Results of monitoring the vegetative phenological phases of European beech (*Fagus sylvatica* L.) in 1991–2006

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Abstract

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There are presented results of a sixteen-year study of vegetative phenological phases in European beech (*Fagus sylvatica L.)* in the area of the Drahanská vrchovina Upland. The results of the monitoring show different starts and durations of phenological phases in individual years. A large range was noted in spring phenological phases. The start and duration of autumnal phenological phases has more regular character. The annual variability in the start and course of phenological phases in beech shows that in addition to genetic factors, also external conditions, particularly meteorological factors, participate in their start and duration. Relationships between the start of phenological phases and changing meteorological parameters are expressed with the sum of effective air temperatures higher than 5 °C. Also growth phases were evaluated in relation to vegetative phenological phases. On the basis of the results obtained it is evident that in recent years, the growth of the sum of effective air temperatures occurs, particularly in the autumnal season with extension of the growing season, which can result in the disturbance of physiological functions causing, in such a way, forest decline. Results of phenological monitoring can contribute to explain effects of climatic changes on the stability of forest stands.

Keywords

phenological phases, beech, air temperature, vegetative period, climate change

Introduction

In our country, forest phenology has a long tradition, but recently, in relation to expected changes in climate, its importance steadily increases. Long-term phenological studies can serve as the bioindicator of climatic changes. Phenology, as the integral part of climatology, encourages attention of climatologists but also botanists, zoologists, ecologists, foresters and farmers, both in our country and abroad.

Phenology is not a descriptive science anylonger, it also studies interrelationships between the development of climate and the start and duration of phenological phases in cultivated and natural species. Although the start and duration of individual phases are conditioned genetically, individual phases can shift also due to weather and disturb further development of the plants. Based on the results of phenological monitoring, climatic regions can be classified according to the average length of growing season corresponding to ecological properties of the tree species (Hofman, 1957; Luknárová, 2000). The start of phenological phases in the first half of the year is primarily controlled by the sum of so-called effective temperatures (exceeding certain temperature limits) preceding the phase. Phenological data within the second half of the year can be affected by all environmental conditions retarding or accelerating the process of maturation and ageing. Temperatures affecting the synthetic activity of plants is of the highest importance again. Other factors include reserves of nutrients, water, and especially effects of diurnal photoperiod (Larcher, 1988). Temperature requirements of plant species for the start of individual phenological phases are best expressed by the sum of effective temperatures (Havlíček, 1986). With respect to potential climatic changes, it is necessary to obtain further detailed information on growth processes in forest tree species, both present currently and those that were autochthonous for the given site. It is also necessary to monitor the stand´s microclimate with its contribution to explaining eco-physiological factors (Bagar et al., 2001). Expected climatic changes and related negative factors can affect the start and course of basic manifestations of life, particularly of forest ecosystems (Kramer, 1996).

Material and methods

Since 1991, phenological monitoring of European beech (*Fagus sylvatica* L.) is carried out in the immediate vicinity of the research site of the Institute of Forest Ecology, the Mendel University of Agriculture and Forestry in Brno. The area is situated in the geographical unit Drahanská vrchovina Upland, on a NE to E oriented slope of a watershed ridge, at an altitude of 625 m, below a short ridgy eluvium. The area has coordinates 16°41'30" E and 49°26'31" N. The climate is classified as slightly warm and slightly humid, with the long-term mean of annual temperatures 6.6 °C, and 683 mm annual precipitation (Collective, 1992).

For the purpose of phenological monitoring, there was used modified methodology developed by the Český hydrometeorologický ústav [Czech Hydrometeorological Institute – CHMI] (1987). Over the 16 years period of the study period, phenological phases were monitored in 10 beech sample trees of the same provenance. During the spring season, phenological monitoring was carried out 3 times a week. In the summer and autumnal season, phenological monitoring was carried out once a week. Basic meteorological parameters were measured directly in the area of the research plot and in the open area at a distance of 250 m. During the recent three years, also diameter increments of beech stems were measured with an automatic dendrometer (DR 22 of EMS Brno Co.) and tape dendrometers. There have been evaluated the following phenological phases: 0 – start of vegetation (buds in winter condition), 1–10% budbreak, 2 – beginning of foliage formation 10%, 3 – beginning of foliage formation 50%, 4 – beginning of foliage formation 100%, 5 – fully developed leaf area, 6 – 10% leaf colouring, 7–100% leaf colouring, 8–10% leaf fall, 9–100% leaf fall. The start of phenological phases was defined as the day when 50%-monitored trees had reached the given phase. For further processing, the ordinal number of this day in calendar was assigned to the individual phenological phases. The day when the mean daily air temperature exceeded 5 °C (Havlíček, 1986) in three subsequent days was determined as the beginning of the growing season. For the whole period of monitoring, there have been calculated cumulative sums of effective temperatures related to the individual phenological phases.

