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Assessment of vegetative phenological phases of European beech (*Fagus sylvatica* L.) in relation to effective temperature during period of 1992–2008 in Czechia

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Abstract

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The paper presents the results of long-term phenological observations of European beech (*Fagus sylvatica L.*) running in years 1992–2008 across the phenological network of the Czech Hydrometeorological Institute, abbr. CHMI, in original language Český hydrometeorologický ústav. The data assembled over this period were used for identification of timing of the following vegetative phenophases: bud burst (BBCH 07), first leaves 100% (BBCH 15), leaf colouring 10% (BBCH 92), leaf fall 100% (BBCH 97). The stations are situated at altidudes from 165 m (Lednice) to 1,102 m (Modrava). The mean date obtained for onset of bud burst is from April 12th to May 7th (on average April 22nd), the mean date for onset of the first leaves 100% is from April 29th to May 17th (on average May 7th), the mean date for onset of leaf colouring is from September 12th to October 14th (on average September 24th), and the mean date for onset of leaf fall 100% is from October 9th to December 8th (on average November 7th). The trend analysis of bud burst stage showed a declining trend – that means a shift of phenological phases towards earlier date (5.7 days). On the other side, the phenophase of leaf fall 100% manifested an increasing trend – that means a shift of phenological phase to later date (6.1 days). The vegetation season is getting longer. The totals of effective temperatures were used as a bio-climatological criterion for assessment of dependence of phenological phases on meteorological variables. The above mentioned totals were obtained as subtotals of average daily temperatures higher than 0 °C, 5 °C, 8 °C and 10 °C (TS0, TS5, TS8, TS10). The average temperature total for bud burst TS0 was found from 286.2 °C (Lednice, 165 m a.s.l.) to TS0 = 144.2 °C (Modrava, 1,102 m a.s.l.). The other effective temperature totals for the average day of bud burst are: TS5 = 71.5 °C; TS8 = 21.4 °C; TS10 = 7.2 °C (Lednice); TS5 = 20.0 °C; TS8 = 4.4 °C; TS10 = 1.6 °C (Modrava). The highest temperature total for leaf fall was from TS0 = 3,822.4 °C (Lednice); the lowest TS0 = 1845.9 °C (Modrava).

Key words

BBCH code, beech, Czech phenology, effective temperature, phenophase

Introduction

The natural distribution area of European beech covers the whole of Central Europe including Czechia. Phenological observations of this species can be a useful bioindicator tool for detecting environmental changes. European beech is a deciduous tree, up to 40 m high and with an average stem circumference of 1 m. The crown is ball-shaped, the wood is skin-rose. European beech is a wood species associated with oceanic and suboceanic climate, sensitive to drought and late frost. It occurs across the whole Czechia from 300 to 1,000 m a.s.l. *Fagus sylvatica* L. has been included into the CHMI phenological observation programme to monitor these phenophases: bud burst, first leaves (10, 50, 100%), fully developed leaves, flower buttons visible, beginning of flowering (10, 50, 100%), end of flowering, bud creation (10%), first fruits visible (10%), green sprouts begin to lignify (10%), colouring of leaves (10, 100%), falling of leaves (10, 100%) and fully ripeness (10%). Bednářová and Merklová (2007) monitored and evaluated spring and autumnal phenological characteristics of *Fagus sylvatica* L. in the Drahanská vrchovina hills from 1991 to 2006. A large range was noted in spring phenophases, autumnal phases showed a more regular course. In the recent years, the sum of effective temperatures displayed an evident growth. The sum of effective air temperatures for budbreak had increased from 10.9 °C to 135.6 °C, for leaf fall from 1,308.0 °C to 2,341.0 °C. Merklová and Bednářová (2007) evaluated phenological and growth phases of European beech in relation to the microclimate in a stand in the Drahanská vrchovina. The beginning of autumnal phenological phases depended more on the precipitation amount during the summer and autumn months. Hanousková (2010) executed temporal variability of European beech from phenological stations Lednice (165 m a.s.l.) and Chřibská (350 m a.s.l.) including influence of meteorological parameters (air temperature, precipitation and sunshine duration) on phenophase onset in period 1991–2009. During the observed period the starts of vegetative phenological phases set on average in April (bud burst) and in May (first leaves 100%). The variation coefficients of vegetative phenophases (sprouting, first leaves 100%, leaves colouring 10% and leaf fall) ranged from 4.0% to 5.6% at Lednice station and from 5.2% to 11.1% at Chřibská station. The mean daily air temperature was found considerably affecting bud burst of oak (*Quercus robur L.*) in a flood plain forest of southern Moravia in period 1961–2007 (Bartošová et al., 2008). Škvareninová (2008) studied the start of spring phenophases in *Quercus robur L.* in relation to temperature sums in period 1987–2006 in the Zvolenská kotlina basin at altitudes about 300 m a.s.l. The values of variation coefficients of all vegetative phenophases ranged from 4.04% to 6.03%, the variation range was 20–27 days. The values of temperature sums (TS0 = 241.3 °C – leaf bud swelling, TS0 = 380.6 °C – leaf bud burst, TS0 = 530.7 °C – leaf unfolding). Škvareninová (2007) also studied the onset of generative phenophase of *Alnus glutinosa* (L.) Gaert. at the Arboretum Borová hora in relation to effective temperatures in 1987–2006 (TS0 = 102.8 °C – beginning of flowering, TS0 = 191.1 °C – bud burst, TS0 = 369.7 °C – fully leaved, TS0 = 3,214 °C – leaves unfolding).

