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A PHENOLOGICAL STUDY ON EUROPEAN LARCH (*LARIX DECIDUA* MILL.) IN THE DRAHANSKÁ VRCHOVINA HIGHLANDS

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Abstract

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The phenological study on the onset and duration of individual phenological phases of European larch (*Larix decidua* Mill.) has been performed using sample trees growing in the research station of the Faculty of Forestry and Wood Technology, MUAF Brno for altogether 15 years. This study involves also recording of meteorological data. In this region, the European larch is an introduced woody species and its share in the stand composition is approximately 8%.
In European larch, the phenological stages have a markedly periodic character but they are also largely dependent on a complex of exogenous conditions, especially of climatic effects; this was corroborated also in studies on the phenology of other forest tree species growing in this region. Results of this phenological study demonstrated that the spring phenophases were influenced above all by air temperatures while the autumn ones were dependent, besides temperatures and precipitation, also on the duration of assimilation apparatus activities. The onset of breaking of needles occurred between Days 89 and the 110 of the calendar year. A full development of the assimilation area was reached between Days 125 and 150. The onset of individual phenophases was determined by threshold air temperatures, which were markedly different in individual forest trees. This requirement could be expressed at best by the sum of effective temperatures (i.e. air temperatures above 5 °C). In the analysed fifteen-year study period, the sum of effective temperatures for European larch ranged from 1 301.0 to 2 337.0 °C within the period delimited by dates of the flushing and 100-percent fall (abscission) of needles.
Results of a long-term phenologic monitoring of forest woody species may be used when evaluating the condition of forest stands from the viewpoint of expected global climatic changes.

phenology, climatic changes, weather, air temperature, European larch

In the Czech Republic, the forest phenology has a relatively long tradition. Phenological data are an important source of information when monitoring and explaining life processes of plants and their dependence on environmental conditions. Although the onset and duration of phenological phases is genetically determined, their onset can be postponed by climatic factors so that the development of plants can be changed and, thus, disturbed. As far as the ecological properties of woody species are concerned, phenological observations can help to characterise a climatic region with an average length of growing season (HOFMAN, 1957; LUKNÁROVÁ, 2000). They directly express and describe the dependence existing between the time course of growth and development of plants on the one hand and values of meteorological elements on the other (KURPELOVÁ, 1980). The dependence of tree phenology on climatic signals is well established (LECHOWICZ, 1995; KRAMER, 1996). Temperature has been found to be the best environmental signal for the tree to use for the optimal timing of the onset of growth. For determining the onset of developmental stages, often the concept of temperature sum has been used (HÄKKINEN & HARI, 1988; KRAMER 1996, 2000; DIEKMANN, 1996; VAN VLIET et al., 2002).

Temperature sum is the accumulated temperature above a certain thereshold value from a certain starting date, calculated by the progressive addition of mean daily temperatures (HAVLÍČEK, 1986; DIEKMANN, 1996; BAGAR, KLIMÁNEK, 1999; BAGAR, NEKOVÁŘ, 2007). For the calculation of temperature sums, most commonly a treshold value is used whitch defines the beginning of the thermal growing season, usually 5 °C. The temperature sum during the growing season is referred to as the effective temperature sum (TUHKANEN, 1980; HAVLÍČEK, 1986; LAPPALAINEN, 1994; DIEKMANN, 1996; BAGAR, KLIMÁNEK, 1999; BAGAR, NEKOVÁŘ, 2007). In the first half of the year, the date of the onset of individual phenophases is dependent above all on the exceeding of certain limit temperatures whilst those that occur in the second half of the year can be influenced by all environmental factors delaying and/or accelerating processes of ripening and ageing (senescence). Also in this case the temperature represents the most important because it influences the photosynthetic activity. Of other important factors it nutrient and water reserves and, above all, the effect diurnal photoperiod should be mentioned (LARCHER, 1988).

The expected climatic changes and the associated effects of negative factors can influence the beginning and subsequent course of basic life processes of forest ecosystems (KRAMER, 1996). With regard to possible climatic changes it is necessary to obtain further detailed data about growth processes of important woody species (both currently occurring and native) and – in connection with monitoring of forest stand microclimate – to contribute to the explanation of ecophysiological phenomena BAGAR et al., 2001).