Results and discussion

The beginning and duration of phenological phases in beech differed considerably between the years. Together with genetic factors, air temperature and soil temperature are critical for the start of spring phenological phases (Bednářová and Kučera, 2002). Considerable variability between particular years at the beginning of phenological phases in beech (Fig. 1) becomes evident particularly in case of spring phenological phases, which also corresponds with the results of papers by Schieber (2006). Since a few years ago, the character of weather in the observed areas has been changed. Winter is longer and low temperatures in March are followed by a rapid onset of high temperatures already in the middle of April. This phenomenon leads to later budbreak and onset of leaf development. This phenomenon is evident in Fig. 1. On the other hand, higher temperatures and prolonged vegetative season with higher sums of effective temperatures are observed during autumn months. Fig. 2 characterizes the time course of spring phenological phases for the period 1991–2006. Results of monitoring the autumnal phenological phases are evident in Fig. 3. On the basis of data obtained, we can conclude that the average timing of 10% budbreak for the 16-year period was the 104th day from the beginning of the calendar year, at the sum of effective temperatures being 53.0 °C (Table 1 and Figs. 4 and 5). The earliest budbreak was found on the 84th day from the beginning of the year, at the minimum sum of effective temperatures 10.9 °C; and at the latest was on the 120th day with the sum of effective temperatures 135.6 °C. The beginning of 10% foliage was dated on average the 114th day from the beginning of the year with the mean sum of effective temperatures 80.1 °C. The shortest period from the beginning of year to the start of the phase was 106 days at the sum of temperatures 26.7 °C, and the longest period was 130 days connected with the sum of temperatures 173.0 °C. The beginning of 50% foliage occurred on average on the 118th day (105.8 °C), the shortest period for the beginning of the phase was 110 days (31.9 °C), the longest was 140 days (193.0 °C). The range of beginning of 100% foliage was the widest range from spring phenological phases over the whole period of monitoring (37 days). The phase occurred earliest on the 113th day (at the sum of temperatures 69.1 °C) and at latest on the 150th day (219.8 °C). On average, this phenological phase started on the 123rd day (138.8 °C). The start of this phase also controlled the next phenological phase, full foliage (fully developed leaf area), with an interval between maximum and minimum representing 36 days for the 16-year period. This phenological phase occurred earliest in 2000 when temperatures were the highest ones from within the whole evaluated period: at the beginning of May, already on the 127th day from the beginning of the year (330.8 °C); and the latest was the beginning of this period dated on the 163rd day (161.6 °C) in 1991. The average day of the beginning of this phase was obtained as the 138th day (246.0 °C) in the year.

