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History and present of phenological observations or phenology at the crossroad

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Abstract

Periodicity in the life of plants and animals is considered to be an indirect indicator for the periodicity in the climate. Global climate change impacts can already be tracked in many physical and biological systems; in particular, terrestrial ecosystems provide a consistent picture of observed changes. Therefore phenological observations are among the most sensitive data for climate impact studies on vegetation at midlatitudes (Hájková, Kožnarová, 2013).

Within the last decade the scientific community's view of phenology as a harmless pastime of natural historians has changed dramatically, because the value of phenological data in climate change research has been recognized (Menzel, 2002). The phenological observations recorded significant changes in recent years, except for subjective monitoring voluntary observers under the established methodology; the phenological records are also obtained through the calendar of nature (e.g. USA) and by special cameras designed for phenological monitoring. This paper summarizes the history and present of phenological observations in the Czech Republic; it also describes the cooperation within the phenology field with the aim to unify the analyses, and thus the possibility of further development of this scientific branch.

First results from the records of phenological cameras show the possibility of using this method as a replacement for conventional phenological observations in the Czech Republic.

Key words: phenology, climate change, USA NPN, PEP 725, phenological camera

Introduction

Phenology, the description of the development stages of wild plants, agricultural fruit and crops, and other organism (for instance insects) has several well-defined applications, in addition to its use in simultaneous models. Commonly observed phenological events include the timing of sprouting and flowering of plants in the spring, colour changes of plants in the fall, bird migration, insect hatches, and animal hibernation. Certain agricultural activities often require advanced information on the dates of specific stages of crop development. Because the occurrences of such seasonal phenomena are generally initiated and driven by climate, phenological record is a sensitive proxy for investigating climate change and its influences on ecosystems over time (Hájková et *al*., 2013). Climate change has both direct and indirect impacts on crop growth and development. Higher ambient levels of carbon dioxide have an impact on C crops by increasing photosynthesis and decreasing water use. Indirect effects result from changes in weather and climate that are caused by higher levels of greenhouse gases. These changes may be within, or beyond, the current observed range of climate variability. Faced with the prospect of global warming, information has been needed about how natural systems may respond. Because of the volume of data, phenology has proved extremely useful in this respect (Menzel and Estrella, 2001). System of phenological observations has changed during the last decades, and the phenology plays more and more important role in the climate change research. The introduction is divided into 4 main parts to describe the history, present and future of phenological observations in the Czech Republic and in the world. Division: 1. History and present of phenological observations in the Czech Republic; 2. Pan European Phenology – PEP 725; 3. USA National Phenology Network and 4. Phenological monitoring by cameras in the Czech Republic.

1. The history of phenological observations in the Czech Republic

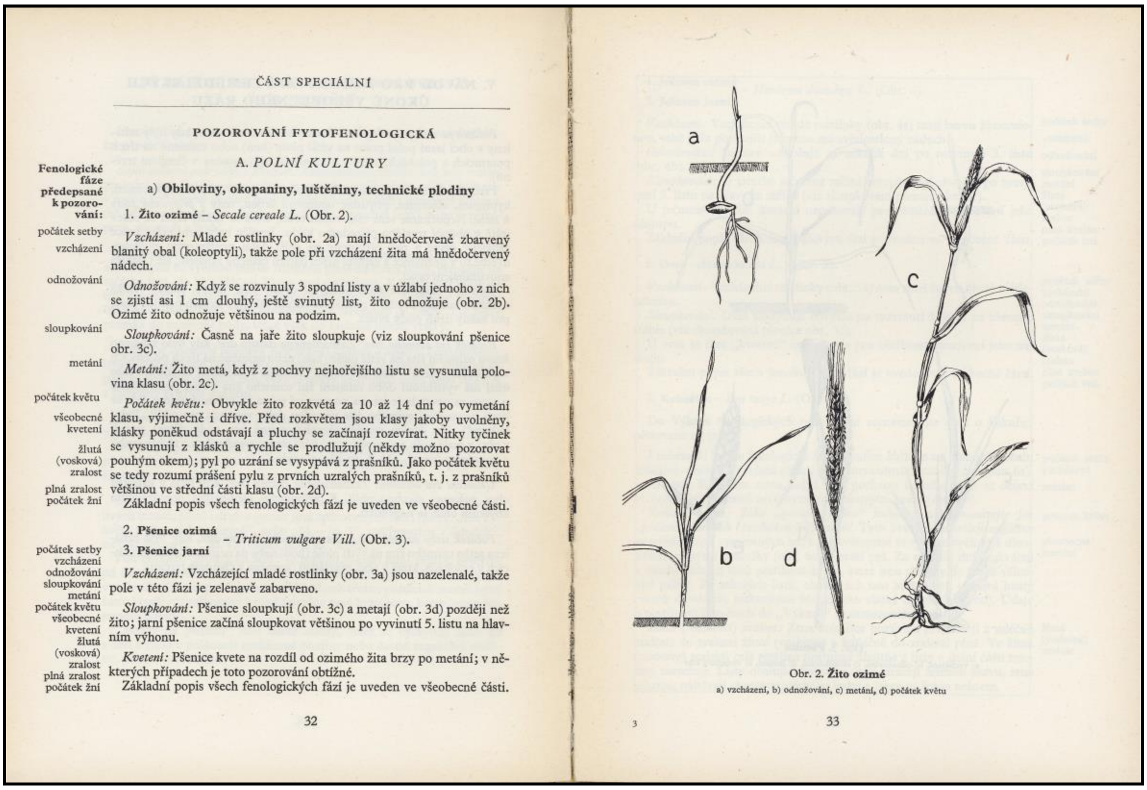
Phenological observations have a long tradition in Czech Lands (Czech Republic later on). The first Czech meteorologists J. Stepling, A. Strnad and M. A. David, whose activities are known from the second half of the 18th century and David's from the 19th century as well, devoted themselves to studying the influence of weather on the life of plants and animals. A. Strnad attached his remarks to regular measures, which he carried out at the Prague observatory from the 1st January, 1775 up to nearly the end of his life (23rd September, 1799). A number of these phenological observations is also attached to his paper “Meteorologischer Beytrag auf das Jahr 1792”. A longer article, containing an economic survey of the year 1791, was published by Strnad in Mannheim Eefemeridas Efemeridés with the heading „Conditio anni generalis“(Seydl, 1954). The Mannheim or Falc meteorological society (Societas meteorologica Palatina), was assigned on the 15th September 1780 as a “meteorological class” to the Academy of Sciences, which has been in existence in Mannheim since 1763, and worked till 1799. The first phenological calendar in our literature was published by Med. Dr. Tadeáš Haenke in his longer paper „Blumenkalendar fűr Noumen in Jahre 1786“. The author carried out in the years 1784 and 1785 a detailed observation on the earlier and later beginning of spring, on its course and the changes of plants during this time (Seydl, 1954).

