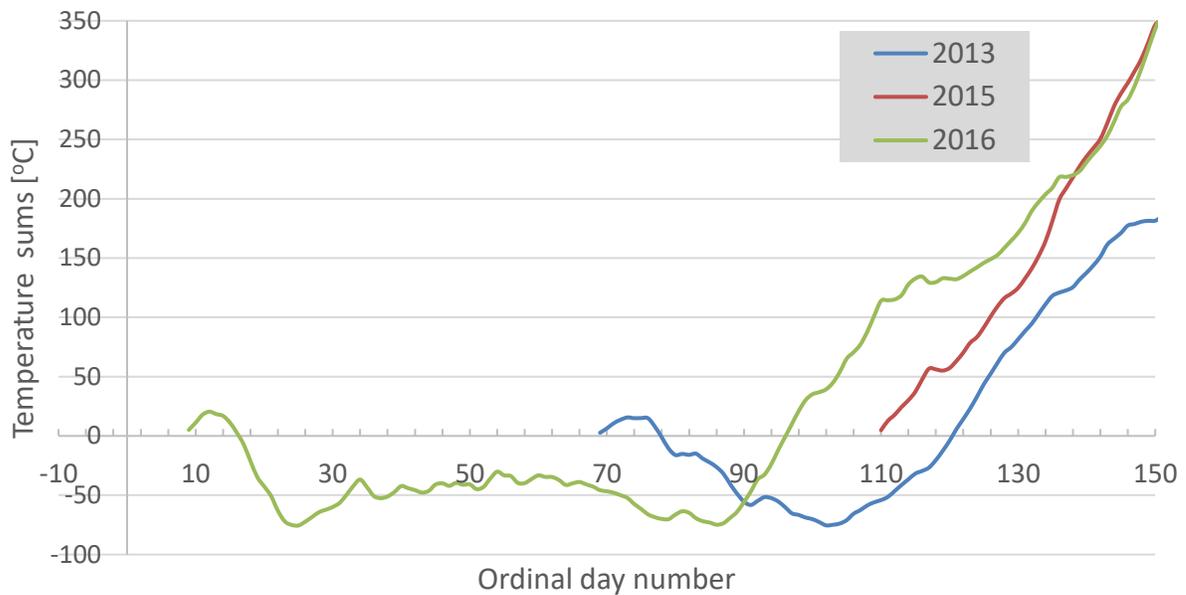


Figure 5. Temperature sums in progeny test Drinić in 2013, 2015 and 2016.

### 3.2 Budburst dynamics

The budburst dynamics differed among the years and the population. In the progeny test in Srebrenica, the fastest budburst was found in 2013 in the populations of Han Pijesak 1 and the slowest in the populations of Han Pijesak 2 and Foča (Figures 6a). In 2015, the fastest budburst was recorded for the population Kneževo, while all other populations had the budburst with approximately the same dynamics (Figure 6b). During 2016, the dispersion of budburst among populations was higher. The seedlings from the Kneževo population had the fastest budburst, while Olovo and Foča populations had the slowest budburst (Figure 6c).

In progeny test Drinić the fastest budburst in 2013 was recorded on the seedlings originating from the population Kneževo, and the slowest budburst was in the population Han Pijesak 1. The differences in the period during the budburst process are negligible at the beginning and end, and the differences are significant in the second observation period. At that time, the differences in budburst seedlings from the population of Kneževo and other populations were 10-25% on average (Figure 7a).

During 2015, the situation is similar in the order of populations, but the differences among them are greater. Thus, these differences go up to 35% of the higher number of budburst in the period of the second and third observation (figure 7b).

In 2016, the differences between the percentages of budburst among populations are smaller than in the previous two years of observation and the differences range up to 20% (Figure 7c).

