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RESULTS OF A PHENOLOGICAL STUDY OF THE EUROPEAN LARCH (*LARIX DECIDUA* MILL.) GROWING IN A MIXED STAND

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Abstract

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This paper presents an evaluation of the onset and duration of phenological stages of the European larch (*Larix decidua* Mill.) growing in a mixed stand in Drahanská vrchovina highlands. It covers the period of 2007–2010 and refers to results obtained in the preceding study period of 1991–2006. In individual years of this study, beginnings and durations of individual phenological stages differed in dependence on climatic conditions. Temperature requirements of European larch regarding the onset of individual phenological stages were evaluated on the base of sums of air temperatures above 0° C and of effective air temperatures higher than +5° C. Obtained results indicate that the onset and duration of spring phenological stages are dependent on air and soil temperatures already in the early spring. As far as the European larch is concerned, the breaking of buds is dependent on temperatures of air and soil; the corresponding correlation coefficients were $R^2 = 0.\ 8684$ ($y = -3.788x + 97.165$) and $R^2 = 0.7627$ ($y = -6.667x + 101.88$), respectively. The obtained results indicate that recently the onset of spring phenological stages occurred earlier and earlier in the study area of Drahanská vrchovina highlands and that their course was also shorter and shorter. In spring months, higher temperatures influence the phenological stage of flushing at most while in the autumn individual phenological stages occur later and later so that the growing season is longer and longer. This finding was corroborated by results of long-term studies.

phenological stages, mixed stand, European larch, effective temperature, air temperature, soil temperature, growing season, weather

Phenological observations enable to reveal rules of the course of plant life manifestations and to explain their dependence on environmental conditions. They also provide very valuable data concerning the onset and duration of the growing season. The variability of the onset and duration of individual phenological stages is significantly influenced not only by genetic factors but also by environmental (above all climatic) conditions. Phenology of forest woody species can be used when evaluating effects of actual environmental conditions on the growth and development of plant associations. This enables to contribute to a widely discussed problem of possible climatic changes and their effects on the health condition and species composition of forest ecosystems (BEDNÁŘOVÁ, MERKLOVÁ, 2011 and 2012; ŠKVARENINOVÁ, 2009a and 2010; GÖMÖRY, 2010; MOŽNÝ, NEKOVÁŘ, 2007; BAGAR, NEKOVÁŘ, 2007). A good knowledge of mutual relationships existing between meteorological characteristics on the one hand and phenophases on the other enables to assess the effect of climatic changes on the establishment of forest stands (Škvareninová 2009b). World studies on changes in plant phenology indicate that, in medium and higher altitudes of the Northern Hemisphere, there is a shift in the onset of phenophases to earlier stages in the spring so that the growing season is also longer and longer, above all due its delayed end. These phenomena influence the duration of the dormancy period (HÁJKOVÁ *et al.*, 2010). Forest woody species, as long-aged plants, can be held for bioindicators of climatic changes. A successful application of phenology in studies on climatic changes is possible only thanks to long time series and monitoring of changes taking place in environmental temperatures (KOCH *et al.*, 2005).

