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IMPACT OF CLIMATOLOGICAL DROUGHT ON THE LEAVES YELLOWING PHENOPHASE SELECTED TREE SPECIES

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This work evaluates drought impacts on initiation and ending of specific phenophases in autochtonous forest woody plants in Slovak republic. The research ran on an assembly of forest woody plants long-term monitored in the locality Borová hora near Zvolen. The study period encompassed years 2007–2017. There were evaluated rainfall amounts in months June – August. The drought was identified based on climatological indicators such as: Thornthwait drought index (TDI), climatic water balance (CWB) and tropical days period (TDP). There is evident a considerable variability among the years. Hydrological extremes were the most conspicuous in years 2014 and 2015, with drought manifested trough premature leaves yellowing and trough altered trends in initiation and ending phenophases in the woody plants studied.

KEY WORDS: drought, phenology, forest woody plants, Slovak Republic

VPLYV KLIMATOLOGICKÉHO SUCHA NA FENOLOGICKÚ FÁZU ŽLTNUTIA VYBRANÝCH DREVÍN. Práca sa zameriava na zhodnotenie dopadu sucha na nástup vybraných fenologických fáz autochtónnych lesných drevín na Slovensku v lokalite Borová hora pri Zvolene. Sledovania sa vykonávali v rokoch 2007 – 2017 na skupine fenologicky dlhodobo sledovaných lesných drevín. Z meteorologických prvkov sa vyhodnotili zrážky v mesiacoch jún až august. Sucho sa sledovalo za pomoci klimatologických ukazovateľov ako napríklad: Thornthwaitov indexu sucha (TDI), klimatická vodná bilancia (CWB) a perióda tropických dní (TDP). Medzi rokmi vidieť výraznú variabilitu. Hydrologické extrémy sa najmarkantnejšie ukázali v roku 2014 a 2015 pričom sucho sa prejavilo napríklad predčasným žltnutím listov a zmenami trendu nástupov a ukončenia fenofáz skúmaných drevín.

KĽÚČOVÉ SLOVÁ: sucho, fenológia, lesné dreviny, Slovensko

Introduction

Drought, in terms of meteorology and climatology means a deficit in atmospheric water, soil water and water accessible for plants. This is the common definition according to the Explanatory and Terminological Dictionary of Meteorology (Collective, 1993). Droughts occurs during certain time periods, mostly irregular. Associated phenomena are high air temperature, low air humidity and numerous hours with solar radiation. Climatological drought is acknowledged based on the ratio between the rainfall situation over the period concerned and the long-term average value (normal) for a standard period (Wilhite, 1991). The drought can also be identified through climatological indicators, dependent on additional climatic variables such as air temperature and humidity, evapotranspiration, wind velocity and solar radiation – potentially alleviating or aggravating the drought impacts on organisms.

Together with fires, windstorms and snow calamities, drought belongs to harmful abiotic environmental phenomena altering the structure of woody plants and deteriorating the health status of forest stands. The current climate change escalates occurrence and impacts of these phenomena. Several authors have analysed the drought-stress induced effects on the increment creation decline in autochthonous woody plants and on increase in biotic pests occurrence (Davi et al., 2006; Hoffmann et al., 2009). Hlásny et al. (2014) report drought as a factor limiting the survival of forest woody plants in lower situated areas. On the other hand, in higher

situated ones, the temperature increase and growing season prolongation can provide profits for forest associations. Phenological manifestations in woody plants represent important bioindicators for the atmospheric conditions the round-the-year. These phenomena enable us to recognize the long-lasting changes to the landscape.
The current climate change cause, especially in summer, distinctly diverse area distribution patterns in rainfall, which results in more and more frequent floods or drought periods. One of the primary indicators for hydrobiological conditions − the annual rainfall sum may sometimes distort or mask their round-the-year variability. Consequently, more appropriate parameters to analyse are monthly rainfall sums affecting the leaves yellowing and, accordingly, the growing season´s length. The rainfall deficit together with temperature extremes negatively affect the physiological processes in woody plants and cause premature leaves yellowing as early as towards the summer end (Středová et al., 2013). The stress resistance capacity in woody plants is specific, determined genetically to some extent, but also depending on the intraspecific variability. The long-lasting impacts from external stress factors can be responded by changes to ecosystems in particular vegetation tiers and changes to occurrence ranges in woody plants.
The aim of this work was to investigate the impacts of extreme drought on initiation and length of the leaves yellowing phenophase in the Zvolenská kotlina, Basin. In years 2007–2017 we evaluated these climatological indicators: Thornthwait drought index (TIS), climatic water balance (CWB), tropical days period (TDP) and their impacts on yellowing leaves in pedunculate oak (*Quercus robur* L.), small-leaved linden (*Tilia cordata* Mill.) and black thorn (*Prunus spinosa* L.).