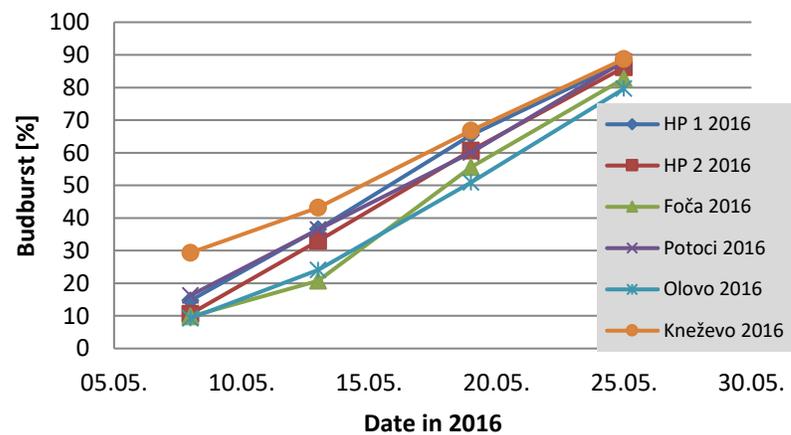
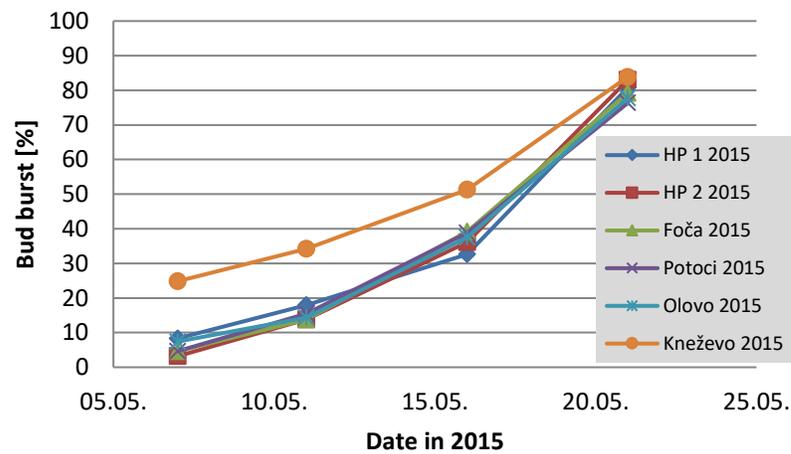
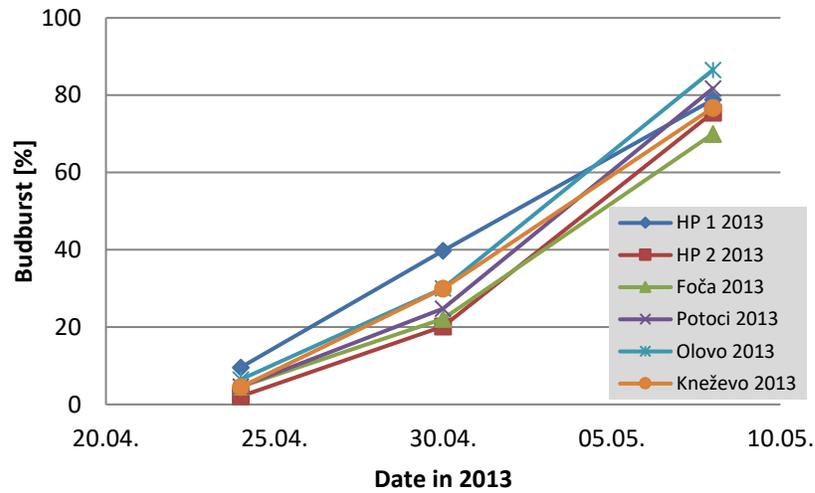


Figure 6 a, b, c. Budburst dynamics in progeny tests Srebrenica in 2013 (a), 2015 (b) and 2016 (c).

