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Spring phenology of European beech (*Fagus sylvatica* L.) in a submountain beech stand with different stocking in 1995–2004

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ABSTRACT: Two spring phenophases (bud-burst and leaf unfolding) of a parent stand and naturally regenerated undergrowth of European beech were observed in conditions under different stand density over the last 10 years. The results proved the unequal onset of phenophases of the parent stand individuals in relation to their sociological status. In the case of codominant and dominant trees the delay of 2–5 days was observed in comparison with subdominant trees. The influence of the parent stand structure on the onset of the undergrowth phenophases was also observed. The onset of phenophases differed by 2–20 days among individuals grown under different density of the parent stand. The onset and course of phenophases also differed between the years. The trend of the average onset of leafing in the period 1995–2004 shows a shift to earlier dates by about three days. Temperature summation of average daily temperatures with the base temperature of 8°C, in the framework of the model predicted bud-burst of beech, showed the lowest variability in comparison with other temperatures.

Keywords: *Fagus sylvatica*; phenology; bud-burst; leafing; temperature sum

European beech, one of the most frequent and widespread autochthonous broadleaved tree species in the region of Central European, takes up approximately 30% of the forest stand area of the Slovak Republic (COLLECTIVE 1998). It is sensitive to continental climate because of very low temperature and drought vulnerability. The species prefers moderate climate without extremities (ZLATNÍK 1978).

In connection with the global climate change influencing also the European continent we have expected such effects as unbalanced temperature and precipitation regime during the year, higher probability of frost damage as well as altered competitive balance between tree species (KRAMER 1995; GANSERT et al. 1999; BOLLIGER et al. 2000). *Fagus sylvatica*, a typical representative of the temperate zone tree species, belongs to woody plants subjected to phenological observations running in the framework of the International Phenological Gardens program (CHMIELEWSKI 1996). It is known that

phenological events reflect biological characteristics (endogenous factors) of the species in relation to the course of climatic factors. According to REED et al. (1994) and LECHOWICZ (1995) the exogenous factors influencing phenology of plants include photoperiod duration, soil moisture and temperature, air temperature, solar illumination, snow cover, etc. However, the details of the physiological control of spring phenophases such as budburst are not still clear. The rest is the period in which tree buds remain dormant due to physiological conditions in the buds (physiological dormancy) while the quiescence is the period in which buds remain dormant due to unfavourable environmental conditions (enforced dormancy). Physiological dormancy is removed when the buds are exposed to chilling temperatures below 10°C for a certain period likewise to long days (HEIDE 1993). Enforced dormancy release takes place when the buds are exposed to forcing temperatures (above 0°C) for a prolonged period (SARVAŠ 1974). The

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influence of the structure of a parent stand (density, canopy, etc.) on phenology, morphology and anatomy of a subsequent beech population was studied by CÍČÁK and ŠTEFANČÍK (1993), COLLET et al. (2002), SCHIEBER (2005). Expected effects of global changes interfere with the survival and the distribution of trees. Therefore it is important to study the phenology as a good indicator of the influences of climate changes on the development of the vegetation.

The aim of the paper is the analysis of two spring phenophases of beech parent trees and naturally regenerated seedlings in a managed submountain beech forest stand of different density during period of 10 years.

MATERIAL AND METHODS

Study site

The study site was established at the Beech Ecological Experimental Station (BEES) in the SE part of the Kremnické vrchy Mts. ($\varphi = 48^{\circ}38'N$, $\lambda = 19^{\circ}04'E$, $H = 450\text{--}520$ m a.s.l.). The BEES is located on a slope $5\text{--}15^{\circ}$ oriented to the west-southwest in a climatically moderate warm area with average annual temperature of $6.8^{\circ}C$ and annual precipitation 780 mm. The investigated stand was about 90 years old with 85% of European beech (*Fagus sylvatica*), and fir (9%), oak (6%) and hornbeam (1%) as associated species. After the intervention in 1989, the station consisted of 5 partial plots (PP) with various degrees of stocking. According to BARNA (2004) the values of stocking in 1996 were as follows: PP K – 0.87 – original stocking; PP M – 0.78; PP S – 0.62; PP I – 0.4. PP H was the cleared area, at the present time with intensive development of natural regeneration (KODRÍK 1997). The plots are separated by isolation strips. Skeletal Cambisols with moderate acid reaction create the soil cover (KUKLA 1993) of BEES. According to KONTRIŠ et al. (1995) the vegetation cover at the locality is primarily composed of patches of *Carici pilosae-Fagetum* and *Dentario bulbiferae-Fagetum* associations.

