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Temporal variability of spring phenological phases and diameter increment of Norway spruce (*Picea abies* /L./ Karst.) provenances

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Abstract

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The presented paper analyses temporal variability of the beginning, end, and the length of growth, and of the selected spring phenological phases of Norway spruce. The experiment was performed on three provenances of Norway spruce (*Picea abies* /L./ Karst.) originating from the orographical unit of Volovské vrchy, and growing in Borová hora arboretum, during the three years 2010, 2011 and 2012. The examined provenances were selected on the base of the elevation gradient from three elevations: 500 m a.s.l., 750 m a.s.l. and 1,100 m a.s.l. Tree stem circumference changes were continuously measured, and spring phenological phases were assessed. Our results proved that a significant temporal shift in the onset of the phenophases to a later period occurs in provenances originating from higher elevation. We found that during the period from 2010 to 2012, the sum of the effective air and soil temperatures needed for the onset of the phenological phases decreased from one year to another. The highest effective sums of air and soil temperatures were required for the provenance originating from the highest elevation (1,100 m). The analysis of diameter increment showed that the lowest increment value equal to 4.35% was recorded in April 2010, while the increment in April 2011 was 13.11% and in 2012 it was 10.09% of the overall increment of the stem diameter in growing season. This was caused by the later onset of spring phenophases in April 2010 caused by lower air temperatures in this month.

Keywords

increment, *Picea abies*, provenances, spring phenological phases, temperature sums

Introduction

In the last years, phenology (Leith, 1974) has become an indicator of global climate changes, mainly during spring months (Crick and Sparks, 1999; Parmesan et al. 1999; Thomas and Lennon, 1999).

Nowadays, spring phenological phases occur earlier in the northern hemisphere than in previous decades (Menzel and Fabian, 1999). Higher temperatures in late summer postpone spring phenophases in the next year (Sparks et al., 2000; Heide, 2003; Chmielewski et al., 2005). Thus, in order to predict the bud reaction in spring it is important to know the climatic conditions during the onset of bud dormancy in previous autumn (Gordo and Sanz, 2010). According to the results of Gordo and Sanz (2010), significant increase of autumn temperatures could cause postponing of spring phenological phases in the next year.

Climate changes cause changes of temperatures mainly in winter and early spring. Flowering time of early flowering species is expected to change most (Gordo and Sanz, 2010). On the base of the models, the flowering date is expected to shift to a later time at a rate of 6.2 days per 1 °C, if GCM temperatures increase by 4.5 °C between 1990 and 2099 and greenhouse gases increase by 1% per year (Osborne et al., 2000).

Spruce is the most important coniferous tree species in Slovakia. It creates pure stands exclusively in the zone of high-elevation spruce forests under the upper timber line. However, in the past centuries spruce was artificially planted at lower elevations, where it nowadays represents a significant part of stands and frequently forms single-species communities. Due to climate changes, spruce at lower elevations begins to suffer from drought, which also affects the survival of Norway spruce seedlings growing under unconstrained moisture conditions (Pichlerová et al., 2013). Nowadays, phenological events are considered one of the most suitable indicators of climate changes and of their impact on tree species.

In this paper we analyse the temporal variability of the onset, the end, and the duration of selected spring phenological phases between the provenances of Norway spruce originating from different elevations during the three years from 2010 to 2012 in connection with the spring growth in stem circumference.

Material and methods

The changes in stem circumference, spring phenological phases and microclimatic characteristics were assessed in Borová hora arboretum in Zvolen, during the growing season of 2010, 2011, 2012. Borová hora arboretum is situated in the watershed of the middle Hron River, approximately 3 km from Zvolen town centre, between 48°35´42´´ and 48°36´06´´ of northern latitude, and between 19°07´58´´ and 19°10´00´´ of eastern longitude. The research plots are situated at an elevation of 350 m above sea level on a hillside with prevailing northwestern aspect and 5–10% slope.

Geological parent rock consists of andesite tuff and travertines, the main soil types are pararendzinas, cambisols and fluvial soils. Arboretum belongs to 2nd beech-oak forest vegetation tier. From the point of climate, the site belongs to a warm, slightly moist region with cold winter.

In the experiment we used three provenances of Norway spruce (*Picea abies* /L./ Karst.), each represented with six 35-year-old sample trees (in the year 2010 only four sample trees), originating from different elevations from the Volovské vrchy mountain range:

- 1st provenance – 500 m a.s.l.
- 2nd provenance – 750 m a.s.l.
- 3rd provenance – 1,100 m a.s.l.

On each sample tree, we installed DRL 26 dendrometer (EMS Brno, CZ) with automated data storage into a built-in datalogger. The changes in tree circumference were recorded continuously in one hour intervals. From the data we derived the beginning, the end and the length of the growth.

For the measurements of soil water potential (SWP) we installed gypsum blocks near each provenance at depths of 15 cm, 30 cm and 50 cm. The blocks were equipped with a data logger for automatic data storage at one hour intervals.