MATERIAL AND METHODS

The phenological monitoring of European larch (*Larix decidua* Mill.) has been carried out in the study area of the Department of Forest Ecology, MUAF Brno since 1992. This site is situated in the Drahanská vrchovina highlands on a north-east to east slope of the dividing range in the altitude of 625 m above sea level below a short ridgy eluvium. Geographical coordinates of the study area are as follows: 16°41´30´´E and 49°26´31´´N. From the climatological point of view it is classified as a moderately warm and moderately humid with a long-term average annual temperature of 6.6 °C and with 683 mm on annual precipitation.

The phenological monitoring was performed regularly in 10 selected sample trees of European larch in the age of 6% years old. During the spring season, observations were performed 3 times per week while in summer and autumn only once per week. Individual phenological phases were evaluated using our own scale that was elaborated in cooperation with the Hydrometeorological Institute of the Czech Republic.

The following phenological phases are distinguished in this study: needle appearance 10%; beginning of foliage formation 10%; beginning of foliage formation 50%; beginning of foliage formation 100%; full foliage formation 100% (i.e. fully developed leaf area); butonization 10%; flowering 10%; flowering 100%; blossom fall 100%, lammas shoots; leaf yellowing 10%, leaf yellowing 100%, leaf fall 10%, leaf yellowing 100%. As the onset of each phenological phase that day was defined when at least one half of sample trees entered into the given phase. In the following analysis and evaluation each date of the onset of individual phenological phases was recorded under the serial number of the day in the calendar year. In individual years of the study period, the effective air temperatures were cumulated for each phenological phase. Air temperatures and the amounts of precipitation were recorded directly in the study area.