Phenological observations

The beginning and the course of the spring phenophases (bud-burst and leaf unfolding) on trees from natural regeneration were separately studied on four PP (PP M was excluded) of the BEES, the parent stand representing one homogeneous group. There were in total 80 parent trees with different sociological status: 20 subdominant (sd), 30 codominant (cd) and 30 dominant (d) trees. The group of natural

regeneration was represented by 100 trees, 25 on each PP. Observations (for the 1995–2004 period) started on 1 March and they were repeated weekly, later in April twice a week. The date when this stage could be observed on 50% of the studied trees was taken as the bud-burst (BB) beginning (BEJDEMAN 1974). Leaf unfolding is defined as a phenological phase when the normal, unwrinkled leaf surface has already been developed, however, the final leaf size has not been attained yet. L1 (L2) were the phases when 50% of the trees had 10% (50%) of their crowns with unfolded leaves. As to the temperature summation model, the temperature sums from 1 February (supposed possible beginning of quiescence stage) to the date of average onset of parent stand BB were calculated for each year of observations separately. Temperatures $0^{\circ}C$, $5^{\circ}C$, $8^{\circ}C$ and $10^{\circ}C$ were regarded as the base temperatures in TS0, TS5, TS8 and TS10, respectively. Temperature sums (TS) were calculated using the relation $TS_i = \sum adt_k$, where adt_k is the average daily air temperature (LIETH 1974). Air temperature was measured with thermographs localised in meteorological cabins (at the standard height 2 m above the ground level) at the BEES and was analysed from thermograms.

RESULTS AND DISCUSSION

Bud-burst and leaf unfolding in parent stand and natural regeneration trees

The BB phenophase of the parent trees started the earliest on subdominant individuals. The timing was nearly the same in observed years – during the fourth pentad of April. However, the years 1997 and 1999 were an exception: the earliest bud-burst took place already during the first decade of this month in 1999. On the other hand in 1997 the latest BB was observed in the middle of the last pentad of April. In the individual years, the time delay of this phase for codominant trees was 2–5 days compared to subdominant trees and the time delay of dominant trees was another 2–9 days compared to codominant trees. The same trend was found out in the case of L1 and L2 phases, subdominant trees flushing first of all. As for L1 phase, its coming was delayed 1 to 6 days on codominant trees, on dominant trees there were 1–3 additional days to the codominants. In the case of phenophase L2, the time delay was 2–8 days (on codominant trees), on dominant trees another 1–2 days were added (Fig. 1). The trend of average onset of leafing in 1995–2004 is illustrated in Fig. 2. There is an evident shift to an earlier date by about three days.