Material and methods

The onset of bud burst (BBCH 07), first leaves 100% (BBCH 15), leaf colouring 10% (BBCH 92) and leaf fall 100% (BBCH 97) was analysed for the period 1992–2008 with the data provided by 27 CHMI phenological stations situated from 165 to 1,102 m a.s.l. There were selected stations with complete time series. The phenological data were obtained according to CHMI methodical instructions, number 10 (2009). The patterns of phenophases are illustrated in the Phenological atlas Coufal et al. (2004). The phenophase onset was expressed as the corresponding growing-degree day. The stations were analyzed separately and according to altitude. We have also evaluated the following inter-start intervals: bud burst – leaf fall 100% (length of vegetation period of European beech in Czechia), bud burst – first leaves 100%, leaf colouring 10% – leaf fall 100%. All the types of analysis were made in Excel and by AnClim programme. The effective temperatures totals (subtotals of average daily air temperatures above 0 °C (TS0), 5 °C (TS5), 8 °C (TS8) and 10 °C (TS10)) were as the most suitable meteorological characteristics when dealing with phenological data. The characteristics of phenological and climatological stations are in Table 1.

Table 1. Characteristics of phenological (P) and climatological (C) stations

Station	Altitude	Longitude	Latitude
Lednice (P)	175	16°48'	48°48'
Přibyslav (P)	533	15°45'	49°35'
Modrava (P)	1,102	13°31'	49°02'
Lednice (C)	176	16°47'	48°47'
Přibyslav (C)	530	15°45'	49°34'
Kvilda (C)	1,059	13°34'	49°01'

Table 2 represents annual meteorological characteristics for meteorological stations Lednice (176 m a.s.l), Přibyslav (530 m a.s.l) and Kvilda (1,059 m a.s.l).

All CHMI phenological stations have been provided with metadata of Phenodata-Oracle database.

The beech observation site Lednice is situated in the Lednice Castle Park, southern Moravia, the river basin of Dyje. The trees are observed at the locality with the following site characteristics: vegetation unit – dispersed green vegetation, macrorelief – flat ground, microrelief – flat ground, geological substrate – clayey drift and combined soil, slope – up to 5 degrees, light conditions – full illumination, humidity conditions – hygromesophyte, initial stand age – 80–100 years, level of protection – the other categories of non forest land.

The station Přibyslav is situated in the Vysočina region, the river basin of Sázava. Beech trees are observed at the locality 7 with the following characteristics: vegetation unit – dispersed green vegetation, macrorelief and microrelief – flat ground, geological substrate – underground volcanic rocks, slope from 5 to 10 degrees, exposition – southwest, light conditions – full illumination, humidity conditions – mesophyte, initial age – 80–100 years, level of protection – the other categories of non forest land.

The station Modrava is situated in the Šumava Mts, the river basin of Vltava. Beech trees are observed at the locality 4 with these characteristics: vegetation unit – dispersed green vegetation, macrorelief – flat ground, geological substrate – underground volcanic rocks, slope from 30 to 40 degrees, exposition – southwest, light conditions – full illumination, humidity conditions – hygromesophyte, initial stand age 100–150 years, level of protection – National Park.