Close to the selected sample trees, we also measured meteorological characteristics: global radiation [W m^{-2}], air temperature [°C], relative air humidity [%], precipitation totals [mm] and soil temperature [°C]. Air temperature and humidity were measured at 2 m height above ground with Minikin TH tool (EMS Brno, CZ), and soil temperature was measured at 10 cm depth. The measurement of global radiation was performed with Minikin RT (EMS Brno, CZ). All data were stored in a datalogger at 10 minute-interval. Since the values of meteorological characteristics were recorded at different intervals, we re-calculated the measured values into hourly sums.

During the spring of 2010, 2011 and 2012, we observed the development of the following phenological phases of vegetative organs of Norway spruce on four sample trees of each provenance:

- leaf bud swelling (LBS) – 10%, 50%, 100%
- sprouting of leaves (SL) – 10%, 50%, 100%
- leaf unfolding (LU) – 10%, 50%, 100%.

We used these data for the determination of the onset, end, and the length of the phenological phases for each provenance.

According to Bednářova et al. (2012) the onset of spring phenological phases is mainly affected by the air temperature above 5 °C and soil temperature of 1 °C. Thus, we calculated the means of sums of effective temperatures for these 1 °C and 5 °C temperature limits from 1st January. The earliest date (10%), when the phenological stage was noticed, was considered as the beginning of the onset of phenological phases.

To determine the differences in the onset, end, and the length of the phenological phases and increment between the provenances, we performed multifactorial analysis of variance using STATISTICA 10 and Microsoft Excel. Significant differences were revealed for the significance level $p = 0.05$.

Results and discussion

Diameter growth

In 2010, diameter growth started on 121 DOY and finished on 279 DOY. In 2011, diameter growth started on 112 DOY and finished on 229 DOY. The third provenance originating from the highest elevation finished its diameter growth earlier, on 220 DOY. In 2012, diameter growth started on 111 DOY and finished on 328 DOY. In August, a temporary cessation of diameter growth was observed due to drought and high air temperatures in the 2012 summer (Table 1). This corresponds with the findings of Nielsen and Jørgensen (2003), who found that the cessation of growth can also be significantly influenced by soil water. In September, increment increased again and growth continued until the end of November. A detailed microclimatic characteristic of the three years in comparison with the long-term average (1961–1990) and the overview of the diameter increment in the years 2010–2012 can be seen in Table 1.

Table 1. Climate assessment of years 2010, 2011 and 2012 compared with the long-term average from 1961 to 1990 and overview of the increment of the stem diameter in these growing seasons; N %, percentage of the long-term average precipitation; AT, air temperature; ΔAT, deviation of the long-term average; GS, growing season; VOP %, percentage of the overall increment of the stem diameter in growing season.

Month	P [mm]	N %	Description	AT [°C]	Δ AT	Description	Increment [mm]	VOP [%]
April	63.0	137.0	Moist / above normal	9.8	1.3	Warm / above normal	1.66	4.35
May	123.2	186.7	Very moist / strongly above normal	14.3	0.9	Normal / normal	9.82	25.71
June	168.8	201.0	Very moist / strongly above normal	18.3	2.0	Warm / above normal	11.90	31.17
July	64.8	101.3	Normal / normal	21.2	3.3	xtremely warm / extremely above normal	10.22	26.76
August	34.0	54.0	Arid / subnormal	18.5	1.4	Warm / above normal	3.79	9.92
September	103.6	191.9	Very moist / strongly above normal	12.8	–0.6	Normal / normal	0.89	2.32
October	32.6	72.4	Normal / normal	6.8	–1.6	Cold / subnormal	–0.23	–0.60
November	89.2	146.2	Moist / above normal	7.0	3.9	Extremely warm / extremely above normal	0.14	0.38
GS 2010	679.2	140.6		13.6	1.3		38.18	100.00
Month	P [mm]	N %	Description	AT [°C]	Δ AT	Description	Increment [mm]	VOP [%]
April	20.6	44.8	Arid / subnormal	11.7	3.2	Very warm / strongly above normal	4.37	12.89
May	39.6	60.0	Arid / subnormal	14.6	1.2	Normal / normal	9.84	29.01
June	106.2	126.4	Normal / normal	18.1	1.8	Warm / above normal	12.48	36.80
July	150.8	235.6	Extremely moist / extremely above normal	18.6	0.7	Normal / normal	5.74	16.91
August	15.0	23.8	Very arid / strongly subnormal	20.2	3.1	Extremely warm / extremely above normal	3.22	9.49
September	3.6	6.7	Very arid / strongly subnormal	16.7	3.3	Very warm / strongly above normal	–0.69	–2.03
October	16.6	36.9	Arid / subnormal	8.3	–0.1	Normal / normal	–0.91	–2.68
November	1.8	3.0	Extremely moist / extremely above normal	1.2	–1.9	Cold / subnormal	–0.13	–0.39
GS 2011	354.2	73.3		13.7	1.4		33.93	100.00
Month	P [mm]	N %	Description	AT [°C]	Δ AT	Description	Increment [mm]	VOP [%]
April	46.6	101.3	Normal / normal	10.5	2.0	Warm / above normal	2.94	10.00
May	17.0	25.8	Extremely arid / extremely subnormal	15.6	2.2	Warm / above normal	7.38	25.12
June	93.2	111.0	Normal / normal	18.8	2.5	Very warm / strongly above normal	10.44	35.50
July	126.0	196.9	Very moist / strongly above normal	20.7	2.8	Extremely warm / extremely above normal	7.73	26.30
August	6.8	10.8	Extremely arid / extremely subnormal	20.2	3.1	Extremely warm / extremely above normal	–1.97	–6.71
September	30.6	56.7	Normal / normal	16.0	2.6	Very warm / strongly above normal	1.23	4.18
October	120.0	266.7	Very moist / strongly above normal	9.4	1.0	Normal / normal	1.65	5.60
November	40.6	66.6	Normal / normal	6.3	3.2	Very warm / strongly above normal	0.00	0.01
GS 2012	480.8	99.5		14.7	2.4		29.40	100.00