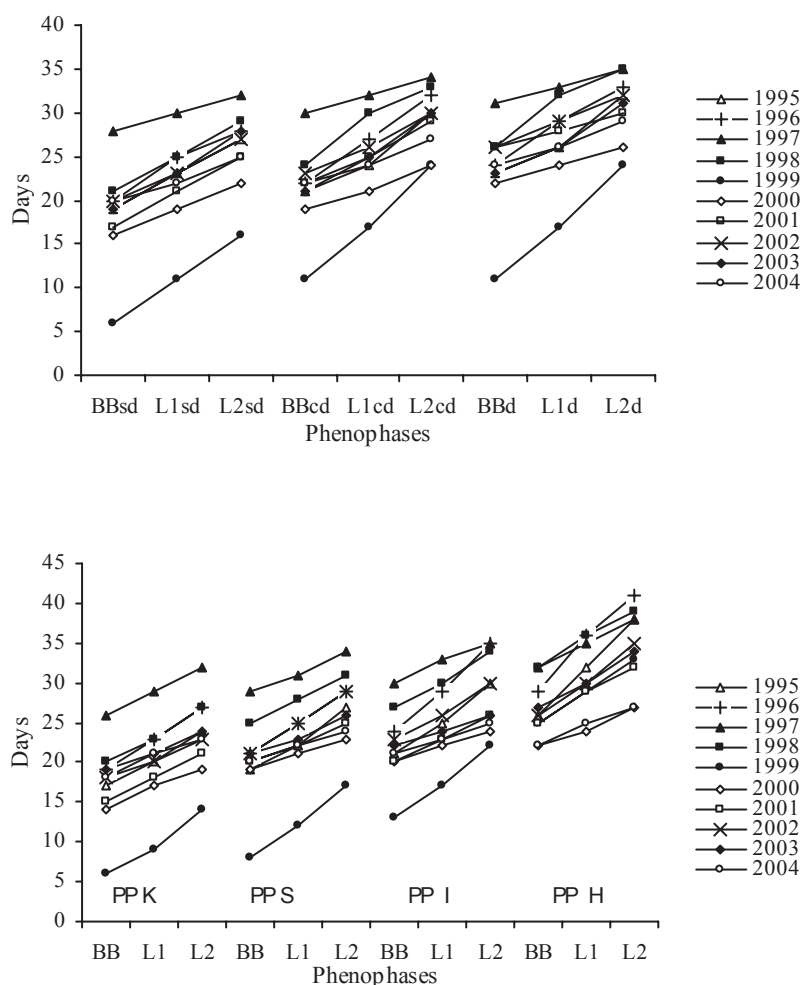


Fig. 1. The onset of the phenophases of parent stand (above) and naturally regenerated seedlings (below) since the 1 April (for a description of the phases see Methods)

The course of phenophases BB, L1 and L2 observed on natural regeneration is illustrated in Fig. 1. The earliest coming of BB phenophase was always observed on PP K with the highest value of stocking. The time interval within which the beginning of BB phase was located on this plot in the period under observation was 20 days: the earliest observation in the midst of the first decade of April in 1999, the latest observation in the midst of the third decade of this month in 1997. On the other partial plots we observed the following time delays of BB onset: on PP S 2–5 days in the individual years, ranging within 21 days in total for all the studied period. The corresponding values for PP I and PP H were 3–7, 17 and 4–19, 10, respectively. The onset of phenophases L1 and L2 was also observed first on PP K. The time interval for L1 in the whole observation period was 20 days on this plot. On the other PPs we observed the following delays for L1 phase: PP S 1–5 days within total 19 days, PP I 2–8 days within 16 days, PP H 4–20 days within 12 days. In the case of L2 phase, the starting was timed within an 18-day interval on PP K. The delays observed on the other experimental

plots were: 1–6 days within 17 days in total on PP S, 2–8 days within 13 days on PP I and 4–19 days within 14 days in total on PP H.

Based on the described results we can conclude that the earliest beginning of phenophase BB of parent trees was detected on subdominant trees. The codominant and dominant trees had time delays. According to ENGLER (1911) this can be explained by morphological differences between shaded and sunlit leaf buds. The sunlit buds are in general greater than the shaded ones and have thicker coat scales which can cause the delay in the opening. On the other hand, subdominant trees growing under the crowns of trees of the other layers have probably buds with thinner coat scales which can promote their earlier development. A similar trend was observed by PRIWITZER and MIŇDÁŠ (1998), who also detected earlier bud-burst on the subdominant beech trees. On the other hand, according to BEŇA (1970) the early beginning of foliage development does not strictly correspond to a tree sociological status in the stand, however the author admitted that most trees with early developed foliage belonged to the