Material and methods

The research ran in the Zvolenská kotlina, Basin, in localities with occurrence of autochthonous woody plants *Quercus robur* L., *Tilia cordata* Mill., *Prunus spinosa* L. at an altitude of 300 m a.s.l. The territory belongs to the warm to moderate warm climatic area, the boundary between the warm, moderate-wet district with cold winters and the moderate-warm, moderate-wet colline to hilly district (Lapin *et al.,* 2002). The sample sets consisting of 10 exemplars for each woody plants served for observing the occurrence of first discoloured leaves (10% occurrence) in accord with the methods proposed by the Slovak Hydrometeorological Institute (Anonymus, 1984). At the international scale, this phase is labelled with a growth stage code BBCH 92. The phenological data were processed statistically, with the days dated absolutely from the year's beginning (so called Julian day). The water regimen in the individual years focused on the rainfall sums in the summer months June−August. We recorded the numbers of days with abundant precipitation over 20 mm, and the maximum daily sums. The drought indicators were: Thornthwait drought index (TDI), climatic water balance (CWB), unbroken tropical days period (TDP) from the station Sliač situated approximately at the same altitude as our study site.
The Thornthwait drought index was calculated according to Thornthwait and Mather (1955):

$$TDI = 100((P/PE)-1) \quad (1)$$

where
TDI – Thornthwait drought index,
P – precipitation (mm),
PE – potential evapotranspiration (mm).

The climatic water balance was calculated with using the potential evapotranspiration according to Ivanov (Novák 1995):

$$CWB = P - PE \quad (2)$$

where
P – precipitation (mm),
PE – potential evapotranspiration (mm),

$$PE = 0.0018\ (25+T)^2\ .\ (100-RH) \quad (3)$$

where
T – air temperature (°C),
RH – relative air humidity (%).

Tropical days period is given by the number of consecutive days with an air temperature ≥ 30 °C. We also recorded the maximum daily air temperature and the numbers of tropical days in particular months.

Results and discussion

During the study period, we recorded the differences in the temperature and rainfall regimens (Tables 1−3). Climatological drought was recognized in years 2007, 2012, 2015 and 2017, which follows from the lowest negative values of climatic water balance and of the Thornthwait drought index. An absolute extreme was the year 2015, whose summer was the most abundant in tropical days, with a longest unbroken period of 13. In this year, there had also been exceeded, by 0.2 °C, the long-term mean air temperature maximum for August valid for the years 1961–2010 (Table 3).
Comparing the tropical days period in 2015 with the mean value for 1987–2012 (Škvareninová, 2013) at the same locality, we can indicate an absolute, 13-day record for the tropical period length since 1988. Evaluating the study years in terms of temperature extremes, there are two others not to overlook: 2007 and 2012 – with their air temperature maxima in summer reaching or exceeding the 50-year normal. The numbers of tropical days in July and in August in these two years were 10−15.