In Figure 1 we can see that after the phenological phase of leaf-unfolding, the increment begins to increase significantly as a result of maximum photosynthetical activity of physiologically mature leaves. Multifactorial analysis of variance revealed that there is a significant difference at the beginning of diameter

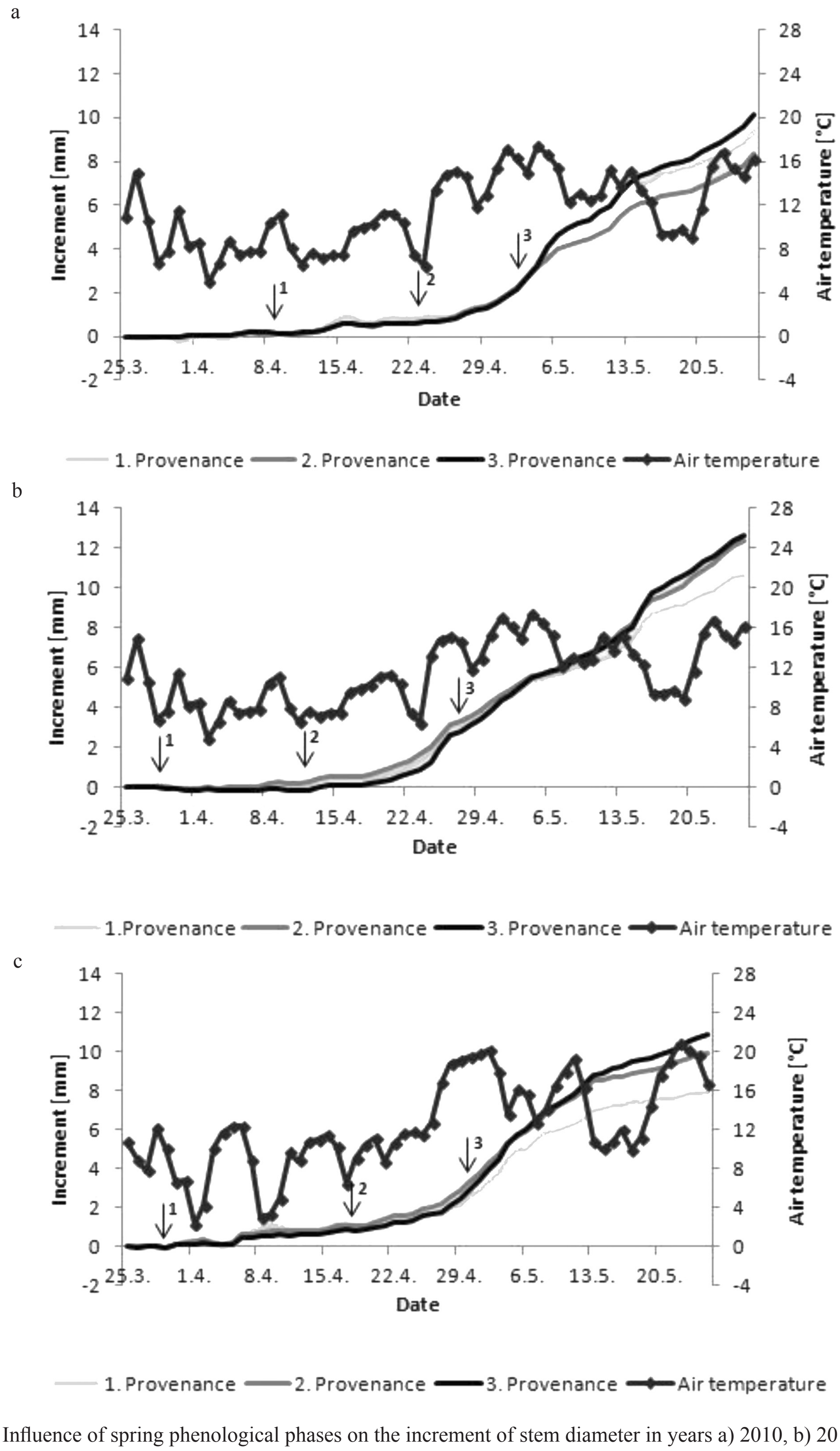

Fig. 1. Influence of spring phenological phases on the increment of stem diameter in years a) 2010, b) 2011, c) 2012; (1, leaf bud swelling; 2, sprouting of leaves; 3, leaf unfolding).