MATERIAL AND METHODS

Phenological observations of European larch have been carried out on the research plot of the Institute of Forest Ecology, Mendel University in Brno, Czech Republic, within the period of 2007–2010. This research plot is situated on the north-eastern to eastern slopes of the watershed ridge at the altitude of 625 m. The area is characterized by coordinates 16° 41'30" E and 49° 26' 31" N in the geographical unit of the Drahanská vrchovina highlands. Climatically, the region is slightly warm and slightly humid with long-term averages of annual temperatures and annual precipitations of 6.6 °C and 683 mm, respectively. Precipitation and temperature characteristics of the locality in years 2006–2010 are presented in Fig. 1 and Fig. 2. The species composition of trees of a 32-year-old mixed forest stand is as follows: Norway spruce 60%, European beech 30%, and European larch 10%. Phenological observations were carried out according to the methodology of the Czech Hydrometeorological Institute (COUFAL *et al., 2004*). Observed were the following phenological stages: onset of flushing (10 %), development of 10% foliage, development of 50% of foliage, beginning of full (100%) development of foliage, full foliaage development (100% of unfolded leaf area), beginning of leaf yellowing (10% of needles), complete (100%) yellowing of needles, beginning of leaf dropping (10 %), and complete (100%) leaf dropping. The day ordinal number from the beginning of a calendar year was assigned to the date of particular phenological stages. Sums of average daily temperatures higher than 0 °C (TS0) a effective temperatures above 5 °C (TS5) were calculated for each phenophase. Sums of soil temperatures measured in corresponding phenophases were assessed at the level above 0 °C. In the studied forest stand, air temperatures were monitored by means of the Datalogger Minikin T sensor placed on the lower margin of crowns. The soil temperature was measured by the MicroLog SP sensor at the depth of 20 cm. For monitoring of precipitations, the Climatronics rain gauge and the datalogger MicroLog ER were installed in the open area.