Table 1. Selected rainfall characteristics in the Zvolenská kotlina, Basin in years 2007–2017
Tabuľka 1. Vybrané zrážkové charakteristiky v Zvolenskej kotline v rokoch 2007 – 2017

Years	Month rainfall sum/ Max. daily rainfall sum (mm)			Number of days with rainfall >20 mm		
	VI.	VII.	VIII.	VI.	VII.	VIII.
2007	35.1/16	29.3/12	71.5/24.2	0	0	2
2008	129.3/37.9	124.2/37.2	23.5/8.1	3	2	0
2009	112.4/35.4	52.2/20.1	39.6/17.1	2	1	0
2010	170.8/37.6	92.5/26.5	117.6/24.5	3	1	3
2011	149.2/34.5	142.9/55	25.3/9.4	3	3	0
2012	98.5/28.8	108.1/23.5	11.5/5.1	1	1	0
2013	102.9/36.1	13.3/8.2	101/61.6	2	0	1
2014	43/28	171.3/41.8	111.5/28.2	1	4	2
2015	25.9/10.2	120.8/37	31.2/16.5	0	3	0
2016	88.9/20.1	107.9/34.5	97.3/28.3	1	2	3
2017	111.1/61.4	85.7/23	56.1/30.7	1	2	1

Table 2. Indicators of drought and water balance in the years from 2007 to 2017 (− drought, + water surplus)
Tabuľka 2. Indikátory sucha a vodnej bilancie v rokoch 2007–2017 (− sucho, + prebytok vody)

Years	CWB			TDI		
	VI.	VII.	VIII.	VI.	VII.	VIII.
2007	−78	−121	−44	−69	−80	−38
2008	19	10	−90	18	8	−79
2009	17	−85	−88	18	−61	−69
2010	68	−31	42	66	−25	56
2011	44	46	−87	42	47	−77
2012	−12	−10	−137	−11	−9	−93
2013	12	−132	−43	13	−91	−30
2014	−103	60	37	−71	54	50
2015	−105	−42	−99	−80	−26	−76
2016	−23	−10	1	−20	−9	1
2017	−42	−22	−77	−27	−21	−58
1961–2010*	−25	−45	−39	−24	−38	−38

* long-term average (1961-2010)

Table 3. Selected temperature characteristics in June–August in Zvolen Basin 2007–2017
Tabuľka 3. Vybrané teplotné charakteristiky v mesiacoch jún – august v Zvolenskej kotline v rokoch 2007 – 2017

Years	Number of tropical days/T_{max} (°C)			Max. period of tropical days		
	VI.	VII.	VIII.	VI.	VII.	VIII.
2007	4/30.9	13/**37.8**	10/33.0	0	7	0
2008	4/30.7	6/33.1	7/31.9	4	7	0
2009	2/30.4	16/34.0	10/33.1	0	6	6
2010	7/33.1	16/35.4	5/31.4	5	9	3
2011	2/30.7	8/34.5	7/35	0	7	6
2012	8/34.2	14/36.7	15/35.5	6	11	7
2013	6/35.8	12/36.9	12/**37.8**	6	12	12
2014	6/35.8	8/32.7	5/31.7	6	3	3
2015	11/34.4	**19**/37.4	16/37	11	9	**13**
2016	5/33.4	12/35.2	1/30.4	0	6	0
2017	9/32.5	5/33.1	15/36.5	4	3	5
1961–2010*	35.6	37.8	36.8	-	-	**-**

* absolute maximum air temperature inyears (1961–2010)

An appropriate bioindicator for the-year-round temperature and rainfall regimen are autochthonous woody plants responding sensitively to the extreme episodes in their environment. Rainfall shortage and long-lasting high air temperature in summer induce stress state in plants. The result is premature initiation of the autumnal vegetative phenophases, especially leaves yellowing occurring as early as towards the end of August (Fig. 1). The year 2015 with summer weather extremes exhibited noticeable phenological extremes manifested through the earliest initiation of leaves yellowing in linden and in black thorn not only over the entire 30-year period but also within the recent 11 years. The linden's sensitivity against the anomalies in meteorological conditions during the last 11 years has also been confirmed with the highest variation coefficient value making s_x%=4.32 (Table 4). The most conspicuous aberrations from the 30-year mean value for this phenophase were identified in the year 2015 in the linden and in the black thorn manifesting a drought-induced 11-day positive shifts in their leaves yellowing (Table 5). The phenological response in woody plants in the dry year 2015 has also been documented by Hájková et al. (2016). The shifts in the leaves yellowing initiation reported by these authors for the small-leaved linden at nearly the same altitude as our study site are shorter (by 4 days) compared to our observed values. Statistically significant dependence of the leaves yellowing initiation date on the rainfall amount in summer (May–August) has also been acknowledged by Schieber et al. (2009). On the other hand, the pedunculate oak can be classified as a drought-resistant species. In years with extremely high air temperature and rainfall deficit, the leaves yellowing in oak started later by 1–7 compared to the long-term average. Table 5 demonstrate the oak's resistance against more extensive drought, with a single exception of the year 2008 (3 days earlier) with the yellowing phenophase in the period 2007–2017 shifted by 1–16 later compared to the 30-year average dating. Schieber and Kubov (2016) have confirmed the pedunculate oak as the woody plant exhibiting the highest stability as for its phenological response to the environmental conditions within a 20-year time series.