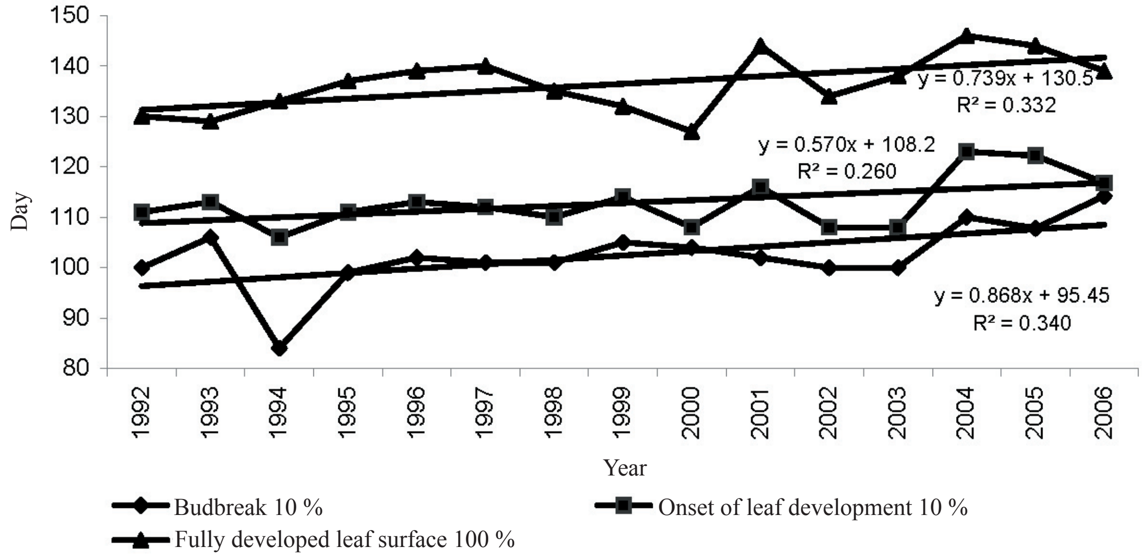

Fig. 1. The trend of onset spring phenological phases in the European beech in 1992–2006

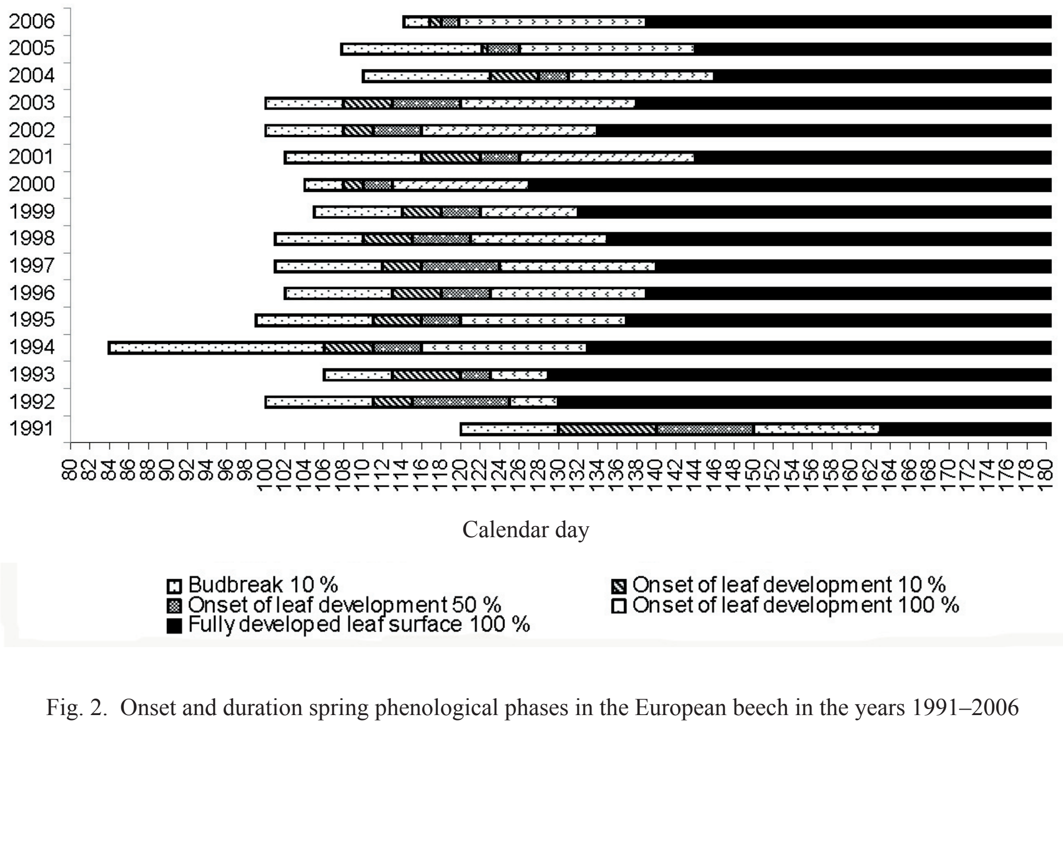

Fig. 2. Onset and duration spring phenological phases in the European beech in the years 1991–2006