Results and discussion

The onset and duration of phenological phases in beech differed considerably between the years. Together with genetics factors, air temperature and soil temperature are critical for the start of spring phenological phases (Bednářová and Kučera, 2002.). Statistical data for the selected stations are in Tables 3, 4. On the basis of the results obtained, we can report that the average timing of bud burst in the 17-year research period in Czechia was the 22nd April, average timing of first leaves (100%) was the 7th May, average timing of leaf colouring (10%) 24th September, and average timing of leaf fall (100%) 7th November. Statistical characteristics of bud burst, first leaves (100%), leaf colouring 10% and leaf fall (100%) for the whole Czechia are given in Table 5. The earliest bud burst in the station Lednice was found on 1st April with the sum of effective temperatures TS5 = 55.0 °C, and at the latest was on the 20th April with the sum of effective temperatures TS5 = 148.2 °C.

In the Modrava station the earliest bud burst was recorded on 25th April with the sum of effective temperatures TS5 = 6.3 °C, and at the latest was on the 12th May with the sum of effective temperatures TS5 = 32.5 °C.

Table 2. Annual meteorological characteristics at the stations Lednice, Přibyslav and Kvilda

Meteorological characteristic	Abbreviation	Unit	Lednice	Přibyslav	Kvilda
Mean annual air temperature	T	°C	10.2	7.5	3.3
Average sum of active temperatures above 5 °C	ΣT > 5 °C	°C	3,716.4	2,864.8	1,709.7
Average sums of active temperatures above 10 °C	ΣT > 10 °C	°C	3,263.0	2,361.4	1,137.9
Average annual maximum air temperature	TMA	°C	15.1	12.0	9.9
Absolute maximum air temperature	TMA MAX	°C	38.1	35.8	31.4
Average active sum of maximum air temperature above 5 °C	ΣTMA > 5 °C	°C	5,452.9	4,372.1	3,648.7
Average active sum of maximum air temperature above 10 °C	ΣTMA > 10 °C	°C	5,047.3	3,945.5	3,196.8
Average annual minimum air temperature	TMI	°C	5.1	3.2	–2.8
Average annual sunshine	SSV	hour	1,832.8	1,737.2	Not observed
Average annual precipitation total	SRA	mm	535.7	683.3	1,226.7
Average annual number of days with daily precipitation total above 0,1 mm	SRA > 0.1 mm	day	114.6	168.1	192.1
Average annual number of days with daily precipitation total above 1 mm	SRA > 1 mm	day	81.7	111.8	155.8
Average annual number of days with daily precipitation total above 5 mm	SRA > 5 mm	day	31.1	40.9	77.8

The earliest first leaves (100%) were found on 24th April (Lednice station) with the sum of effective temperatures TS5 = 226.0 °C, and on 4th May (Modrava station) with the sum of effective temperatures TS5 = 179.9 °C. The latest first leaves (100%) were on 11th May (Lednice station) with the sum of effective temperatures TS5 = 259.0 °C, and on 29th May (Modrava station) with the sum of effective temperatures TS5 = 187.8 °C.

The earliest leaf colouring (10%) was found on 2nd September (Lednice station) with the sum of effective temperatures TS5 = 2,488.5 °C, and on 26th August (Modrava station) with the sum of effective temperatures TS5 = 933.5 °C. The latest leaf colouring (10%) was observed on 21st October (Lednice station) with the sum of effective temperatures TS5 = 2,588.3 °C, and on 2nd October with the sum of effective temperatures TS5 = 990.4 °C.

The earliest leaf fall (100%) were found on 3rd November (Lednice station) with the sum of effective temperatures TS5 = 2,358.0 °C, and on 20th September (Modrava station) with the sum of effective temperatures TS5 =1,052.1 °C. The latest leaf colouring (10%) was on 23rd December (Lednice station) with the sum of effective temperatures TS5 = 2,373 °C, and on 30th October (Modrava station) with the sum of effective temperatures TS5 = 881.4 °C. Statistical characteristics for onset of phenophase bud burst and leaf fall are

Table 3. Statistical characteristics of bud burst and leaf fall (100%) phenophase onset in European beech

Bud burst	Lednice	Přibyslav	Modrava
Average	14. 4.	13. 4.	6. 5.
Median	16. 4.	14. 4.	7. 5.
Upper q.	10. 4.	6. 4.	2. 5.
Lower q.	18. 4.	20. 4.	10. 5.
Standard deviation	5.3	9.0	5.2
Min.	1. 4.	27. 3.	25. 4.
Max.	20. 4.	26. 4.	12. 5.
Variation range	19	30	17
Variation coefficient	5.1	8.7	4.1
Leaf fall (100%)	Lednice	Přibyslav	Modrava
Average	23. 11.	30. 10.	9. 10.
Median	21. 11.	29. 10.	9. 10.
Upper q.	14. 11.	26. 10.	26. 9.
Lower q.	29. 11.	6. 11.	17. 10.
Standard deviation	14.3	10.6	14.0
Min.	3. 11.	15. 10.	20. 9.
Max.	23. 12.	26. 11.	30. 10.
Variation range	50	42	40
Variation coefficient	4.4	3.5	4.9