An opposite extreme occurred in years 2010 and 2014 with high rainfall sums and with short periods of tropical days. Due to this, the two years have been ranked to the maximum hydrological extremes with the highest drought indication values. All the woody plants exhibited initiation of leaves yellowing shifted later by 7–20 days compared to the long-term normal. The trend analyses (Fig. 1) detected later initiation of leaves yellowing in: oak by 21 days, black thorn by 11 days and linden by 6 days. Since 2012 have occurred the most extremes weather, which was reflected by the highest deviations of phenological phase from the trend line.

The results suggest that the premature leaves yellowing is, beside extremely high air temperature, also influenced by rainfall amount.

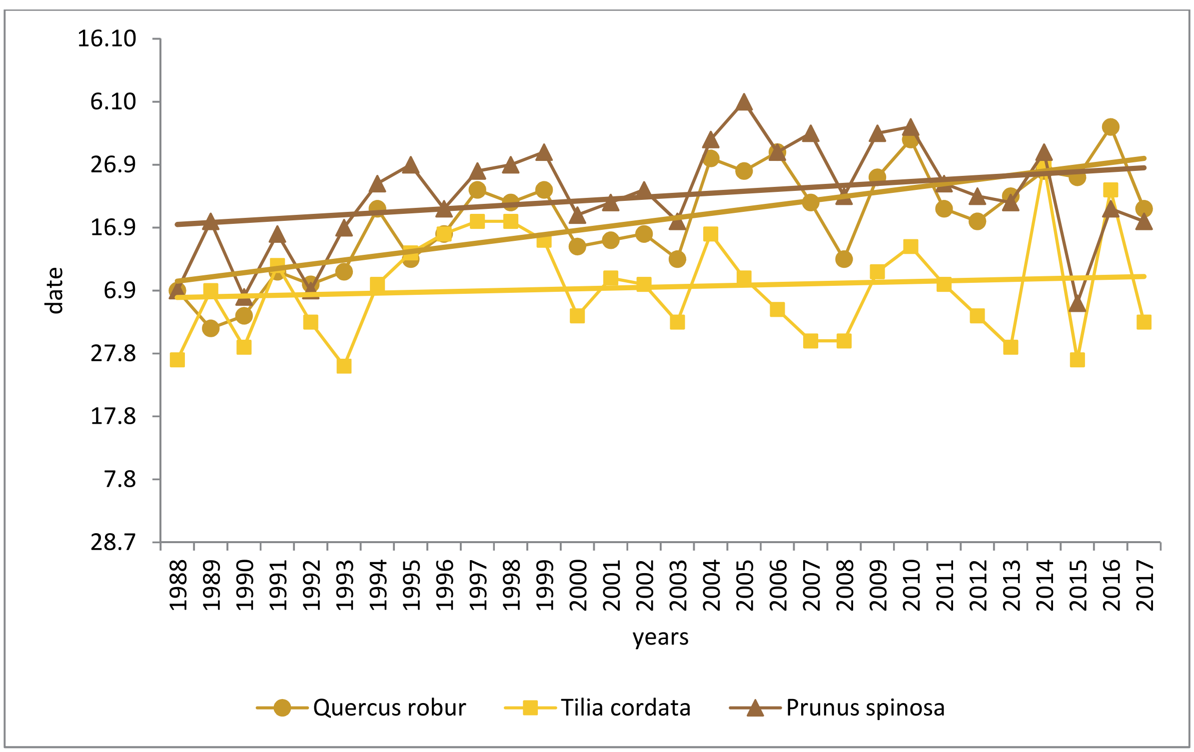

Fig. 1. The onset and trends of yellowing leaves of selected forest trees in 1988–2017.
Obr. 1. Nástup a trendy žltnutia listov vybraných lesných drevín v rokoch 1988 – 2017.