growth between the provenances and the years 2010, 2011 and 2012 (Fig. 2a). This confirms the knowledge that provenances from higher elevations begin their diameter growth later than provenances from lower elevations.

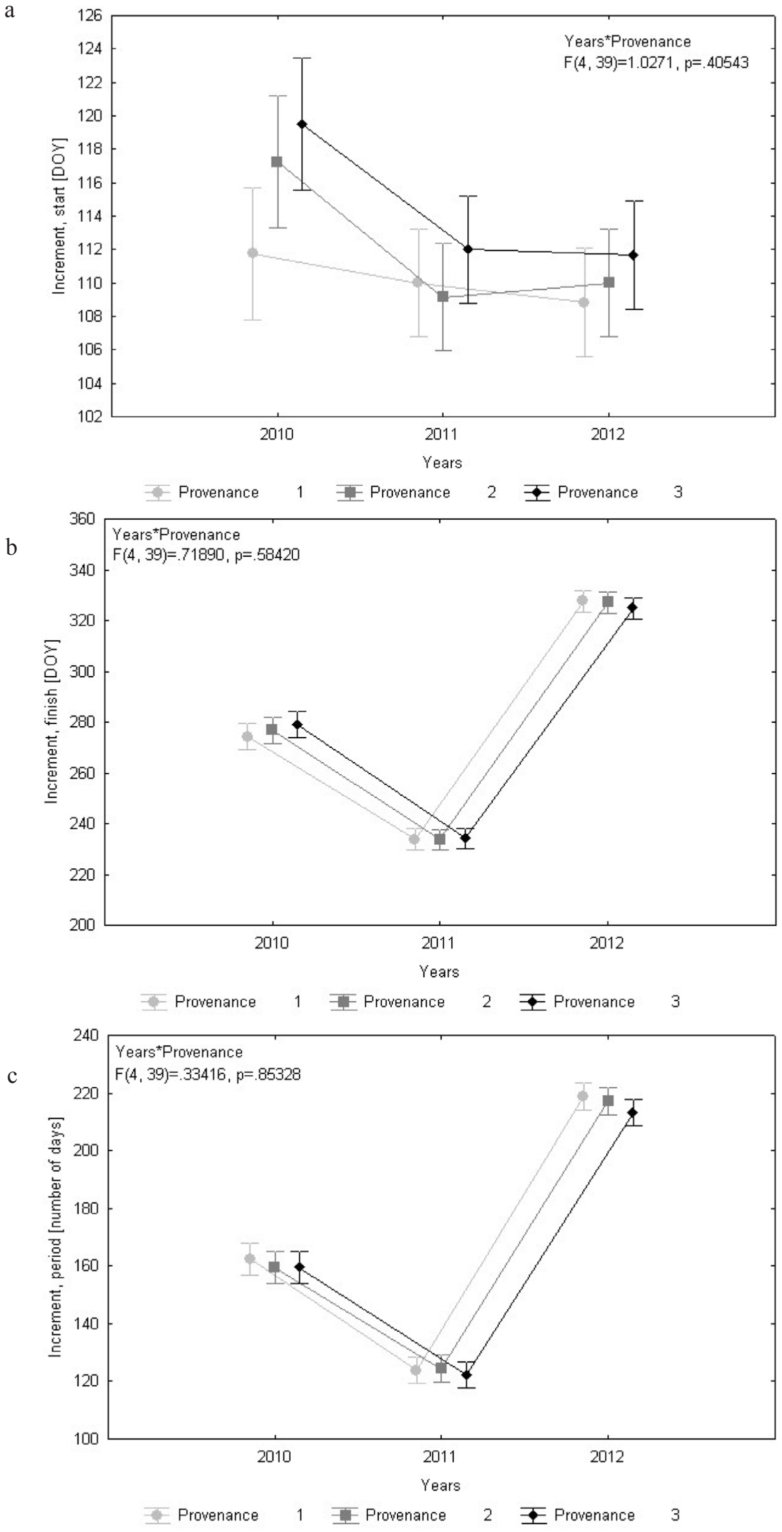

Fig. 2. Multifactorial analysis of variance of the beginning (a), end (b) and the length of growth period (c) between the provenances and years.

