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THE ONSET AND DURATION OF VEGETATIVE PHENOLOGICAL STAGES IN EUROPEAN BEECH (*Fagus sylvatica* L.) UNDER CHANGING CONDITIONS OF THE ENVIRONMENT

E. Bednářová, J. Kučera, L. Merklová

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Abstract

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A phenological study on the onset and duration of particular phenological stages of European beech (*Fagus sylvatica* L.) was carried out using sample trees growing in a research area of the Faculty of Forestry and Wood Technology, MENDELU Brno for a period of 17 years (1991–2007). The paper describes the onset and duration of particular phenological stages depending on effective temperatures. In spring phenological stages, the high dependence was proved on air temperatures. To evaluate temperature requirements of studied species the cumulative sum of temperatures which activated the beginning of a respective phenological stage was used. It is evident that the onset and the course of particular phenological stages were very variable being subject to the effect of temperature changes, particularly in the spring season. In recent years, the earlier onset is noted of spring phenological stages and the length of their duration shortens. Effects of temperature on the onset and duration of the stage of budbreak and the beginning of foliage became evident in European beech most markedly. 2007 was a very extreme year from the aspect of the early onset of spring vegetative phenological stages. In that year, a marked shift was noted in the onset of particular staged as compared to previous years. To specify phenological observations, records of phenological data of a camera placed in the central part of a crown were used. Results obtained show that some spring phenological stages take only several hours, which corresponds with higher temperatures during spring months in last years. In the area described, higher temperatures were measured even in autumnal months as compared with a long-term average. Owing to high temperatures in the pre-dormancy period, the extension of a growing season occurs and thus also shortening the dormancy playing an irreplaceable role in forest trees. Shortening the dormancy can result in the disturbance of physiological processes and subsequently the decline of trees.

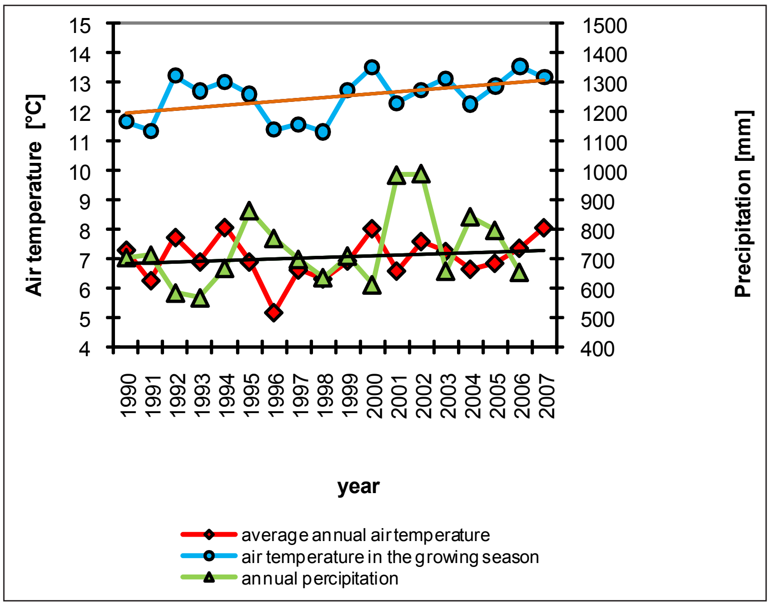
phenological stages, climatic changes, weather, temperature sum, vegetative period, European beech, forest tree species