Table 4. Statistical characteristics of interphase intervals (Bud burst – Leaf fall 100%, Bud burst – First leaves 100%, Leaf colouring 10% – Leaf fall 100%) in European beech

Bud burst – Leaf fall 100%	Lednice	Přibyslav	Modrava
Average	223	201	156
Median	220	201	147
Upper q.	215	194	152
Lower q.	230	208	144
Standard deviation	15.4	12.8	12.4
Min.	200	173	142
Max.	255	225	183
Variation range	55	52	41
Variation coefficient	24.6	6.4	8.0

Table 4. Continued

Bud burst – First leaves 100%	Lednice	Přibyslav	Modrava
Average	20	19	9
Median	21	20	6
Upper q.	16	15	5
Lower q.	22	23	13
Standard deviation	3.7	6.4	6.5
Min.	14	9	2
Max.	27	24	22
Variation range	13	25	20
Variation coefficient	18.7	33.9	69.2
Leaf colouring 10% – Leaf fall 100%			
Average	55	45	26
Median	55	44	26
Upper q.	40	41	12
Lower q.	79	48	40
Standard deviation	23.9	12.6	14.0
Min.	16	19	5
Max.	104	75	47
Variation range	88	56	42
Variation coefficient	43.1	28.3	53.3

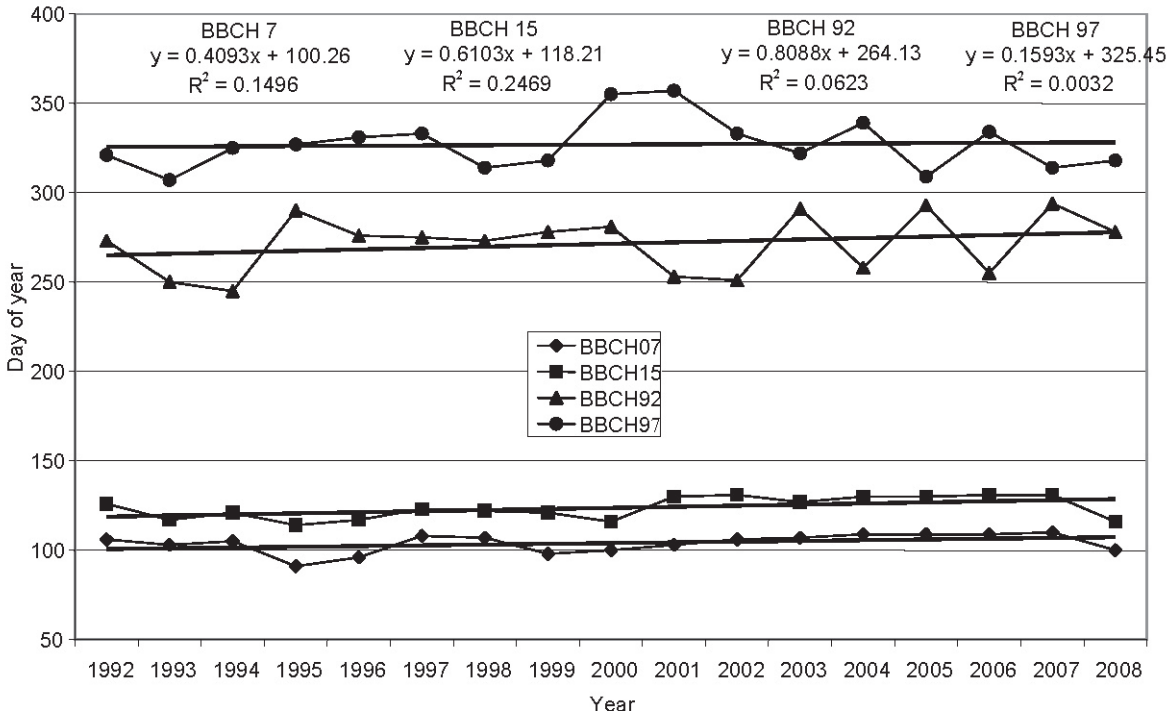

Fig. 1. The trend of onset of phenological phases European beech in 1992–2008 at Lednice station (165 m a.s.l.).