The end date of the growth and the growth length significantly differed only between the years (Fig. 2b, c). In the year 2012, the average growth period was by about 53 days longer than in the year 2010, and by 94 days longer than in the year 2011.

According to the findings of several authors, populations from high latitudes or higher elevations seem to start their growth earlier (Ekberg et al., 1985; Skroppa and Magnussen 1993; Hannerz, 1998), finish their growth earlier, have a shorter period of sprout lengthening (Modrzyński, 1995; Hannerz and Westin, 2000).

The analysis of diameter increment revealed significant differences in the monthly increments during April and May (Table 1) between individual years. In the year 2010, the average difference between monthly increments in April and May was 8.16 mm, while in 2011 the difference was 5.47 mm and in 2012 it was only 4.44 mm. This difference can be explained by the fact that in April, new foliage of spruce trees was not sufficiently developed (in relation to phenological phases), nor the optimum monthly mean air temperature for the sufficient tree activity was achieved. In the years 2011 and 2012, the onset of spring phenophases was faster and hence, the differences in the increment between April and May gradually decreased.

Phenological phases

The sums of effective air temperatures above 5 °C and soil temperatures above 1 °C that are needed for the onset of spring phenophases are given in Tables 2 and 3. For example, in the year 2010 the first phenophase leaf bud swelling (LBS) required the sum of effective air temperatures to be equal to 208 °C, 230 °C, and 275 °C for the first, second, and third provenance from elevations 500, 750 and 1,100 m a.s.l., respectively. From these results we can see that the sum of effective air temperatures required for the onset of the phenological phase increases with the increasing elevation. In the year 2011, lower sums of effective air temperatures were required, and in the year 2012 they further decreased (Table 2). Similar trend can also be observed in the effective sums of soil temperatures in Table 3.

Hence, we can state that the required sum of effective air and soil temperatures decreases from year to year. We also found that the third provenance, which originates from the highest elevation, requires the greatest sums of effective air and soil temperatures. Similar findings were presented by Magová (2011).

The differences in the onset of vegetative phenological phases between provenances and years we can see in Figure 3. The results of the onset of vegetative phenological phases of spruce in Slovakia showed the time shift between elevation groups (Škvareninová, 2013). Our results showed that the ability of gradual time delay of the onset of other vegetative phenophases of spruce with the increasing elevation remained also

Table 2. Sums of effective air temperature above 5 °C for the onset spring phenological phases, LBS, leaf bud swelling; SL, sprouting of leaves; LU, leaf unfolding

Year	2010						2011						2012					
Provenance/Phenol. phase	LBS	Date	SL	Date	LU	Date	LBS	Date	SL	Date	LU	Date	LBS	Date	SL	Date	LU	Date
1. 500 m a.s.l.	208.7	11.4.	315.6	23.4.	468.6	4.5.	125.3	28.3.	298.9	14.4.	466.6	28.4.	181.4	30.3.	318.7	18.4.	471.2	30.4.
2. 750 m a.s.l.	230.3	14.4.	365.4	27.4.	468.6	4.5.	202.7	5.4.	358.0	20.4.	496.1	30.4.	205.0	4.4.	392.1	25.4.	578.4	6.5.
3. 1,100 m a.s.l.	275.2	19.4.	420.3	1.5.	584.0	12.5.	213.2	6.4.	400.8	23.4.	576.5	8.5.	241.4	7.4.	416.3	27.4.	594.1	7.5.

Table 3. Sums of effective soil temperature above 1 °C for the onset spring phenological phases, LBS, leaf bud swelling, SL, sprouting of leaves; LU, leaf unfolding

Year	2010						2011						2012					
Provenance/Phenol. phase	LBS	Date	SL	Date	LU	Date	LBS	Date	SL	Date	LU	Date	LBS	Date	SL	Date	LU	Date
1. 500 m a.s.l.	178.6	11.4.	275.4	23.4.	399.9	4.5.	85.4	28.3.	221.9	14.4.	361.5	28.4.	53.6	30.3.	174.4	18.4.	296.3	30.4.
2. 750 m a.s.l.	194.0	14.4.	315.8	27.4.	399.9	4.5.	142.3	5.4.	273.8	20.4.	385.5	30.4.	72.4	4.4.	239.4	25.4.	379.0	6.5.
3. 1,100 m a.s.l.	236.2	19.4.	361.7	1.5.	510.5	12.5.	151.1	6.4.	306.0	23.4.	475.4	8.5.	92.9	7.4.	260.3	27.4.	393.1	7.5.

after its plantations in new uniform conditions of Zvolenská valley.