The principles for regular and methodologically unified phenological observations in a station net were laid by the Swedish botanist Carl von Linné. He established the network of 18 stations in Sweden in the years 1752–1755. Regular phenological observations in the Czech countries were first introduced by the Patriotic – economic company, the successor of K. k. Ackerbau-Gesellschaft, based in 1769 as an order of the Empress Maria Teresia in Prague for the enhancement of agriculture. The following phenological elements were observed: the development of buds into leaves, the beginning of blossoming, and the end of blossoming, maturation of seeds. Further, some animals e.g. bats, hamsters, badgers, snakes and lizards, frogs, which do not leave our countries and hibernate in winter, mainly their awakening in spring and the beginning of hibernation were observed. The Prague lawyer Karl Fritsch as a significant part of his work in the field of phenology. His first work on phenology was devoted to the influence of weather on vegetation. In the paper „Elemente zu einer Untersuchung űber den Einfluss der Witterung auf die Vegetation“Fritsch explained the link between the yearly amount of warmth and moisture to the most important phases of the development of a plant, he presents eight charts of meteorological data (e.g. gradual total of positive values of the air temperatures, the differences in gradual total of precipitation) (Seydl, 1954).

The state phenological service was organized in Moravia by the Department for soil science and agricultural meteorology of the Regional research office of agriculture in Brno. Novák set up in 1923 one of the first national phenological services in the world. The observation net was soon so extensive (with 650 observers involved in its activities), that it was unsustainable in the long term. The organization of phenological services was so sophisticated, several challenges in newspapers and professional press were published in order to acquire other observation sites, national schools and public corporations were asked for cooperation (Hájková *et al*., 2012). The results of these observations were gradually processed in a long-term average of phenological phases, the so-called phenography. Coming out of these observations, phenological yearbooks were published, with map enclosures for the years 1923 and 1924 – and thus the principles of the beginning of the Czech phenography were laid. The phenological phases follow one after the other in a certain stable order; the first phenological calendar was published by the above mentioned T. Haenke. Arising from these long-term phenological observations, we can create the so called “Calendars of nature” for a certain place and its surrounding. We can also add a border data of the beginnings of these phases (the earliest and the latest, their amplitudes, phenoanomaly, the curve of phenodynamics) (Brablec, 1952).

In 1939, all meteorological services in the area of protectorate Bohemia and Moravia were brought together and the Central meteorological institute for Bohemia and Moravia was established, from the year 1940, phenological observations were overtaken by the Czech meteorological service with the whole net (about 1 000 places) and the archive of data since 1923. From that time up to the present, the phenology makes up a part of the meteorological service, included in 1954 in the Hydrometeorological Institute (Miháliková, 1983; Krška & Vlasák, 2008).

Phenological observations were conducted according to the principles included in the Handbook for phenological observers from the year 1956 (Pifflová *et al*., 1956). It was determined for the observers of the institutes for general phenology, which served mainly the needs of agriculture production (Figure 1).


ČÁST SPECIÁLNÍ

POZOROVÁNÍ FYTOFENOLOGICKÁ

A. *POLNÍ KULTURY*

Fenologické fáze předepsané k pozorování:

a) **Obiloviny, okopaniny, luštěniny, technické plodiny**

1. **Žito ozimé** – *Secale cereale L.* (Obr. 2).

počátek setby

vzcházení — *Vzcházení:* Mladé rostlinky (obr. 2a) mají hnědočerveně zbarvený blanitý obal (koleoptyli), takže pole při vzcházení žita má hnědočervený nádech.

odnožování — *Odnožování:* Když se rozvinuly 3 spodní listy a v úžlabí jednoho z nich se zjistí asi 1 cm dlouhý, ještě svinutý list, žito odnožuje (obr. 2b). Ozimé žito odnožuje většinou na podzim.

sloupkování — *Sloupkování:* Časně na jaře žito sloupkuje (viz sloupkování pšenice obr. 3c).

metání — *Metání:* Žito metá, když z pochvy nejhořejšího listu se vysunula polovina klasu (obr. 2c).

počátek květu, všeobecné kvetení, žlutá (vosková) zralost, plná zralost, počátek žní — *Počátek květu:* Obvykle žito rozkvétá za 10 až 14 dní po vymetání klasu, výjimečně i dříve. Před rozkvětem jsou klasy jakoby uvolněny, klásky poněkud odstávají a pluchy se začínají rozevírat. Nitky tyčinek se vysunují z klásků a rychle se prodlužují (někdy možno pozorovat pouhým okem); pyl po uzrání se vysypává z prašníků. Jako počátek květu se tedy rozumí prášení pylu z prvních uzralých prašníků, t. j. z prašníků většinou ve střední části klasu (obr. 2d).

Základní popis všech fenologických fází je uveden ve všeobecné části.

2. **Pšenice ozimá**
3. **Pšenice jarní** – *Triticum vulgare Vill.* (Obr. 3).

počátek setby, vzcházení, odnožování, sloupkování, metání, počátek květu, všeobecné kvetení, žlutá (vosková) zralost, plná zralost, počátek žní

Vzcházení: Vzcházející mladé rostlinky (obr. 3a) jsou nazelenalé, takže pole v této fázi je zelenavě zabarveno.