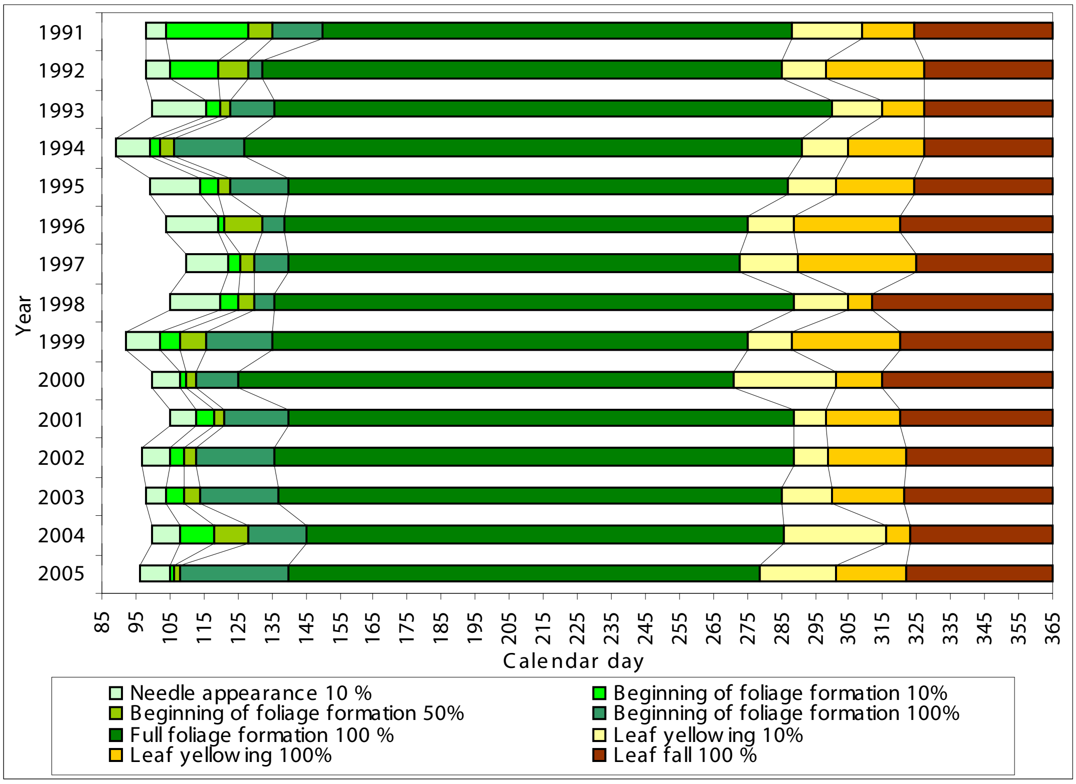
RESULTS AND DISCUSSION

There were considerable differences in the onset and duration of phenological phases in individual years of the study period. Besides some other exogenous and endogenous effects, air and soil temperatures were the most important factors that influenced the onset and duration of phenological phases of woody species (BEDNÁŘOVÁ, KUČERA, 2002; MERKLOVÁ, BEDNÁŘOVÁ, 2005). The time course of vegetative and generative phenophases of European larch during growing seasons of individual years is presented in Figs 1 and 2, respectively. The effect of weather on the onset of individual phenophases and their course was manifested also in our study and corresponded with changing air temperatures. Within the fifteen-year study period a slight increase in average air temperatures was recorded in the growing season (i.e. the average number of days a year with a 24-hour average temperature of at least 5 °C) and this obviously could influence the onset and duration of individual phenophases (Fig. 3).

Average dates of onset and duration of individual phenophases in European larch as recorded within the period of 1991–2005 are presented in Tab. I. The average date of needle appearance (10%) fell on the Day 99 of the calendar year and its spread of distribution was 21 days. This observation corresponded both with the average cumulative effective air temperature (34.2 °C) and with the minimum temperature at which the breaking of needles took place (8.3 °C). For this phenophase, the measured maximum was 52.6 °C. In average, the beginning of foliage formation 10% fell on the Day 110 and its spread of distribution was 23 days. For this phenophase the average sum of effective air temperatures was 67.3 °C with the minimum and the maximum values of 23.7 °C and 124.0 °C, respectively. The beginning of foliage formation 50% was found out on Day 116 with the spread of distribution of 23 days and average sum of temperatures 92.4 °C. For the onset of this phenological phase the minimum and the maximum sums of effective temperatures were 31.9 °C and 166.3 °C, respectively. The average beginning of foliage formation 100% was recorded on Day 121 (with a range of 29 days) and the average value of cumulative effective air temperatures was 124.0 °C. In this case, the minimum and the maximum sums of temperatures were 45.3 °C and 210.6 °C, respectively. The stage of full (100%) foliage formation (i.e. with fully developed leaf area) began on Day 137 of the calendar year (with the spread of distribution 25 days). In this phenophase, the average sum of effective temperatures was 236.4 °C and the necessary minimal and maximal initial sums of temperatures were 85.4 °C and 340.5 °C, respectively.