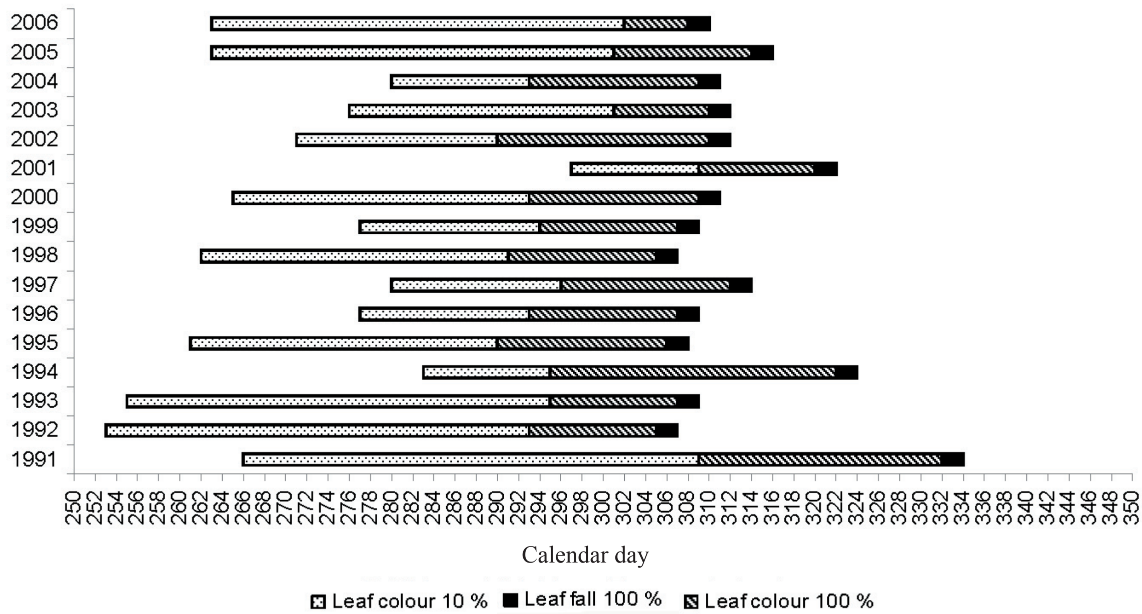

Fig. 3. Onset and duration autumnal phenological phases in the European beech in the years 1991–2006

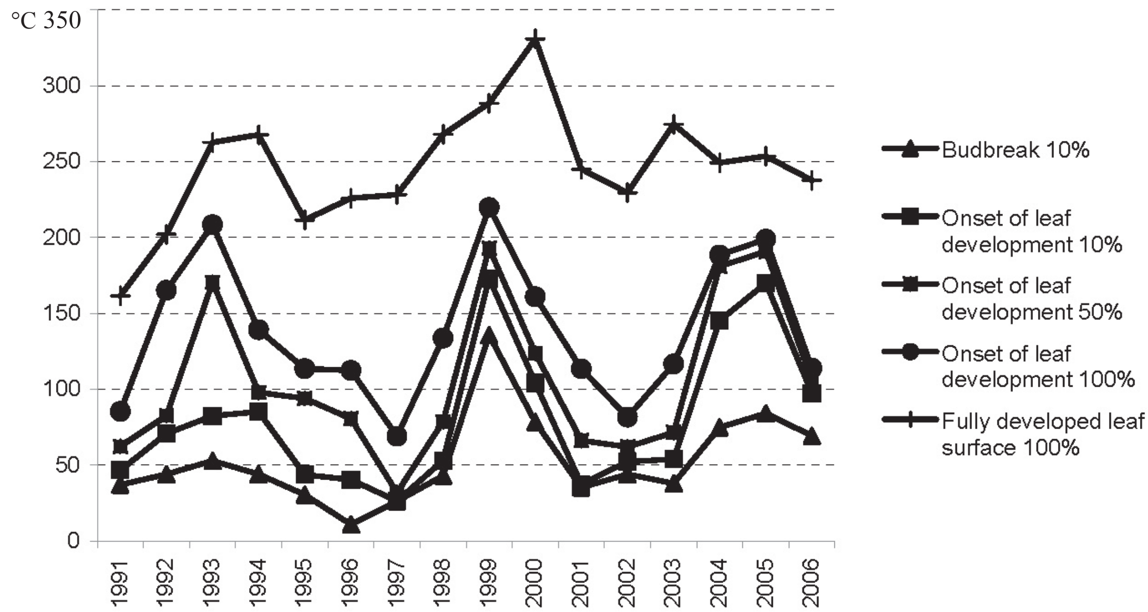

Fig. 4. Sums effective temperatures above 5 °C in the spring phenological phases in the European beech in the year 1991–2006