A period of the onset and duration of phenological stages of forest trees is to a great extent dependent, except genetic factors, on outside conditions, particularly on meteorological factors. The beginning of flushing, leaf unfolding, bud developing and flowering is usually possible when the air and soil temperature exceeds a certain critical point characteristic of every life stage of the plant cycle (LARCHER, 1995; BEDNÁŘOVÁ, KUČERA, 2002). "Temperature sum" is the accumulated temperature above a certain threshold value from a certain starting date calculated by the progressive addition of mean daily temperatures. For the calculation of temperature sums, most commonly a threshold value is used, which defines the beginning of the thermal growing season, usually 5 °C. The temperature sum during the growing season is referred to as an effective temperature sum (LAPPALAINEN, 1994; DIEKMANN, 1996; BAGAR, NEKOVÁŘ, 2007). Phenological observations can characterize a climatic region with a mean length of the growing season taking into account ecological properties of forest trees (LUKNÁROVÁ, 2000). Depending on changes of weather under given climatic conditions we can evaluate also trends in changes of climate on the basis of monitored changes in phonological stages. Expected climatic changes and related negative factors can affect the course of basic life phenomena of plants, particularly of forest ecosystems (KRAMER, 2000; LUKNAROVÁ, 2002; ŠKVARENINOVÁ, 2005). With respect to possible climatic changes, it is necessary to obtain further more detailed information on growth processes of forest trees both existing and those, which were autochthonous on the given site. Thus, with respect to monitoring the microclimate and phenology of a stand to contribute to explain ecophysiological factors (BAGAR et al., 2001). The monitoring of phenological stages of cultivated and wild plants and their evaluation can provide the signalling of ingoing climatic changes. Due to warming, changes in the development of forest trees and herbs can also occur. Thus, plants can be considered as bioclimatic indicators and phenological observations can be used for assessing effects of potential climatic changes (KOCH et al., 2005; ŠKVARENINOVÁ et al., 2006). Conditions of the successful use of phenology in problems of the evaluation of climatic changes consist in long time series and possibilities to compare various localities and the knowledge of relationships between temperature and a similar change in a corresponding temperature series in the course of time KOCH et al., 2005).

MATERIAL AND METHODS

Monitoring the phenology of European beech (*Fagus sylvatica* L.) is carried out at this locality since 1991. To specify data obtained, the study was completed (in 2007) by data aimed at monitoring spring phenological stages using a camera system. The research area is situated on the NE to E slope of a watershed ridge at an altitude of 625 m, the Drahanská vrchovina Upland geographical unit. The research area is determined by coordinates 16° 41´ 30´´ E long. and 49° 26´31´´ N lat. Climatically, the area is characterized as slightly warm and slightly humid with a long-term annual temperature 6.6 °C and 683 mm annual precipitation (KOLEKTIV, 1992). The actual situation of the locality is characterized on a Fig. 1. Phenological observations were carried out according to adapted methods of the ČHMÚ (Czech Hydro-Meteorological Institute) (1987) in nine selected sample trees. During the spring season (March to June), phenological observations are carried out 3 times a week. In the summer and autumnal season, once a week. To a date of particular phenological stages, an ordinal number was assigned of a day from the beginning of a calendar year. To each of the phenological stages, sums of mean daily air temperatures were calculated at a threshold value of 0 °C and 5 °C (TS 0 °C, TS 5 °C) and sums of the soil temperature at a threshold value of 0 °C and 3 °C (TSp 0 °C and TSp 3 °C). In the monitored stand, sensors are installed to measure air temperature (Datalogger Minikin T) on the lower limit of the tree crown. The soil temperature at depth of 25 cm (Micrology SP), are another measured characteristic. Parameters of the environment are characterized using instruments of the Environmental Measuring System, Brno (EMS Brno).

Camera – a programmable photographic module used for the detailed monitoring of pheno-



1: *Average annual air temperature and total annual precipitation in 1990 to 2007* logical stages includes a modified digital camera BENQ E 310 and a controlled microprocessor unit. The camera was placed in the central part of the crown of sample trees of beech. The photography was carried out in 1-hour intervals between 9 and 18 hours. By means of the camera, the onset and course of phenological stages were documented from the stage of buds in winter until the fully developed leaf area when the leaf apparatus is quite photosynthetically active.

RESULTS AND DISCUSSION

The presented study of phenological stages in beech (*Fagus sylvatica* L.) shows a considerable variability in the onset and duration of phenological stages. To characterize phenological data for a period 16 years (tab. I)), following parameters were calculated: arithmetical mean, maximum and minimum values, variation range and standard deviation.

