Phenology of pedunculate oak (*Quercus robur* L.) in the Zvolen basin, in dependence on bio-meteorological factors

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Abstract

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The paper presents the course of phenophases in pedunculate oak (*Quercus robur* L.) in the Zvolenská kotlina basin. The phenophases were observed according to the SHMÚ methodology. There were evaluated vegetative (leaf unfolding, bud-burst, leafing, autumn leaf discolouration, leaf-fall) and generative (flower buds, flowering, end of flowering, ripening of fruits) phenophases over 2003–2006, in relation to the bio-meteorological variables. The average day of onset of leaf bud swelling was the April 12, the blossoming phase began towards April 24. Significant for starting these phenophases was the mean daily air temperature not sinking below 0 °C. The spring generative phenophases were launched when the effective air temperature was higher – at 8 °C. The flower buds were observed towards May 6. The flowering started on about May 10. The autumn leaf discolouration started in average on October 9 and the leaffall on November 8. The beginning of these phenophases also depended on temperature and precipitation conditions in the growing season. The ripening of fruits was influenced by temperature and the rate of solar radiation, but it may be conditioned by genetic properties, too. Ripening of pedunculate oak fruits was observed towards September 19. The autumn phenophases finished sooner in dry years than in wet years.

Key words

phenology, Pedunculate Oak (*Quercus robur* L.), temperature sums

Pedunculate Oak (Common Oak, English Oak (*Quercus robur* L.)) belongs to the most productive woody plants in forest stands. Sharing with 13.5% (Anonymus, 2003) on the species composition of Slovak forests, it is the second most abundant woody plant in the country. In the Zvolenská kotlina, basin, oak trees are present in high amounts from the hill slopes to the basin bottom, in spite of an evidently continental character of the territory (Magic, 1997). Pedunculate oak tolerates appropriately also low temperatures; the discussed territory, however, only contains small remnants of the original hornbeam-oak forests in areas that have been declared protected. One of these localities with occurrence of old pedunculate oak trees is the Arboretum Borová hora of the Technical University in Zvolen. We have subjected the fragments of the original stands in this locality to phenological observations.

In context of the ongoing climate development and supposed climate change, phenological observations would contribute to recognising development of biotic components of the environment and changes in spatial distribution of woody plants, Defila (1996), Schieber (2006), Schieber and Kováčová (2000), Štefančík and Cicák (1991).

Material and methods

Our analysis of observations of phenological events in pedunculate oak in the Zvolenská basin has been elaborated for the period 1990–1994 (Škvareninová, 2003).

We carried out phenological observations in a fragment of pedunculate oak stand, cca 70–75 years in age. As for topography, the plot is situated on the SW of the Zvolenská upland, a sub-unit of the Zvolenská basin area. Character of the territory is hilly, altitude ranging 290–380 m asl, prevailing orientation N-NW. The long-time mean annual temperature is 8.2 °C, the mean annual precipitation total is 757 mm (Labanc et al., 1992).

The plot was selected in an area with natural occurrence of pedunculate oak and it comprised ten oak trees. The particular vegetative and generative phenophases were observed and recorded in years 2003–2006, following the methods proposed by the Slovak Institute of Hydrometeorology (SIHM) in Bratislava (Anonymus, 1984). We recorded the following phenophases and their stages:

- vegetative: leaf bud swelling (LBS 10%, 50%, 100%), bud-burst (BB 10%, 50%, 100%), leafing (L 10%, 50%, 100%), leaf discolouration (LD 10%, 50%, 100%), leaf-fall (LF 10%, 50%, 100%)
- generative: flower buds (FB 10%, 50%, 100%), flowering (F 10%, 50%, 100%), blossom fall (BF 100%), running to seed (RS 10%, 50%, 100%).

The observation intervals for monitoring the spring phenophases were short (2–3 days), the autumn phenophases were observed in general once a week. In case of spring phenophases we recorded their start, that means the day when at least 10% of the individuals had reached the concerned phase. The general arrival was considered the day when the phenophase could be observed in 50% trees. The full arrival meant that the phenophase could be observed in 100% trees. To facilitate the data processing, the phenophases-related dates were provided with the absolute numbers ordering the days since the January 1.

The start of particular phenological phases is influenced by several biometeorological factors. Governing is the sum of mean daily air temperature values. We evaluated the impact of sum of mean temperatures exceeding 0 °C (TS0), 5 °C (TS 5), 8 °C (TS8), and 10 °C (TS10).