Table 4. Statistical characteristics of the phenological phase of leaf colouring (Ø – average value, min – minimal value, max – maximal value, s_x% – variation coefficient)
Tabuľka 4. Štatistické charakteristiky fenologickej fázy žltnutia listov (Ø – priemerná hodnota, min – minimálna hodnota, max – maximálna hodnota, s_x% – variačný koeficient)

Wood species	$Ø_1$ 2007–2017	min	max	s_x%	$Ø_2$ 1988–2017	s_x%	min	max
Quercus robur	23.9.	12.9. 2008	3.10. 2016	2.12	18.9.	3.08	1.9. 1989	3.10. 2016
Tilia cordata	8.9.	27.8. 2015	27.9. 2014	4.32	7.9.	3.38	27.8. 1988,2015	27.9. 2014
Prunus spinosa	23.9.	5.9. 2015	29.9. 2014	2.91	22.9.	3.06	5.9. 2015	7.10. 2005

Table 5. Shifting the beginning of yellowing leaves of selected trees from normal (1988–2017) (number of days: + earlier, − later)
Tabuľka 5. Posun začiatku žltnutia listov vybraných drevín od normálu (1988 – 2017) (počet dní: + skôr, − neskôr)

Years	*Quercus robur*	*Tilia cordata*	*Prunus spinosa*
2007	−5	+8	−5
2008	+3	+8	0
2009	−8	−3	−10
2010	−15	−7	−11
2011	−4	−1	−2
2012	−1	+4	0
2013	−4	+9	+2
2014	−9	**−20**	−7
2015	−7	**+11**	**+11**
2016	**−16**	−16	+2
2017	−2	+5	+5

The year 2012 can be, based on the drought indicators, classified as a dry one. In this case, however, the woody plants did not respond the drought influence through their leaves yellowing. Higher rainfall sums in July of this year mitigated the drought-induced effects, and this resulted in shifting the yellowing leaves initiation of wood species was not so expressive. In years 2007–2017 the best tolerance against drought extremes associated with the current climate change was observed in pedunculate oak without noticeable manifestations of earlier leaves yellowing, even in years with the longest tropical periods of tropical days. Contrarily, this phenophase had been shifted later. On the other hand, there were found negative shifts in this phenophase timing for the small-leaved linden and for the black thorn responding the temperature extremes very sensitively with shift phenological phase. In case of frequent drought occurrence, these woody plants may suffer from lowering their vitality and they might be forced to adjust their occurrence range.

Conclusion

In years 2007–2017, from June to August, we investigated influence of temperature and rainfall in the Slovakia (locality Borova hora – Zvolen) on initiation of leaves yellowing in summer oak (*Quercus robur* L.), small-leaved linden (*Tilia cordata* Mill.) and blackthorn (*Prunus spinosa* L.) Each species was represented with 10 exemplars for recording 10% presence of initiation this phenophase according to the methods set up by the Slovak Hydrometeorological Institute.

The study years exhibited considerable differences in their temperature and rainfall regimens, which was also reflected in the physiological response in the woody plants. The calculated Thornthwait drought index values and the climatic water balance values indicated the drought occurrence in years 2007, 2012, 2015 and 2017. The most conspicuous drought impact in 2015 was evident on the small-leaved linden and on the black thorn starting their leaves yellowing by 11 days earlier compared to the 30-year average. Contrarily, the pedunculate oak, the species with the most invariable phenological response to the environmental conditions, responded the climatological drought by leaves yellowing delay by 7 days.