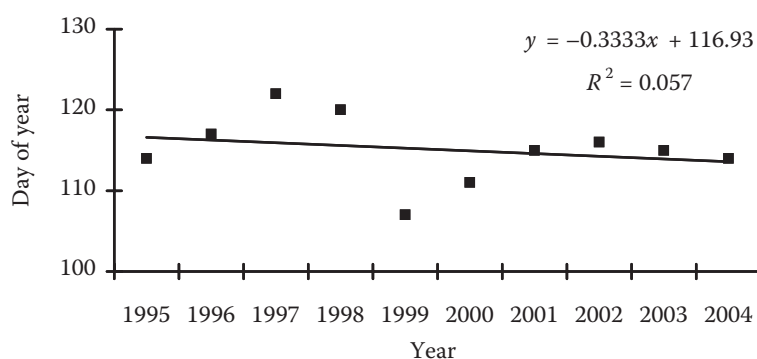


Fig. 2. The trend of average onset of leafing in 1995–2004

category of subdominant trees. As for phenology on juvenile trees, AUGSPURGER and BARTLETT (2003) observed differences in leaf phenology between juvenile and adult trees in some tree species. Our results confirmed the fact that the parent stand structure influenced the phenology of juvenile natural regeneration of beech. The earliest start was observed on trees growing under the crowns of parent stand with the highest density (PP K). Time delay in the onset of BB phase between PP K and PP H ranged from 4 to 19 days between the compared years. Similar results were also obtained by ČIČÁK and ŠTEFANČÍK (1993). These authors observed that the bud-burst on trees from natural regeneration on a plot with the highest parent stand density (0.9) always preceded the bud-burst in the parent stand itself. According to the authors the cause of this phenomenon cannot always be explained by the bud morphology alone but it is necessary to try to reason it also on the basis of eco-morphophysiological responses of beech trees to different phyto-climatic conditions closely connected with the parent stand density. Also according to HEJTMÁNEK (1958) the bud-burst on regenerated natural seedlings under a parent stand preceded the

bud-burst on natural seedlings exposed to direct solar radiation. In the latter case the bud-burst on seedlings was even retarded compared to the parent stand. Because beech is a woody species with natural regeneration under a parent shelter, we can say that natural seedlings growing on the plot of former cleared area (H plot) are exposed to several “stress” factors. First of all it is a wider temperature range (Fig. 3) connected with considerable warming during the day followed by stronger cooling during the night. Among other factors we mention here strong solar radiation reaching considerably higher values on plots without parent stand (STŘELEČ 1992). This condition probably influences the morphology of coat scales (thickening) on individuals growing on this plot, which may also cause the later bud-burst.

Analysing the onset of L1 and L2 phenophases on the parent stand we found that, similarly like in BB, the first were subdominant trees again and the trees belonging to the other stand layers showed time delays. In the case of natural regeneration, the earliest start of L1 and L2 was detected on the plot with the highest stand density and the other plots kept the same order as in the case of BB. Table 1 shows the

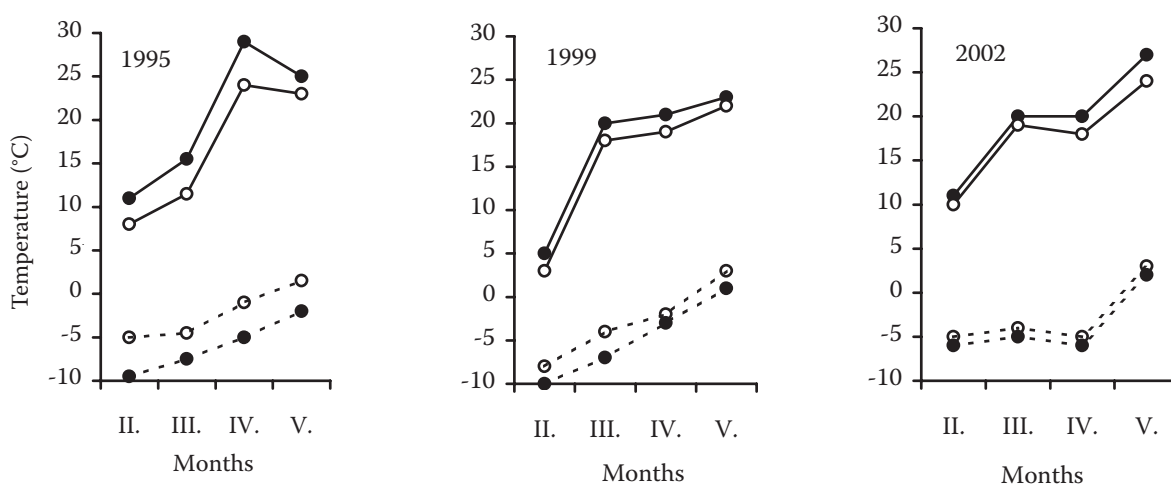


Fig. 3. The values of absolute minimum (dashed line) and maximum (full line) air temperatures measured on two plots of BEES in selected years (PP K – open circle, PP H – full circle)

