Phenology: Nature's Calendar*

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Phenology is the study of recurrent biological events of animals and plants. In this article, we trace the history of phenological studies, understand the factors that drive phenology, discuss various ways one can observe phenological events, and how these observations are important and cost-effective ways to detect signatures of climate change. Finally, we discuss how using the latest technology, we can contribute to furthering phenological studies.

While going to the field or even walking along the roads, how often have we wondered why the trees shed leaves at a particular time of the year? Why do the flowers bloom at a certain time? Why are there specific timings for planting or harvesting specific crops? Phenology answers all of these questions. Originating from Greek roots, the word Phenology comes from the combinations of the words '*phainō*', which means 'to show, to bring to light, make to appear', and '*logos*', which amongst others means 'study, discourse, reasoning'. Thus, phenology primarily means studying the appearance or occurrence of something. First appearing in scientific writing in 1853 by Belgian botanist Charles Morren, the term phenology means the study of the timing of life cycle events at the population level, most often focusing on how organisms respond to climate change at different levels of biological organization. This field often uses long-term records and includes events such as flowering, leaf fall, hatching, hibernation, annual migration, etc. Although there are various definitions of phenology, the most widely accepted was given by the United States/International Biological Program (US/IBP) Phenology Committee in 1972. It states that "phenology is the study of the timing of recurring biological events, the causes of their tim-

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*Vol.28, No.7, DOI: https://doi.org/10.1007/s12045-023-1641-1

Keywords
Phenology, leaf flush, remote sensing images, ecological mismatch, climate change, citizen science.

ing with regard to biotic and abiotic forces, and the interrelation among phases of the same or different species". In simpler words, phenology essentially is nature's calendar. The timings of cyclical or seasonal biological events of plants or animals, such as migrations, egg laying, flowering, and hibernation are often influenced by climatic factors and these timings and resulting changes are the basis of phenology. Thus, phenology has a great impact on almost every aspect of ecology and evolution.

History of Phenology

Though the term phenology was conceived in the 1850s, people have been recognising and recording the changing seasons and resulting changes in the life cycles of plants and animals for a long time in different parts of the world. Such notable history of earlier phenological observations or calendars can be found in various cultures.

Though the term phenology was conceived in the 1850s, people have been recognising and recording the changing seasons and resulting changes in the life cycles of plants and animals for a long time in different parts of the world. Such notable history of earlier phenological observations or calendars can be found in various cultures, such as the great Mediterranean civilisations (Egypt, Mesopotamia), as well as those in Asia (China) and Europe (Rome) [1]. In those earlier days, changes in the natural world over time were recorded for religious or economic reasons. The ancient Greeks used the timing of leaf fall as a guide for sowing winter crops, which shows their recognition of the value of phenology. However, Swedish botanist Carolus Linnaeus (1707–1778) is often considered to have brought phenology into modern science and is dubbed the father of modern plant phenology and phenological observation networks [2]. Linnaeus considered biorhythmic and phenological aspects of living things, relating them to geographical and climatic factors, and contributed towards making a calendar or clock for different stages of plant life throughout his life. This is evident in his various writings, such as *Vernatio arborum*, 1753; *Philosophia Botanica*, 1751, and C*alendarium florae*, 1756. In *Vernatio arborum*, 1753, Linnaeus reported the results of a three-year campaign of phenological investigation on the emission of leaves in about twenty trees and shrubs in eighteen different locations in Northern Europe. It was perhaps the first report covering an international phenological network, carried out following a precise protocol regarding the choice of sites, phenophases (stage or phase in the annual life cycle of a plant or animal that can be defined by a start and end point lasting over a variable time period), and surveying methods [1]. French academic René-Antoine Ferchault de Réaumur is famous for his studies on the relationships between environmental temperature and phenophases. He discovered that flowering takes place when the sum of the environmental temperatures of the previous months reaches a particular value. He formalised these relations in mathematical terms in 1735 in the model of thermic summations, which was later modified by fellow French naturalist M. Adanson in 1750 and gave birth to the concept of 'thermal threshold', which is still used with modifications and variations to make phenological forecasts based on the meteorological trends [1]. Between the 18th and 19th centuries, phenological monitoring networks were developed. They are survey networks to monitor phenological events in their spatial and temporal dimension over large territories. The phenology network coordinates a group of people to simultaneously monitor phenological events across a wide geographic area and record such information. The first such network came up in 1781–1792 in central Europe; the first Russian network was started in 1850 with more than 600 observatories; the British network was started in 1857, and the American network was developed in 1851–1859 encompassing 33 states and 86 different species.