The differences at the end of vegetative phenological phases between provenances and years we can see in Figure 4. The differences in the length of vegetative phenological phases between provenances and years we can see in Figure 5. The average length of LBS phenophase was 10–13 days, 11–17 days, and 9–17 days,

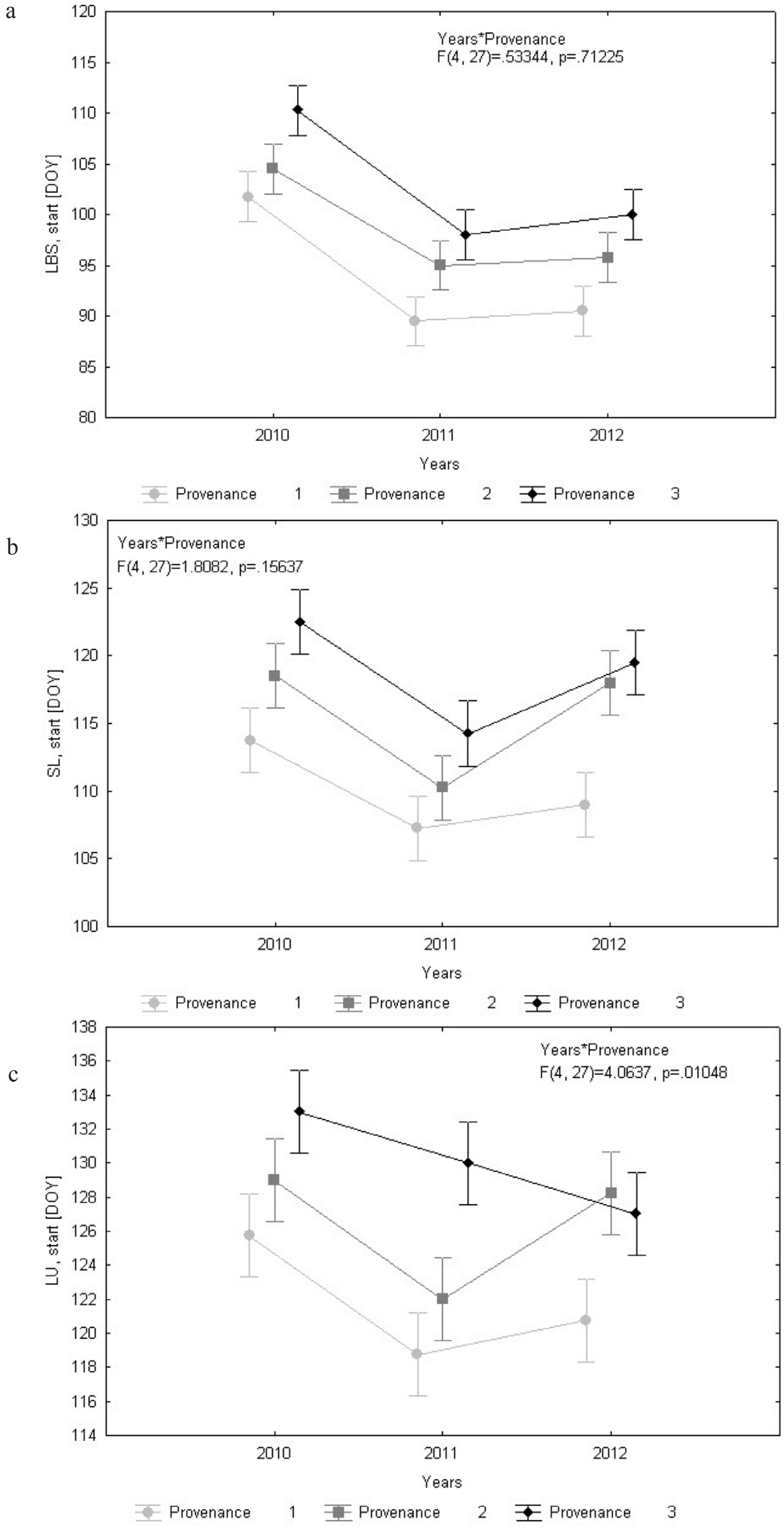

Fig. 3. Multifactorial analysis of variance of the onset of spring phenological phases between the provenances and years, a) LBS, b) SL, c) LU.

in the case of the first, second, and third provenance, respectively. The average length of SL phenophase for the first, second and third provenance was 7–10 days, 8–10 days, and 9–13 days, respectively.