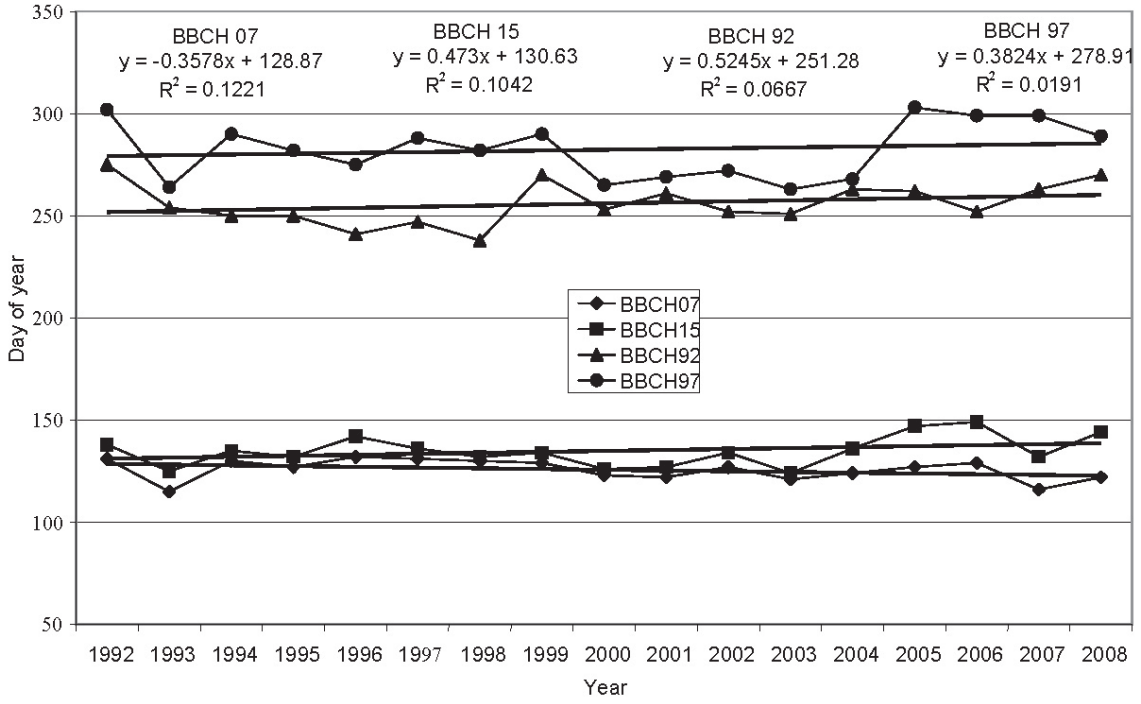

Fig. 2. The trend of onset of phenological phases in European beech in 1992–2008 at Modrava station (1,102 m a.s.l.).

given in Table 3. Relative variation coefficients at all three stations were low – unlike in interphase interval – especially at the mountain station. Statistic description of interphase duration is in Table 4. Figs 1 and 2 illustrate the trends of onset of spring and autumn phenological phases in the lowland and in the mountain. We have found positive trends in all phenophases at Lednice station – the highest in leaf colouring 10%. The trends observed at the mountain station Modrava were also positive, except bud burst in which the onset was found earlier.

The phenological data from all 27 phenological stations were evaluated statistically. The results are summarized in Tables 5, 6. The onset of bud burst was on average on 22nd April, of the first leaves 100% on 7th May, of leaf colouring 10% on 24th September, and of leaf fall 100% on 7th November.

The sums of effective temperatures were calculated for each selected station (Lednice, Přibyslav and Modrava) according to the representative climatological stations (Lednice, Přibyslav and Kvilda stations) from the beginning of year to the particular phenophase onset. The average sums of effective temperatures are given in Table 7. In Table 8 are summarised statistical characteristics of sums of effective temperatures above 5 °C. Variation coefficients in autumnal phenological phases were smaller than in spring phenological phases. Fig. 3 represents course of sums of effective temperatures above 5 °C in autumnal phenological phases with regression equation in the European beech at different altitudes during period 1992–2008.

Table 5. Statistical characteristics of selected phenophases from all phenological stations for European beech in Czechia

Fagus sylvatica L. 1992–2008 Phenophase	Statistical characteristics					
	X	s_x	R	Min.	Max.	s_x%
Bud burst (BBCH 07)	112	8.4	25	102	127	7.5
First leaves 100% (BBCH 15)	127	8.0	18	119	137	6.3
Leaf colouring 10% (BBCH 92)	267	17.8	32	255	287	6.6
Leaf fall 100% (BBCH 97)	311	17.4	60	282	342	5.6

X – arithmetic mean, s_x – standard deviation, R – variation range, Min. – minimum, Max. – maximum, s_x% – variation coefficient.