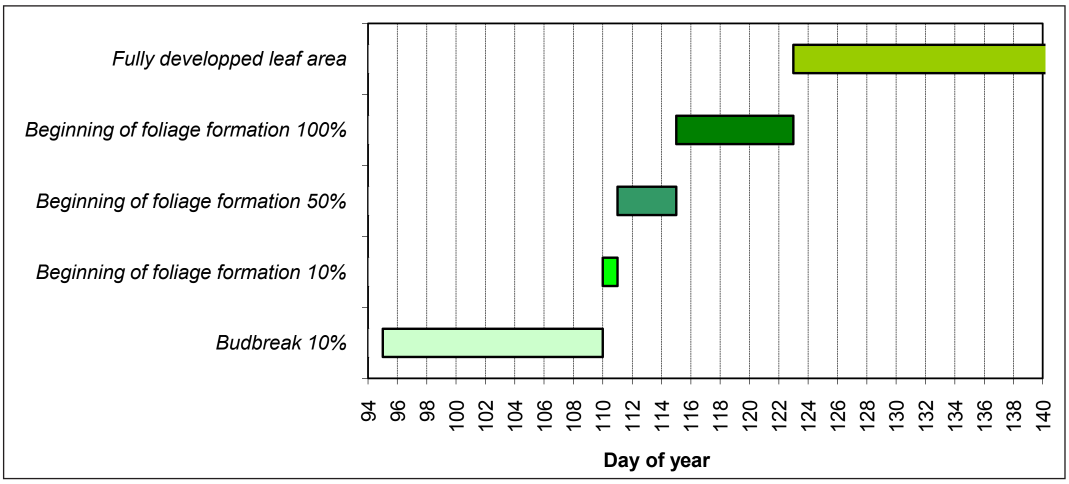
Variability in the onset and duration of phenological stages in beech becomes evident particularly in spring phenological stages, which also corresponds with results of studies of SCHIEBER (2006). Due to warming, the more frequent onset of flushing occurs and the period of duration of particular stages shortens. This finding has been also proved in the presented paper. In recent years, some phenological stages cannot be noted by mere monitoring because they take only several hours (Fig. 2).

In this year a very short period was found of the duration of particular phenological stages using the special camera monitoring, which is evident from the applied photographic documentation (Figs. 3–7). On the basis of previous results we can state that the mean time of flushing (10%) for the period 1991–2006 was the 104th day from the beginning of the year at the sum of effective air temperatures TS5 = 53.00 °C. In 2007, the onset of flushing occurred already the 95th day (Fig. 3). The beginning of flushing in this year was affected by the sum of air temperatures TS5 = 36.00 °C and TS0 = 259.00 °C. The sum of soil temperatures reached at this stage TSp0 = 317 °C and TSp 3 = 63.00 °C in 2007. The beginning of leaf unfolding (10%) was (in the 16-year period) on average the 114th at the duration of five days and the sum of air temperature TS 5 = 80.10 °C. In 2007, the onset of this stage was recorded the 110th day from

I: *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					Temperature sums above 5 °C				
Phenophases	$\bar{x}$	s_x	R	min	max	$\bar{x}$	s_x	R	min	max
Budbreak 10 %	103.5	7.7909	36	84	120	53.0	29.8	124.7	10.9	135.6
Onset of leaf development 10 %	113.87	6.4688	24	106	130	80.1	46.8	146.6	26.4	173.0
Onset of leaf development 50 %	118.36	7.4717	30	110	140	105.8	51.1	161.1	31.9	193.0
Onset of leaf development 100 %	123.49	8.3404	37	113	150	138.8	46.7	150.6	69.1	219.8
Fully developed leaf area 100 %	138.13	8.64	36	127	163	246.0	38.7	169.2	161.6	330.8
Leaf colouring 10 %	270.56	11.622	44	253	297	1709.8	265.3	1064.7	1137.4	2202.1
Leaf colouring 100 %	296.56	6.0988	19	290	309	1833.6	280.4	975.6	1298.4	2274.0
Leaf fall 10 %	292.69	6.1937	22	281	303	1827.7	290.3	1015.1	1276.3	2291.4
Leaf fall 100 %	311.44	7.3663	27	305	332	1858.4	288.3	1032.4	1308.1	2340.5

Note: $\bar{x}$ – arithmetic mean, s_x – standard deviation, R – variance range, min – minimal values, max – maximal values