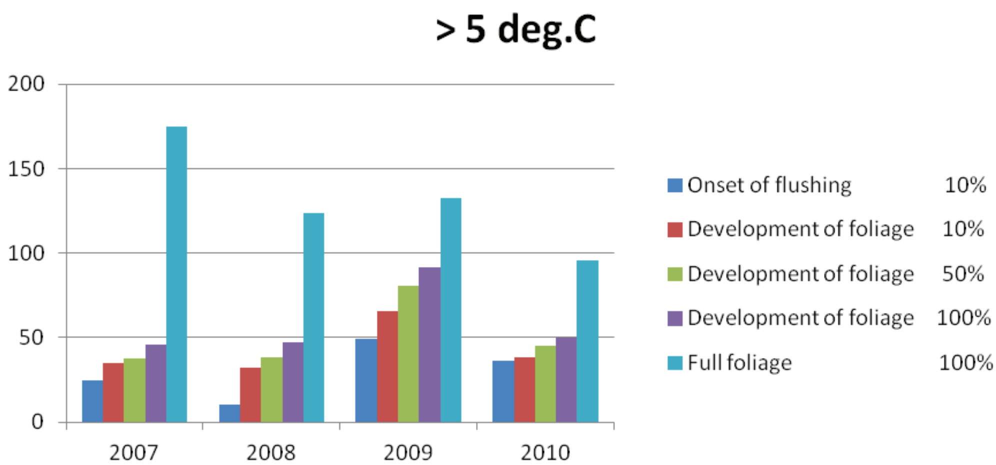
RESULT AND DISCUSSION

Response of phenological stages of the variability of weather

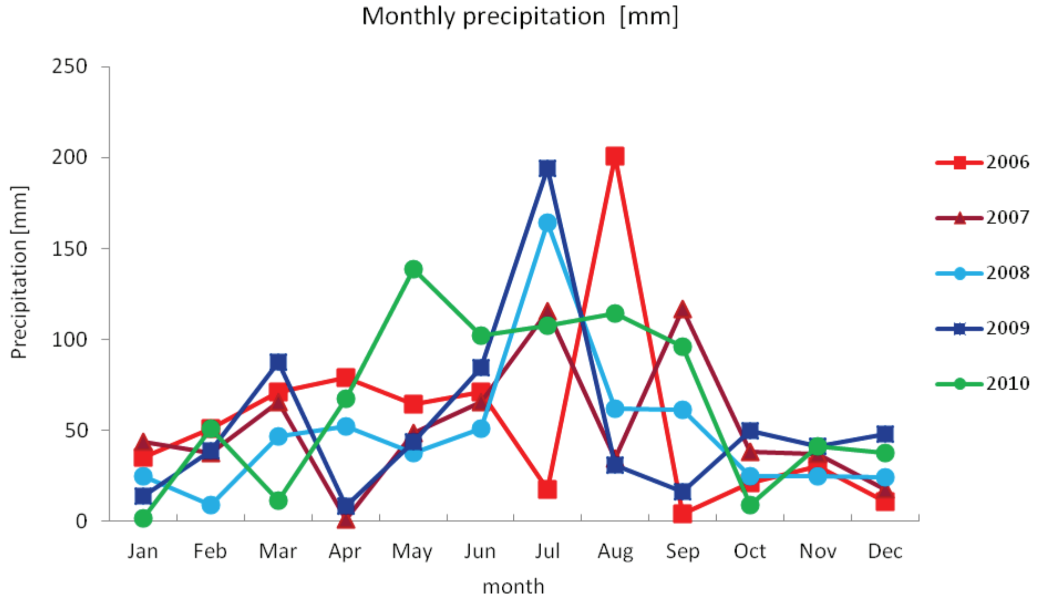
In individual years, onsets and durations of phenophases differed in dependence on climatic conditions. The onset of spring phenological stages was markedly influenced by air and soil temperatures. The time of their onset was dependent above all on the date when certain temperature limits were exceeded. The onset of spring phenophases was dependent above all on the moment of exceeding certain temperature limits.

The course of spring phenophases in European larch is presented in Fig. 3.

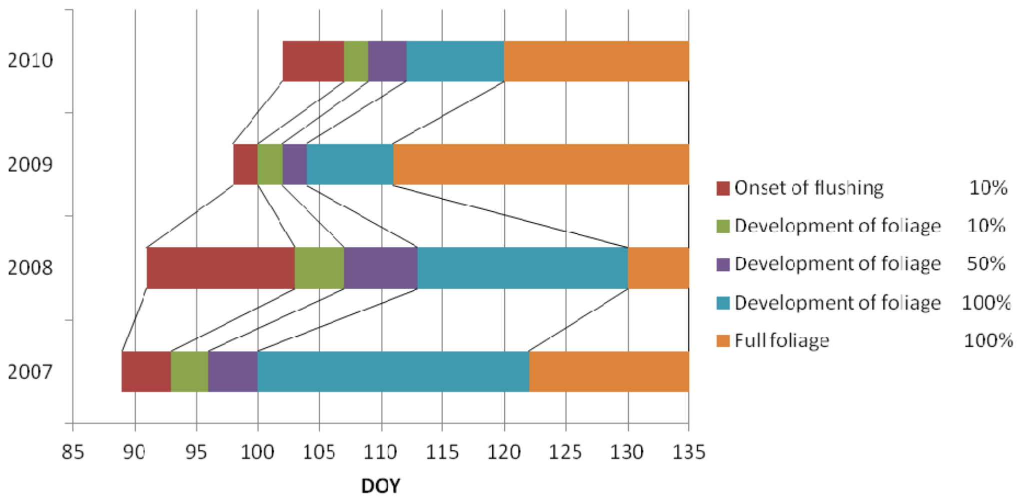
Within the study period of 2007–2010, the earliest onset of flushing (with 10 % of needles already formed) was observed already on the 89th day of the calendar year; as compared with a long-term average (1991–2006), this was by 11 days earlier (BEDNÁŘOVÁ, MERKLOVÁ, 2008). Within the period of 2007–2010, the beginning of foliage formation (with as much as 10 % of needles) was recorded in average already on the 101st day of the calendar year. In individual years, the onset of this phenophase ranged within the limits of 14 days. The phenophase "onset of foliage" (> 50 %) began on average on the 103rd day of the calendar year. The difference between the earliest and the latest