Table 6. Statistical characteristics of selected interphases from all phenological stations of European beech in Czechia

Fagus sylvatica L. 1992–2008 Interphase	Statistical characteristics					
	X	s_x	R	Min	Max	s_x%
Bud burst – first leaves (100%)	14.1	1.5	5.4	11.7	17.2	10.9
Bud burst – leaf fall 100%	198.3	5.1	20.9	185.8	206.8	2.6
Leaf colouring 10% – leaf fall 100%	43.6	3.7	13.6	39.0	52.6	8.5

X – arithmetic mean, s_x – standard deviation, R – variation range, Min. – minimum, Max. – maximum, s_x% – variation coefficient.

Table 7. Average sums of effective temperatures for selected phenological phases in European beech

Phenophase	TS0		TS5		TS8		TS10	
	Lednice	Kvilda	Lednice	Kvilda	Lednice	Kvilda	Lednice	Kvilda
Bud burst (BBCH 07)	287.5	143.7	71.6	20.2	21.3	4.6	7.0	1.7
First leaves 100% (BBCH 15)	611.2	403.0	250.3	134.6	126.2	56.7	72.1	27.8
Leaf colouring 10% (BBCH 92)	3,384.3	1,730.2	2,413.9	871.5	1,758.0	483.8	1,365.3	288.8
Leaf fall 100 % (BBCH 97)	3,838.4	1,856.1	2,461.6	904.9	1,774.3	492.5	1,372.4	291.2

Table 8. Statistical characteristics of sum of effective temperatures above 5°C for bud burst, first leaves 100%, leaf colouring 10% and leaf fall in European beech

Bud burst	Min.	Max.	R	s_x	s_x%
Lednice	1.2	148.2	147.0	34.0	47.5
Kvilda	3.5	52.8	49.3	14.6	72.3
First leaves					
Lednice	143.9	377.7	233.8	58.8	23.5
Kvilda	66.4	193.5	127.1	33.6	24.9
Leaf colouring					
Lednice	2,165.2	2,605.2	440	121.4	5.1
Kvilda	622.6	1,037.6	415	107.1	12.3
Leaf fall					
Lednice	2,245	2,687	442	123.3	5.0
Kvilda	647.3	1,052.1	404.8	105.4	11.7

Min. – minimum, Max. – maximum, R – variation range, s_x – standard deviation, s_x% – variation coefficient.