Results and discussion

Course of spring phenophases

The objective of this work was to evaluate pedunculate oak phenophases in connection to bio-meteorological conditions at the site in 2003–2006. There were observed differences in start and course of spring phenophases between the individual years – air temperature was the decisive factor controlling the phase start and duration. For start of spring phenophases is necessary an appropriately long raising air temperature in several days previous to the start, and reaching the temperature sum appropriate for the activation. The timing of spring phenophases over the study period as well as statistical characteristics are summarised in Table 1. For each phenophase we calculated sums of mean daily air temperatures for threshold temperatures at which the phenological processes are activated most frequently. The average sums of effective temperatures necessary for activation of the phenophases are in Table 2. Sums of temperatures exceeding 0 °C at start of spring vegetative phenophases in years 2003–2006 are in Fig 1.

The leaf bud swelling in the study period was dated on average from the early days of April (5.4.) to the mid of this month (16.4.). The general arrival was observed on April 12, on average. In case of this phase we recorded the biggest differences in phase length (9–19 days), and also in the start timing between the years. This fact has also been confirmed with variation coefficient values ranging from 2.60% to 4.82%. Instable, considerably fluctuating, weather in the spring caused that in 2003 lasted this phase 18 days, in spite of its early beginning. In the last two years was the duration of this phase 6–8 days only. The start of coming this phenophase (LBS 10%) depends on the temperature limit of 0 °C (TS0 = 152.2 °C) with the lowest measure of variability and uniform course of values. The temperature sums (TS5) exceeding 5 °C assign to this phase a temperature sum of 34.7 °C on average. Low and zero values of temperature sums over 8 °C and 10 °C in individual years might result in distorted values when evaluating temperature demands of this woody plant.

The first manifestations of bud-burst were observed in first days of the third ten-day period of April, the variation range was 4 days. The average timing of arrival the phenophase in 50% was April 24, at a temperature sum TS0 = 332.2 °C. This phenological stage also depended on occurrence of higher average air temperatures exceeding 5 °C (TS5 = 124.1 °C), which was indicated by the smallest variation coefficients of the temperature sums. The variation range of this phenophase course was 8–11 days. The beginning of leaf unfolding (10%) occurred on May 3, on average. The average date of general leafing (50%) was May 7, the total leafing was observed on May 10, on average. Comparing with the observation results obtained in years 1990–1994 (Škvareninová, 2003) according to that the average date of 50% leafing was May 6, we can see that this parameter, shifted by one day backwards, does not indicate a change in climatic conditions in this territory. Such change could only be indicated by evaluation over longer time periods. For the whole Slovak territory and the years 1986–1995 (Kamenský and Braslavská, 1999) the average beginning of leafing phenophase was reported on April 30, which is 3 days earlier compared to our results. The phenophase length was from 6 to 10 days. The earliest start was recorded on April 24, year 2005. The phase of general leafing occurred at a temperature interval of 0–5 °C, when the course of temperature sums was most equalised (TS0 = 490.5 °C, TS5 = 222.4 °C) and the variation coefficients values were lowest (8.9–9.3%). In the spring phenophases, the highest variability was observed in the phase bud swelling. The other two spring vegetative phases (leaf bud-burst and leaf unfolding) had considerably lower variability (1.09–2.77%), which allows

Table 1. History of spring phenophases in Pedunculate Oak (*Quercus robur* L.) and their statistical characteristics in years 2003–2006 (x – arithmetic mean, s_x [%] – standard deviation)

Year	2003	2004	2005	2006	x	s_x [%]
Phenophase			Julian Days (date)			
LBS 10%	87	97	95	100	95 (5. 4.)	4.82
LBS 50%	99	105	99	103	102 (12. 4.)	2.60
LBS 100%	105	110	101	108	106 (16. 4.)	3.39
BB 10%	108	112	109	111	110 (20. 4.)	1.58
BB 50%	114	116	112	115	114 (24. 4.)	1.48
BB 100%	118	119	116	118	118 (28. 4.)	1.09
L 10%	123	126	119	123	123 (3. 5.)	2.49
L 50%	127	128	122	132	127 (7. 5.)	2.49
L 100%	131	131	125	132	130 (10. 5.)	2.77
FB 100%	124	127	125	127	126 (6. 5.)	1.30
F 100%	127	129	131	130	130 (10. 5.)	1.48
BF 100%	131	132	138	139	135 (15. 5.)	3.54