What Drives Phenology?

Although scientists and researchers are still working on finding the possible mechanisms and drivers of phenology, it is currently thought to be a result of a complex interplay among an organism's genotype and several other external environmental factors such as precipitation, temperature, photoperiod, nutrient availability, etc. These may directly (by controlling the timing of biological events) or indirectly (by acting as cues that set the organism's internal 'biological clock') drive the timings of the phenological events [3]. There are, however, various uncertainties regarding the extent of the influence of such factors. The specific responses

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depend on the molecular or physiological properties of the individual or species. To advance understanding of the phenological mechanisms, drivers, strategies, and their variations among species will require extensive, intensive, and long-term observations of phenological data [4]. The science of phenology has been evolving rapidly, and as the discourse on climate change progresses, phenology is also being discussed as one of the major indicators of global climate change. Advancements in science and technology have been a major contributing factor toward the evolution of phenological studies and the collection of phenological data, establishing it as a predictive science. The ability to predict the timing of biological events could help researchers understand the effects of climate change and other ecosystem shifts and help us devise mitigation strategies accordingly.

Methods of Phenological Study

One of the traditional methods of phenological study is ground-based observation.

One of the traditional methods of phenological study is ground-based observation. It is perhaps the most basic, cost-effective, and highly useful method in studying phenology, which provides first-hand and direct evidence of phenological changes. This method was employed by most of the earlier phenological networks mentioned above to study phenological changes. It is very useful as it can accurately record the timing of phenological events for specific sites and species in real time. This method is also helpful for investigating phenological variations across a broad geographical range [5] and species [6] and their possible changes in response to climate change [7]. However, it also has a few shortcomings, including uneven data and a lack of uniform protocol in the collection of data, as well as the reliability of collected data [5].

Another method of phenological study is remote-sensing-based phenology observations, which is a result of the technological advancements of the past few decades.

Another method of phenological study is remote-sensing-based phenology observations, which is a result of the technological advancements of the past few decades. Remote sensing technology has rapidly advanced in terms of radiometric, spatial, and spectral resolution, and the tools for management, processing, analysing, and visualising such data have also evolved (*Box* 1). Often used in landscape-scale plant phenology studies, this method uses data from remote sensing satellite, which can detect the timing of phenological events in the temporal profile of greenness-related vegetation indices. These indices include the normalised difference vegetation index (NDVI) and the enhanced vegetation index (EVI) [5]. However, the accuracy of the comparison of such vegetation indices depends on various factors. These factors include poor observation conditions (e.g., clouds, snow, and ice), bidirectional reflectance distribution function (BRDF) effects, shifts in sensors, and coarse spatial and temporal resolutions [5]. One example of such limitations can be seen in the case of mixed-canopy forests, where different species having different phenophases at the same time can cause difficulty in the interpretation of data. For example, in deciduous forests, greening often occurs first at the ground level, and the spring greening date, as identified by remote sensing approaches, may reflect the greening date of herbs and shrubs and not that of the dominant trees in these forests that tend to green-up later. Also, for understory cover detection, normal optical remote sensing images are not useful because of the reflectance of tree leaves on overstory canopy covers.

Most remote sensing phenology studies utilize data collected from the red and near-infrared portions of the electromagnetic spectrum that are transformed into a vegetation or greenness index.

Vegetation indices are a remote sensing technique that can be used to identify vegetation and measure its health and vitality.

Box 1. Remote Sensing in Phenology and the Different Terms

Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance (typically from satellite or aircraft). Special cameras collect remotely sensed images, which help researchers 'sense' things about the Earth. Most remote sensing phenology studies utilize data collected from the red and near-infrared portions of the electromagnetic spectrum that are transformed into a vegetation or greenness index.

Vegetation indices (VIs) are a remote sensing technique that can be used to identify vegetation and measure its health and vitality. It is designed to take advantage of the spectral reflection/absorption characteristics of plants to describe the 'greenness' of each pixel in a satellite observation. Plants absorb red light and reflect energy in the near-infrared portion of the electromagnetic spectrum. The output is presented in the form of a heatmap, where the green colour shows healthy vegetation, and the red colour indicates less healthy plants.

Contd.