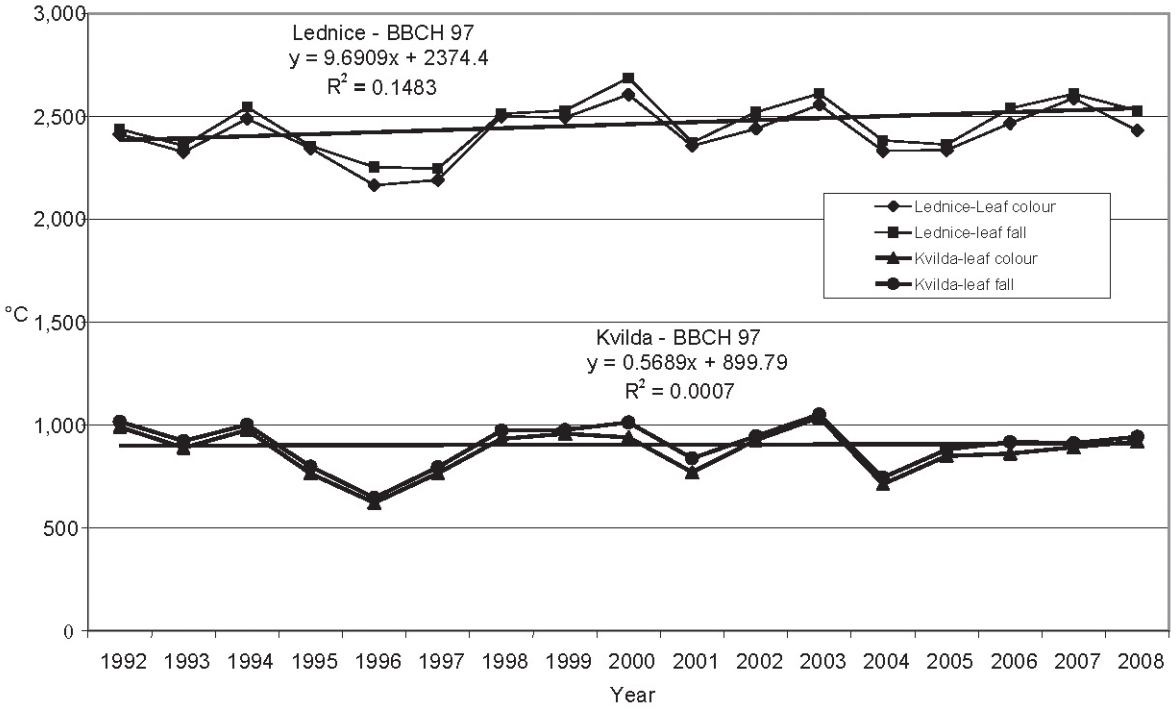

Fig. 3. Sums of effective temperatures above 5 °C for the autumnal phenological phases in the European beech in the years 1992–2008.

Finally, Fig. 4 represents average vegetation season length for all phenological stations according to altitude.

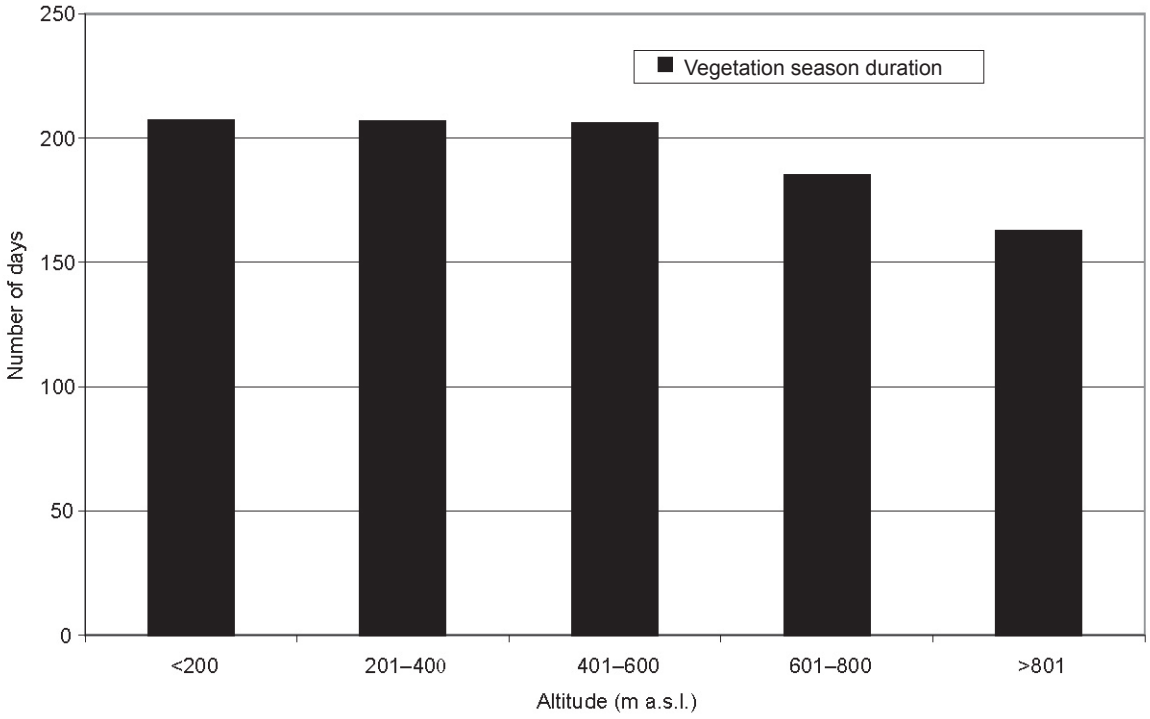

Fig. 4. Vegetation season length dependent on altitude in European beech in Czechia in 1992–2008.

Conclusions

European beech has been included into the phenological observation programme carried out across Czechia by the Czech Hydrometeorological Institute at its phenological stations. The results of phenological observations during 1992–2008 show considerable inter-annual differences in start and duration of individual phenophases. In the phase bud burst, the difference was 19–17 days (lowland station, mountain station), the lowest sum of effective temperature (TS5) for the phase start was 1.2 °C – lowland (3.5 °C – mountain), the highest was 148.2 °C – lowland (52.8 °C – mountain). Bednářová and Merklová (2007) studying European beech phenophases in the Drahanská vrchovina hills report for bud break the lowest sums of effective temperatures 10.9 °C, and the highest 135.6 °C . Hanousková (2010) calculated the average sums of effective temperatures to bud burst onset (123.7 °C – Lednice station, 112.5 °C – Chřibská station), to first leaves 100% onset (283.6 °C – Lednice station, 161.5 °C – Chřibská station) and to leaf fall onset (2,450.4 °C – Lednice station, 1,899.5 °C – Chřibská station).