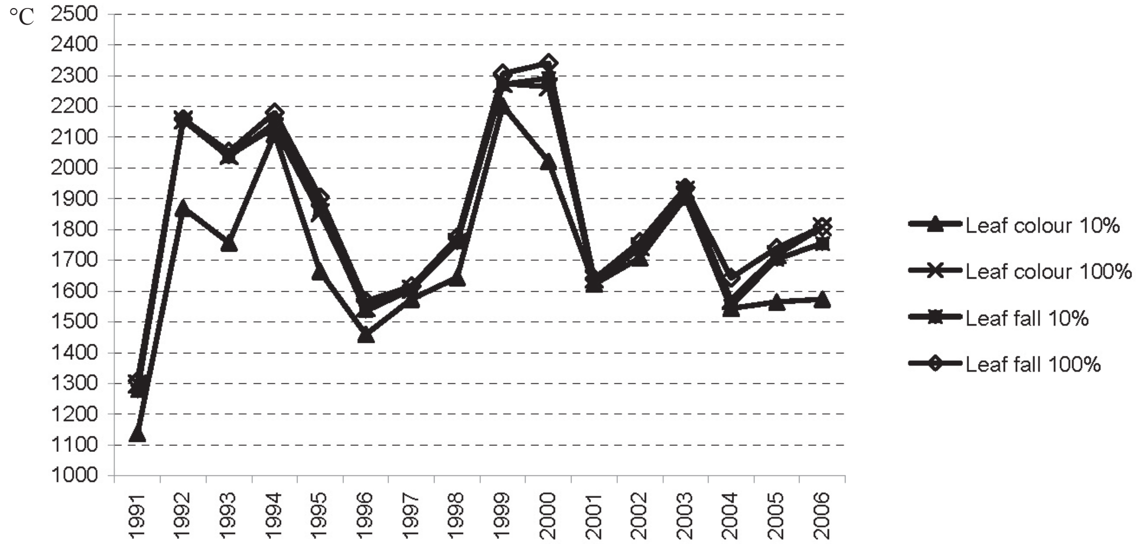

Fig. 5. Sums effective temperatures above 5 °C in the autumnal phenological phases in the European beech in the years 1991–2006

Table 1. Statistical characteristics of the onset of phenological phases and temperatures sums in European beech

Fagus sylvatica L.	Statistical characteristics									
1991–2006	Day of the years					Temperatures sums above 5 °C				
Phenophases	$\overline{x}$	sx	R	min	max	$\overline{x}$	sx	R	min	max
Budbreak 10 %	104	7.8	36	84	120	53.0	29.8	124.7	10.9	135.6
Onset of leaf development 10%	114	6.5	24	106	130	80.1	46.8	146.6	26.4	173.0
Onset of leaf development 50%	118	7.5	30	110	140	105.8	51.1	161.1	31.9	193.0
Onset of leaf development 100%	124	8.3	37	113	150	138.8	46.7	150.6	69.1	219.8
Fully developed leaf area 100%	138	8.6	36	127	163	246.0	38.7	169.2	161.6	330.8
Leaf colouring 10%	271	11.6	44	253	297	1709.8	265.3	1064.7	1137.4	2202.1
Leaf colouring 100%	297	6.1	19	290	309	1833.6	280.4	975.6	1298.4	2274.0
Leaf fall 10%	293	6.2	22	281	303	1827.7	290.3	1015.1	1276.3	2291.4
Leaf fall 100%	311	7.4	27	305	332	1858.4	288.3	1032.4	1308.1	2340.5

$\overline{x}$ – arithmetic mean, sx – standard deviation, R – variance range, min – minimal values, max – maxima

The character of winter termination and the start of spring warming dominantly determine the beginning and course of spring phenological phases. The character of weather in the spring season can be very variable in case when a warm period follows a very cold period and late budbreak occurs (Kurpelová, 1980; Larcher, 1988; Ditmar and Elling, 2006). The presented paper also comes to the same conclusions (see Figs. 6, 7).