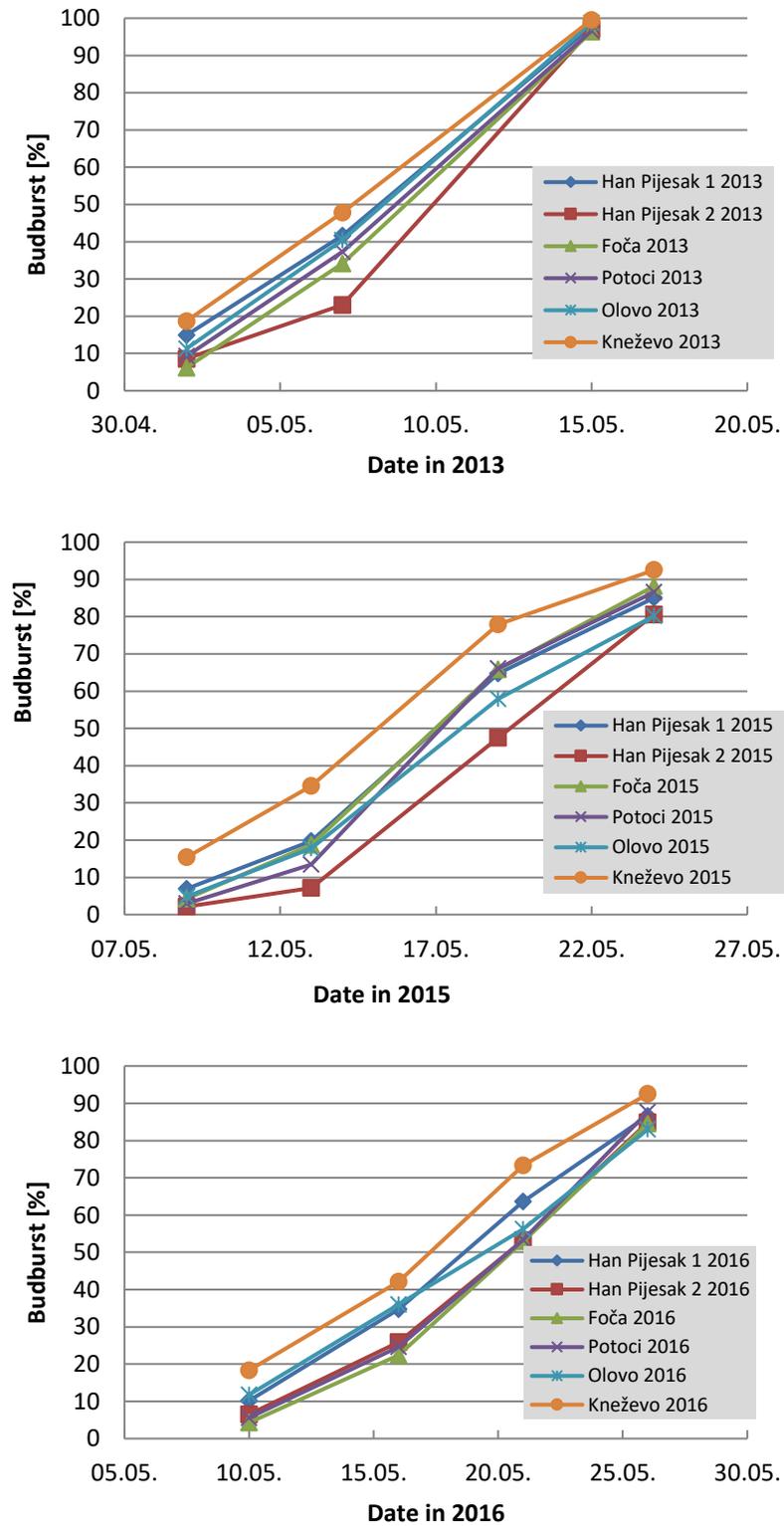


Figure 7 a, b, c. Budburst dynamics in progeny tests Drinic in 2013 (a), 2015 (b) and 2016 (c).

### 3.3 Estimation of budburst beginning

Hannerz (1994) and Hannerz et al. (1999) stated that budburst timing predicted with a high accuracy (two-day accuracy) can be attained during only one year of temperature and the dynamics of budburst monitoring, which could help to solve the problem of adequate starting population selection for the production of seedlings resistant to late spring frosts.

In the progeny test in Srebrenica, the earliest budburst was recorded on 114<sup>th</sup> day in the populations of Han Pijesak 1 and Kneževo in 2013, at a temperature sum of 27°C. In 2013, which was the year of the earliest budburst, the earliest beginning of budburst and the lowest temperature sum were determined. An average, 118.8 days was needed for budburst at the progeny test level. The latest budburst was recorded for the population Han Pijesak 2 - 128 days, with a temperature sum of 175.80°C. The difference between the beginning of budburst of the seedlings from the populations of Han Pijesak 1 and the seedlings from the populations of Han Pijesak 2 and Kneževo was 2 weeks. Based on the ranking population by date of budburst, this is a significantly larger difference among populations in comparison to the progeny test Drinić, where in 2013 the time of budburst was only 3 days. In 2015, the earliest budburst was recorded for seedlings from the populations of Foča and Kneževo - 122 days and a temperature sum of 74°C. At the latest, budburst occurred on seedlings originating from the Han Pijesak 2 population - 128 days and with a temperature sum of 175.80°C. Compared to 2013, the beginning of budburst was delayed by 7 days (Table 4).