2: *The time course of spring phenological stages of the European beeches in the year 2007* the beginning of the year (Fig. 4) at the sum of air temperatures TS5 = 103.00 °C and TS0 = 400.00 °C. The temperature of soil reached a sum of values TSp0 = 428.78 °C and TSp3 = 126.04 °C. According to photographs from the phenological camera, this phenological stage took only 18 hours. Another spring phenological stage, the beginning of leaf unfolding from 50%, was on average the 118th day (for the period 1991 to 2006) at the sum of effective air temperatures TS5 = 105.00 °C. In 2007, the beginning of leaf unfolding was recorded already the 111th day (Fig. 5) at the air temperature TS5 = 106.00 °C and TS0 = 407.86 °C. The determined sum of soil temperatures reached in this stage TSp0 = 428.78 °C and TSp3 = 126.04 °C. The phenological stage of the beginning of leaf unfolding from 100% occurred on average the 123rd day at the sum of air temperatures TS5 = 138.8 °C. In 2007, this stage occurred already the 115th day (Fig. 6) at the sum of air temperatures TS5 = 125.00 °C and TSO = 448.00 °C. The sum of soil temperatures at the beginning of this stage amounted to TSp = 458.80 °C and TSp3 = 144.06 °C. The phenological stage of full leaf unfolding in the previous season occurred the 138th day at the sum of effective temperatures TS5 = 246.00 °C. In 2007, this phenological stage was noted the 123rd day of the calendar year (Fig.7) at the sum of air temperatures TS5 = 175.00 °C and TS0 = 537.50 °C. Sums of soil temperatures reached TSp0 = 531.90 °C and TSp3 = 193.15 °C in this period. In 2007, the leaf area of beech reached its final size the 149th day. The onset and course of spring phenological stages is dominantly determined by the winter termination character and by the onset of spring warming. The character of weather in the spring season can show variable nature when a warm period changes with a very cold period and late flushing occurs (DITTMAR, ELLING; 2006).

Autumnal phenological stages are characterized by termination of the photosynthetic activity of a leaf area. The gradual yellowing of leaves is process taking more days. Based on results of many authors it is evident that the autumnal yellowing of leaves begins in our conditions at the beginning of September, the first leaf-fall occurs at the end of September until the beginning of October and the total fall of leaves occurs generally in November (ŠTEFANČIK, 1997). The onset and duration of autumnal phenological stages are conditioned not only by air and soil temperatures before the onset of a monitored stage but also by precipitation conditions of the monitored locality as mentioned by CHALUPA (1969). At the monitored locality, the beginning of leaf yellowing from 10% (for the period 1991 to 2006) occurred the 271st day at the sum of temperatures TS5 = 1709.80 °C. The beginning of this stage was characterized during the 16-year period by the highest variability of all phenological stages (Tab. I). In 2007, the onset of the stage of leaf yellowing (10%) was noted the 258th day at the sum of effective temperatures TS5 = 1608.00 °C and TS0 = 2639.00 °C. The phenological stage of leaf yellowing (100%) was characterized for the 16-year period by the very small range of only 19 days. It began on average the 297th day at the sum of temperatures TS5 = 1833.60 °C. In 2007, the 100% yellowing of leaves was noted the 289th day at the sum of effective temperatures TS5 = 1745.00 °C and TS0 = 2935.00 °C. The onset of leaf-fall (10%) occurred the 293rd day at the sum of effective temperatures TS5 = 1827.70 °C. In 2007, the onset of leaf-fall of beech occurred the 271st day at the sum of effective temperatures TS5 = 1678.00 °C. The total leaf-fall (100%) occurred (long-term average) the 311th day from the beginning of the calendar year at the sum of temperatures TS5 = 1858.40 °C. In 2007, this phenological stage occurred the 309th day at the sum of temperatures TS5 = 1762.00 °C.

Fig. 1 shows that from 1991 to 2007, gradual increasing the air temperature occurred throughout the year particularly in the growing season, which affected the earlier onset of spring phenological stages, shortening their duration and extending the growing season with higher temperatures in autumnal months. Worldwide studies on changes in the phenology of plants show a shift in the onset of phenological stages and the start of growth at medium and higher locations in an earlier spring season and at the same time, extending the growing season occurs (MENZEL, DOSE, 2004; KOCH, et al., 2005). This situation is also evident from the monitored onset and duration of phenological stages on the evaluated research plot in the region of the Drahanská vrchovina Upland for the period 2004 to 2007. In 2004, the beginning of flushing occurred the 110th day (TS5 = 75.00 °C), in 2005, this stage occurred the 107th day (TS5 = 72.00 °C), in 2006 the 110th day (TS5 = 30.00 °C) and in 2007 already the 95th day (TS5 = 36.00 °C). For flushing European beech, high dependence was found on air temperature in spring months (March, April) before the onset of the phenological stage for the period 2004 to 2007 with $R^2 = 0.923$, ($r = -0.8453$). In 2004, the beginning of leaf unfolding from 10% was noted the 123rd day (TS = 145.00 °C). In 2005, this stage began the 123rd day from the beginning of the year (TS5 = 144.00 °C), in 2006, the beginning of leaf unfolding was noted the 121st day (TS5 = 97.00 °C) and in 2007, already at the sum of effective temperatures TS5 = 103.00 °C.