Sloupkování: Pšenice sloupkují (obr. 3c) a metají (obr. 3d) později než žito; jarní pšenice začíná sloupkovat většinou po vyvinutí 5. listu na hlavním výhonu.

Kvetení: Pšenice kvete na rozdíl od ozimého žita brzy po metání; v některých případech je toto pozorování obtížné.

Základní popis všech fenologických fází je uveden ve všeobecné části.

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Obr. 2. **Žito ozimé**

a) vzcházení, b) odnožování, c) metání, d) počátek květu

3

33

Figure 1. Handbook for phenological observers (1956) – demonstration

A constituent part of the handbook was also phenological observations of animals. The following phenomena were observed e.g. the date of arrival, mass arrival, the first singing, herding and departure of thrushes, martins, quails, cuckoos, swifts, larks, starlings and swallows. With bee melliferous, the first flight and the first congeries of pollen were observed.

A significant change in phenological observations came in the year 1983; observation sites were divided into stations observing field crops and fruit trees. Separate instructions for both types of stations were issued for observers. The transformation was finished in the year 1987 by issuing methodological instructions for the activities of phenological stations observing forest plants (from January 1st 1987). From January 1st 2005, Phenological atlas (Coufal *et al.*, 2004) became an aid for observers in the net of the CHMI.

In the year 2004 a trial run of the database Oracle Phenodata started, for acquiring and storing phenological data (application pod Clidata in environment Oracle) and since 1st January 2005 phenological data have been stored in this database up to the present. Older data were transferred to this database from environment Excel, where they had been stored till that time.

The phenological net (till the year 2012) in the area of the Czech Republic was consisting of the three types of stations (forest plants, fruit trees, field crops). Voluntary observers monitor the beginnings of phenophase according to the methodological instructions of the CHMI (art. 2, 3 and 10 – in the year 2009 new, updated instructions for observers were issued), data are recorded in the phenological notepad and then transferred to current reports. Part of results of phenological observations in period 1991–2010 (Figure 8) were processed in the Atlas of Phenological conditions in Czechia (Hájková *et al*., 2012).

The latest change in the CHMI phenological observation network happened in the year 2013 January 1st) – the density of phenological stations has dramatically reduced – from more than 160 stations to 25 stations for the whole republic (Figure 2), only wild plants phenological stations have left.

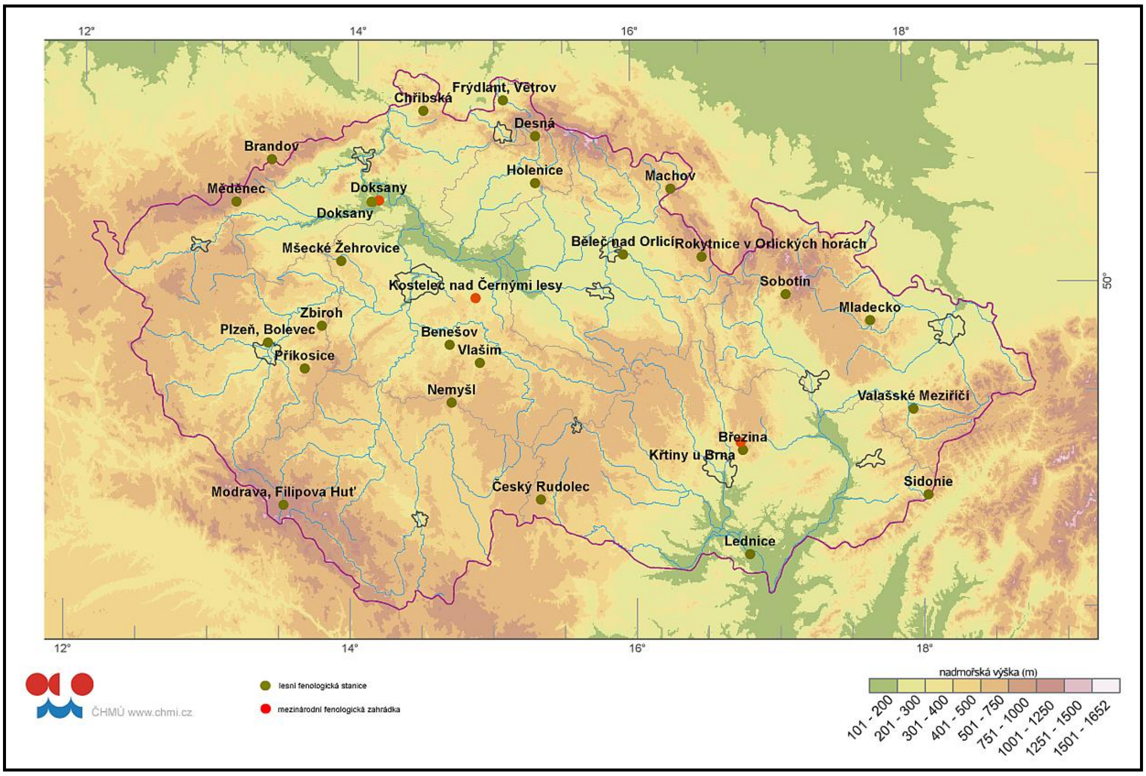


Figure 2. CHMI phenological stations

2. The Pan European Phenological Database (PEP 725)

Most European countries maintain networks that collect phenological data (Figure 3). For instance, the German Weather Service (Deustscher Wetterdienst, or DWD) currently runs a phenological network comprising approximately 1 550 stations. The phenological observation programme of DWD has 167 stages of development.

PEP725 (the successor of the COST Action 725) is a project funded by ZAMG, the Austrian ministry for science & research and EUMETNET (the network of European meteorological services) - with the goal to establish an open access database with plant phenology data sets for science, research and education.

The main objective of PEP725 is to: promote and facilitate phenological research by delivering a pan European phenological database with an open, unrestricted data access for science, research and education (data policy). So far 17 European meteorological services and 5 partners from different phenological network operators have joined PEP725 (Figure 3).

Currently the database implements:

- 9 003 075 observations,
- 20 375 locations,
- 254 different plants/cultivars.