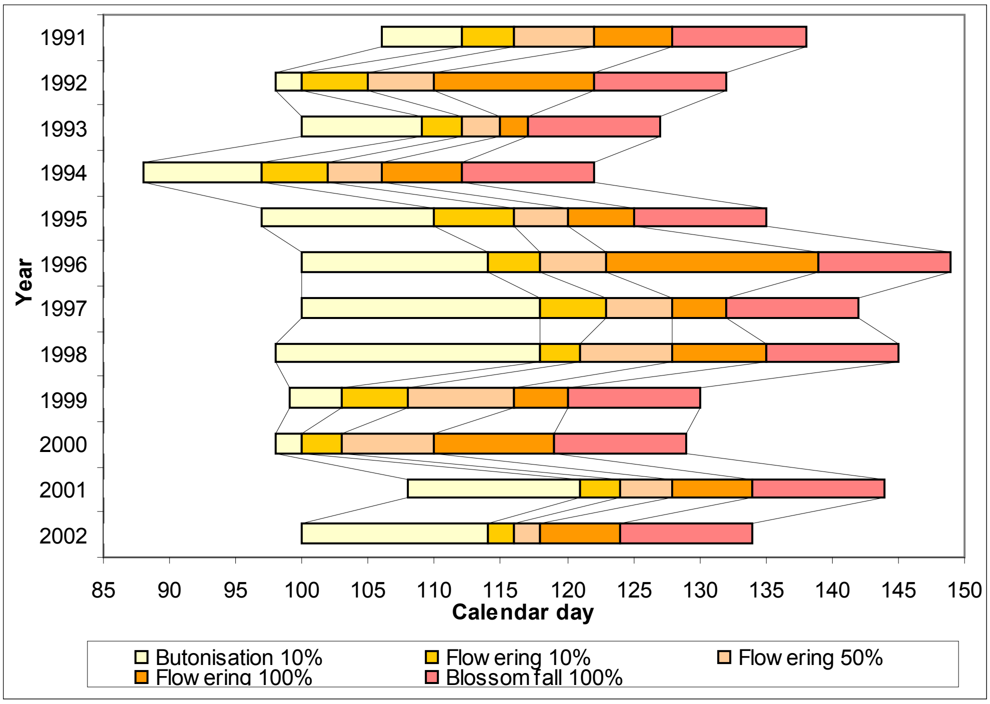
The period of photosynthetic activity of the assimilation apparatus of European larch is finished by the vegetative phenophase of autumnal yellowing of leaves (needles). In the study area, the average beginning of leaf yellowing (10%) occurred on Day 284 of the calendar year and its spread of distribution was 29 days. This observation corresponded also with the average sum of effective temperatures (1 786.5 °C). In this phenophases, the values of minimal and maximal effective temperatures were 1 284.6 °C and 2 188.6 °C, respectively. According to CHALUPA (1969), KRAMER (1996), and LARCHER (1988; 1995), in the European larch the onset of needle yellowing occurs in the middle of October; this corresponded also with our results. A complete (100%) yellowing of needles was recorded on Day 301 of the calendar year (with the range of 28 days). The average sum of effective temperatures was 1 841.1 °C and the minimum and the maximum values of 1 298.4 °C and 2 283.8 °C, respectively. The leaf fall (10%) began in average on Day 302 (with the spread of distribution 38 days); the average cumulative effective temperature was 1 840.2 °C. In this phenophase, the minimal and the maximal effective temperatures were 1 298.4 °C and 2 286.1 °C, respectively. The average phenological phase of leaf fall (100%) was recorded on Day 322 and its spread of distribution was only 15 days. In this case, the average sum of effective temperatures was 1 863.9 °C. Within the fifteen-year study period, the range of minimal and maximal cumulative temperatures for the period from needle appearance to leaf fall (100%) was 1 301.4 °C to 2 336.5 °C. Also these data indicate that within the study period the temperatures were rather variable and influenced not only the onset of individual phenological phases but also the total length of growing season.

In European larch the study of generative phenophases revealed that the variability of their onset and duration was smaller than in the vegetative phenophase in the spring. In the Drahanská vrchovina highlands, butonisation (10%) occurred in average on Day 100 of the calendar year (with the spread of variation 20 days. The average sum of effective temperatures was 37.3 °C and the minimal and maximal temperatures of 4.8 °C and 103.7 °C, respectively. The average onset of flowering (10%) was recorded on Day 110 (with the spread of distribution in individual years of 24 days).