Evaluation of the onset and duration of autumnal phenological stages for the period 2004 to 2007 shows that even in the region of the Drahanské vrchovina Upland, the onset of phenological stages occurs at the increasing sum of effective temperatures. In 2004, the beginning of leaf yellowing occurred the 280th day at the sum of temperatures TS5 = 1544.00 °C. In 2005, already the 266th day at the sum of temperatures TS5 = 1559.00 °C. In 2006, the onset of leaf yellowing was noted the 270th day being affected by the sum of air temperatures TS5 = 1608.00 °C and in 2007 already the 258th day at the sum of temperatures TS5 = 1608.00 °C. In 2004, the 100% leaf yellowing occurred at the sum of temperatures TS5 = 1570.00 °C, in 2005 at a value of 1712.00 °C. In 2006, the 100% yellowing of leaves occurred at the sum of effective temperatures TS5 = 1783.00 °C and in 2007, this stage occurred at the sum of temperatures TS5 = 1745.00 °C. Also the stage of 100% leaf yellowing was affected by the increasing sum of effective temperatures. In 2004, the stage of total leaf-fall (100%) occurred at the sum of temperatures TS5 = 1643.00 °C. In 2005, the sum of air temperatures at this stage amounted to TS5 = 1726.00 °C. In the following year (2006) in the stage of the 100% leaf-fall, the sum of air temperatures was TS5 = 1789.00 °C and in 2007, the total leaf-fall occurred at the sum of air temperatures 1762.00 °C. Monitoring the phenological stages and their evaluation can serve as the bioindicator of climatic changes. Results presented characterize the earlier onset of vegetation and shortening the length of duration of spring phenological stages, extending the growing season owing to higher temperatures and thus, shortening the period of dormancy. This situation can result in the negative health condition of forest stands.

Statistical characteristics – the dependence of the onset of phenological stages on the sum of effective temperatures in 2004–2007: statistical processing showed the highest variability in European beech in the phenological stage of full 100% foliage. On the contrary, the lowest variability was observed in the stage of 100% leaf yellowing. To evaluate the relations by means of the sums of effective temperatures above 5 °C the stage of budbreak was most important of all monitored stages. Phenological stages copy the course of weather in the particular years. The most marked effect of air temperature on the onset of phenological stages was recorded in 2007, when high temperatures in the winter and early spring season started the development of plants very early.

A close relationship between the onset of phenological stages and air temperature in a period before the onset of monitored stages is demonstrated by calculated negative correlation coefficient. The dependence of budbreak on air temperature became evident most markedly in European beech. In monitored tree species, correlation coefficient was statistically significant ($\alpha > 0.001$). Dependence between the onset of phenological stages and air temperatures where $R^2 = 0.923$ ($y = -4.097*x + 129.9$). Determined correlations correspond with the results of other authors. ŠKVARENINOVÁ (2003) evaluated the phenological observations of forest tree species of the Zvolen upland and mentioned the earlier onset of phenological stages by 9 days. SCHIEBER (2006) also stated that the trend of the average onset of leafing showed a shift to earlier dates by about three days. SPARKS and MENZEL (2002), SPARKS et al. (2006) reported a high correlation between air temperature in spring months (March, April) and phenological stages of foliage and flowering of plant species and always more frequent onset of phenological stages due to increasing temperatures.