Table 2. Average sums of effective temperatures on days with temperature exceeding 0 °C (TS0), 5 °C (TS5), 8 °C (TS8), 10 °C (TS10) over the period 2003–2006

Spring Phenophase	Average sums of effective temperatures for days exceeding 0 °C, 5 °C, 8 °C, 10 °C			
	TS0	TS5	TS8	TS10
	[°C]			
LBS 10%	152.20	34.68	6.90	1.23
LBS 50%	197.85	52.40	12.63	2.98
LBS 100%	237.90	70.63	19.80	4.93
BB 10%	287.13	99.85	37.03	14.15
BB 50%	332.23	124.05	49.98	20.70
BB 100%	373.58	147.90	63.55	28.03
L 10%	442.00	191.33	91.98	46.60
L 50%	490.53	222.35	112.50	60.28
L 100%	542.28	256.60	136.25	77.30
FB 100%	483.03	217.35	109.00	57.73
F 100%	523.55	240.38	122.50	65.85
BF 100%	608.35	296.43	161.30	93.70

us to conclude that their course was quite equalised, thanks to uniform temperature course without abrupt fluctuations. The probable cause of such a low variability was uniform temperature course in late spring in the preceding year. The preliminary results show that there were no remarkable shifts in beginning of spring vegetative phenophases. Their arrival and course is controlled by character of weather. In Fig 1 we can see that in 2004, the spring phenophases came at higher effective air temperatures, exceeding 0 °C, than in the other years, which was caused by the cold end of winter. The year 2003 was characterised by mild temperatures towards the end of winter and by a relatively warm beginning of spring. This fact was reflected in the low sum of effective temperatures conditioning the arrival of swelling and burst of leaf buds. In the study period we did not record a remarkable increase in effective temperature sum at the beginning and during the course of individual phenophases.

The flower buds came together with leaf unfolding. Fully developed male flowers, but without pollen release yet, occurred towards May 6, on average. The length of this phenophase in the study years was only 3–4 days. The start was always dated very similarly – which has also been confirmed with very similar values of variation coefficient (1.3–1.92%). The obtained values of temperature sums suggest as decisive for this phase at 50% the value 8 = 101.2 °C, at 100% the value of TS8 = 109 °C – with the most uniform values and the lowest variation coefficients of temperature sums ranging from 8.9% to 10.4%.

The flowering of pedunculate oak starts immediately after the total, 100% leafing. It is the phenophase with the most stable arrival and the lowest variability (s_x% = 1.30–1.48). The phase of full 100% average flowering was recorded on May 10, after reaching the sum TS8 = 122.5 °C. At that time we calculated the lowest value of variation coefficients of temperature sums (5.4%), and recorded the smallest differences between the temperature sums in the individual years. The length of flowering ranged from 2 to 4 days, which is in comparison with the period 1990–1994 (Škvareninová, 2003) less by 2–4 days.

The full running to seed occurred on May 15, on average, and it lasted quite shortly, 3–7 days after having reached the TS8 = 161.3 °C. The spring generative phenophases are characterised with a short time history, and their arrival is controlled with air temperature average values exceeding 8 °C.

Course of autumn phenophases

The arrival dates of autumn phenophases in years 2003–2006 are in Table 3, the sums of effective temperatures are in Table 4.

The first autumn vegetative phenophase, signalising the end of photosynthetic activity, is leaf discolouration (yellowing). This phase started on September 24, on average, and lasted up to October 21. The earliest start was recorded in the year 2003, when the first yellow leaves were already observed on September 12. The latest was the beginning dated in 2006, when