According to the results of several authors, time shift of spring phenophases to earlier dates was more profound than the shift of summer and autumn phenophases; and also early spring phenophases seem to have

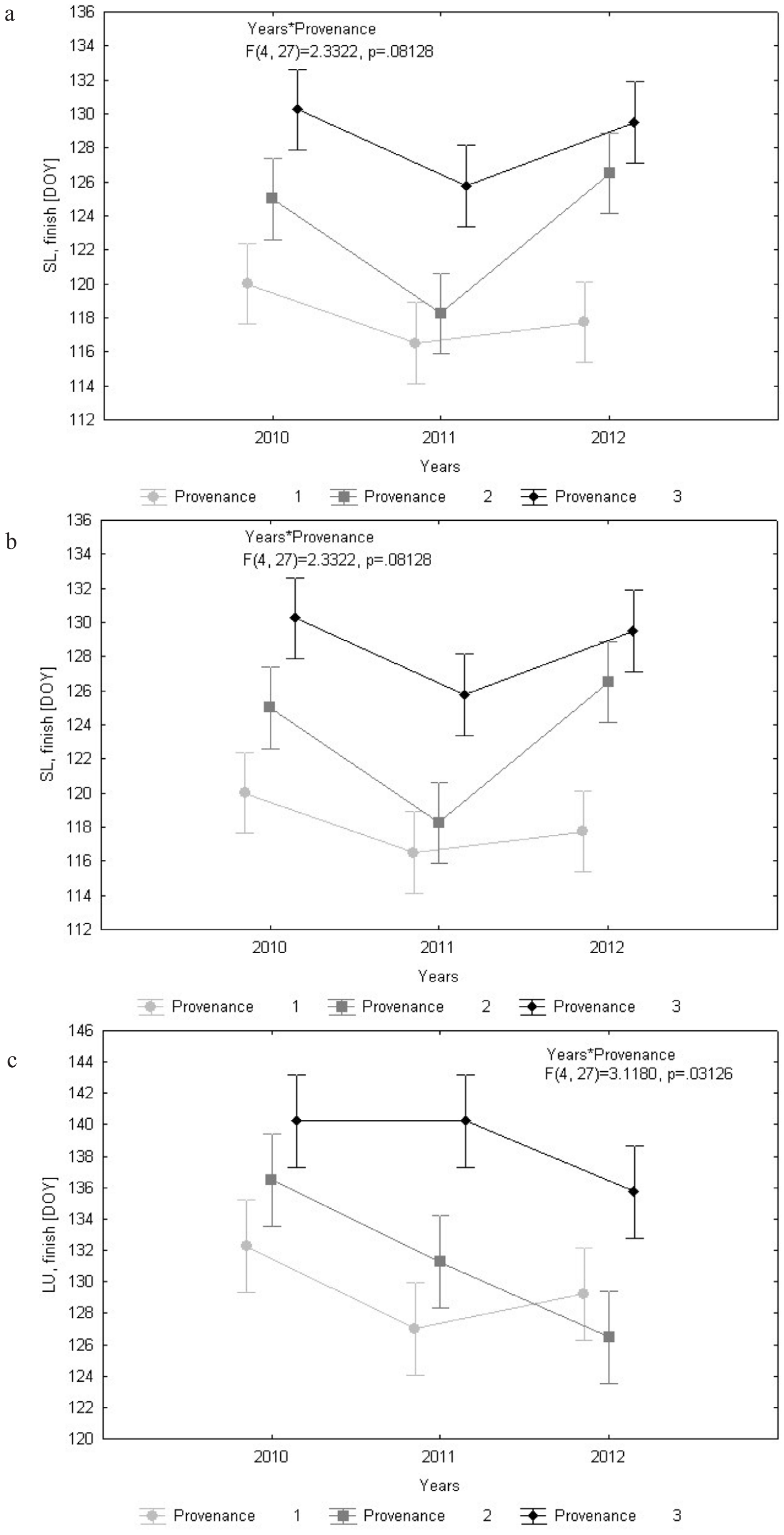

Fig. 4. Multifactorial analysis of variance of the end date of spring phenological phases between the provenances and years, a) LBS, b) SL, c) LU.

larger time shifts to earlier dates than late spring and early summer phenophases (Menzel, 2004; Gordo and Sanz, 2005; Wolfe et al., 2005; Miller-Rushing et al., 2007).

Conclusion

The research was performed on the sample trees of Norway spruce (*Picea abies* /L./ Karst.) originating

