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PHENOLOGY (STUDY OF APPEARANCE) AND ITS IMPORTANCE

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Abstract
Phenology is the study of periodic biological events in the life cycles of plants and animals, and how these events are influenced by seasonal and interannual variations in climate and habitat factors. Typical phenomena that are studied in phenology include the timing of flowering, leaf unfolding, bird migration, breeding seasons, and animal hibernation.
Phenological data is crucial for understanding ecological responses to climate change, as shifts in the timing of these biological events can affect species interactions, ecosystem dynamics, and food webs. For example, if a plant species flowers earlier due to warmer temperatures but its pollinators do not shift their life cycles accordingly, this can lead to mismatches in timing that affect reproduction.
In recent years, the study of phenology has gained importance as scientists and conservationists look to understand the impacts of climate change on ecosystems and biodiversity.

1 Introduction

Phenology is concerned with the temporal occurrence of biological events in plants and animals, with particular attention to seasonal changes and their effects on environmental factors. Phenological observations can help us to understand how organisms respond to climate change and how this affects environmental change and the evolution of ecosystems.

Phenological events include, for example, flowering, fruit ripening, leaf fall, the time of wintering or migration of animals, the time of swarming of plant pests. Collecting and analyzing phenological data allows scientists to gain a better understanding of how ecosystems work and to predict future changes. Phenological research takes into account temperature, precipitation, sunlight and other environmental factors that affect the life cycles of organisms.

A very important question in agro-meteorology is how the environment, environmental factors and microclimate affect plant development. For both wild plants and animals, or even for cultivated plants and farmed animals, there is an optimal climatic requirement for the emergence of certain phenophases. In the case of plants in their natural environment, we can talk about site-specific conditions. The meteorological data of these habitats and the observation and comparison of phenophases in the life of the plant are called phenological observations, or phenometry.

Phenology links the different stages of development to calendar dates. It also studies the relationships between the different developmental stages. Growers and biologists use it to monitor the growth, development and physical changes of plants. Phenology studies the natural annual cycle and draws conclusions about the development of different organisms and ecosystems. In recent

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decades, the importance of phenological observations has increased and they have become very important indicators of climate change. Various tools, including satellite imagery and citizen science programs, are used to collect phenological data, helping researchers monitor changes over time.

Phenological observations are also used in pollen forecasting in medical meteorology.

Humanity has been concerned with plant development and seasonality since prehistoric times. Knowing the ripening time of each edible plant was essential for survival. Each plant was used as a marker of the changing seasons. For the agricultural man, knowing the exact time of sowing and harvesting of economic crops was necessary.

Etymologically, the word means phainesthai (Greek word) = to appear; logia (Greek) = doctrine, science; it means the science of appearance.

The nomenclature of phenology was first used by the botanist Morren in the 19th century [2], but the discipline was created by Linne in his "Philosophia Botanica", in which he defined the method and aims of phenological measurements [3]. Nowadays, microscopic changes and tissue variations can also be observed [1].

2 The concept of phenology and related definitions

Phenology refers to all the phenomena that are apparent during the development of plants, fungi or animal organisms, some of which are visible to the eye and some of which can be traced at the microscopic level through tissue changes, possibly genetic changes (meiotic division-pollen formation).

Phenological running: all the observable phenological phenomena (macro and micro phenological phenomena) that occur during a growing season (from the beginning of bud break to the end of leaf fall).

Phenological process: part of the phenological running during which the development of a plant part takes place (e.g. the process of fruit ripening). It includes phenophases and microphenophases.

Phenological phase or phenophase: a small but distinct stage in a phenological process, which is a phenomenon or change that is visible to the eye (bud break, splitting, spreading, foliage).

Phenological stage: stage within the phenophase (e.g. stages of floral organ change: glossy pistil; time of pollen dispersal; pistil dull, brown)

Microphenophase: the smallest unit of phenological processes that can no longer be observed with the naked eye, but only with a microscope (e.g. the beginning, process and end of microsporogenesis).

Phenometry: A measure of the change in state that can be measured over the duration of each phenophase. Examples are plant height, leaf area and its leaf area index (LAI).

Phenological maps: provide information on the regional distribution of phenological phenomena, displayed on map(s).

Phenological calendar: linking a phenological phenomenon to a calendar date.

Isofloral maps: Provides information on the spatial distribution of flowering of a given plant.

Base temperature: Species-specific temperature point. It represents the biological 0 point, which means that each plant species starts its vegetation period and exits forced dormancy at different temperature ranges [1,2,3].

1. table: Base temperature of different plant species

Plant	*Basis temperature (°C)*	*Plant*	*Basis temperature (°C)*
Autumn wheat	1-2	Apricot	5
Vetch	1-2	Peach	5
Lentils	1-2	Japaniese plum	5
Poppy	2-3	Plum	7
Sunflower	3-5	Apple	7

(Kajtárné Czinege(edit) 2024; based on [1,2,3]

3 The importance of phenology

The appearance of organisms, plants, fungi and animals is linked to changes in meteorological elements. From these observations, laws are deduced. Thus, phenological observations are very important, for example, in crop production in relation to the timing of certain crop protection treatments, prediction of flowering. It is important for fruit ripening and its forecasting, for planning the harvest, but there are countless examples from the mushroom growing and livestock sectors. The timeliness of certain agro- and phytotechnical interventions is also indicated by the phenophases.