Table 4. Estimation of the beginning of bud opening in the progeny test in Srebrenica.

Year	Population	Function	Correlation	Budburst start	Temperature sum
2013	Han Pijesak 1	5.2847x - 596.72	R <sup>2</sup> = 0.9967	114	27,00
	Han Pijesak 2	5.6289x - 718.83	R <sup>2</sup> = 0.9334	128	175,80
	Foča	5.1203x - 587.28	R <sup>2</sup> = 0.9836	115	36,7
	Potoci	6.0438x - 694.22	R <sup>2</sup> = 0.9815	115	36,7
	Olovo	5.0456x - 640.59	R <sup>2</sup> = 0.9331	127	170,0
	Kneževo	5.5851x - 638.71	R <sup>2</sup> = 0.9987	114	27,0
2015	Han Pijesak 1	4.998x - 633.54	R <sup>2</sup> = 0.8918	127	135,5
	Han Pijesak 2	5.6289x - 718.83	R <sup>2</sup> = 0.9334	128	141,6
	Foča	5.3597x - 682.64	R <sup>2</sup> = 0.9512	122	74,0
	Potoci	5.1175x - 650.65	R <sup>2</sup> = 0.9604	127	135,5
	Olovo	5.0456x - 640.59	R <sup>2</sup> = 0.9331	127	135,5
	Kneževo	4.1695x - 509.12	R <sup>2</sup> = 0.9515	122	74,0
2016	Han Pijesak 1	4.3493x - 541.47	R <sup>2</sup> = 0.9975	124	77,5
	Han Pijesak 2	4.4596x - 560.01	R <sup>2</sup> = 0.9997	126	82,4
	Foča	4.4755x - 567.57	R <sup>2</sup> = 0.9786	127	88,0
	Potoci	4.1927x - 521.06	R <sup>2</sup> = 0.9985	124	77,5
	Olovo	4.1916x - 530.13	R <sup>2</sup> = 0.9912	126	82,4
	Kneževo	3.5464x - 426.18	R <sup>2</sup> = 0.9961	120	67,5

In 2015, the earliest budburst was recorder for the seedlings from the population of Kneževo and Foča - 122 days, at a temperature of 74°C. The latest budburst was recorded for the seedlings from the Han Pijesak population for 2 - 128

days, at a temperature sum of 141.6°C. The difference between the first and the last day of the budburst by populations was 6 days, with a difference of temperature sums of 67.6°C.

In 2016, the earliest budburst was recorded in the population of Kneževo – on 120<sup>th</sup> day, with temperature sums of 67.5°C. The latest budburst opening was determined for the seedlings from the population Foča - 127 days with a temperature sum of 88°C. The difference between the earliest and the latest budburst was 7 days, while the difference in temperature sums is only 27.5°C (Table 4).

In both progeny tests, the seedlings originating from the population Kneževo had the earliest budburst and were thus most exposed to the risk of later spring frosts. This is in accordance with the previous research on genetic variability where Norway spruce populations in the wider Kneževo area stand out as introduced compared to other B&H populations (Ballian et al. 2006; 2007; Cvjetković et al. 2017).

The earliest budburst in the progeny test in Drinić occurred in 2013, on 119<sup>th</sup> day from the beginning of the year at a temperature sum of 82.10°C. In 2013, the earliest budburst was recorded for seedlings from the Kneževo population. In that year, the seedlings of all populations needed 120.7 days an average for budburst start. The differences in the ordinal number of days of bud opening were minimal, only 2-3 days and the differences in temperature sums were 36.4°C (Table 5).

Table 5. Estimation of bud opening in the offspring test in Drinić.