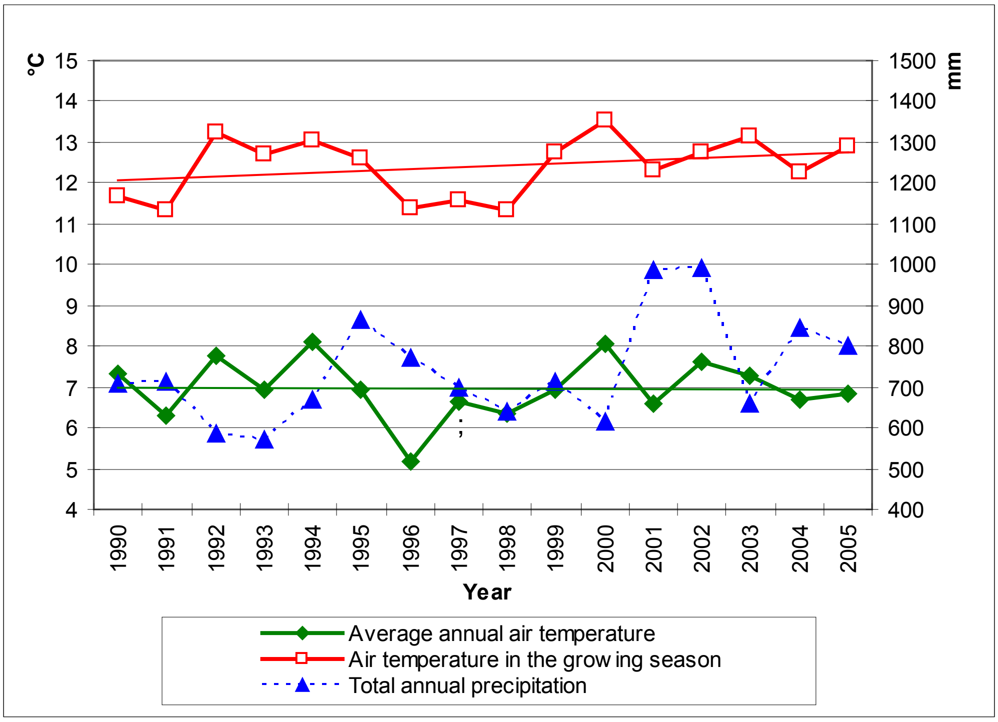


1: *The onset and duration of vegetative phenological phases in European larch during 1991–2005*

In this phenophase, the average sum of effective temperatures was 58.2 °C. In this phenophase, values of the necessary minimum and maximum were was 27.0 °C and 129.7 °C, respectively. Full (100%) flowering occurred in average on Day 119 and its spread of distribution was 22 days. For this phenophase the average sum of effective temperatures was 105.0 °C. The fifteen-year minimum was 41.1 °C.



2: *The onset and duration of generative phenophases in European larch within the period of 1991–2002*



3: *Average annual air temperatures and total annual precipitation within the period of 1990–2005*

I: *Statistical characteristics of the onset of selected phenological phases in European larch*

	Statistic characteristics									
	Calendar Day					Sum of temperatures above 5 °C				
Phenophase	$\bar{x}$	s_x	R	min	max	$\bar{x}$	s_x	R	min	max
Needle appearance 10 %	99	5.2	21	89	110	34.2	13.3	44.3	8.3	52.6
Beginning of foliage formation 10%	110	7.2	23	99	122	67.3	32.4	100.3	23.7	124.0
Beginning of foliage formation 50%	116	8.0	26	102	128	92.4	42.1	134.5	31.9	166.3
Beginning of foliage formation 100%	121	9.2	29	106	135	124.0	56.8	165.3	45.3	210.6
Full foliage formation 100%	137	6.3	25	125	150	236.4	57.7	255.1	85.4	340.5
Butonisation 10%	100	4.9	20	88	108	37.3	24.6	98.9	4.8	103.7
Flowering 10%	110	8.0	24	97	121	58.2	30.8	102.7	27.0	129.7
Flowering 100%	119	7.5	22	106	128	105.0	43.6	142.6	41.1	183.7
Leaf yellowing 10%	284	8.0	29	271	300	1 786.5	281.0	904.0	1 284.6	2 188.6
Leaf yellowing 100%	301	8.3	28	288	316	1 841.1	292.8	985.4	1 298.4	2 283.8
Leaf fall 10%	302	9.1	38	274	312	1 840.2	288.0	987.7	1 298.4	2 286.1
Leaf fall 100%	322	4.3	15	312	327	1 863.9	298.2	1,035.1	1 301.4	2 336.5

Note: $\bar{x}$ – arithmetic mean; s_x – standard deviation; R – spread of distribution; min – minimal values; max – maximal values