No phenophase is more or less important, as they are successive phases built on each other. Each is significant in its own right. For example, flowering forecasting may be important to provide for controlled bee pollination, or for the timing of protection against pathogens that may be infectious at flowering, or for the need to apply a frost protection technology if the weather conditions are critical.

In the fruit growing sector, knowledge of the time and duration of each phenophase is of great importance, as it determines: optimal planting, technology for protection against adverse weather conditions, initiating and managing active protection against frost, planning and implementing bee-guided pollination, forecasting the appearance of pests (pathogens and pests) and timing of passive and active control, timing of phyto- and agrotechnical interventions, planning the harvesting period and the harvesting method, preparation of trees for winter (agrotechnical elements, nutrient replenishment, plant protection), management of invasive pests

4 The tasks of phenology include:

Recording the evolution of phenomena observed in different production sites; phenology is also a science that searches for regularities and correlations; phenological observations apply mainly to economic crops, but also to the monitoring of natural succession; it also involves linking the succession of phenophases to a calendar date through many years of observation; it also involves recording climatic phenomena and meteorological processes; monitoring climate research and changes in global warming.

A sequence of phenological events is a complex display of site characteristics [3]. The species composition of plants in an area evolves according to soil conditions, while changes in phenophases over time are the result of climate [3].

We can also use it to analyse the effects of climate change. Flowering dates are shifted earlier, the migration of insect pests and their swarming can be observed at different times than usual, and leaf colouring and leaf fall is delayed in native production areas. As long as they occur once in a while, they are considered a harmless event, but their regular occurrence can cause serious problems and, based on the principle of a domino effect, can lead to an imbalance in the ecosystem.

The science of phenology that can be measured and quantified is called phenometry.

Phenometry reflects the measurable state changes that occur during phenophases. Each state change is defined by a phenometric metric. These phenometric metrics reflect changes over time in the dynamics of a particular characteristic of a plant or animal organism (e.g., shoot growth dynamics) and reflect the effect of environmental factors on the organism [3].

There are various phenometric indicators such as plant height; shoot length; stem length; stem number; number of nodes; distance between stem nodes; leaf area and leaf area index (LAI); degree of succulence; leaf area productivity.

The different meteorological events are best reflected in the development of the leaves. Even small changes in environmental factors are reflected in the leaves. Thus the most suitable plant organ for phenometric measurements is the leaf. Leaves have different properties, the most measurable is leaf surface area. This can be used to quantify the relationship between plant development and weather. With a planimeter, leaf area can be measured easily, quickly and relatively accurately.

5 Good examples…

Phenological monitoring is carried out all over the world, but a good example is the National Phenology Network (NPN) in the USA, a nationwide monitoring and research initiative to collect, systemize and forecast phenological data and information. It does this in order to manage natural resources appropriately, support decision making, advance the field of phenology, and is also important for understanding phenological processes. The practical benefit is that those who sign up to the website can get a picture of the occurrence of each phenological stage, linked to location and time, all over the USA. This makes it possible to track where and when which plant species are flowering, when insect invasions occur, when birds migrate, etc.

The UK also has a website collecting phenological observations. https://naturescalendar.woodlandtrust.org.uk/. These websites provide updates on significant phenological phases for the general public.

Observations have also been made in Germany and the Balkans, monitoring the effects of climate change on apple and cherry fruit crops, covering the flowering period of these fruits. In Slovenia, Serbia, B & H and at Bonn, the flowers of Golden Delicious apples may open 10-14 days earlier than 5 decades earlier [6].

Observations were also carried out in Brazil:" Phenological events, such as flowering, are highly responsive to temperature and are directly influenced by the establishment of a dormancy period in temperate fruit trees. Increased temperatures, due to climate change, can cause advancement, delay or no change to temperate fruit tree flowering, putting production at risk and raising uncertainty about the future of crops in traditional apple producing regions."Their Conclusion: „Also, they emphasize the importance of tree breeding or low chill and higher heat requirements cultivars, in addition to the development of suitable managements to assist apple production in warmer climates" [7].

In Norway, observations covered plum phenology, especially flowering and ripening. „Increasing March and April temperatures during the last 30 years has advanced blooming and spring phenology in plum and the resulting extension of the growing season has led to increasing fruit size at harvest. We conclude that so far, the ongoing climate warming appears to have been positive for plum production in the cool Nordic environment. However, an increasing risk of frost associated with earlier blooming will represent a potential negative effect of continued warming" [8].

Observations in China have also concluded that apple blossoming time is speeding up, they are more susceptible to frost and have setting problems due to global warming [9].

6 Summary:

In this paper, we learn about the concept of phenology and the various definitions associated with it. I discuss its importance, its role and its functions. Phenology is both a calendar of nature and a prominent indicator of climate change. One way of monitoring the effects of global climate change is to systematically observe phenological processes.

Finally, I mention the well-established NPN and Nature's Calendar phenology networks in the US and the UK. They observe phenomena and infer regularities from the data set, helping to track global climate change over the last decades and thus helping decision-makers to form opinions and decisions on cardinal issues.

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