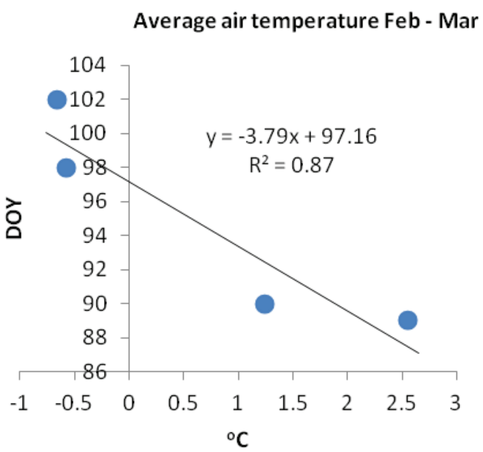
1: *Monthly averages of air temperature in the years 2007 to 2010*



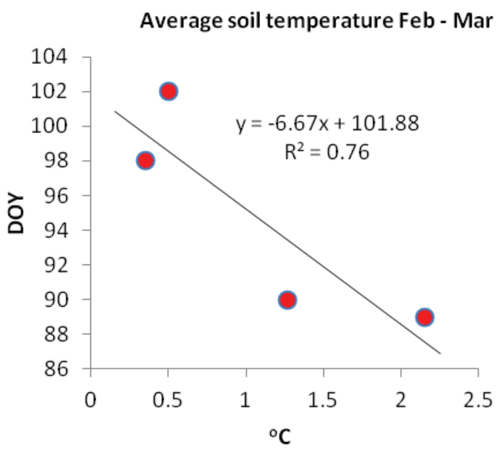
2: *Monthly totals of precipitation in the years 2006 to 2010*



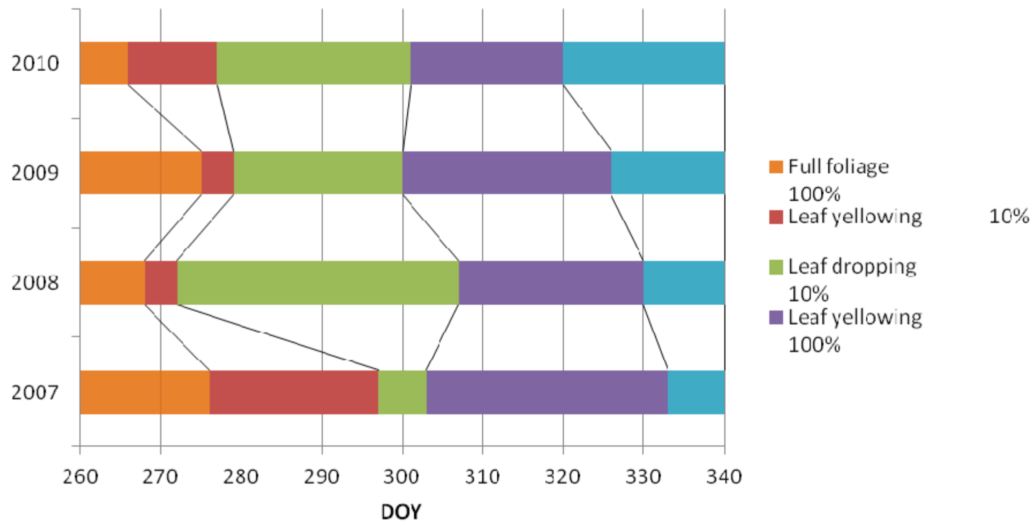
3: *Onset and duration of spring phenologicalstages of European larix*



4: *Onset of flushing as a funcion of average air temperature in February to March*



5: *Onset of flushing as a funcion of average soil temperature in February to March*



6: *Onset and duration of autumn phenologicalstages of European larix*

beginning of this phenophase was 13 days. The average beginning of a hundred-per-cent foliage formation was recorded on the 107th day of the calendar year 0n average, the stage of a complete development of the leaf area was recorded on the 120th day, i.e. 16 days earlier than on a long-term average (1991–2006). The phenophase of full foliage development was the most variable of all evaluated spring phenophases. Obtained results demonstrated that the onset and duration of spring phenophases were dependent above all on the end of winter and on air and soil temperatures existing already in the course of early spring. The dependence of the onset of flushing on air temperatures occurring during the period under study is illustrated in Fig. 4; it was also corroborated by the calculated coefficient $R^2 = 0.8684$ ($y = -3.788X + 97.165$).