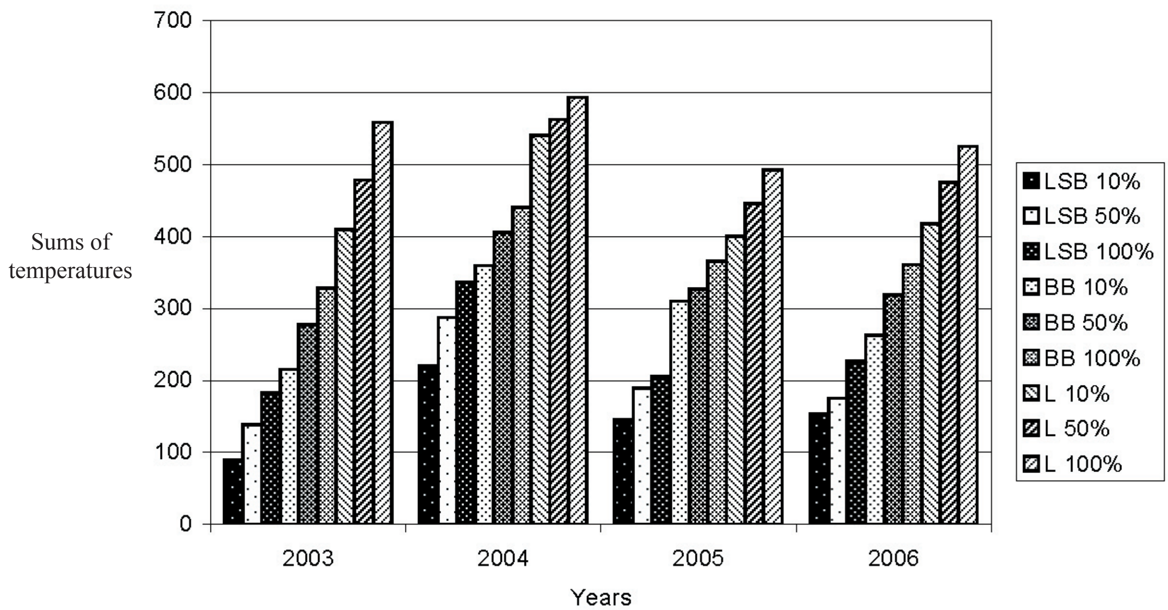

Fig 1. Sums of temperatures exceeding 0 °C at start of spring vegetative phenophases in Pedunculate Oak (*Quercus robur* L.) in years 2003–2006

Table 3. Start of autumn phenophases in Pedunculate Oak (Quercus robur L.) and their statistical characteristics in years 2003–2006 (x – arithmetic mean, s_x [%] – standard deviation)

Years	2003	2004	2005	2006	x	s_x [%]
Phenophases			Julian Days (date)			
LD 10%	255	271	269	272	267 (24. 9.)	6.87
LD 50%	272	279	291	286	282 (9. 10.)	7.18
LD 100%	289	292	297	296	294 (21. 10.)	3.20
LF 10%	295	297	298	303	298 (25. 10.)	2.94
LF 50%	304	306	320	318	312 (8. 11.)	7.07
LF 100%	314	312	332	325	321 (17. 11.)	8.17
RS 10%	232	257	248	251	247 (4. 9.)	9.25
RS 50%	255	267	264	263	262 (19. 9.)	4.44
RS 100%	265	273	271	276	271 (28. 9.)	4.02

Table 4. Average sums of effective temperatures on days with temperature exceeding 0 °C (TS0), 5 °C (TS5), 8 °C (TS8), 10 °C (TS10) for autumn phenophases in years 2003–2006

Autumn Phenophase	Average sum of effective temperatures on days exceeding 0 °C, 5 °C, 8 °C, 10 °C			
	TS0	TS5	TS8	TS10
	[°C]			
LD 10%	2,927.5	1,956.8	1,426.6	1,098.0
LD 50%	3,110.0	2,063.3	1,488.8	1,135.1
LD 100%	3,207.1	2,105.4	1,507.6	1,143.9
LF 10%	3,244.3	2,121.0	1,513.9	1,145.7
LF 50%	3,319.4	2,149.9	1,529.0	1,154.7
LF 100%	3,360.4	2,164.6	1,534.2	1,155.7
RS 10%	2,630.5	1,758.6	1,287.6	997.6
RS 50%	2,865.1	1,917.0	1,400.2	1,026.8
RS 100%	2,574.4	1,706.2	1,237.4	949.2

it was shifted to September 29. The average date of start of leaf discolouration in Slovakia in the decade 1986–1995 (Kamenský and Braslavská, 1999) was calculated September 19, which is 20 days earlier compared to our results. The start of this phenophase (10%) is dependent on the weather course in summer months. For the full arrival (100%) it was necessary to reach the appropriate sum of effective temperatures. This sum was highest in year 2003 (TS0 = 3,318 °C), lowest in 2004 (TS0 = 3,050 °C).