Year	Population	Function	Correlation	Budburst start	Temperature sum
2013	Han Pijesak 1	6.4358x - 772.26	R <sup>2</sup> = 0.9952	120	90,50
	Han Pijesak 2	7.0353x - 857.59	R <sup>2</sup> = 0.9439	122	118,50
	Foča	7.0112x - 851.82	R <sup>2</sup> = 0.9931	121	106,80
	Potoci	6.7815x - 820.27	R <sup>2</sup> = 0.9948	121	106,80
	Olovo	6.779x - 817.51	R <sup>2</sup> = 0.9967	121	106,80
	Kneževo	6.2403x - 743.34	R <sup>2</sup> = 0.9993	119	82,10
2015	Han Pijesak 1	5.5235x - 708.45	R <sup>2</sup> = 0.9799	128	218,03
	Han Pijesak 2	5.4762x - 711.77	R <sup>2</sup> = 0.9603	131	242,80
	Foča	5.906x - 760.44	R <sup>2</sup> = 0.9829	129	227,53
	Potoci	6.0208x - 778.08	R <sup>2</sup> = 0.9668	129	227,53
	Olovo	5.257x - 676.08	R <sup>2</sup> = 0.9872	129	227,53
	Kneževo	5.4071x - 681.61	R <sup>2</sup> = 0.9764	126	199,25
2016	Han Pijesak 1	4.8622x - 623.41	R <sup>2</sup> = 0.9958	128	158,58
	Han Pijesak 2	4.921x - 637.7	R <sup>2</sup> = 0.9778	130	171,18
	Foča	5.0814x - 661.47	R <sup>2</sup> = 0.9732	130	171,18
	Potoci	5.149x - 669.03	R <sup>2</sup> = 0.9716	130	171,18
	Olovo	4.4053x - 562.27	R <sup>2</sup> = 0.9951	128	158,58
	Kneževo	4.7787x - 604.09	R <sup>2</sup> = 0.9908	126	149,05

In later years (2015 and 2016), budburst began on average 8 days later than in 2013. The earliest budburst was recorded on the seedlings from the population of Kneževo. The number of days required for budburst was 126 at a temperature sum of 199.25°C. The latest budburst began on the seedlings from the Han Pijesak 1 population. The opening of buds in this population began on 131<sup>st</sup> day at a temperature sum of 242.80°C. The difference among the populations with the earliest and the latest budburst was 5 days, while the difference in the temperature sum was

43.55°C. The seedlings originating from other populations began to budburst at approximately the same time (Han Pijesak 1 – 128<sup>th</sup> day, Foča, Potoci and Olovo - 129<sup>th</sup>). The temperature sums reached higher values, over 200°C, except in the population of Kneževo where this sum was approximately 200°C (Table 5).

The budburst in 2016 follows the pattern from 2015, with the temperature sums being slightly lower. The earliest budburst was recorded on the seedlings originating from the population Kneževo - on the 126<sup>th</sup> day, with a temperature sum of 149.05°C, while the latest budburst was recorded on the seedlings originating from the populations Han Pijesak 2, Foča and Potoci - on the 130<sup>th</sup> day with a temperature sum of 171.18°C. The difference between the beginning of budburst of the first and the last population was 4 days (Table 5). It can be stated there is a consistent pattern in temperature sum requirements among populations in three years. Populations had similar budburst ranking over the years.

Hannerz (1994), based on Prescher (1982) research, found that the temperature sum required for Norway spruce budburst in the former Yugoslavia varied between 193 and 196°C, averaging 195°C for seedlings aged four and five years. Rötze and Chmielewski (2001), found that bud opening and flowering begin three days later with an increase in altitude of 100 m, 0.6 days per every 100 km going from west to east and 2.4 days later every 100 km going from south to north.

If we compare the results of the research with other European research, the results partially coincide. Thus Beuker (1994) cites a wide range of values of the initial day of budburst - from 114 days to 263 days, depending on the origin. The results of Norway spruce research in progeny tests in B&H coincide with the values of northern Norway spruce populations. According to Hannerz (1994) and Hannerz et al. (1999) data obtained for progeny tests are in the range of Norway spruce from the Scandinavian area which needs a minimum temperature sum of 96°C for the budburst. Based on the obtained results, it is not possible to establish the exact temperature sum at which the budburst on the seedlings from different provenances starts but most of them are higher than 96°C in progeny test Srebrenica and lower in progeny test Drinić which indicate a strong impact of others environmental conditions in combination with the seedling's origin. Hannerz's (1994) research, who recalculate earlier Prescher (1982) data for the area of former Yugoslavia indicates that seedlings aged 4-5 years require a temperature sum of 193-195°C, while in these studies these temperature sums are significantly lower except for year 2015 in the progeny test in Drinić. When it comes to the variability between the budburst among populations, the values range from the interval reported by Rötzer and Chmielewski (2001) which is 6 days on average, while the maximum values are around 12-13 days, which was also in line with the obtained results.