The dependence of the beginning of spring phenophases (10 % of flushing) on soil temperatures is illustrated in Fig. 5 and its coefficient was $R^2 = 0.7624$ ($y = -6.667x + 101.88$).

These observations were similar as those published by other authors (SPARKS *et al.*, 2006; ŠKVARENINOVÁ, 2007; MERKLOVÁ, BEDNÁŘOVÁ, 2008; MIGLIAVACCA *et al.*, 2008; BEDNÁŘOVÁ, KUČERA, 2002).

The onset and duration of autumn phenophases are illustrated in Fig. 6.

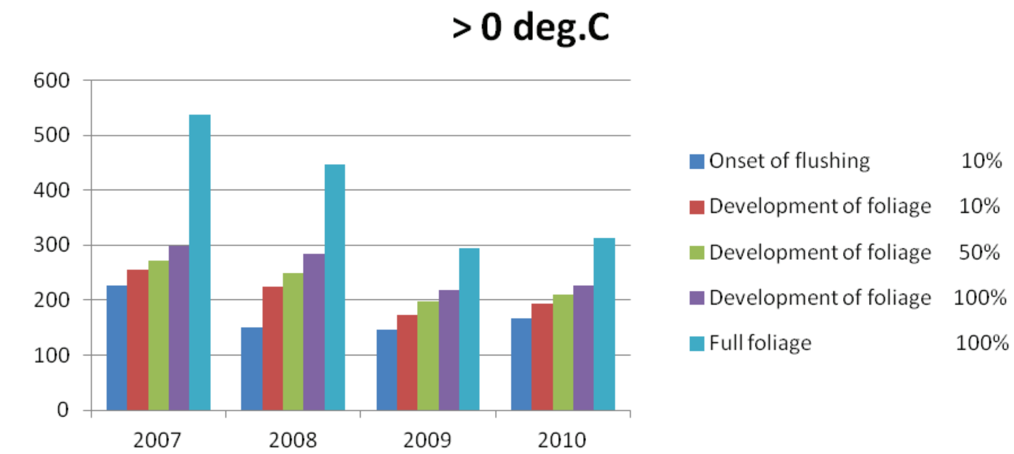
Within the period of 2007–2010, the beginning of autumn yellowing (10 %) occurred on average 272 days after the beginning of the calendar year. Within the period under study, the length of this stage was 15 days. Altogether 100 % of yellow leaves were recorded on the 303rd day of the calendar year. On the long-term average (1991–2006), this phenophase occurred on the 300th day of the year (BEDNÁŘOVÁ, MERKLOVÁ, 2008). Within the time interval of 2007–2010, the dropping of 10 % of leaves was recorded on the 284th day of the calendar year. In individual years of the study period, the time span of this stage was 13 days. The latest onset of leaf dropping (10 %) was recorded on the 297th day of the year 2007. Within the period of 2007–2010, the phenophase of 100 % dropped leaves was observed as late as on the 327th day of the calendar year, i.e. 5 days later than on the long-time average. The onset of autumn phenophases was influenced not only by air temperatures but also by the course of rainfalls in this season. Similar observations were published also by a number of other authors (e.g. LARCHER, 2003; MERKLOVÁ, BEDNÁŘOVÁ, 2008; SPARKS, MENZEL, 2002).