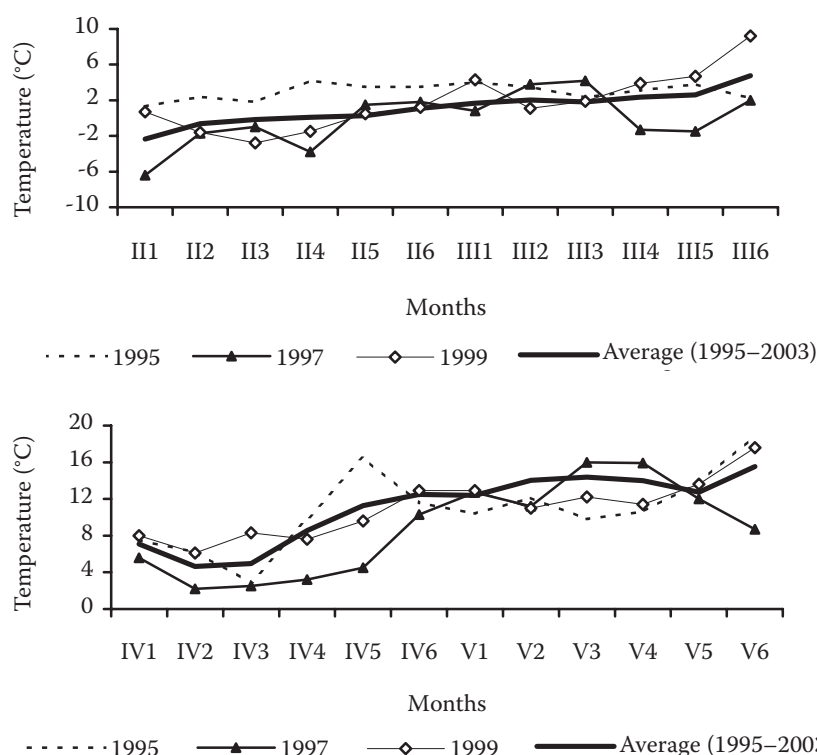


Fig. 4. Average pentad air temperature at the BEES in the period from February to May

variability of the time behaviour of phenophases on natural regeneration and parent stand expressed by differences in the number of days of interphase interval. It is evident that the lowest variability was found out in the case of natural regeneration growing on PP K and in subdominant trees of parent stand. As for differences in the onset of phenophases on parent trees as well as on natural regeneration between the years, we can suppose the influence of climatic factors, especially of the course of air temperatures. The onset of the individual phenophases (BB, L1 and L2) was situated between the fifth pentad of April and the end of the first pentad of May. In 1997 relatively cold March and very cold April caused the delayed onset of phenophases. On the other hand, in 1999 the corresponding interval was from the

second pentad of April up to the end of the fifth pentad of April. This acceleration in 1999 can be explained by favourable temperature conditions when in 1999 (since the third pentad of March) the mean air temperature was the highest. The temperatures in the third decade of the month were higher by 2 to 6 degrees compared to the other years, and in the end there was a steep increase in temperatures during the last pentad of March (Fig. 4). As for the trend of the leafing onset in 1995–2004, there was a shift to an earlier date by about three days. Some authors reported a shift towards the earlier occurrence of phenophases for the period of the last 50 years. They assumed this trend was probably connected with global climate changes (DEFILA, CLOT 2005; MENZEL 2000).

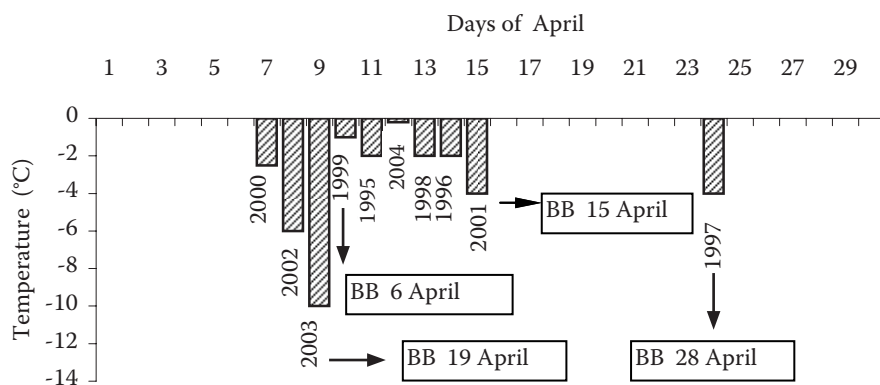


Fig. 5. Late spring frosts in April in 1995–2004 and the onset of bud-burst phenophases of naturally regenerated undergrowth in some risky years