The leaf fall is influenced by several factors. Apart from abrupt drops in temperature, there are genetic predispositions expressed through delayed leaf-fall in the same individuals in each year. There can be also considerable contribution of wind, significantly accelerating the rate of the process. The leaf-fall occurred in average from October 25 to November 17. The earliest arrival of this phenophase was recorded in 2003, the latest in 2005. In all the study years, the total leaf fall was observed at almost the same values of temperature sum with average exceeding TS0 = 3,360.4 °C. Compared to the period 1990–1994 (Škvareninová, 2003), the general leaf fall was shifted almost 30 days later.

The fruit maturity in oak is manifested through brown-coloured acorns releasing from the cupules. Based on our observations, we have dated the average beginning of this phenophase on September 4, and the total ripeness on September 28. In comparison with the observations carried out in 1986–1995 (Kamenský and Braslavská, 1999), this phenophase arrived 15 days earlier; in comparison with observations carried out in 1990–1994 (Škvareninová, 2003), it was 9 days earlier. The beginning of this phase was observed earliest in 2003, on August 20, but the phase was also the longest one (34 days). On the other hand, the latest beginning was recorded in year 2004 (September 14), and the phenophase length was shortest – 22 days. In spite of the fact that the date of beginning fruit maturity was shifted towards the end of the summer period (the first days of September), the average length of this phenophase was maintained without changes. The autumn phenophases are also characterized with higher variability (s_x = 2.94–9.25%), caused probably by abrupt temperature changes and drops below the freezing point in this period.

The beginning of leaf discolouration in 2003 (10%) was connected with a very warm end of summer, which has also been confirmed with a high temperature sum (Fig 2). The following autumn phenophases in all the study years arrived with almost equal sums of effective temperatures exceeding 0 °C, without remarkable changes. We can conclude that there is neither warming a prolonged vegetation period in this season. The preliminary results obtained in evaluation of course of autumn phenophases of pedunculate oak in the Zvolenská kotlina basin show that these changes are not dependent on air temperature only but also on a range of factors involving, according to Hofman (1957), the length of solar radiation and moisture conditions in summer, abrupt temperature changes in autumn, and, according to our observations, strong wind, too. Hejtmánek (1958) states that the light intensity and site quality have also important role for ending the growing cycle. The autumn phenophases, unlike the spring ones, are more influenced by precipitation total over the growing season. In years with lower summer precipitation, the autumn phenophases are dated earlier. In our study period, the earliest was the timing in 2003, because this year was very poor in precipitation. The autumn phenophases were characterised with higher variability than the spring ones, which is also documented by the values of variation coefficient ranging from 2.94% to 9.25%.

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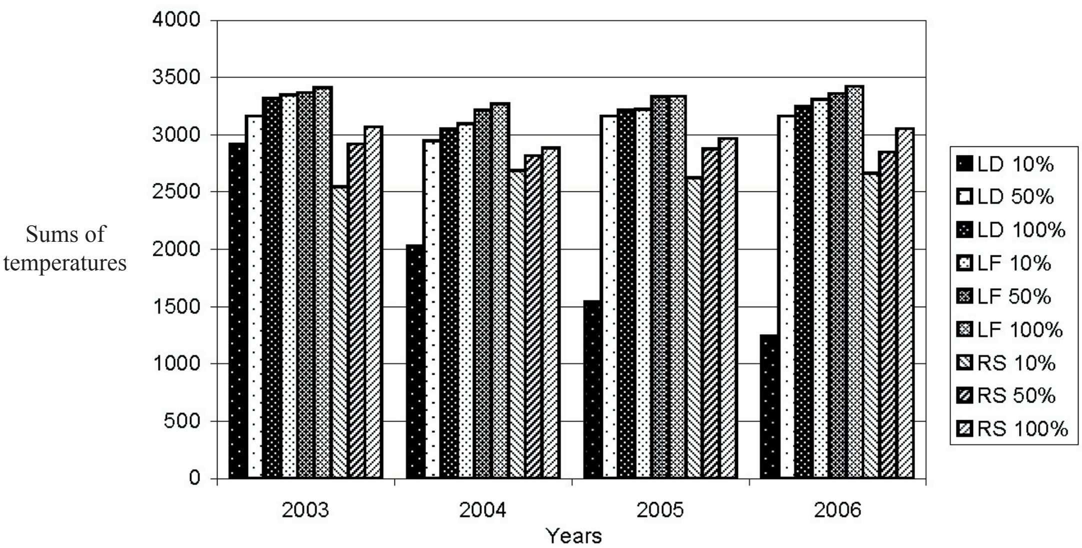

