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THE DEVELOPMENT OF PHENOLOGICAL STAGES OF EUROPEAN BEECH (*FAGUS SYLVATICA* L.) IN SLOVAKIA DURING THE PERIOD OF 1996–2010

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Abstract. The paper presents results of 15 years lasting observations of European beech (*Fagus sylvatica* L.) in Slovakia within the altitude of 177–1265 m. During the years of 1996–2010 the start of vegetative phenological stages of first leaves, full leafing, beginning of leaf colouring, beginning of leaves fall at 40 phenological stations has been observed. The statistical analysis pointed out that the first leaves were created on the average from 20. 04. till 05. 05. The full leafing was approached on the average from 27. 04. till 10. 05. The spring phenological stages were shifted and started sooner by 5–6 days. The beginning of leaf colouring occurred on the average from 11. 09. till 24. 09. and its trend was also shifted and occurred later by 2 days. The beginning of leaves fall was recorded on the average from 01. 10. till 10. 10. and its trend approached the balanced state. The soonest autumn phenological stages started on the average in 2009 and the latest ones were recorded in 1997. The detailed analyses of 3 stations Zvolen (300 m), Observatory Modra (531 m) and Telgart (825 m) pointed out the sooner starts of spring phenological stages only in the lower and medium altitudinal areas of Slovakia. This trend has not been detected within mountainous areas. The dependence of leaf colouring on the influence of environmental factors as temperature and rainfall on its beginning has been confirmed at the all 3 phenological stations.

Introduction

European beech belongs among the tree-species of the oceanic and transient climate. Its occurrence in natural forest ecosystems is conditioned first of all by temperature and soil humidity. The optimum climate conditions for beech represents the amplitude of mean monthly air temperature between the coldest and warmest months within 15–25 °C. The beech stands in Slovakia reach their optimum at the mean annual temperature of 10 °C and rainfall of 800-1000 mm (Pagan 1992). Its optimum growing conditions in the territory of Slovakia are situated within the altitude of 600-800 m prevailingly on wet soils situated in inversion sites at the bases of slopes. As the most of the Slovak territory fulfils these favourable conditions for its growth, beech approaches the highest percentage (30,5 %) among all broadleaved tree-species grown here.

The development of tree-species and their communities during a year consists of several stages. This process is conditioned by both the internal and external factors, first of all by the genetic properties of a given species and by the run of weather in a given year. The time succession of regularly repeating phenological stages is at a great extent influenced by meteorological elements. The greatest influence on their start and development during spring period has air temperature. As the decisive characteristics is considered the sum of efficient temperatures preceding the start of a given phenological stage. The evaluation of phenological stages of European beech, but also other tree-species according to this factor has been used in their works by several authors (Bednářová–Merklová 2007, Střelcová *et al.* 2006, Škvareninová 2009). Some of them have found that the start of bud swelling and full leafing of beech in the territories in the altitude of 625–850 m occur at the mean daily temperature of 0-5 °C. A strong dependence of spring phenological stages and the generation of annual rings on a mean air temperature is analysed also by Čufar *et al.* (2008). Except the air temperature, the autumn phenological stages of beech are significantly influenced also by the amounts of rainfall especially during a vegetation period. A water deficit is manifested by a leaf colouring and can cause the shortening of vegetation peace period and eventually also a decreasing of adaptability. These changes can result in the changes of competition relationships among particular tree-species and whole communities (Bolliger *et al.* 2000, Gessler *et al.* 2007).

Data and methods

The phenological observations of European beech have been processed only for the period of years 1996-2010. The data of an older period became incompatible, because the methodology of observation had been changed during the year of 1996. This tree-species has been observed in 40 sites of Slovakia in the altitudes 177-1265 m a. s. l. according to the present methodology of the Slovak Hydro-meteorological Institute (SHMI) (Braslavská–Kamenský 1996). The start of each phenological stage was observed in sites with the occurrence of minimum 10 adult trees when the trees with a phenological extremes were excluded. The recorded data were transformed into a numerical code where each day of a year was replaced by the order number of a day from the very beginning of a year. There were evaluated the following vegetation phenological stages:

- The first leaves – FrL (the first incomplete leaves of a light-green colour occurred at least in the half of all observed trees)
- The full leafing – FL (the first complete leaves occurred at least in the half of all observed trees)
- The leaf colouring – BC (leaves with a changed colour occurred at least in the half of all observed trees)
- The beginning of leaves fall – BF (the first leaves with a changed colour fell on the soil spontaneously)

Except these data, the influence of environmental factors such as temperature and rainfall on the beginnings and development of autumn phenological stages have been analysed in more detail. The leaf colouring has been evaluated in 3 selected stations within the altitudinal range of 1088 m. Recorded data concerning air temperature and rainfall were taken from the meteorological stations of SHMI that were situated in the vicinity of particular phenological stations. In order to analyse the autumn phenological stages were used the standard deviations from normal totals of rainfalls for the periods May – August and the standard deviations of mean August air temperature from its long-term normal.