Box 1. ***Contd.***

Depending on the transformation method and the spectral bands used, different aspects pertaining to the vegetation cover in the image could be evaluated, say, the percentage of vegetation cover, amount of chlorophyll content, leaf area index, and so on.

Simple ratio (SR) is the simplest VI, which is a ratio between the reflectance recorded in the near-infrared (NIR) and red bands. This is a quick way to distinguish green leaves from other objects in the scene and estimate the relative biomass present in the image. Also, this value may be very useful in distinguishing stressed vegetation from non-stressed areas.

The normalized difference vegetation index (NDVI) is one of the most commonly used VIs for monitoring the percentage of green cover in an area. Developed in the 1970s, it is calculated by taking a ratio between the difference of reflectance from NIR and red bands and the sum of reflectance from NIR and red bands to identify the amount of chlorophyll in leaves. Since it is a ratio, this index is invariant to the difference in illumination conditions, slope, seasons, etc., and thus is suitable for plant monitoring throughout the growth seasons. However, it lacks subtlety when it comes to warning signs early in the growing season and vegetation changes late in the season.

The enhanced vegetation index (EVI) is an advanced vegetation index created with higher sensitivity to biomass, atmospheric background, and soil condition. It is regarded as the modified version of NDVI with a high potentiality of vegetation monitoring by correcting all the external noises, and it uses the blue, red, and NIR bands. Bright features such as clouds and white buildings, along with dark features such as water, can result in anomalous pixel values in an EVI image.

Solar-induced fluorescence, or SIF, is an innovative measurement that serves as a proxy of plant photosynthetic activity. When plants absorb white light from the sun, they initially absorb light across the entire spectrum. When photosynthesis occurs, some of the unused energy absorbed from the sun is emitted as heat and a red glow, or SIF. This is normally invisible to the human eye, but by using a blue flashlight and a pair of red glasses and shining the light on a plant in a dark room, one can actually be able to see the red glow being emitted from the plant's photosynthetic process. SIF goes one step further than normal VIs and actually provides a read on a plant's photosynthetic process rather than just relying on visible changes. With SIF, instead of observing outward signs of change to an event, the plant's physiological response to it can be observed.

The bidirectional reflection distribution function (BRDF) is a theoretical concept that describes the relationship between a target's irradiance geometry and the viewing angle of the remote sensing system relative to the target. The BRDF can significantly affect the radiometric characteristics of remotely sensed data. An understanding of BRDF is needed in remote sensing to correct for Sun illumination angle and sensor viewing angle effects when mosaicking images, deriving albedo, improving land cover classification accuracy, enhancing cloud detection, and correcting for atmospheric conditions.

In recent times, remotely sensed solar-induced chlorophyll fluorescence (SIF) data have proved to be useful tools for studying seasonal variations in gross primary productivity (GPP) (*Box* 1) [5]. With its direct link to photosynthetic activity and the fact that its performance is not affected by cloud and atmospheric scattering, SIF can be an alternative approach to retrieving phenology events more efficiently than traditional NDVI and EVI data [8].

In addition to these, near-surface remote sensing phenology has emerged as a prevalent tool in the last decade for phenology studies due to its repeated, high-frequency image collection using commercial networked cameras, also called phenocams (see *Box* 2), which have allowed the detection of leaf phenological events through the analysis of colour changes along time [9]. Digital cameras monitoring canopy vegetation play an important role by filling the 'gap of observations' between satellite monitoring and traditional on-the-ground phenology [9]. This method of using imagery data over traditional phenological observations has multiple advantages, including simultaneous multi-site monitoring, long-term monitoring collecting high-frequency data, and reduced human labour for data collection. Alberton et al. (2017) [9] laid down a protocol with the main information about the repeated photography method and preferable setup to increase the potential of a new tropical phenology research program through network and collaboration. With the improvement in camera technology, global networks can be built that can monitor not only plants but also all biodiversity.

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Multi-source data fusion can also be used to tackle the problems of single remote-sensing data by the fusion of different spatiotemporal datasets, which generate time-series data with both high spatial resolution and higher frequency. To date, the development of more than 60 different spatiotemporal data fusion models has been reported using different principles and strategies to produce synthesised satellite images, which have proven to be more efficient in plant phenology studies [5].