Effect of air temperatures on the onset and duration of phenological stages

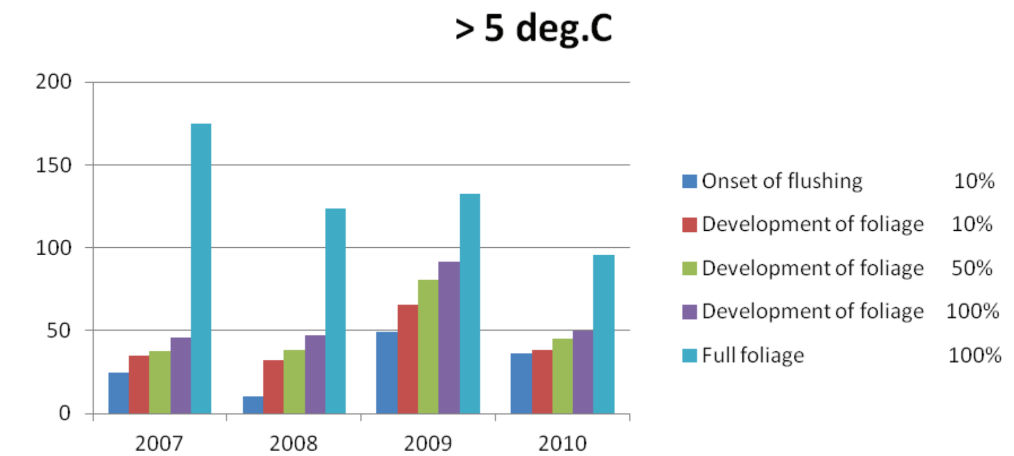
According to Havlíček (1986), the cumulative sum of effective air temperatures is the best way how to express temperature requirements of plants with regard to the onset of individual phenophases. The time of the onset of spring phenophases depends on the moment when a certain temperature level is exceeded. However, it is necessary to mention that the beginning of each phenological stage is dependent also on several other factors, e.g. humidity, light intensity, soil properties etc. In this study, sums of average daily air temperatures higher than 0 °C (TS0) were used as a bioclimatological criterion enabling to evaluate the dependence of phenological stages on meteorological elements and sums of effective air temperatures (TS5), respectively (see Figs. 7 and 8).

To express temperature limits necessary for the onset of individual phenophases, sums of soil temperatures above 0 °C were used as well because also the soil temperature is one of the factors that contribute to the course of spring phenological stages (Fig. 9).

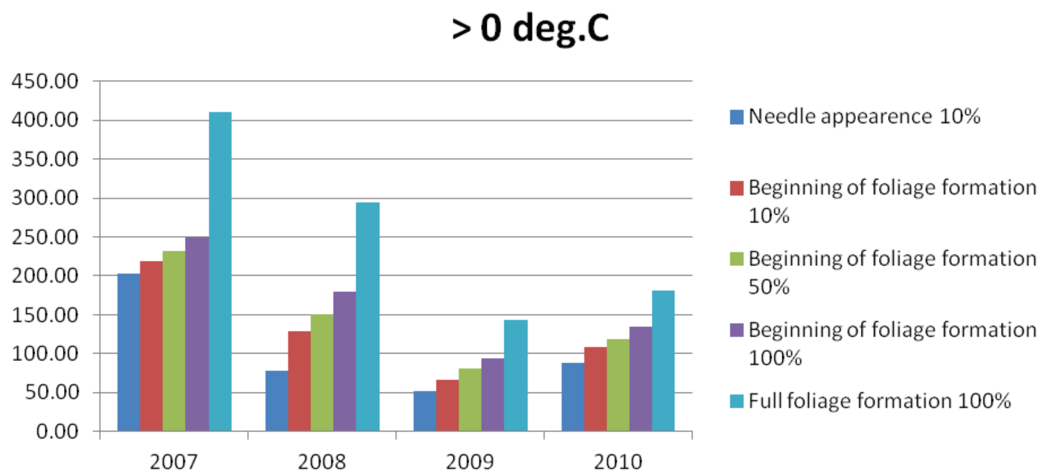
Within the study period (2007–2010), the onset of flushing (> 10 %) was recorded on average at TSO and TSS sums of 173 °C and 30 °C, respectively. For the onset of foliage formation (10 %) the necessary sums of TSO and TS5 were 212 °C and 43 °C, respectively.