Results and disscussion

The survey of beginnings and variability concerning occurrence of particular observed phenological stages for the 15 years lasting period including their extreme values are given in Table 1. The *first*

leaves of beech occurred in Slovakia during the evaluated period on the average from 20. 04. till 05. 05. As the date of their soonest occurrence was recorded the April 13th, 2007 in the station of Zhdana (300 m). This year belonged to ones with the warmest spring periods. The latest day of the first leaves occurrence has been recorded on the May 23rd, 1996 at the station of Stare Hory (485 m). Though this year did not belong to the coldest ones, this late start is possible to explain by a cold air flowing into this valley. The development of observed phenological stages (Figure 1) points out the obviously decreasing trend caused by the shifting these stages to the sooner dates by 6 days. However, from the evaluation of the assumed climate change these observations represent only a relatively short period.

Table 1. The survey of beginnings and variability concerning occurrence of particular phenological stages of European beech in Slovakia during the period of years 1996-2010

Phenological phase	Ø	min	max	s_x %
LU	20.4. –5.5.	13.4.2007	23.5.1996	4,7–8,6
FL	27.4. –10.5.	15.4.2009	29.5.1996	4,5–7,8
LC	11.9. –24.9.	29.8.2003	23.10.1997	3,3–5,2
LF	1.10. –10.10.	7.9.1997	15.11.1997	4,1–6,4

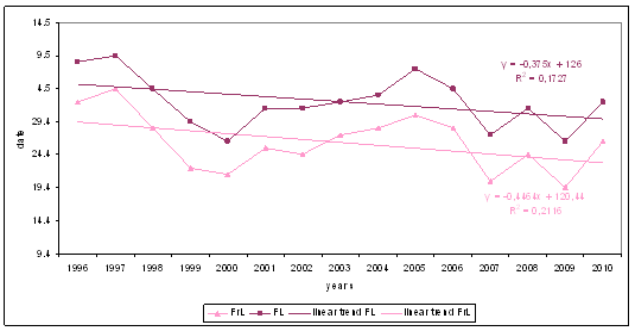

Figure 1. The development of spring phenological stages of European beech in Slovakia in the period of 1996-2010

The phenological stage of ***full leafing*** lasted on the average from 27. 04. till 10. 05. and its first start was recorded on the April 15th, 2009 at the station of Svinica (272 m), when also occurred the mean soonest start of the phenological stage within the analysed period. The latest start was recorded on the April 29th, 1996 at the station of Stare Hory, what caused, regarding the not very big altitude (485 m), the site of a station situated in the very vicinity of the Stare Hory mountains belonging to the range of Velka Fatra. The phenological stage development trend there started sooner by 5 days in Slovakia, here. The shift of full leafing trend of a beech stand in the Kremnicke Vrchy mountains by 3 days sooner is also consistent by the paper of Schieber (2006). The results concerning spring phenological stages point out the annual variability expressed by the coefficient of variance (s_x = 4,5–8,6 %). Its higher values are caused by a phenological response to the volatility of main climatic elements during the spring periods. The autumnal vegetative pheno-stage starts by the ***leaf colouring***. Its average start at beech was recorded from 11th till 24th September (Figure 2), although its soonest start occurred on the August 29th, 2003 at the station of Stakcin (256 m). This year belonged to the warmest ones, with the soonest average start on the September 11th.