To supply the data in a good and uniform quality it is essential to establish and develop data quality control procedures, so that the collected, partly new digitized historical resp. updated datasets, can be tested in an appropriate way. One of the main tasks within PEP725 was and still is the conception of a MULTI-STAGE-QUALITY CONTROL. Currently some tests are running in operational mode, others are in test or conception phase. They are stepwise performed in 6 various checks from A to F and FLAGGED in an appropriate way (0 default, 1 corrected, 2 interpolated, 3 pests-phases starts earlier, 101 completeness check, 102 plausibility check, 103 time consistency check, 104 spatial consistency check, 105 climatological check, and 106 inner consistency check). You can find more information at PEP 725 (www.pep725.eu).

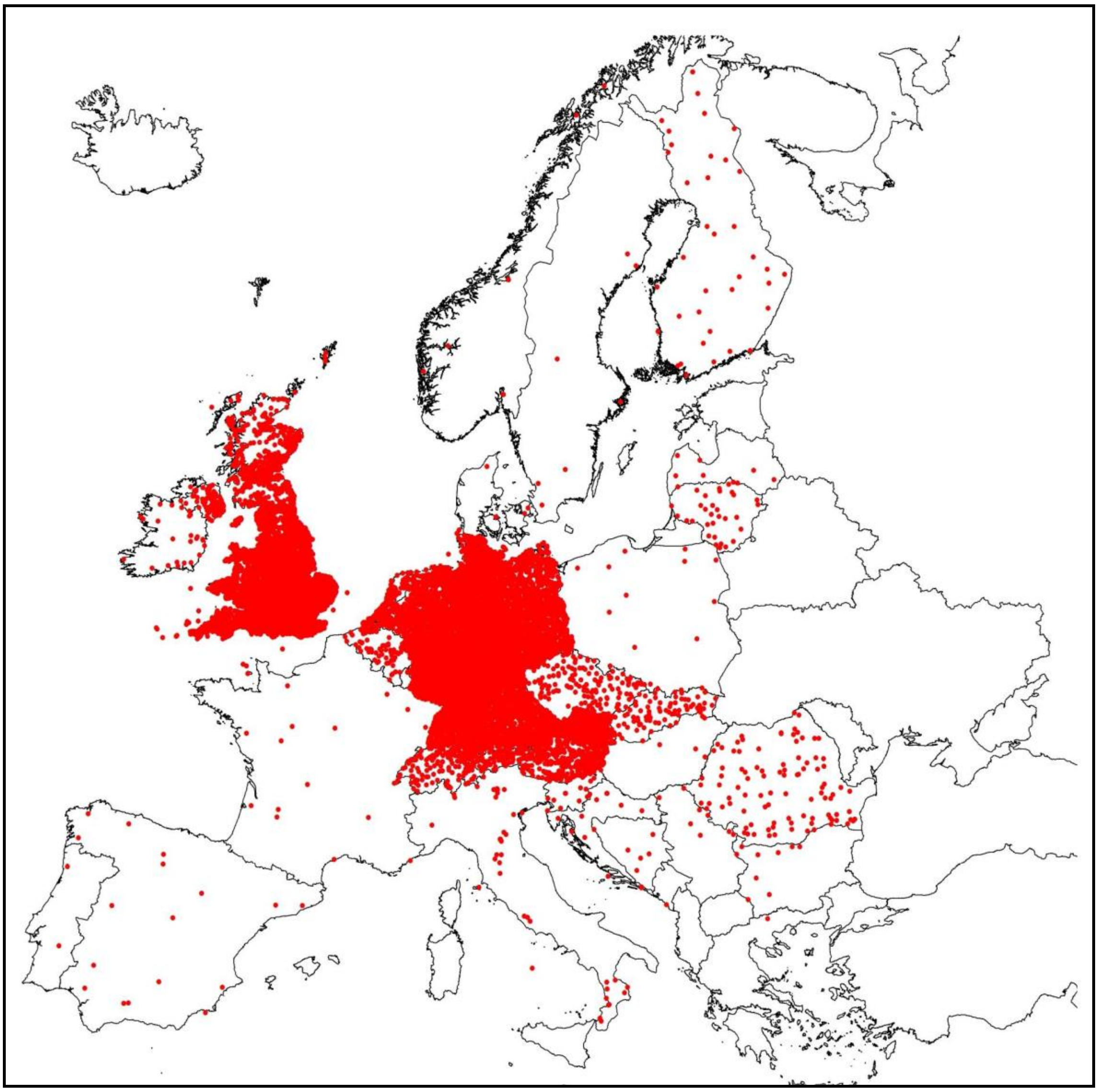


Figure 3. PEP 725 – station network.

3. The USA National Phenology Network

The USA National Phenology Network encourages people of all ages and backgrounds to observe and record phenology as a tool to discover and explore the nature and pace of our dynamic world. The Network makes phenology data, models, and related information freely available to empower scientists, resource managers and the public in decision-making and adaptation in response to variable and changing climates and environments. The National Coordinating Office (NCO) of the Network is a resource centre that facilitates and encourages widespread collection, integration, and sparing of phenology data and related information (for example, meteorological and hydrological data). The NCO develops and promotes standardized methods for field data collection and maintains several online user interfaces for data upload and download, as well as data exploration, visualization, and analysis. The NCO also facilitates basic and applied research related to phenology, the development of decision-support tools for resource managers and planners, and the design of educational and outreach materials and programs.

Changes in phenology affect human health by changing timing and patterns of allergy seasons. The Network is collaborating with many partners on a new project to predict the timing of human allergic reactions caused by juniper pollen. Researches intend to integrate data from citizen scientist observers of juniper phenology, satellite images of tree green-up, and data from health centre to better understand the dynamics of seasonal allergies. Better forecasting of environmental triggers can lead to more effective public health measures and, consequently, improved duality of life for seasonal allergy sufferers. The observations are made through Nature’s Notebook all over the country on www.usanpn.org.

4. Phenological monitoring by cameras in the Czech Republic

Phenological observations of forest plants are time demanding and labor-intensive, the automated monitoring with digital cameras can serve as an alternative to substitute traditional phenological observations by human observers. The first results of phenological observation by phenological camera were processed in this contribution.