The variation range for the 100% leaf fall was 50 days (Lednice) at the sum of effective temperatures 2,245.0 °C to 2,687 °C, and 40 days (Modrava) at the sum of effective temperatures 647.3 °C to 1,052.1 °C. The corresponding results from the Drahanská vrchovina hills (Bednářová and Merklová, 2007) were for the same phenophase in European beech 1,137.4 °C to 2,200 °C. We can see that altitude and locality has a considerable influence on phenophase onset.

The phenophase bud burst manifested higher relative variation coefficient than the phenophase leaf fall (100%); on the other hand, the variation range was larger in defoliation. The phenophase bud burst starts earlier in lowlands, leaf fall (100%) in mountains. The length of interphase interval bud burst – leaf fall (100%) was on average 223 days in the lowlands and 157 days in the mountains, length of interphase interval bud burst – first leaves (100%) was on average 19.8 days in the lowlands and 9.2 days in the mountains, and the length of interphase interval leaf colouring (10%) – leaf fall (100%) was on average 55.5 days in the lowlands and 26.4 days in the mountains.

The results show a high variability of phenophase onset during the last 17 years, in dependence on the weather course and location (altitude). The differences in totals of effective temperatures between lowlands and mountains were relatively high. The length of interval between bud burst – leaf fall (100%) (meaning the length of vegetation period) was 223 days in the lowlands and 157 days in the mountains. The sums of effective temperatures at the start of autumnal phenological phases in the recent years show an increasing tendency, resulting from gradual warming and thus prolongation of the growing season.

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Vývoj vegetativních fenologických fází buku lesního (*Fagus sylvatica L.*) ve vztahu k efektivním teplotám vzduchu za období 1992–2008 v Česku

Souhrn

Fenologické pozorování má v českých zemích dlouhou tradici. Vzhledem ke změně metodiky v 80. letech 20. století jsme pro zpracování využili výsledky fenologických pozorování lesních rostlin – buk lesní (*Fagus sylvatica L.*) vybraných vegetativních jarních a podzimních fenofází. I když je počátek fenofází podmíněn hodně genetickými vlastnostmi rostlinného druhu, počasí může ovlivnit nástup fenofází a tím narušit další vývoj rostlin. Z meteorologických prvků má největší vliv na počátek a trvání fenofází teplota vzduchu – za rozhodující charakteristiku lze považovat sumu efektivních teplot, která fázím předchází. Ve studii jsou ukázány výsledky sedmnáctiletého pozorování zvolených fenofází rašení, první listy (100 %), žloutnutí listů (10 %) a opad listů (100 %) jednak ze všech fenologických stanic ČHMÚ a detailně jsou zpracovány fenologické stanice v extrémně rozdílných nadmořských výškách (Lednice, 165 m n. m., Přibyslav 533 m n. m. a Modrava 1 102 m n. m.). Výsledky prokázaly vliv nadmořské výšky na nástupu fenofází, průměrné datum nástupu fenofáze rašení nastává na stanici Lednice (165 m n. m.) dne 14. 4. a na stanici Modrava (1 102 m n. m.) dne 6. 5., průměrné datum fenofáze prvních listů 100 % nastává dne 4. 5. (Lednice) a dne 15. 5. (Modrava), průměrné datum žloutnutí listů 10 % nastává dne 28. 9. (Lednice) a 13. 9. (Modrava) a průměrné datum opadu listí 100 % přichází dne 23. 11. (Lednice) a dne 9. 10. (Modrava). Průměrná suma efektivních teplot nad 5 °C je u nížinné stanice Lednice 71,6 °C (BBCH 07), 250,3 °C (BBCH 15), 2 413,9 °C (BBCH 92) a 2 461,6 °C (BBCH 97) a u horské stanice Kvilda 20,2 °C (BBCH 07), 134,6 °C (BBCH 15), 871,5 °C (BBCH 92) a 904,9 °C (BBCH 97). Průměrná délka vegetačního období je 198,3 dne v průměru ČR, v nížinných polohách 223 dní a v horských 157 dní. Suma efektivních teplot nad 5 °C vykazuje u podzimních fenofází stoupající tendenci, tedy prodlužování délky vegetačního období v posledních letech.

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