7: *Sums of air temperature over 0 deg. C related to spring phenological stages.*



8: *Sums of air temperature over 5 deg. C related to spring phenological stages.*



9: *Sums of soil temperature over 0 deg. C related to spring phenological stages.*

The subsequent spring phenological stage (i.e. with more than 50 % of needles opened) was influenced by sums of TSO and TS5 equal to 232 °C and 51 °C, respectively. The beginning of the full foliage development (100 % of unfolded leaves) occurred after the temperature sums of TS0 = 257 °C and TS5 = 59 °C, respectively. The phenological stage of fully developed foliage (100 %) was observed at the moment when the recorded sums of temperatures reached levels of 393 °C and 130 °C (for TS0 and TS5, respectively).

In the autumn, the first autumn phenological stage of yellowing (with 10 % of yellow needles) was recorded at the moment when sums of temperatures were 2,622 °C and 1,604 °C (for TSO and TS5, respectively). A completely yellow foliage (100 % of needles) was recorded at temperature sums of 2,830 °C and 1,630 °C for TSO and TS5, respectively. The beginning of foliage dropping occurred at temperature sums of 2,693 °C and TS5 1,630 °C (for TSO and TS5, respectively). A complete dropping of 100 % of needles was recorded at the moment when sums of temperatures were 2,926 °C and 1,704 °C (for TSO and TS5, respectively).

Regarding the fact that the study area was localised in a slightly warm and slightly humid region, the beginning of the growing season was not negatively affected by a deficit of humidity and by its inadequate availability for plants. A long-term monitoring (supported by a statistical analysis of obtained results) demonstrated a great dependence of the onset of individual spring phenophases not only on air temperatures but also on that of soil in the course of early spring (BEDNÁŘOVÁ, KUČERA, 2002; BEDNÁŘOVÁ *et al.*, 2012). This observation corresponded with data published by other authors (LAVANDER *et al.*, 1973; TIMIS, WORRAL, 1974 and MERKLOVÁ, BEDNÁŘOVÁ 2008). Within the period of 2007–2010, the onset of flushing (10 % of leaves) occurred on average at the moment when the sum of soil temperatures TS0 = 106 °C. The beginnings of foliage formation (10 % and 50 %) occurred at sums of TS0 = 131 °C and 145 °C, respectively. The beginning of the stage of full foliage development (100 %) occurred at soil temperature sums TS0 = 165 °C and the phenological stage of full foliage development took place at TS0 = 254 °C.

The obtained results indicate that in the study area the phenological phase of flushing occurred earlier and earlier while the onset of total (100 %) foliage dropping was delayed as compared with the long-term average. In recent years, higher early-spring temperatures enabled not only an earlier onset of spring phenophases but also their accelerated course. This observation corresponded also with data published by other authors (ŠKVARENINOVÁ, 2008; STŘÍŽ, NEKOVÁŘ, 2010). In the autumn, the occurrence of high temperatures together with an uneven distribution of rainfalls during the year resulted in a prolongation of the growing season to the late autumn. In the study area, an earlier beginning of phenological stages of flushing and foliage development as well as a delayed onset of autumnal phenophases could be observed already for a longer time interval. In the Czech Republic, similar observations were published also by other authors (HÁJKOVÁ *et al.*, 2012). Within the study period of 2007–2010, the growing season of European larch lasted altogether 233 days; this was by 10 days more than the long-term average of years 1991–2006 (BEDNÁŘOVÁ, MERKLOVÁ, 2008). Recently, this phenomenon resulted in an extension of the growing season and in a shortening of dormancy period (that is very important and indispensable role in the life cycle of forest woody species). Our results coincided also with data published by other authors (HÁJKOVÁ, *et al.*, 2010; MOŽNÝ, NEKOVÁŘ, 2007; MERKLOVÁ, BEDNÁŘOVÁ, 2008).