Material and methods

The sensing with fixed cameras allows to obtain continuous data with high resolution and to describe the dynamics of canopy development by using simple vegetation indices (proportion of each colour) in deciduous trees.

Digital cameras (Figure 4) for long-term phenological observations of monitored tree are situated at the International Phenological Garden in Doksany (Czech Republic,50°27'31" N, 14°10'14" E, at 158 m asl, 45 km northwest of Prague).

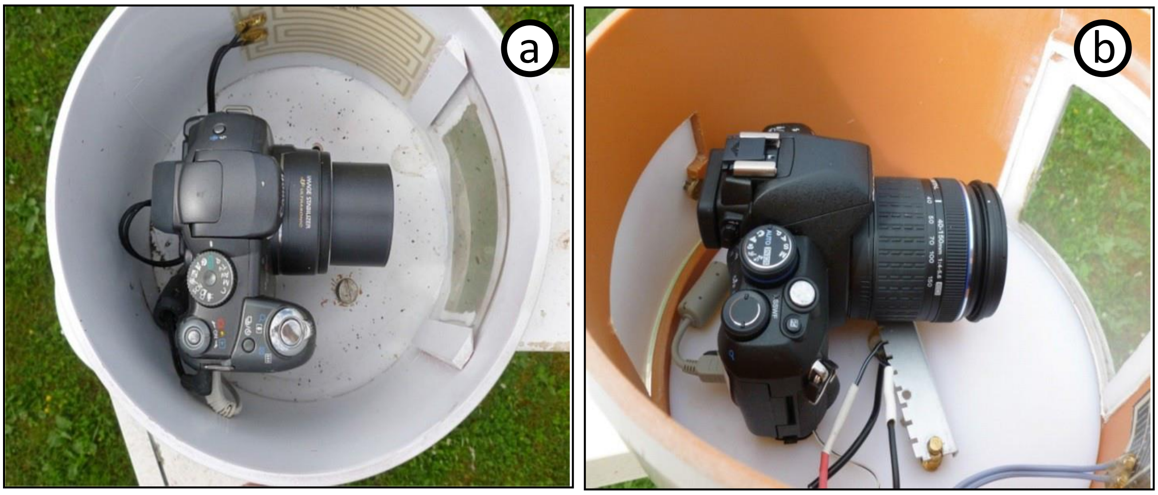


Figure 4. Digital cameras for phenological monitoring: a) Canon PowerShot S3 IS, b) Olympus E-410.

Canon Power Shot S3 IS and Olympus E-410 cameras made images in the automatic mode every hour (05 am – 7 pm) during the whole vegetation period. This monitoring was supplemented by measurements of CO_2 (LI-6252) and Normalized Difference Vegetation Index (sensor Skye SKR-1800). Red-green-blue (RGB) colour channel information from digital images can be separately extracted in digital form (by using Sigma Scan Pro 5.0 software) and subsequently summarized through Green Index (GI = G/[R+G+B]). To reduce the effects of changes in scene illumination we used the method by Sonnentag *et al*., 2012. We used a moving window approach that assigns the 90th percentile of all daytime values within a three-day window to the centre day (per90), resulting in three-day gcc. First, we calculated gcc for each species, then the average value of gcc. Local polynomial regression fitting (Loess curve; Cleveland and Devlin, 1988) with a low degree of smoothing of gcc was used.

Results and discussion

The results demonstrate the possibility of using models as an appropriate tool for monitoring temporal changes in canopy development and phenological events. The relationship between Green Index and optimized Growing Season Index (iGSI) was found (R^2 = 0.92, $p < 0.01$). Subsequently the relationship between iGSI and Normalized Difference Vegetation Index are represented by results R^2 = 0.7, $p < 0.01$

and Net Ecosystem Exchange is characterized by $R^2 = 0.81$, $p < 0.01$. Comparison of the dynamics of NDVI is shown in Figure 5.

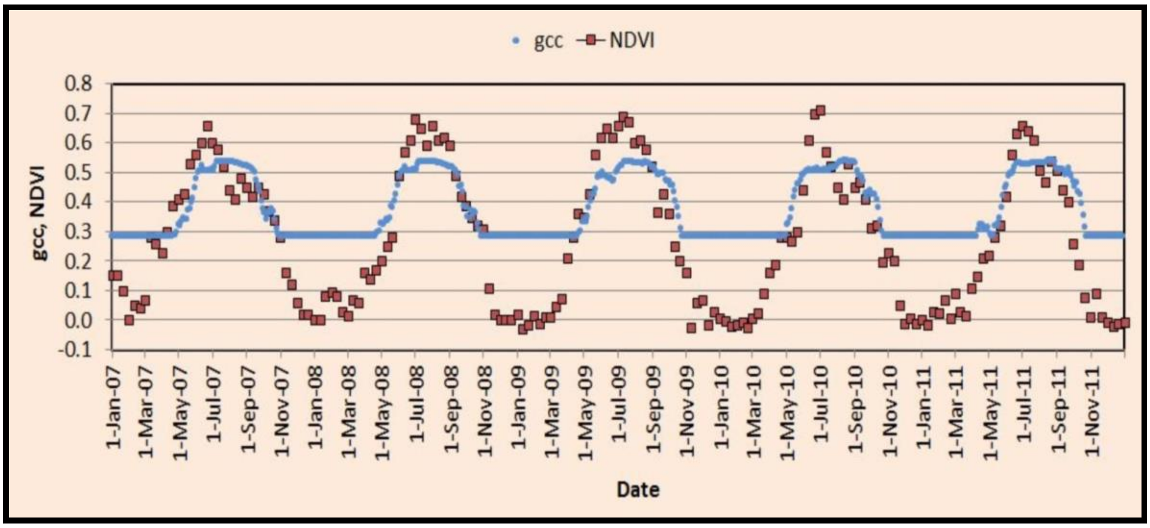


Figure 5. Comparison of the dynamics of NDVI (Source: MODIS – Terra satellite; resolution 250 m) and the green chromatic coordinate (gcc).