Box 2. PhenoCam

The technique of using repeated digital photographs to track phenological changes answers many of the limitations of empirical or mechanistic phenology studies giving access to high-resolution data at a relatively low cost, reduced work, and easy setup. Digital images are typically based on the RGB colour model (red, green, and blue colour channels). These channels encode the brightness values of the scene and can be combined in more than 16 million colours, representing basically all the colours perceived by humans [28]. Using phenocams, by capturing daily digital images of a given site, the RGB colour changes can be monitored over time and by quantifying the RGB colour channels of the digital photographs, it is possible to calculate vegetation indices, which are related to leaf colour changes representing the phenological status of the vegetation over time. Such networks of high-quality phenocams are already covering various parts and ecosystems of the world, namely the PhenoCam Network in the United States, the EuroPhen in Europe, and the Phenological Eyes Network (PEN) in Japan.

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Manipulative experiments are also valuable tools for studying plant phenology. Experiments can help understand the underlying drivers of phenology and patterns of changes clearly compared to the ground- and remote-sensing-based observations, which only help in recording the patterns of change. Two broad types of climate warming experiments, i.e., passive and active warming, have been used in phenology studies. While experimentation may be the most direct method of studying phenological responses and drivers of climate change, it has various limitations. These experiments are often short-term and species-specific and thus cannot provide a complete understanding of long-term phenological responses of plants to environmental changes [5]. Another shortcoming of such experiments is that they are normally conducted on saplings or seedlings as opposed to mature trees, but young and mature trees may show substantially different phenological responses to the same environmental changes [5]. Again, the phenological responses in natural and controlled environments may differ at a great level.

Phenology modelling is yet another major tool for studying phenology. Long-term monitoring of phenological events and an improved understanding of key drivers and mechanisms have provided enough data to simulate the timing of phenology and to project likely future changes by creating phenology models. Such models can help investigate the response of plant phenology to future climate change [7] and understand how the phenological changes may affect ecosystem functions, such as carbon cycling and energy flows, and their feedback to the climate system [10]. Phenology modelling has a long history; earlier modelling studies employed only statistical approaches (i.e., empirical models) that resulted in biases toward spring phenological events. There is relatively little documentation of autumn phenology events, and it was assumed that spring phenological events occur when a certain accumulation of heat units is achieved. However, future warming may exceed the past temperature range, and using statistical models to estimate future phenology changes may result in considerable biases. Recently, scientists have also developed more mechanistic models (i.e., process-based models) to yield more realistic predictions [5]. Such models explicitly consider various other variables, such as the developmental phases of the plants as well as the effect of photoperiod and nutrition acquisition, etc. However, uncertainties remain in these model studies, even with recent advancements in species- and ecosystem-level models. However, simulations are limited in predictive power without a clear understanding of the interconnected physiological mechanisms that drive phenology and may only reflect correlative findings within specific spatiotemporal scales [4].

Recently, scientists have developed more mechanistic models (i.e., process-based models) to yield more realistic predictions. Such models explicitly consider various other variables, such as the developmental phases of the plants as well as the effect of photoperiod and nutrition acquisition, etc.

To answer such limitations of using singular methods of studying phenology, Liang and Schwartz (2009) [11] proposed the idea of using 'landscape phenology' (LP) as an integrative tool and perspective to link different means and scales of phenological observation and connect phenology back to its spatial, temporal, and ecological contexts.

Latitudinal Gradient in Phenology Studies

Comparison of the phenology of plant communities in different climate zones highlights the latitudinal gradients in the major phenological traits. There is a rich and noticeable diversity in plant phenology from temperate and tropical climates as a result of the adaptation of plants to geographically different environments [12]. Such adaptations have created differences in phenological patterns of plants among temperate, tropical dry, and tropical rainforests, which have been extensively studied. As seasonal environmental changes are less pronounced in tropical forests, there is a wide variation in phenological patterns and their climatic drivers. In neotropical dry forests, dry and wet season cycles influence the timing of leaf, flower, and fruit production [13]. Though there is no dry season in the Atlantic rainforest in Brazil, there is still clear seasonality in leafing and reproductive events that can be affected by slight changes in photoperiod and temperature [12]. In ever-humid rainforests in Southeast Asia, seasonality in leafing and reproductive events has become unclear, but between-year fluctuations in flowering and fruiting events at the community level are prominent [12]. Researchers further observed that although the most species-rich biomes of the Earth are located in the tropics, tropical plant phenology remains poorly understood as tropical phenological data are comparatively scarce, and often such data are viewed through the lens of a 'temperate phenological paradigm' [14].

Phenology and Climate Change

Phenological shifts are among the first reported biological footprint of the impact of climate change and are among the most conspicuous signs of global warming.