Phenological manifestations in woody plants serve as a bioindicator for changes to the local climatic conditions. These manifestations also belong to the main indicators for the species resistance against weather extremes. Their explanatory value is in recognising the links associated to the climate course and in predicting distributional and areal changes, in dependence on the fundamental meteorological features.

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VPLYV KLIMATOLOGICKÉHO SUCHA NA FENOLOGICKÚ FÁZU ŽLTNUTIA VYBRANÝCH DREVÍN

Sucho patrí spolu s požiarmi, víchricami a snehom k abiotickým škodlivým faktorom prostredia, ktoré výrazne menia štruktúru drevín a zhoršujú zdravotný stav lesných porastov. Pri nastupujúcej klimatickej zmene sa ich pôsobenie prejavuje častejšie. Fenologické prejavy drevín predstavujú dôležité bioindikátory stavu atmosféry počas roka. Prostredníctvom nich je možné zaznamenať dlhotrvajúce zmeny v krajine.
Cieľom práce bolo zistiť vplyv extrémov sucha na nástup a trvanie fenologickej fázy žltnutie listov autochtónnych drevín v Zvolenskej kotline. V priebehu rokov 2007 – 2017 sme vyhodnotili klimatologické ukazovatele Thornthwaitov index sucha (TDI), klimatická vodná bilancia (CWB), perióda tropických dní (PTD) a ich vplyv na žltnutie listov duba letného (*Quercus robur* L.), lipy malolistej (*Tilia cordata* Mill.) a trnky obyčajnej (*Prunus spinosa* L.).
Výskum prebiehal na Slovensku v lokalite Borová hora pri Zvolene s prirodzeným výskytom autochtónnych drevín. Na skupine 10 jedincov každého druhu sme pozorovali prvé žlté listy (10 % výskyt) podľa metodiky Slovenského hydrometeorologického ústavu. V medzinárodnej stupnici je táto fenofáza označená kódom rastového štádia BBCH 92. Pri hodnotení vodného režimu v jednotlivých rokoch sme sa zamerali na zrážkové úhrny letných mesiacov jún až august. Zistili sme počet dní s výdatnými zrážkami nad 20 mm a tiež maximálne denné úhrny. Ako indikátor sucha sme použili Thornthwaitov index sucha (TIS), klimatickú vodnú bilanciu (KVB), periódu tropických dní (TDP) pre stanicu Sliač, ktorá leží približne v rovnakej nadmorskej výške.
Medzi sledovanými rokmi sa vyskytli výrazné rozdiely v teplotnom a zrážkovom režime, čo sa odrazilo aj na fenologickej reakcii drevín. Na základe výpočtu Thornthwaitovho indexu sucha a klimatickej vodnej bilancie sa klimatologické sucho vyskytlo v rokoch 2007, 2012, 2015 a 2017.
Dobrým bioindikátorom teplotného a zrážkového režimu počas roka sú autochtónne dreviny. Nedostatok zrážok a dlhotrvajúce vysoké teploty vzduchu v letnom období vyvolávajú pri drevinách stres. Dôsledkom je skorý nástup jesenných vegetatívnych fenologických fáz najmä žltnutia listov, ktoré začína už koncom augusta. Rok 2015 s extrémnymi prvkami letného počasia priniesol aj výrazné fenologické extrémy. Tie sa

prejavili najskoršími nástupmi žltnutia listov lipy a trnky za celé tridsaťročné obdobie, ale aj za posledných jedenásť rokov. Dub letný ako drevina s najstabilnejšou fenologickou odpoveďou na podmienky prostredia reagovala na klimatologické sucho oneskorením fenofázy o 7 dní. Opačným extrémom boli roky 2010 a 2014 s vysokými zrážkovými úhrnmi, krátkymi periódami tropických dní, čo ich zaradilo k maximálnym hydrologickým extrémom.

Fenologické prejavy drevín slúžia ako bioindikátor zmien klimatických podmienok na danej lokalite a sú jedným z hlavných ukazovateľov odolnosti druhov na extrémy počasia. Ich význam spočíva v objasnení vzťahov v súvislosti s vývojom klímy, ale aj predpokladu rozšírenia a zmeny ich areálov v závislosti od kľúčových meteorologických prvkov.

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