The daily gross primary productivity (GPP) in the interval (10 days) is shown in Fig. 6.

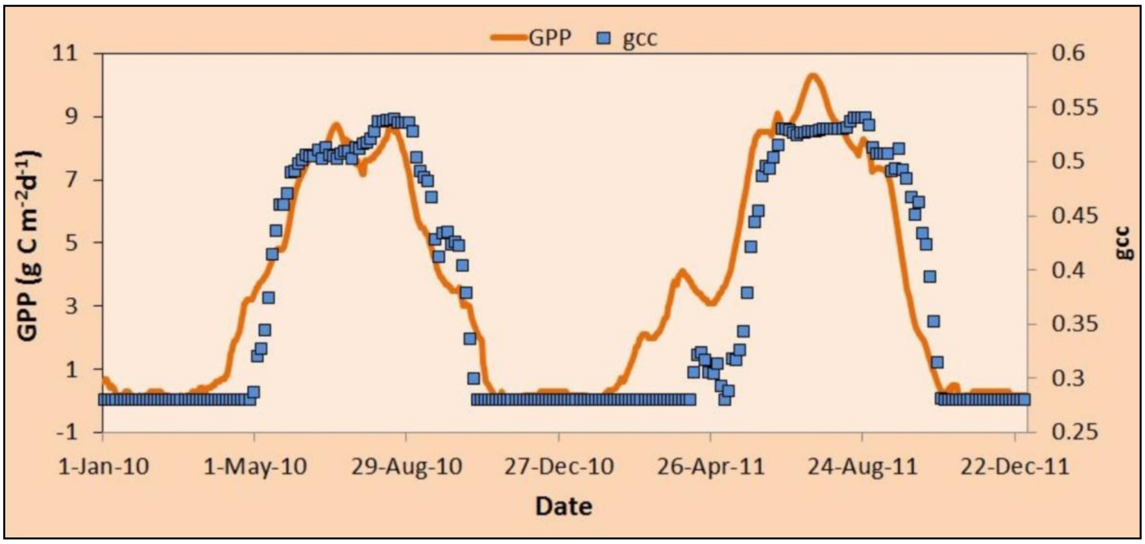