Autumnal phenological phases mean the termination of the leaves´ photosynthetic activity. The interval of start and duration of these phases is very wide. The yellowing of leaves is a process taking several days, which is also mentioned by Chalupa (1969). At the locality studied by our team, the earliest 10% leaf yellowing (the start of autumnal yellowing) occurred on the 253rd day (1,137.4 °C) and at the latest on the 297th day (2,200 °C). The range for this phase was 44 days. On average, the start of the phase of the beginning of autumnal leaf yellowing occurred on the 271st day (1,709.8 °C). The interval of the phenological phase of 100% leaf yellowing was the shortest from all evaluated phenological phases, 19 days only. The phase started earliest on the 290th day from the beginning of the year (1,298.4 °C) and latest on the 309th day (the sum of effective temperatures 2.274.0 °C). On average, this phase started on the 297th day (1,833.6 °C). The phenological phase of 10% leaf fall started on average on the 293rd day (1,827.7 °C), also with a small range (22 days).

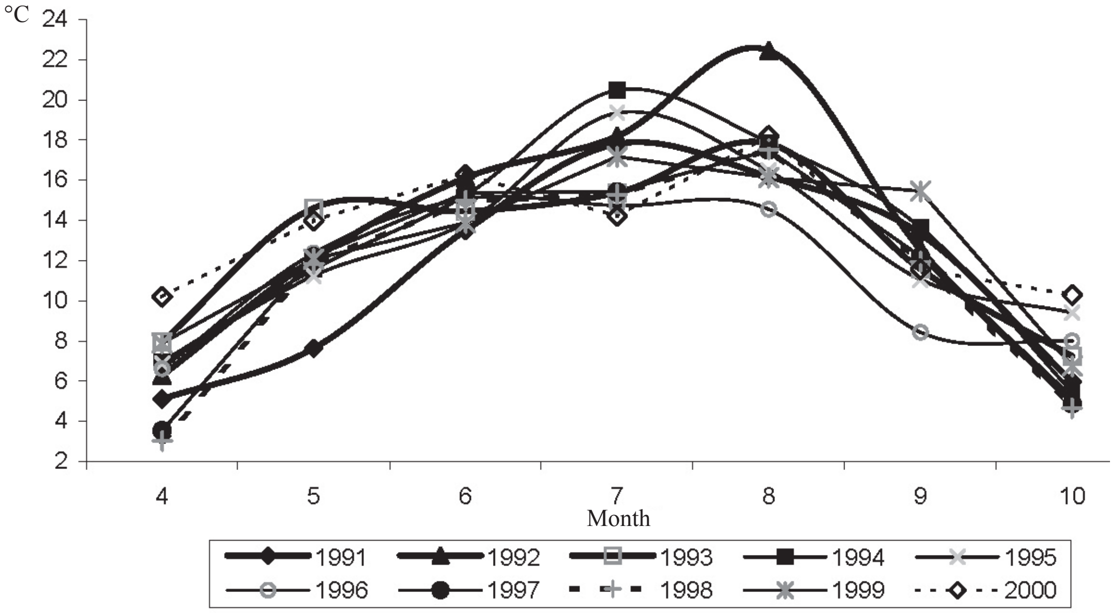

Fig. 6. Mean monthly temperature in the growing period in the years 1991–2000

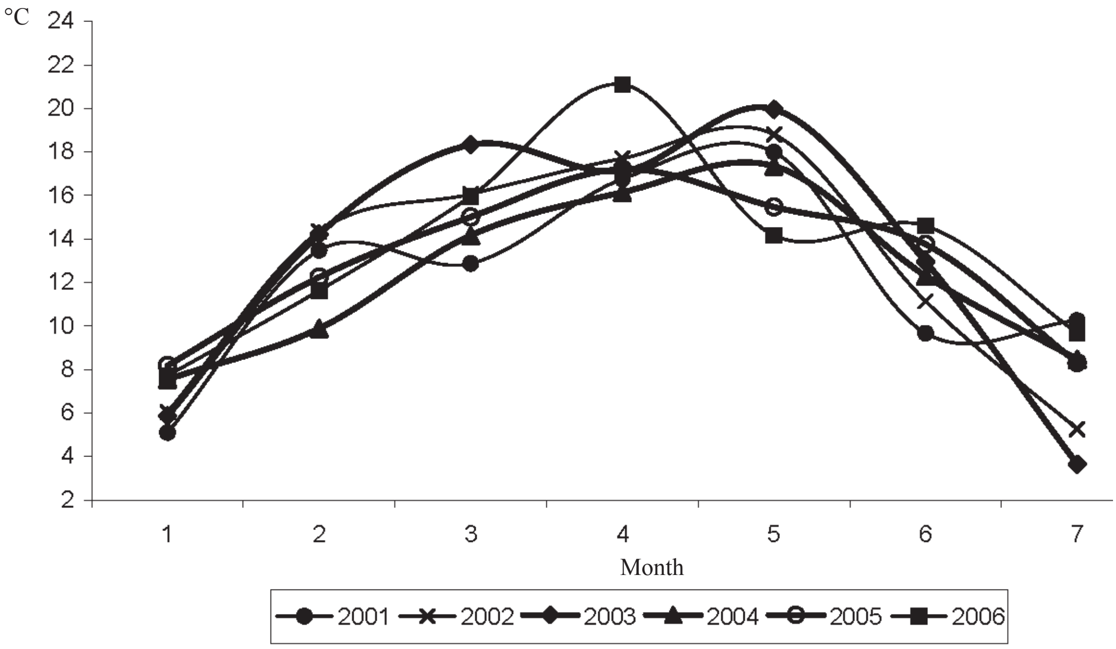

Fig. 7. Mean monthly temperature in the growing period in the years 2001–2006

The earliest beginning of leaf fall was observed on the 281st day (1,276.0 °C) and the latest on the 303rd day (2,291.4 °C). The stage of 100% leaf fall occurred in the studied area on average on the 311th day from the beginning of the year (the mean sum of temperatures was 1,858.4 °C). This finding corresponds also with the data provided by other authors. Chalupa (1969) mentions that in years when minimum temperatures do not fall below the freezing point and soil moisture is sufficient, considerable part of leaves maintain on trees until the first decade of November. In some years, smaller part of leaves remains on trees even