Table 1. Variability of the time behaviour of phenophases on natural regeneration and parent stand from 1995 to 2004 (CV– coefficient of variation)

Natural regeneration		
Partial plots	Interphase interval	CV (%)
PP K	BB-L1	19.6
	BB-L2	19.8
	L1-L2	28.7
PP S	BB-L1	32.8
	BB-L2	30.2
	L1-L2	31.6
PP I	BB-L1	32.1
	BB-L2	37.3
	L1-L2	43.1
PP H	BB-L1	37.3
	BB-L2	32.4
	L1-L2	32.3
Parent stand		
Subdominant trees	BB-L1	29.9
	BB-L2	25.1
	L1-L2	25.6
Codominant trees	BB-L1	43.8
	BB-L2	35.1
	L1-L2	36.9
Dominant trees	BB-L1	48.4
	BB-L2	42.2
	L1-L2	47.8

In connection with the tree leafing, it is also necessary to consider the danger of late spring frosts, primarily after the bud-burst when the assimilatory apparatus is not protected with the scales any more. In the case when the frost is strong or long lasting, the frost damage can be severe, even causing the freezing of the whole young leaves. This danger is more important primarily for young trees, because, in comparison with the parent trees, their leaves are situated at lower stand layers near the soil surface, which entails a higher risk of freezing. The second

factor causing higher vulnerability in young trees follows, as we could already see, from their earlier bud-burst – in general a few days before the parent stand. However, in the period of observations we did not observe any damage to tree leaves caused by late spring frosts. A frost of -1°C recorded on the control PP K in 1999 (in the period of the leafing of natural regeneration) did not cause any damage to the developing foliage. On the other hand, in the bud-burst period of the critical years 1997 and 2001, the morning frost measured at the standard level of 2 m above the ground reached the value of -4°C , and in the case of fully developed foliage it could have caused serious frost damage to leaves. The highest intensity frost in April before the leafing period was recorded in 2003, and it reached the value of -10°C (Fig. 5). This frost was observed about ten days before the beech leafing onset, but in the case of current leafing or full-leaved trees, the damage would certainly have been considerable. In the next month (May) no frost was observed that would cause any damage to the assimilatory apparatus of naturally regenerated trees.

Temperature summation for bud-burst onset

The beginning and course of phenophases in the individual years largely depend on the courses of climate variables, first of all on temperature, precipitation and photoperiod duration (HÄKKINEN, HARI 1988; HEIDE 1993; HOFFMANN 1995; FALUSI, CALAMASSI 1997). The thermal time model elaborated by CANNEL and SMITH (1983) is based on the influence of forcing temperatures above the base temperature. Forcing temperatures are accumulated after a starting date till the beginning of the corresponding phenophase (in this case BB). According to KRAMER (1994), for the species growing in the temperate zone, after a cold period a period of forcing temperatures is necessary to start the bud-burst process. RÖTZER et al. (2004) described the model that calculated the timings of the beech leafing on the basis of the daily maximum temperature. Ac-

Table 2. The values of temperature sums ($^{\circ}\text{C}$) with various base temperatures from 1995 to 2004 (CV– coefficient of variation)

	Years										Mean	CV (%)
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004		
TS 0	304	192	219	315	208	239	314	338	208	312	265	21.3
TS 5	148	115	121	250	120	185	248	218	141	202	175	30.2
TS 8	94	98	77	99	105	102	110	104	104	130	102	12.9
TS 10	61	79	44	64	12	83	55	41	53	55	55	36.8