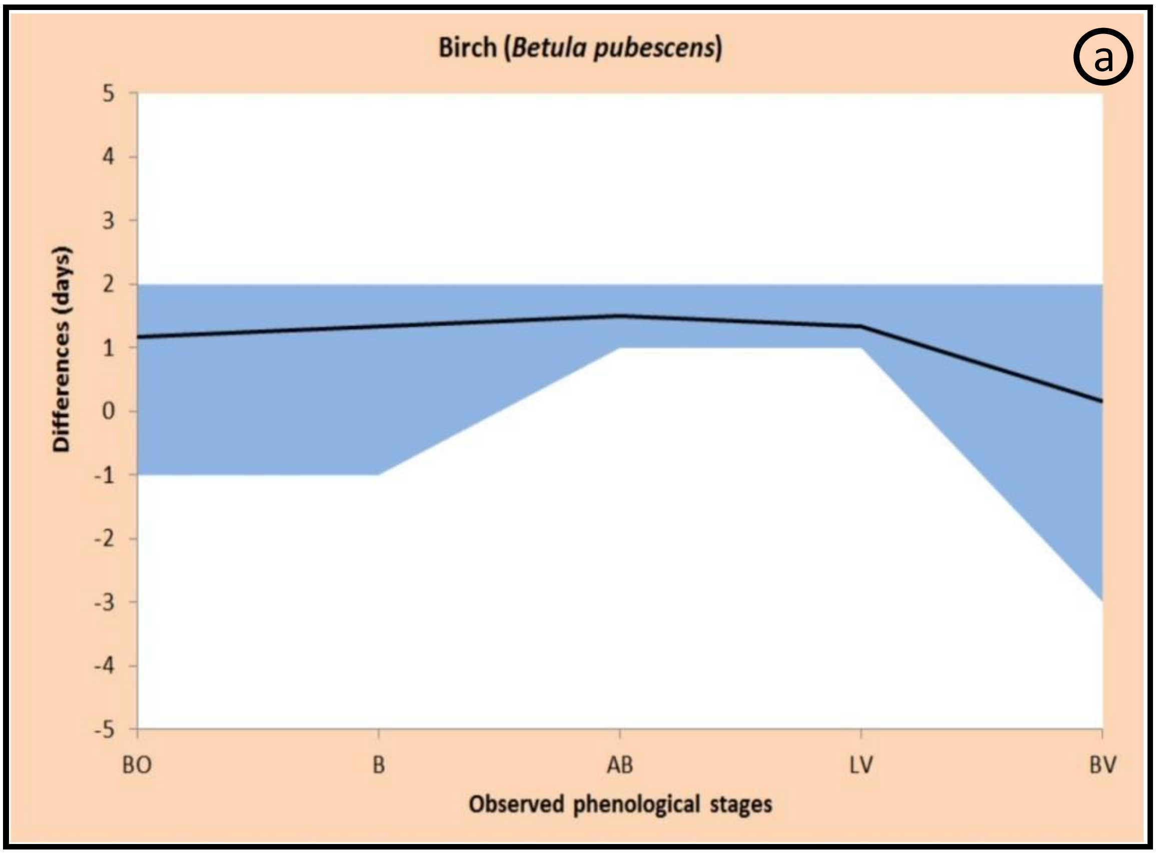
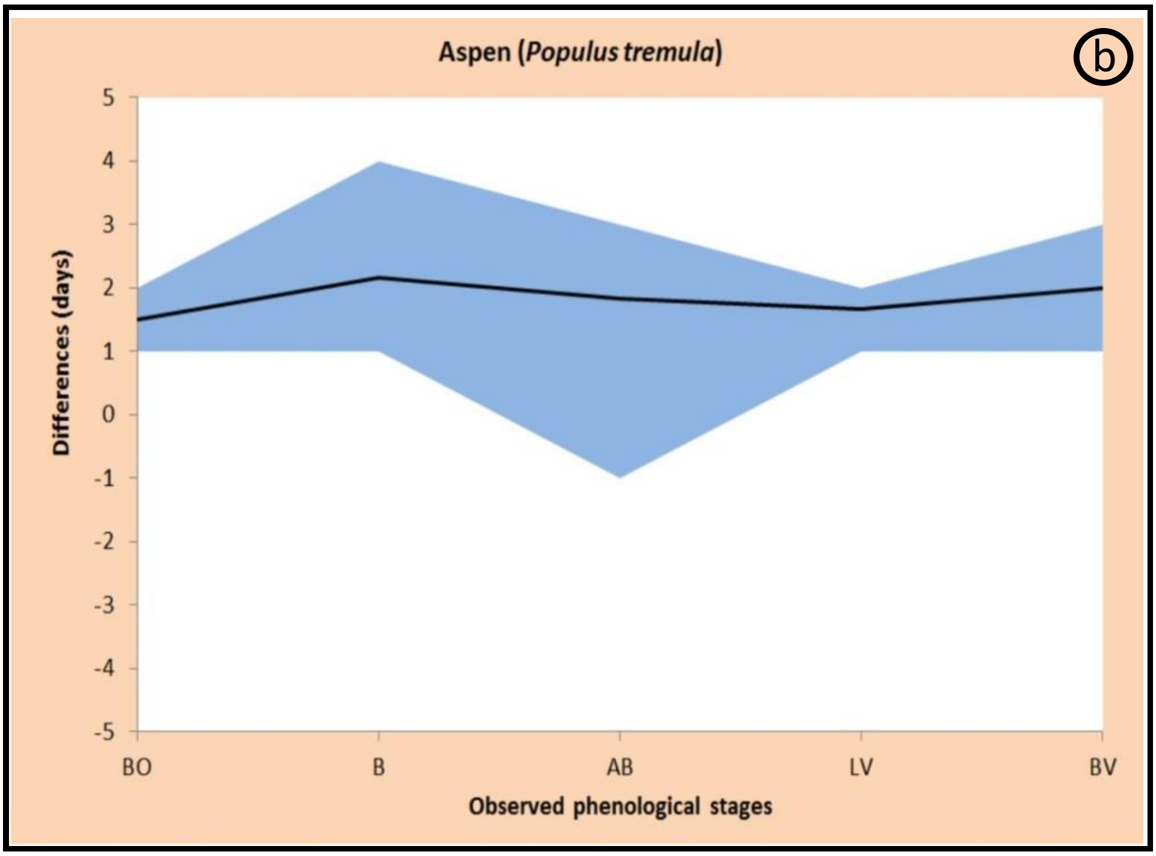
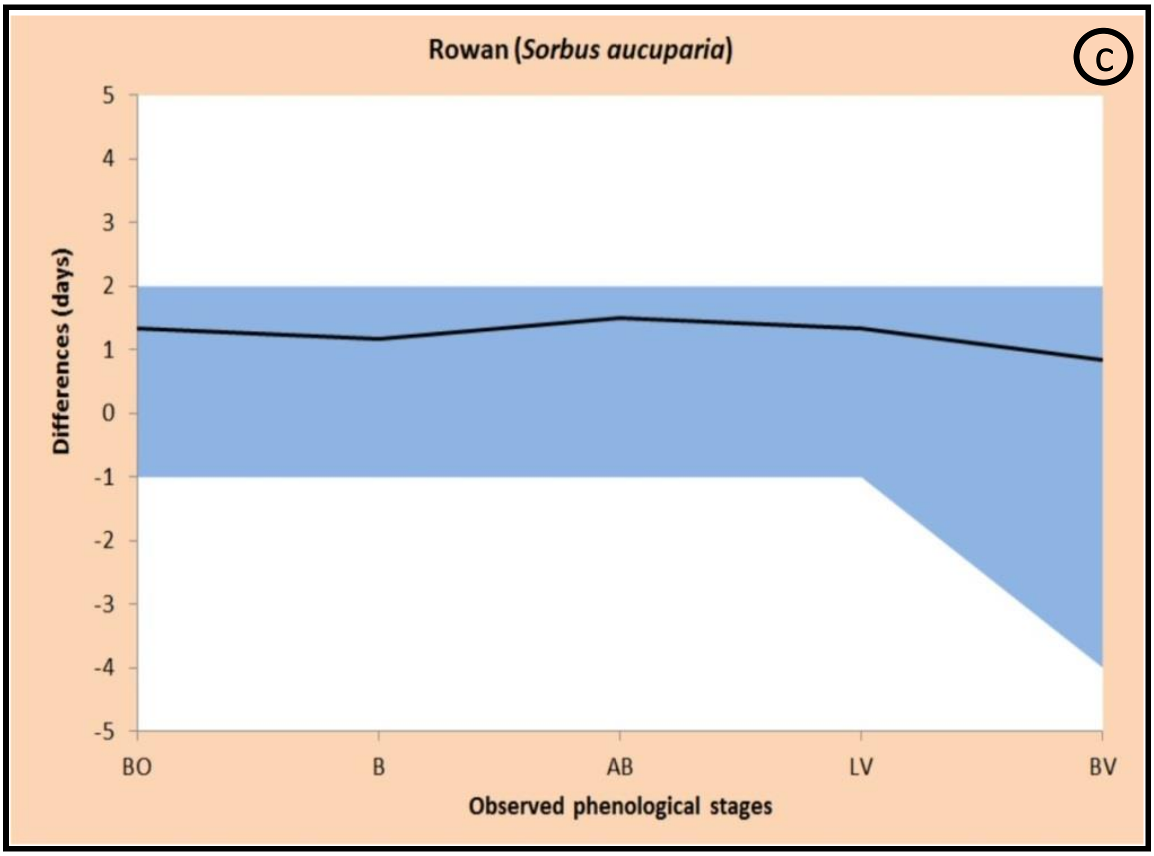