until December. In the beech stand evaluated in this paper, the fall of leaves was noted as the latest on the 28th of November, which corresponded to the 332nd day, with the sum of temperatures 2,340.5 °C. The 100% fall of leaves occurred earliest on the 305th day (1,308.1 °C). A number of authors link the start of autumnal phenological phases with the previous rapid decline in temperatures and with a period of abundant precipitation (Haspelová-Horvátovičová, 1981; Priwitzer and Minďáš, 1998). These facts have also been confirmed for the locality monitored by our team.

The first diameter increment in beech stems occurred since the 130th day of the year. This date corresponded to the period between the start of 100% foliage and the phase of totally unfolded leaf area. An increment maximum was noted as late as the 208th day of the calendar year. The second phase of increment creation in beech occurred towards the beginning of August. The process ended after the 260th day, in the period corresponding to the phenological phase of 10% leaf yellowing. The obtained results show that in recent years, an increase in effective air temperatures occurred especially in the autumn season. This phenomenon can result in the extension of the growing season – and entail possible disturbances in physiological functions of the studied species. From the point of view of forestry, the length of a period when forest trees can produce new photosynthates is of considerable importance. However, the marked extension of the growing season due to the warming can induce reduction of the period of rest and winter dormancy. Premature yellowing (termination of assimilation) and possible disturbance of the endogenous dormancy of forest woody plants due to unfavourable climatic conditions could cause the reduction of vitality of trees. Expected climatic changes may cause impairment of growth conditions for forest woody plants and disturb their natural stability.