The relationship between phenology and climate change has been explored by scientists and researchers for a very long time. In fact, phenological shifts were among the first reported biological footprint of the impact of climate change [15] and are among the most conspicuous signs of global warming [16]. Climate change is impacting phenology across taxa and ecosystems, and a trend toward the advancement of spring is widely observed [17]. The recent Intergovernmental Panel on Climate Change (IPCC) Report 2021 indicates that in mid to high latitudes, phenological shifts are distinct, especially in terms of growing season lengths. A large number of studies have reported phenological changes as a result of climate change in various types of organisms [12]. It is reported through various studies that the impact of climate change has resulted in the earlier onset of spring flowers, leaf bud burst, migration of birds, breeding of frogs, advanced first flights of butterflies, and altered generation time in insects, to name a few changes. One such popular example is the Japanese cherry blossoms. Multiple studies encompassing century-old data confirm that in recent decades, the blossoms have emerged much sooner than they once did. Researchers reported that the full flowering of Kyoto's cherry trees in 2021 was observed on the 26th of March, the earliest date recorded in over 1200 years [18]. They further demonstrated that Kyoto's cherry flowering season arrives on average 1–2 weeks earlier because of anthropogenic climate change, with a projected shift of an extra week by the end of the century [18]. Quansheng Ge and his team analysed historical observation data of 112 species, including taxonomic groups of trees, shrubs, herbs, birds, amphibians, and insects collected at 145 sites across China between 1960 and 2011. This study showed that 90.8% of the spring/summer phenophases time series show earlier trends, and 69.0% of the autumn phenophases records show later trends [19]. Due to the differences in responses of different species to temperature shifts, mismatches of phenological events among interdependent species can impact their reproduction and survival. Phenological shifts can cause species declines by generating asynchronies between plants and pollinators, plants and herbivores, migrant birds and their prey or floral resources, and hosts and parasites [20].

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While it is well established that climate change impacts phenology at a deep level, there has been none to very few studies that have employed phenological studies to predict the trend of future climate change or the probable impacts of such changes on lifeforms in the future. Reviews in recent times have shown that spring phenological events are changing at an average of 2.3 days per decade and more than 2.5 days per degree Celsius for many species [21]. As a result, there is an urgency to translate a basic understanding of phenology into forecasts of how phenology will change given continued and rapid climate change and to predict the ecological consequences of these changes [22]. Y Aono attempted to estimate the change in March mean temperature in Tokyo using the phenological data for cherry blossoms in historical times since the 18th century, which showed a gradual increase in the mean temperatures [23]. There have been reports of case studies involving plant communities and insects to explore the implications of variability across levels of organisation (within and among species and among communities) for forecasting responses to climate change (see [22]) but not to predict the trends of climate change in general. Significant variability in species' responses to phenological changes, together with limited data, limits efforts to forecast the trend or effects of future climate change.

Role of Citizen Science in Phenological Studies

Among the recent developments in the field of ecology, 'citizen science' plays a significant role, engaging non-professionals and professionals alike to contribute to data collection for amateur or professional scientific research, ranging from long-standing, large-scale projects to more personalised research experiences.

Among the recent developments in the field of ecology, 'citizen science' plays a significant role, engaging non-professionals and professionals alike to contribute to data collection for amateur or professional scientific research, ranging from long-standing, large-scale projects to more personalised research experiences.

Citizen science is the practice of public participation and collaboration in scientific research to increase scientific knowledge. Through citizen science, people share and contribute to data monitoring and collection programs, and many such projects involve monitoring plants, animals, and atmospheric conditions. People around the world can report what is happening near them using the internet and geographic information system (GIS) enabled web applications that allow participants to collect large volumes of location-based ecological data [6] and submit them electronically to centralised databases and scientists can develop a better idea of worldwide trends in ecology and the environment. The impacts of citizen science are clearly visible in biological studies of global climate change, including analyses of phenology. These platforms provide a rich source of spatially and temporally extensive phenology data. Further, there are very few empirical phenological studies across large geographical scales despite having the importance as such studies require frequent simultaneous observations across different latitudes, which is very time-intensive and often require larger collaborations, which makes observations costly and hard to organise. On the contrary, citizen science observations can be very useful in phenological research, answering all these limitations [24].