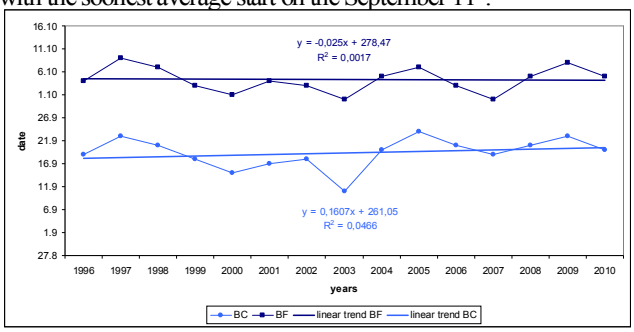

Figure 2. The development of autumnal vegetative phenological stages European beech in Slovakia during the period of 1996-2010

The latest date was registered on the October 23rd, 1997 at the station of Stupava (177 m). The development trend of the pheno-stage has shifted into the sooner period by 2 days. The ***leaves fall*** of European beech in Slovakia occurred on the average in the first October decade (01. – 10. 10.). Both the extreme values were recorded in 1997 year, the soonest in the locality of Opatova (07. 09.) and the latest in the locality of Stupava (15. 11.). Their development trend depicts the balanced state. Their variability measured by the coefficients of variance approached values of 3.3 – 6.4 %, what represents the more balanced state in comparison with the spring pheno-stages.

The presented results of shifts concerning spring and autumnal trends of particular pheno-stages point out the lengthening of a vegetation period. The mean length of the vegetation period of beech is 145 days. Its vegetation period shortens as the altitude ascends. In lowland areas beneath 300 m a. s. l. this period lasts 152 days on the average, but in mountainous areas above 800 m a. s. l. it lasts only 123 days. The similar conclusions are made by Hájková *et al.* (2010), where the mean length of a vegetation period of European beech in the Czech Republic lasts 198 days when the longer vegetation period was detected as the result of increasing tendency of efficient temperature totals above 5 °C. The detailed analysis of starts and the developments of spring phenological stages has been carried out at the phenological stations of Zvolen (300 m), Modra Observatory (531 m) and Telgart (825 m). Figures 3 – 5 presents detected different development treds. While in the lower and medium altitudial sites was detected a trend of sooner starts of the first leaves and full leafing stages by 4 – 9 days, their later starts by 0.5 day were revealed at the station of Telgart what can be considered as an insignificant and negligible shift.

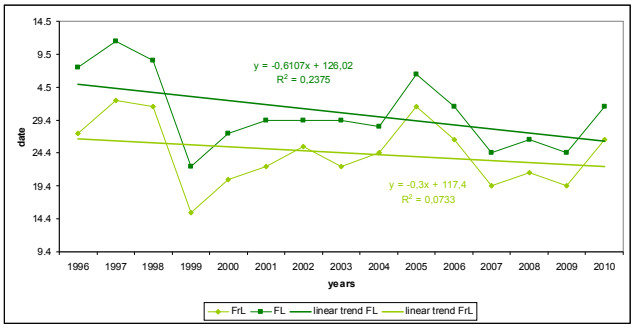

Figure 3. The development of spring phenological stages of European beech at the phenological station of Zvolen during the period of 1996–2010

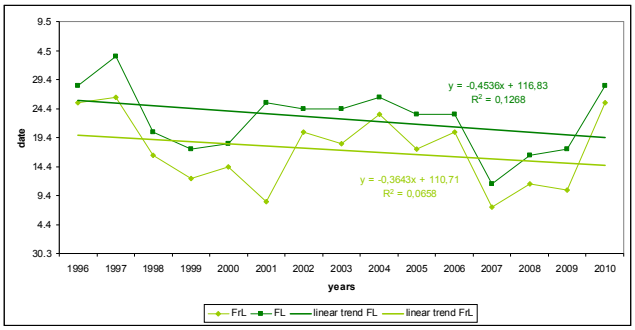

Figure 4. The development of spring phenological stages of European beech at the phenological station of Modra Observatory during the period of 1996–2010

The development trends of autumnal pheno-stages are given in Figures 6 - 8. It can be seen that the beginning of leaf colouring is late at all stations by 6 – 11 days. The leaves fall occurs at the stations of Zvolen and Modra Observatory sooner by 1 day. This trend is late at the station of Telgart by almost 6 days what can be caused by higher totals of rainfall during the summer period. This phenological stage does not depend only on the weather development in summer months, but is also influenced by temperatures beneath zero and the power of wind during autumnal months.