Conclusions

In the area of the Drahanská vrchovina Upland, spring and autumnal phenological characteristics in European beech (*Fagus sylvatica* L.) were monitored and evaluated from 1991 to 2006. There were considerable differences in start and duration of phenological phases between the individual years. In the phase of budbreak, the timing varied in an interval of 36 days, reflecting the dependence of spring phenological phases on air and soil temperatures. The sum of effective air temperatures preceding this phase can be considered to be crucial for timing the budbreak start. The lowest temperature for the phase start was 10.9 °C, the highest was 135.6 °C. A large variability over the 16-year monitoring was also found for the phase of 100% foliage (fully developed leaf area). Sums of effective temperatures related to this phase ranged from 161.6 to 330.8 °C. The autumnal phenological phase of 10% leaf yellowing had the widest variation range, with the start dated from the 253rd to the 297th day in the year and the interval of the sum of effective temperatures 1,137.4 °C to 2,200 °C. Other autumnal phenological phases appeared to be more balanced. The interval for the 100% fall of leaves was 27 days, with sums of temperatures from 1,308 to 2,341 °C. The start and duration of autumnal phenological phases is influenced not only by air temperatures before the beginning of the phase, but also by precipitation in the locality. The first increment of wood in beech was created in the period when the leaf area of the trees was nearly fully unfolded. The termination of wood increment was noted immediately after the phenological phase of 10% autumnal leaf yellowing. The study of the wood increment by means of the diameter increment measurements in relation to phenological phase can contribute to understanding eco-physiological properties of tree species and possibilities of their adaptability to potential changes in climatic conditions. The sum of effective temperatures at the start of autumnal phenological phases until the end of the growing season shows an increasing tendency in recent years, resulting from the gradual warming and thus prolongation of the growing season. This fact can affect physiological functions of trees. The long-term disturbances of physiological functions and prologation of the growing season after the start of the phenological phase of leaf yellowing can be a cause of forest decline.

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Výsledky sledování vegetativních fenologických fází u buku lesního (*Fagus sylvatica* L.) v letech 1991–2006

Souhrn

Lesnická fenologie má v našich zemích již dlouholetou tradici, ale v poslední době s očekávanými klimatickými změnami klimatu nabývá stále více na významu. Dlouhodobá fenologická sledování mohou posloužit jako bioindikátor klimatických změn. I když je počátek jednotlivých fenologických fází podmíněn genetickými vlastnostmi, vlivem počasí se mohou jednotlivé fenofáze posunout a tak narušit další vývoj rostlin. Z výsledků předkládané práce je patrno, že počátek a trvání jednotlivých fenofází se ve sledovaných letech velmi odlišoval. V práci jsou uváděny výsledky šestnáctiletého pozorování jarních a podzimních fenologických fází v období 1991 až 2006 u buku lesního (*Fagus sylvatica* L.). Výzkum byl realizovaný na výzkumné ploše ÚEL, LDF MZLU v Brně v oblasti Drahanská vrchovina. Sledované vzorníky buku lesního se nachází v nadmořské výšce 625 m. Klimaticky je tato oblast řazena jako mírně teplá a mírně vlhká s dlouhodobým průměrem roční teploty 6,6 °C a 683 mm ročních srážek. Za rozhodující charakteristiku při hodnocení počátku jarních fenologických fází lze považovat sumu efektivních teplot, která těmto fázím předchází. Jako efektivní teploty byly sumační metodou hodnoceny, ve vztahu k jednotlivým fenologickým fázím, teploty s prahovou hodnotou 5 °C. Počátek

a trvání vegetativních fenofází je ovlivněn nejen teplotou vzduchu, půdy ale i srážkovými poměry sledované lokality. Tento vliv se projevuje především u podzimních fenofází. V návaznosti na fenologické fáze byl sledován i nárůst dřevní hmoty pomocí měření tloušťkového přírůstu kmene. Zkoumaný vztah může rovněž přispět k objasnění ekofyziologických vlastností lesních dřevin v možnosti jejich adaptability k eventuálním měnícím se klimatickým podmínkám. K prvnímu přírůstu dřevní hmoty docházelo u buku lesního až ve fázi, kdy byla téměř zcela rozvinutá listová plocha. Ukončení dřevního přírůstu bylo zaznamenáno bezprostředně po podzimní fenofázi počátek žloutnutí listí. Suma efektivních teplot od nástupu podzimních fenofází do konce vegetačního období má v posledních letech zvyšující se charakter, což vyplývá z postupného oteplování ve sledované oblasti a tím prodlužování vegetační doby. Dlouhodobé narušování fyziologických funkcí a prodlužování vegetačního období po nástupu fenofáze – žloutnutí listí – může být příčinou chřadnutí lesů, zvláště pak u nepůvodních dřevin.

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