Different results of temperature sums indicate the need to include a wider range of factors in the analyses. One of the factors that can affect the dynamics of budburst is winter temperatures. The emergence of the so-called "warm spells" can slow budburst (Hannerz 1999; Heide 2003; Partanen et al. 2005; Hänninen 2006; Sjøgaard et al. 2008; Granhus et al. 2009; Hänninen and Tanino 2011; Junttila and Hänninen 2012; Olsen et al. 2014; Körner and Bassler 2014; Lange et al. 2016; Konnert et al. 2015; Olsson et al., 2016; Partanen et al. 2016; Partanen et al. 2020). If average daily temperatures are observed, it is evident that there was a significant variation in temperature in both progeny tests each year. The differences in the beginning of budburst at the level of years (between 2013 on the one hand and 2015 and 2016 on

the other hand) could be attributed to significantly lower temperatures at the end of the vegetation period in 2012. For the other two years, temperatures below 0°C did not occur until almost the last days of December and the first days of January. This can partially explain the difference in the budburst at the level of observed years, i.e. that low temperature in the autumn of the previous year was a kind of a "trigger" for the earlier budburst the following year. Chilling requirement was found to be necessary for Norway spruce budburst (Hannerz et al. 1999; Konnert et al. 2015). Thus Sjøgaard et al. (2008) state that the influence of the cold period accelerates the budburst especially if Norway spruce is not exposed to warmer conditions which is in line with results obtained by Körner and Bassler (2014); Partanen et al. (2005); Hänninen (2006); Junttila and Hänninen (2012); Olsen et al. (2014), which point out the importance of the cold period, as well as the importance of cumulative temperatures on the dynamics of budburst. Combination of cold temperatures and mild spells can promote budburst (Granus et al. 2009) which happened in the winter 2012 in both progeny tests.

There are other factors that might influence the budburst dynamics which can be considered such as the length of the photoperiod (Partanen et al. 2001; 2005; Sjøgaard et al. 2009; Migliavacca 2012; Lee et al. 2014; Luoranen and Sutinen 2017; Lee et al. 2017; Wallin et al. 2017), Körner and Basler 2010; 2014; Basler and Körner 2012), the influence of fertilizer and the type of planting material (Fløistad and Kohmann 2004; Luoranen and Rikkala 2011; Johansson et al. 2012), relative humidity (Laube et al. 2014), the method of seedling production as well as a the combination of factors (temperature, precipitation, light), (Čepl et al. 2020).

## 4 Conclusions

Studies on Norway spruce have shown that there are significant differences in the budburst and the budburst dynamics. The seedlings originating from the Kneževo seed stand had earliest budburst in comparison to the other populations. Planting new forests with seedlings originating from the Kneževo seed stand should be done in the areas where the risk of late spring frosts is lower. The latest budburst opening, on average, was recorded in the population of Han Pijesak 2. The seedlings originating from other populations behaved differently, depending on the year of observation and the progeny test. Bearing in mind that earlier budburst for tested population does not mean faster and better growth, which was found in previous research (Cvjetković et al., 2015; Cvjetković et al. 2016), it is justified to choose populations with late budburst.

Temperature sums did not prove to be reliable for defining the budburst since they were different each year. This leads to the fact that it is necessary to include other parameters that can affect the opening of the buds, such as photoperiod and the influence of the cold period during winter. Although the connection between temperature sums and budburst has not been clearly proven, the obtained results can be used from the aspect of the classification of forest reproductive material sources according to the beginning and the dynamics of budburst. This can place emphasis on the production of planting material that reduces the risk of the damage caused by late spring frosts. The influence of weather conditions in the previous year should also be related to the events in the current year, but several parameters such as photoperiod should be taken into account.

Changes in phenology, in correlation with frosts, must be taken into account in the production of planting material and the raising of new forests in order to reduce the losses after afforestation due to frost damage.

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