CONCLUSIONS

Results of this study corroborated that the beginning of spring phenological stages was dependent on the end of winter season and temperatures of air and soil existing already in the early spring. In individual years, the onset of spring phenophases was dependent on existing climatic conditions. Their beginning was dependent on the date when certain temperature limits were exceeded. The earliest beginning of flushing (10 % of needles) was recorded already on the 89th day of the year, i.e. by 11 days earlier than the long-term average (1991–2006). Within the study period, the onset of 10 % of foliage development was recorded as early as on the 101st day of the year. The onset of the stage of 50 % of foliage formation occurred in average on the 103rd day of the year, i.e. one weak earlier than in the preceding time intervals. The onset of 100 % foliage formation was recorded on the 107th day of the year. The full development of the leaf area occurred on 120th day of the year, i.e. by 16 days earlier than on the long-term average. Beginnings of phenological stages of flushing and fully developed leaf area showed the highest degree of variability. In recent years, the onset of other spring phenophases was earlier and their duration shorter just because of higher temperatures.

As far as the beginning of individual phenological stages of European larch is concerned, its temperature requirements can be expressed at best on the base of temperature sums. The lowest sum of temperatures required for the onset of flushing (10 %) was TS0 = 152 °C. The requirements concerning formation of 10 % and 50 % of leaves were TS0 = 174 °C and 199 °C, respectively, while the beginning of 100 % of foliage development was observed at the sum of TS0 = 220 °C. The full development of leaf area occurred at TS0 = 295 °C. The statistical analysis demonstrated a high dependence of the onset of flushing on both air and soil temperatures existing within the period of two months before the beginning of this phenological stage. In the autumn, however, the onset of individual phenophases was delayed as compared with the long-term average. This phenomenon could be explained on the base of higher air temperatures and an uneven distribution of rainfalls during the autumn months. A delayed beginning of phenophases in the autumn resulted in an extension of the growing season on the one hand and a shortening of dormancy on the other. Within the study period, the growing season was prolonged by 10 days as compared with results of a long-term monitoring.

Long-term phenological studies can be therefore used (together with results of a simultaneous monitoring of environmental parameters) as a reliable bioindicator of climatic changes.

SUMMARY

The paper presents results of a phenological study of European larch (*Larix decidua* Mill.) performed within the period of 2007–2010. Obtained results were compared with data covering the preceding period of 17 years. The study was performed in a mixed forest stand (Norway spruce 60 %, European beech 30 %, and European larch 10 %). The research area was situated at the altitude of 625 m in the Drahanská vrchovina highlands. In the experimental stand, all basic environmental parameters were recorded. Evaluation of individual phenological stages was carried out according to the methodology of the Czech Hydrometeorological Institute. In individual years, onsets and durations of individual phenophases differed in dependence on the course of weather. Temperature requirements of European larch were expressed using sums of temperatures recorded prior to the onset of each phenological stage. As far as the beginning of individual spring phenophases was concerned, air and soil temperatures played a decisive role; this observation was corroborated also by means of the statistical analysis of obtained results. Because of higher temperatures recorded to the end of winter and in early spring, the beginning of the flushing phenophase of European larch was advanced. As compared with a long-term average, the onset of this stage occurred by 10 days earlier in recent years. The length of spring phenophases was gradually decreasing. The beginning of autumn phenophases was delayed and shifted to later dates. These observations corresponded with information about changing environmental parameters in the study area. On the other hand, however, the length of autumn phenophases was extended. As compared with the period of 1991–2006, the phenological stage of leaf dropping was delayed on average by 7 days. Due to this phenomenon, the duration of the growing season was prolonged and shifted to the late autumn so that the period of dormancy was shortened. A permanent shortening of dormancy period might show a negative effect on the healthy condition of forest stands because of disturbances in physiological processes. Subsequently, this could also result in wilting and etiolation, above all of non-native species growing in new habitats and under changed environmental conditions.

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