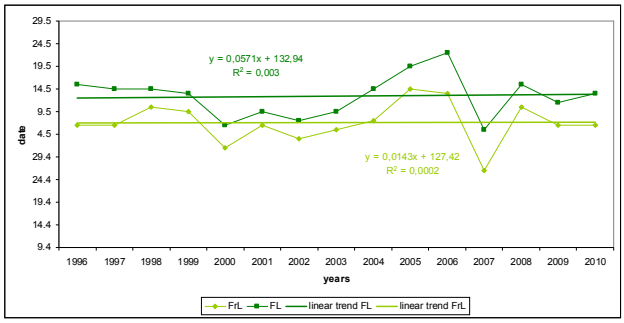

Figure 5. The development of spring phenological stages of European beech at the phenological station of Telgart during the period of 1996–2010

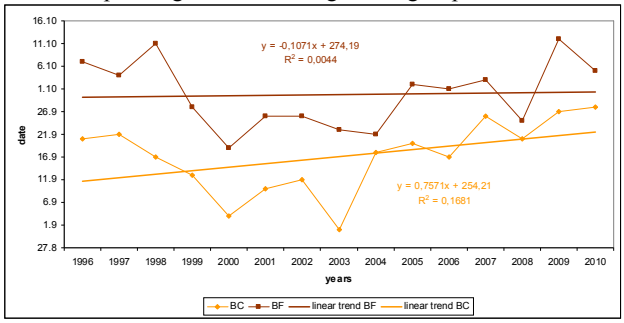

Figure 6. The development of autumnal phenological stages of European beech at the phenological station of Zvolen during the period of 1996–2010

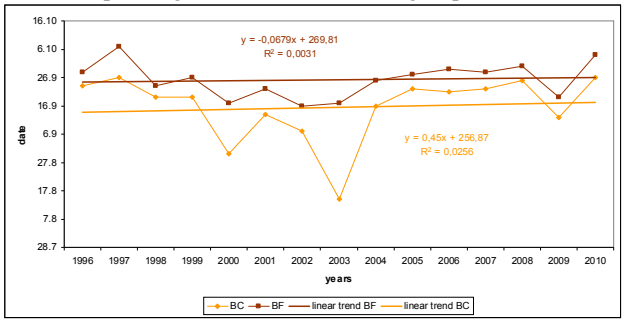

Figure 7. The development of autumnal phenological stages of European beech at the phenological station of Modra Observatory during the period of 1996–2010

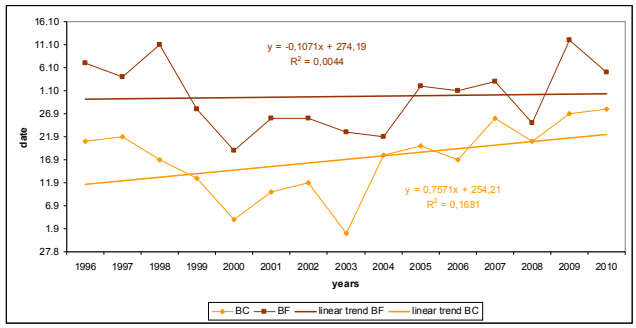

Figure 8. The development of autumnal phenological stages of European beech at the phenological station of Telgart during the period of 1996–2010

The leaf colouring depends on the weather development during a summer period. This pheno-stage is influenced at the great extent by the run of air temperature and amount of rainfall. The rainfall totals and mean air temperature for months of May – August including the mean air temperature in August at particular phenological stations are presented in Figures 9 -11. Figures 6 and 9 inform that the soonest leaf colouring occurred at the station of Zvolen in the year of 2003 when 4 month rainfall totals approached only 29.4 mm beneath the long-term normal at the August air temperature 2.7 °C above its normal. The latest leaf colouring occurred here in the year of 2010, although the August temperature was not the lowest by a normal, but the amount of rainfall represented the highest totals for the all observed period (243 mm). The soonest leaf colouring started at the Modra Observatory station in the year of 2003 (Figure 7) at the increased August air temperature by 2.6 °C above its long-term normal and at a low rainfall total (Figure 10).

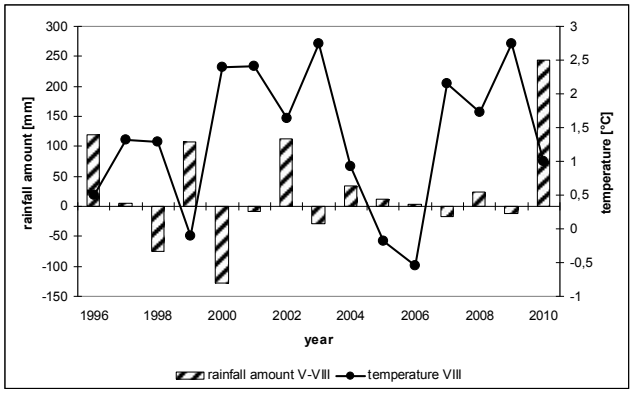

Figure 9. The deviations of rainfall amounts and mean air temperature in the period of May - August from their normal (1961–1990) compared to the mean air temperature in August at Zvolen