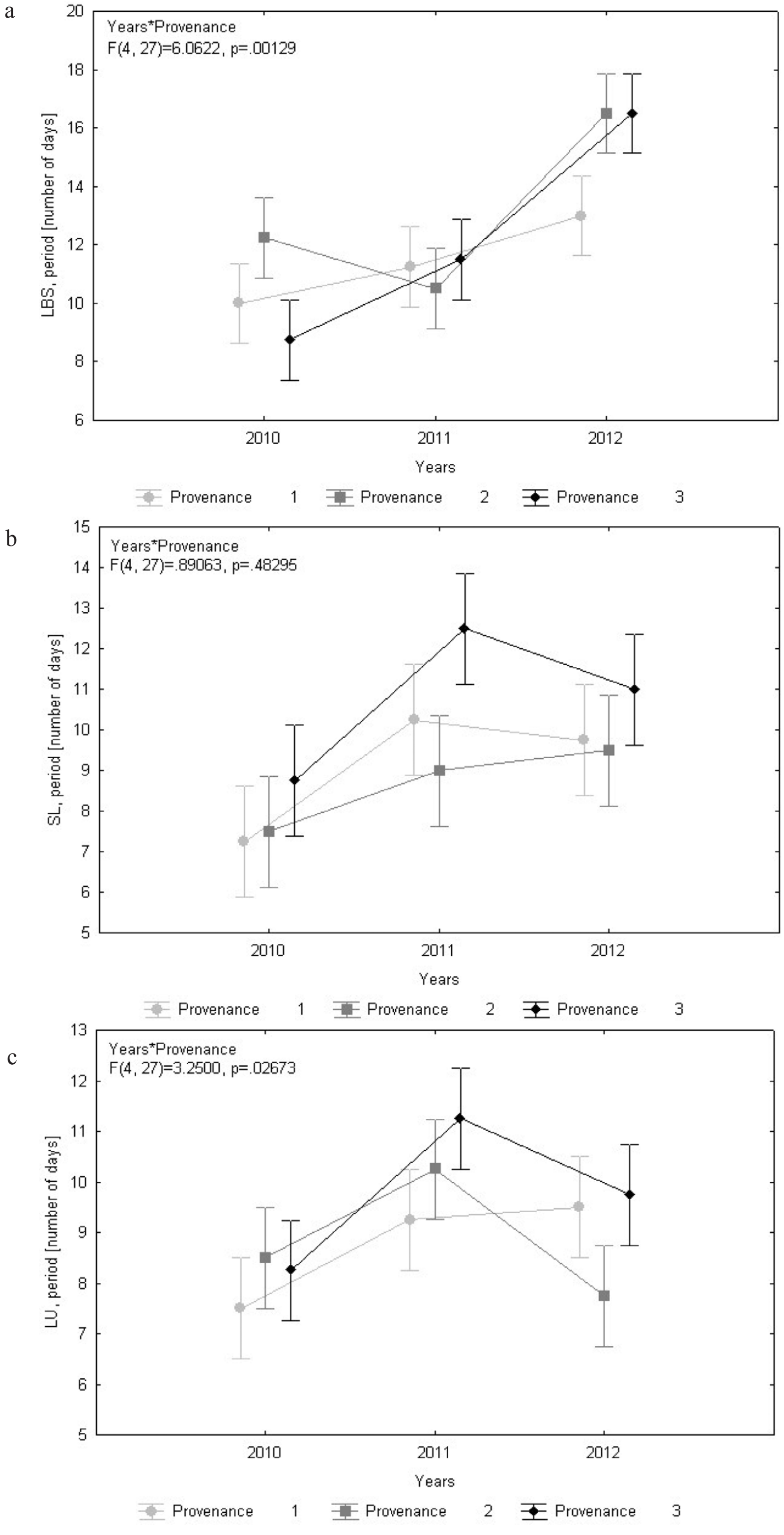

Fig. 5. Multifactorial analysis of variance of the duration of spring phenological phases between the provenances and years, a) LBS, b) SL, c) LU.

from three different elevations (500, 750 and 1,100 m n. m.) from the Volovské vrchy Mts and growing in Borová hora arboretum, in the years 2010, 2011 and 2012. The analysis of variance revealed significant differences at the beginning, end, and length of growth between the years. We also found significant differences between the provenances at p = 0.05 significance level, but they did not have a clear positive or negative trend during the three years. The differences changed every year. Multifactorial analysis of variance did not show any clear positive or negative trend in significant differences between the provenances and years during the investigated period at p = 0.05 significance level.

The research confirmed the knowledge that the provenances from higher elevations begin their diameter growth later than the provenances from lower elevations. Diameter growth of the third provenance coming from the highest elevation started last, on average by 3–8 days later than in the case of the first and second provenance. In 2010, the first provenance finished its growth on average by 3 and 5 days earlier than the second and the third provenance, respectively. In the year 2011, all provenances finished their growth at the same time, and in 2012, the third provenance finished its growth by 3 and 2 days earlier than the first and the second provenance, respectively. In the year 2012, the growth period was by 53 and 94 days longer than in the years 2010 and 2011, respectively. The analysis of diameter increment revealed the lowest increment values equal to 1.66 mm in April 2010, while the increment in 2011 was 4.37 mm and in 2012 it was 2.94 mm. This was caused by the later onset of spring phenophases in April 2010 caused by lower air temperatures in this month.

We can conclude that during the years 2010 and 2012, each year a lower sum of effective air and soil temperatures required for the onset of phenological phases was needed. The highest effective sums of air and soil temperatures are needed for the third provenance originating from the highest elevation. Our results confirmed that the origin of the provenances causes significant time shifts of phenophases, the phenophases of the provenances originating from higher elevations are shifted to a later time. This could be in future efficiently utilised for planting provenances from higher elevations at lower elevations with the aim to eliminate frost damage of spring sprouts.

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