3: *The onset of flushing (10%, 95th day)*

4: *The onset of leaf unfolding (10%, 110th day)*

5: *The onset of leaf unfolding (50%, 111th day)*

6: *The onset of leaf unfolding (100%, 115th day)*

7: *Fully developed leaf area (123th day)*

SUMMARY

Based on the results obtained it is evident that the course of phenological stages is very variable being subject to temperature changes, particularly in the spring season. In comparison with long-term monitoring, the more frequent onset of spring phenological stage occurs in recent years (2004–2007) due to higher temperatures in the studied region. The effect of higher temperatures became evident most markedly on the onset and duration of the stage of flushing and on the beginning of leaf unfolding. Statistical processing proved high dependence of the onset of spring phenological stages on the sum of effective temperatures. The year 2007 was a very extreme year from the aspect of the early onset of spring phenological stages. Flushing occurred very early (95th day from the beginning of the year) and a phenological stage of the beginning of leaf unfolding occurred (from 10%) during 18 hours, which is the shortest time within the whole 17-year period of monitoring. In 2007, the onset of this stage was recorded the 110th day from the beginning of the year. The beginning of leaf unfolding (from 50%) was recorded already the 111th day of year. Also other phenological stages in the spring season showed the shorter time of duration. It was possible to record this new situation by means of the camera monitoring of phenology. Also the phenological stage of the fully developed leaf area occurred in this year within the shortest time during the whole period of monitoring. Autumnal phenological stages are in last four years affected by higher air temperatures as against long-term monitoring. This situation can result in the enlargement of the growing season and thus the disturbance of phenological functions. From the point of view of forestry, the length of a period is considerably important when forest trees can create new photosynthates. Nevertheless, the marked extension of the growing season owing to warming can result in the consumption of assimilates and shortening the period of dormancy. Extension of the growing season within a long time period can result in disturbances of physiological processes and subsequently in the decline of trees, particularly of allochthonous species. Results of the long-term monitoring of forest trees can help in the evaluation of the condition of forest stands in connection with the expected global changes of climate.

SOUHRN

Začátek a trvání vegetativních fenologických fází u buku lesního (*Fagus sylvatica* L.) v měnících se podmínkách prostředí

Ze získaných výsledků je patrné, že nástup a průběh jednotlivých fenologických fází je velmi variabilní a podléhá vlivu teplotních změn, zvláště v jarním období. Oproti dlouhodobému sledování od roku 1991 dochází v posledních letech (2004 až 2007) k časnějšímu nástupu jarních fenologických fází a zkracování jejich trvání, následkem vyšších teplot ve sledované oblasti. Nejvýrazněji se projevil vliv vyšších teplot na začátek a trvání fáze rašení a počátek olisťování. Statistické zpracování prokázalo vysokou závislost nástupu jarních fenologických fází u buku lesního, na sumě efektivních teplot. Závislost je vyjádřena koeficientem determinance $R^2 = 0{,}923$ ($y = -4{,}097*x + 129{,}9$). Velmi extremním byl rok 2007. Rašení nastalo již 95. den od počátku kalendářního roku a fenologická fáze, počátek olisťování z 10 %, proběhla během 18 hodin, což je nejkratší doba za celé sedmnáctileté období sledování. I další fenologické fáze v jarním období měly kratší dobu trvání než v předcházejících letech. Tuto mimořádnou situaci se podařilo zaznamenat pomocí kamerového systému nainstalovaného v porostu, za účelem zpřesnění sledování fenologie. Rovněž fenofáze „zcela rozvinutá listová plocha“ nastala v roce 2007 za nejkratší dobu od počátku sledování. Oproti dlouhodobému pozorování byly podzimní fenologické fáze v posledních čtyřech letech ovlivněny vyššími teplotami vzdu-

chu. Tento stav může mít za následek prodlužování vegetačního období a následně narušování fyziologických funkcí. Z lesnického hlediska je velmi důležitá délka období, po kterou mohou lesní dřeviny vytvářet nové asimiláty. Výrazné prodlužování vegetační doby následkem oteplování však může mít za následek spotřebování vytvořených asimilátů, zkrácení odpočinkového období a zimního klidu. Prodlužování vegetačního období v dlouhém časovém úseku může vyvolávat u dřevin jejich chřadnutí. Výsledky dlouhodobého fenologického monitoringu lesních dřevin mohou pomoci při zhodnocení stavu lesních porostů v souvislosti s očekávanými klimatickými změnami.

buk lesní, lesní dřeviny, fenologické fáze, efektivní teploty, vegetace, klimatické změny, počasí

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Address

doc. Ing. Emilie Bednářová, CSc., Ústav ekologie lesa, Mendelova univerzita v Brně, Zemědělská 1, 613 00 Brno, Česká republika, e-mail: bednarov@mendelu.cz, Ing. Jiří Kučera, Turistická 5, 621 00 Brno, Česká republika, e-mail: kucera@emsbrno.cz, Ing. Lucie Merklová, Ph.D., Krajský úřad Středočeského kraje, odbor životního prostředí, Zborovská 11, Praha 5, Česká republika, e–mail: merklova@email.cz