Figure 6. Daily gross primary productivity (GPP) averaged over 10-day intervals and the green chromatic coordinate (gcc) derived from digital camera imagery as the average.

The differences between the traditional manual phenological observations (TM) and the camera systems (CS) fluctuated between –2 and 2 days. These results are shown in Figure 7.




Aspen (*Populus tremula*)
b
5
4
3
2
1
0
-1
-2
-3
-4
-5
Differences (days)
BO
B
AB
LV
BV
Observed phenological stages


Rowan (*Sorbus aucuparia*)
c
5
4
3
2
1
0
-1
-2
-3
-4
-5
Differences (days)
BO
B
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LV
BV
Observed phenological stages

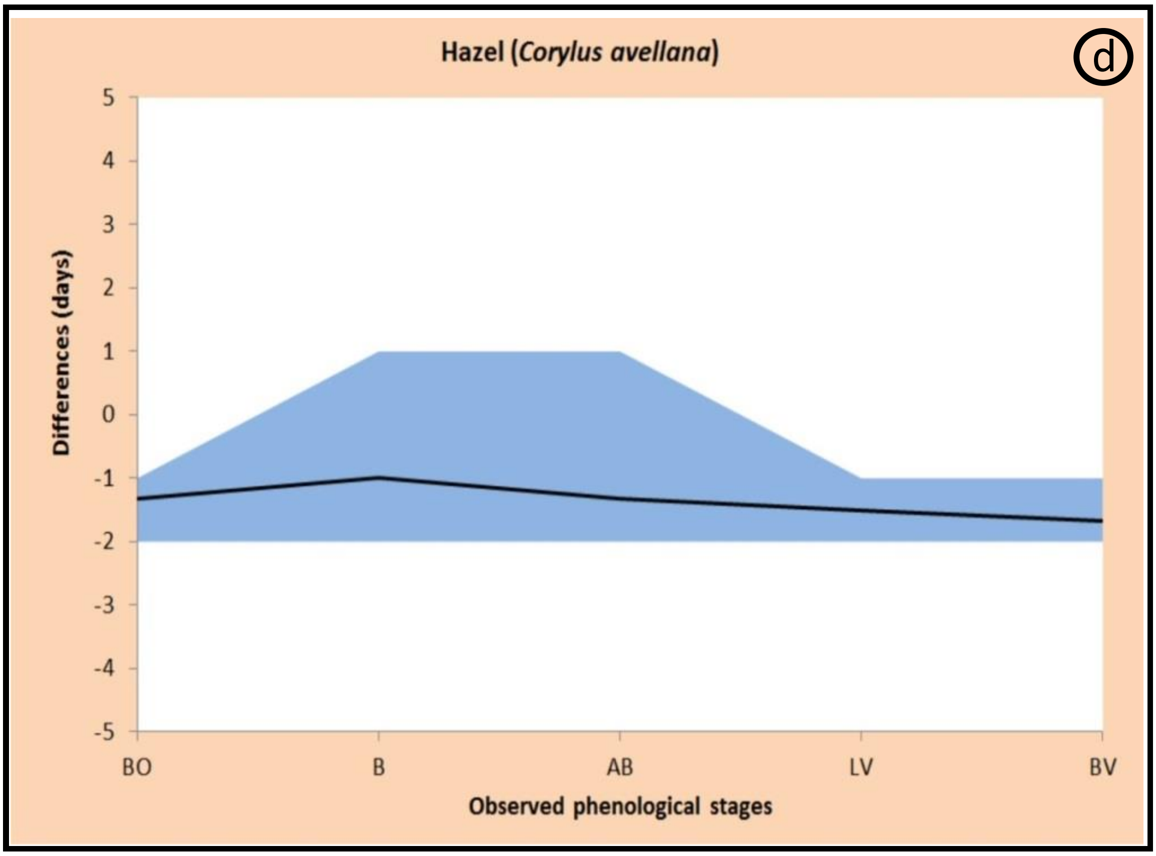

Figure 7. The mean phenophase difference of a) *Betula pubescens* (birch), b) *Populus tremula* (aspen), c) *Sorbus aucuparia* (rowan) and d) *Corylus avellana* (hazel) between traditional manual monitoring and camera system for the period of comparison 2007–2012 at IPG Doksany. Blue area shows the range of values.

Conclusions

The history of phenological observation in the Czech Republic is rather long, even though there were many changes in the recent years. It is really important to thicken the current phenological network in the Czech Republic by usage of the latest phenological methods used in the world. The CHMI is a member of the PEP 725 (phenological data are supplied continuously every year). The PEP 725 outlook: development of more sophisticated QC routines, data import and exchange in operational mode, implementation of new / historical datasets, implementation of animal observations and definition of pseudo BBCH codes, redesign of table plant with uniform taxonomical descriptions and acquisition of new members/partners

The continuous monitoring with digital cameras can serve as an alternative to traditional phenological observations, the gcc is an appropriate tool for monitoring temporal changes in canopy development and phenological events and the gcc provides data required for the calibration and direct validation of satellite observations and products. The high correlation between the iGSI and the net ecosystem carbon exchange proved that CO_2 exchange processes depend significantly on the canopy development.

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Souhrn

Změny a kolísání klimatogenních faktorů (přirozených i antropogenních) jsou příčinou časové variability klimatu na Zemi, která se projevuje jeho změnami a kolísáním. Fenologická pozorování, která se zabývají sledováním časového nástupu každoročně se opakujících vývojových fází rostlin, jsou velmi vhodným prostředkem ke sledování klimatické změny.

Fenologická pozorování mají různě dlouhou historii, nejdelší časové řady jsou v evropských státech včetně České republiky. Systém fenologických pozorování se v posledních letech významně mění, kromě subjektivního sledování dobrovolnými pozorovateli podle stanovené metodiky, jsou fenologické záznamy získávány prostřednictvím tzv. kalendáře přírody (např. USA) a speciálních kamer určených pro fenologický monitoring.

Předložený příspěvek shrnuje historii a současnost fenologických pozorování v České republice a ve světě, popisuje vzájemnou spolupráci a sdílení společných databází fenologických a meteorologických informací s cílem unifikace provedených analýz a tím i možnosti prognóz dalšího možného vývoje.

První výsledky ze záznamů fenologických kamer ukazují na možnost využití této metody jako náhradu za klasické fenologické pozorování.