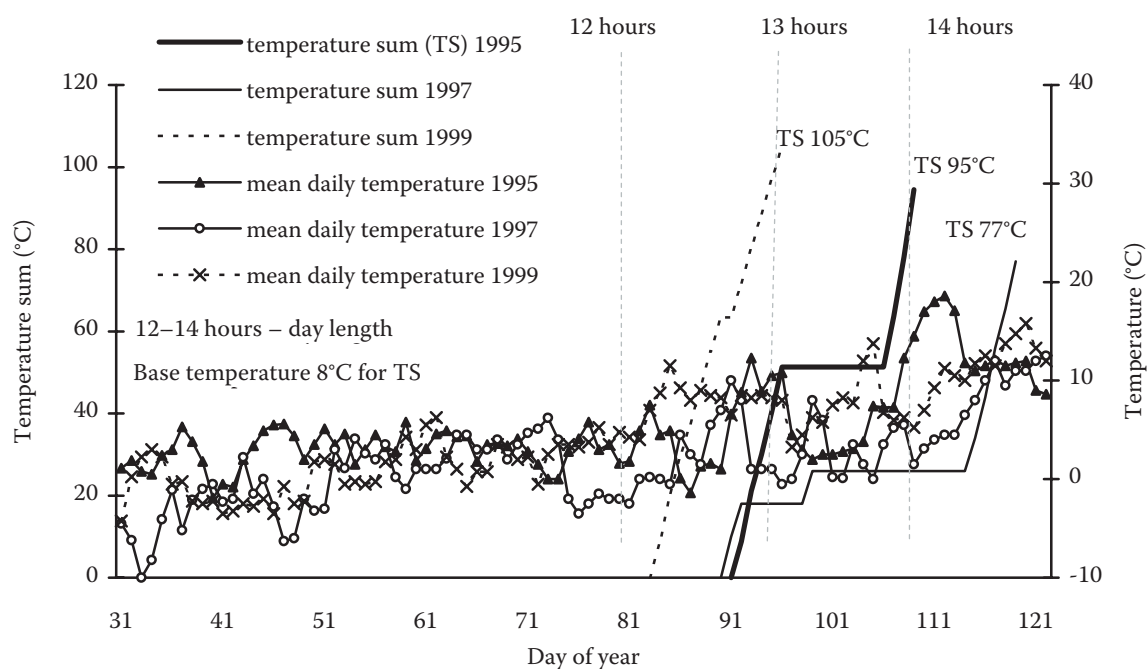


Fig. 6. The course of daily air temperatures and temperature sums in selected years

cording to ROLOFF (1987), the rest period for beech trees lasts approximately up to the second decade of February. Then the stage of quiescence follows when beech trees can sprout under favourable conditions. On the basis of this fact we calculated temperature sums from 1 February to the onset of BB. The threshold temperature value has not been unified (MURRAY et al. 1989; VONWUEHLISCH et al. 1995; WIELGOŁASKI 1999). We used the values of 0°C, 5°C, 8°C and 10°C for this purpose. Table 2 shows the values of temperature sums accumulated in the individual years. It is evident that the temperature sums differed between the years. The lowest variability was found out when TS 8 was applied (coefficient of variation 12.9%), in the other cases these values ranged from 21.3 to 36.8%. The course of average air temperatures and temperature sums with the base temperature of 8°C in selected years (1995 as a typical “normal” year, 1997 the latest date of bud-burst, 1999 the earliest date of bud-burst) is shown on Fig. 6. We suppose that this model of temperature summation would be appropriate for the analysis of beech phenology in our conditions.

CONCLUSION

The results of the analysis of spring phenological phases observed in the beech stand prove an interannual variability in the onset of phases as well as the influence of the parent stand structure on naturally

regenerated seedlings. The unequal onset of phenophases among the individuals of parent stand was also observed in relation to their sociological status. Using temperature summation with various base temperatures for the period from 1 February to the date of the bud-burst onset in 1995–2004, the lowest variability of temperature sum was found out by the application of the base temperature 8°C.

Because phenological observations provide useful information in the context of forest research, and also in connection with the influence of climate changes on forest ecosystems, it is necessary to monitor and analyse the phenological manifestations of forest tree species in relation to climate factors.