SUMMARY

In the area of the Drahanská vrchovina Upland, spring and autumnal phenological charakteristics in European larch (*Larix decidua* Mill.) were monitored and evaluated from 1991 to 2006. The onset and the duration of all important developmental stages of plants year by year in dependence on the course of weather. The effect of weather on the onset of individual phenophases and their course was manifested also in our study and corresponded with changing air temperatures. Within the fifteen-year study period a slight increase in average air temperatures was recorded in the growing season (i.e. the average numbers of days a year within a 24-hour average temperature of at least 5 °C) and this obviously coul influence the onset and duration of individual phenophases. The onset of phenological and growth phases in the temperate woody species is influenced by day air temperature exceeding 5 °C because at the temperature 5 °C plants start or stop growing, reduce metabolic reactions and energy transformation. It was found out that in the first half of the growing season the onset of individual phenological phases is dependent above all on temperatures, i.e. on the exceeding of a certain temperature limits. As usual, the beginning of leaf apperance and their development or on flowering is possiblle only when the soil and air temperatures exceed a certain critical point, which is characteristic for each individual phenophase. The induction /onset of individual phenophases does not depend on threshold values but on sums of temperatures. In the spring, the spread of variation in the onset of individual phenophases and in their duration was greater than in the autumn.The average date of needle appearance (10%) fell on the Day 99 of the calendar year and its spread of distribution was 21 days. In average, the beginning of foliage formation 10% fell on the Day 110 and its spread of distribution was 23 days. The average beginning of foliage formation 100% was recorded on Day 121 (with a range of 29 days), the stage of full (100%) foliage formation (i.e. with fully developed leaf area) began on Day 137 of the calendar year (with the spread of distribution 25 days). In the study area, the average beginning of leaf yellowing (10%) occured on Day 284 of the calendar year and its spread of distribution was 29 days. A complete (100%) yellowing of needles was recorded on Day 301 of the calendar year (with the range of 28 days). The average phenological phase of leaf fall (100%) was recorded on Day 322 and its spread of distribution was only 15 days. After the beginning of autumn phenophases, the sum of effective air temperatures recorded till the end of growing season ahowed an increasing tendency in recent years. This fact can influence physiological functions of woody species. A long –lasting duration of growing season after the onset of the phenophase of yellowing of leaves can be one of causes of a gradual withering of trees.

SOUHRN

Sledování fenologie modřínu opadavého (*Larix decidua* Mill.) v oblasti Drahanská vrchovina

V oblasti Drahanská vrchovina byly v letech 1991 až 2005 sledovány a vyhodnoceny jarní i podzimní fenologické charakteristiky u modřínu opadavého (*Larix decidua* Mill.). Počátek a trvání důležitých vývojových fází se mění rok od roku podle charakteru počasí. Vliv počasí na dobu nástupu fenofází a jejich průběh je patrný i v našem hodnocení a koresponduje s teplotou vzduchu. Nástup fenologických a růstových fází u dřevin mírného pásma je ovlivněn denní teplotou vzduchu přesahující 5 °C, neboť při teplotě 5 °C rostlina začíná nebo přestává růst, omezuje metabolické procesy a transformaci energie. Během hodnoceného patnáctiletého období došlo ve sledované oblasti k mírnému vzestupu teploty vzduchu, za velké vegetační období, což může ovlivnit nástup a trvání jednotlivých fenofází. Bylo zjištěno, že čas nástupu fenologických fází v první polovině vegetačního období závisí především na době překročení určitých teplotních hranic. Začátek rašení, olisťování či kvetení je možný teprve, když teplota vzduchu a půdy překročí kritický bod, charakteristický pro každou fázi. Pro vyvolání jednotlivých fenofází nejsou důležité prahové hodnoty, ale jejich suma. Průměrné datum počátku rašení modřínu opadavého (z 10 %) za sledované období bylo 99. den od počátku kalendářního roku s variačním rozpětím 21 dnů. Počátek olisťování z 10 % byl v průměru 110. den, s variačním rozpětím 23 dnů. Začátek olisťování ze 100 % byl v průměru 121. den, rozpětí za sledované období 29 dnů. K plnému olistění (100 % rozvinutá listová plocha) došlo v průměru 137. den od počátku kalendářního roku při variačním rozpětí 25 dnů. K počátku žloutnutí jehlic z 10 % docházelo na sledované lokalitě v průměru 284. den při variačním rozpětí za patnáctileté období 29 dnů. Ke žloutnutí jehlic ze 100 % došlo v průměru 301. den kalendářního roku, s variačním rozpětím 28 dnů. Fenologická fáze opad jehlic ze 100 % byla v průměru 322. den s rozpětím pouze 15 dnů. Variační rozpětí nástupu a trvání jarních fenologických fází bylo širší jak u fází podzimních. Ze získaných výsledků je patrné, že v posledních letech dochází k narůstání efektivních teplot vzduchu, zvláště v podzimním období. Tato skutečnost může ovlivnit fyziologické funkce dřevin a dlouhodobé prodlužování vegetačního období po nástupu fenofáze žloutnutí listí může být příčinou chřadnutí dřevin.

fenologie, klimatické změny, počasí, teplota vzduchu, modřín opadavý

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