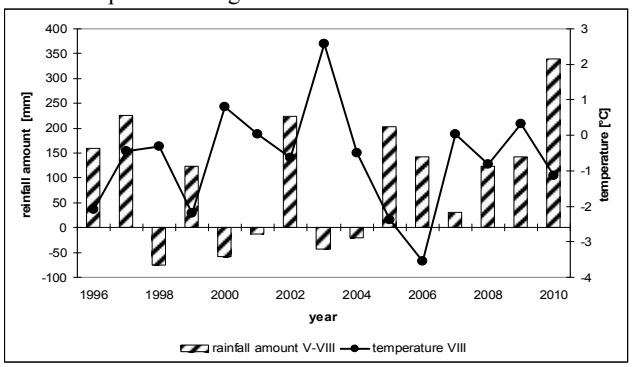

Figure 10. The deviations of rainfall amounts and mean air temperature in the period of May - August from their normals (1961–1990) compared to the mean air temperature in August at Modra Observatory

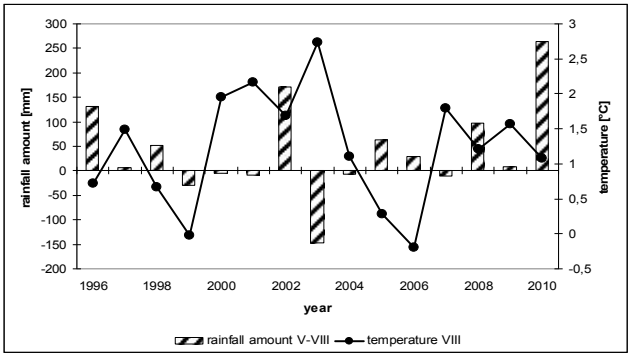

Figure 11. The deviations of rainfall amounts and mean air temperature in the period of May - August from their normals (1961–1990) compared to the mean air temperature in August at Telgart

The longest vegetation period lasted here during the years of 1997 and 2010 at the high amounts of rainfall totals (226 – 339 mm) and at the air temperature lower than a normal by 0.4 – 1.1 °C. In the mountainous area of Telgart, the years of 2000 and 2003 proved to be as the warmest and with the lowest rainfall totals duringall vegetation periods. It resulted in the soonest leaf colouring (Figure 8) in the very beginning of September. The years of 1996 and 2005 at Telgart can be regarded as comparatively cold and the rich of rainfalls when the leaf colouring has occurred here at the latest. Although Figure 11 suggests the assumption of this maximum for the year of 2010, but the higher August air temperature than a long-term normal by 1.1 °C has shifted this phenological stage to the sooner date.

Conclusions

There have been observed 4 phenological stages of European beech (*Fagus sylvatica* L.) growing within a large altitudinal range (177 – 1265 m a. s. l.) at 40 sites situated in Slovakia during the period of 1996 – 2010 years. The phenological stage of the first leaves lasted on the average from 20th of April till 5th of May and the full leafing occurred on the average from 27th April till 10th of May. The autumnal phenological stage of a leaf colouring started on its average from 11th till 24th of September and a leaves fall began from 1st till 10th of October. The higher variability of spring pheno-stages (s_x = 4,5 – 8,6 %) in comparison with the autumnal ones (s_x = 3,3 – 6,4 %) within the observed altitudinal interval of 1088 meters has been detected.

The trend of spring pheno-stages development was decreasing with their sooner beginnings by 5 – 6 days. The autumnal pheno-stage of a leaf colouring was late by 2 days. No time trend change at the leaves fall pheno-stage occurrence has been detected. The presented results point out the obvious lengthening of a vegetation period. However, these changes of a trend require a more thorough testing based on the longer time series.

The results of the detailed analyses carried out at 3 stations of Zvolen (300 m), Modra Observatory (531 m) and Telgart (825 m) proved that the sooner start of spring pheno-stages of European beech occurs only in lower and medium altitudinal areas of Slovakia. This trend has not been revealed in mountainous areas, at all. The reason can be the penetrating of colder air from higher situated sites and thus lower temperatures during a spring period. The analyses of leaf colouring observations at the all 3 phenological stations confirm its dependence of its start on environmental factors such as temperature and rainfall.

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