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Jarné fenofázy buka v submontánnej bučine s rozdielnym zakmenením v rokoch 1995–2004

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ABSTRAKT: V práci sa uvádzajú výsledky desaťročného pozorovania dvoch jarných fenofáz (rozpuknutie pupeňa a zalisťovanie) materského porastu ako aj prirodzeného zmladenia buka v podmienkach submontánnej bučiny s rôznou denzitou materského porastu. Výsledky poukázali na rozdielny nástup fenofáz u jedincov materského porastu v závislosti od ich sociologického postavenia v poraste ako aj na vplyv štruktúry materského porastu na fenológiu pučania a zalisťovania prirodzeného zmladenia. U úrovňových a nadúrovňových jedincov bolo zistené opozdenie fenofáz v priemere o 2–5 dní v porovnaní s podúrovňovými jedincami. Začiatok a priebeh fenofáz sa odlišoval medzi jedincami prirodzeného zmladenia v priemere o 2 až 20 dní v závislosti od štruktúry materského porastu, pod ktorým rástli. Takisto bola zistená aj medziročná variabilita v nástupe a priebehu fenofáz. Trend priemerného zalisťovania jedincov materského porastu v rokoch 1995–2004 poukazuje na posun ku skorším termínom asi o tri dni. Použitím sumačnej metódy priemerných denných teplôt s rozdielnou hodnotou prahovej teploty pre obdobie od začiatku februára do nástupu rozpuknutia pupeňa sme zistili, že najnižšia variabilita bola zistená v prípade teplotnej sumy s prahovou teplotou 8 °C.

Kľúčové slová: *Fagus sylvatica*; fenológia; rozpuknutie pupeňa; zalisťovanie; teplotná suma

V súčasnom období sa opäť začína venovať väčšia pozornosť štúdiu fenologických prejavov lesných drevín. Tento trend nepochybne súvisí aj s avizovanými klimatickými zmenami, ktoré začínajú ovplyvňovať aj lesné ekosystémy. Pri výbere vhodných „indikačných“ fenologických fáz pre dlhodobý monitoring v nadväznosti na spomenuté zmeny je dôležité, aby sa tieto dali ľahko a spoľahlivo identifikovať. Rozpuknutie pupeňa a zalisťovanie u buka predstavujú vhodné fenofázy pre spomenutý cieľ.

V práci sa uvádzajú výsledky desaťročného pozorovania dvoch jarných fenofáz (rozpuknutie pupeňa a zalisťovanie) materského porastu ako aj prirodzeného zmladenia buka v podmienkach rôznej denzity materského porastu. Výskum bol realizovaný na BEES v Kremnických vrchoch v submontánnej bučine. V rámci materského porastu bol vybraný súbor 80 jedincov rôzneho sociologického postavenia. Prirodzené zmladenie bolo tvorené súborom 100 jedincov na štyroch plochách s rôznou denzitou materského porastu. Fenologické pozorovania boli doplnené aj klimatickými meraniami teploty vzduchu.

Z výsledkov vyplynulo, že nástup a priebeh fenofáz u jedincov materského porastu bol rozdielny

v závislosti od ich sociologického postavenia. Najskorší priemerný nástup fenofáz bol pozorovaný u podúrovňových jedincov. U jedincov prirodzeného zmladenia nástup a priebeh fenofáz varíroval v závislosti od štruktúry materského porastu, pod ktorým rástli. Najskoršie rašili a zalisťovali jedince pod materským porastom s najvyššou denzitou, kým jedince rastúce na ploche bez materského porastu (na pôvodnej holine) výrazne zaostávali v nástupe uvedených fenofáz. Trend v nástupe priemerného zalisťovania materského porastu v období rokov 1995–2004 poukázal na posun ku skoršiemu termínu približne o tri dni. Sumačnou metódou priemerných denných teplôt s rozdielnou hodnotou prahovej teploty pre obdobie od začiatku februára do nástupu rozpuknutia pupeňa sme zistili, že najnižšia variabilita v desaťročnom období bola v prípade teplotnej sumy s prahovou teplotou 8 °C.

Na záver možno konštatovať, že aj naďalej bude potrebný systematický a dlhodobý fenologický monitoring lesných drevín, ktorého výsledky pomôžu pri objektívnom zhodnotení reálneho stavu lesných porastov ako aj ich ďalšieho managementu v súvislosti s očakávanými globálnymi zmenami klímy.

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