Fig. 2. Sums of temperatures exceeding 0 °C at start of autumn vegetative phenophases in Pedunculate Oak (*Quercus robur* L.) in years 2003–2006

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Vybrané fenofázy duba letného (*Quercus robur* L.) v Zvolenskej kotline vo vzťahu k biometeorologickým faktorom

Súhrn

Z výsledkov fenologických pozorovaní duba letného v Zvolenskej kotline v rokoch 2003–2006 sme zistili odlišný nástup a dĺžku trvania jarných fenofáz v jednotlivých rokoch. Rozhodujúcu úlohu zohráva teplota vzduchu. Všeobecný nástup pučania listových púčikov prebiehal v sledovaných rokoch v prvej polovici apríla, priemerný deň nástupu bol 12. apríla. Pre začatie procesu rastu púčikov duba je rozhodujúci vzostup priemerných denných teplôt vzduchu nad 0 °C, kedy teplotná suma TS 0 dosiahla hodnotu 197,85 °C a zaznamenali sme najnižšiu mieru variability. Pučanie listových púčikov dosahuje vyššie hodnoty variačných koeficientov (2,60–4,82 %), čo súvisí s väčším výkyvom teplôt v skoršom jarnom období. Fáza všeobecného rozpuku listových púčikov pripadá v priemere na 24. apríl. Začína pri priemernej teplotnej sume TS 0 = 332,2 °C, a je už podmienená aj nástupom vyšších priemerných denných teplôt vzduchu nad 5 °C (TS 5 = 124,1 °C). Priemerný dátum nástupu všeobecného zalistenia (50 %) pripadá na 7. máj a nastáva v teplotnom intervale 0–5 °C pri dosiahnutí sumy teplôt TS 5 = 222,4 °C.

Z predbežných výsledkov pozorovaní vyplýva, že nedochádza k výraznému posunu termínov nástupu vegetatívnych fenofáz oproti predchádzajúcim rokom. Pri fenofáze pučania listových púčikov sme zaznamenali najväčšiu variabilitu v dĺžke trvania fenofázy, ako aj v časovom nástupe v jednotlivých rokoch. Pri nástupe fenofáz sme nezaznamenali výraznejší nárast sumy efektívnych teplôt.

Jarné generatívne fenofázy sa vyznačujú krátkym časovým priebehom a na ich aktivovanie je potrebná priemerná teplota vzduchu nad 8 °C. Potvrdzujú to najnižšie variačné koeficienty a vyrovnané hodnoty teplotných súm TS 8.

Priemerný začiatok žltnutia listov nastáva 9. októbra, opad listov 8. novembra. Z predbežných výsledkov vyhodnotenia priebehu jesenných vegetatívnych fenofáz duba letného v Zvolenskej kotline je zrejmé, že nastupujú neskôr oproti predchádzajúcim rokom, ale ich dĺžka sa výrazne nemení. Zrelosť plodov sa výrazne posunula na koniec letného obdobia, priemerný začiatok fenofázy nastáva 19. septembra, ale dĺžka trvania ostáva nezmenená.

Zistili sme, že jesenné fenofázy nesúvisia len s teplotami vzduchu, ale ich výrazne ovplyvňuje dĺžka slnečného žiarenia a vlhkostné pomery počas letných mesiacov, náhle zmeny teploty v jesennom období a sú čiastočne podmienené aj genetickými vlastnosťami jedincov, čo sa prejavilo odchýlkami fenofáz na tých istých jedincoch v každom roku. Jesenné fenofázy nastupovali v suchých rokoch skôr, ako v rokoch bohatých na zrážky. Takmer vyrovnané sumy efektívnych teplôt vzduchu počas štvorročného obdobia dokazujú stálosť klimatických podmienok.

Výsledky fenologických pozorovaní duba letného je možné využiť na rozšírenie poznatkov o jeho nárokoch na podmienky prostredia a tiež ako bioindikátor klimatických zmien pri vyhodnotení dlhšieho radu pozorovaní.

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