Use of smartphone-based applications for species identification and monitoring, such as iNaturalist (inaturalist.org), Pl@ntNet (plantnet.org), Flora incognita (floraincognita.com), eBird (ebird.org), NestWatch (nestwatch.org), SeasonWatch (seasonwatch.in) (*Box* 3) India Biodiversity Portal, Naturkalender (Nature's Calendar-from Austria), ClimateWatch (from Australia), Spot-a-Bee, Budburst (budburst.org), FeederWatch (feederwatch.org) and many more have become widely popular over the last few years, and these directly or indirectly contribute towards monitoring phenological changes. According to the official data published by the respective apps, in 2020 alone, iNaturalist users logged 12.6 million research-grade observations, and eBird users logged 169 million observations [25]. However, most of these biodiversity-focused citizen science programs are not specifically designed to track species' phenology. However, images in such databases can be manually annotated to study phenology by using deep learning tools [24]. R A Reeb and his team have shown that the deep learning tool convolutional neural networks (CNN) can successfully extract phenological data from iNaturalist image sets with comparable accuracy to manual annotation by humans but at a lower labour cost and higher speed providing a promising solution to integrate citizen science datasets with cutting-edge phenological research [25]. Y P Klinger and his team propose a workflow for the use of publicly available photo observations from the citizen science programs to track phenological events at large scales dubbed as phenology, which comprises data acquisition, cleaning of observations, phenological classification and modelling spatiotemporal patterns of phenology [24]. Using the example of an invasive herbaceous species in Europe, *Lupinus polyphyllus*, this study shows the suitability of this framework to track key phenological events of widespread species by observing key phenological stages in the plant reproductive cycle of the model species

Use of smartphone-based applications for species identification and monitoring have become widely popular over the last few years, and these directly or indirectly contribute towards monitoring phenological changes.

and discusses limitations and future prospects of the approach. Researchers used the help of NestWatch data of 47,023 bird nests of 110 species, laid between 1997 and 2015 to show phenological advancement in Californian avifauna where early summer temperatures can have substantial demographic impacts on bird populations via their impact on nest success [27].

Box 3. Citizen Science Program for Phenology Monitoring

A few such citizen science programs are directly involved in monitoring phenology, such as the Austrian app Naturkalender, which focuses on the development of certain phenological indicator plants. Through community science observations of plants that start to bloom, bear fruit, or shed their leaves, or animal activities, they support the data collection of the Austrian Central Institute for Meteorology and Geodynamics (ZAMG) and the European Phenology Database.

ClimateWatch is another such app, developed by Earthwatch Australia with the Bureau of Meteorology, Australia, and the University of Melbourne to understand how changes in temperature and rainfall are affecting the seasonal behaviour of Australia's plants and animals, the first continental phenology project in the Southern Hemisphere.

Another example is the web-based North American Bird Phenology Program, where participants curate historical data from the Bird Migration and Distribution program by logging into the website and creating a database of avian life history and trends spanning more than a century. This project is helping scientists and the general public understand how climate change is affecting bird migration across North America.

Kosmala et al. (2016) created a citizen science project called Season Spotter (seasonspotter.org) that used imagery from a network of phenology cameras from The PhenoCam Network, the largest near-surface phenology camera network in the world consisting of 300 elevated cameras located primarily in North America [29]. They showed that citizen science data, in combination with near-surface remote sensing of phenology, can be used to link ground-based phenology observations to satellite sensor data for scaling and validation that can provide huge opportunities in the field of phenology by reducing various limitations [29].

SeasonWatch is an India-wide phenology monitoring program that studies the changing seasons by monitoring the annual cycles of flowering, fruiting, and leaf-flush of trees with the official website reporting 624,678 unique observations where observers register one or more trees from a list of suggested species with the project and record phenology weekly. A recent study by K Anujan and his team successfully used SeasonWatch data of 165,006 observations spread over 19,596 individual trees of three of the most frequently observed species ranging over nine years (2014–2022) in the Indian state of Kerala to study the influence of climate on tropical tree reproductive phenology and extent of variability among years and individuals [30].

Originating as a sub-branch of natural history, phenology has evolved rapidly over time, and now it is a crucial branch of science that has found prominence with the development of the climate change discourse. Interdisciplinarity is one of the main aspects of phenology studies, and better coordination between all related fields can be very beneficial for the progress of phenological studies that can provide more robust data regarding the prediction of climate change trends and impacts on the biological world.

Next time, when you see a plant in full bloom or a tree with a new leaf flush, spare some time to observe the marvel of nature, but at the same time, do not forget to take out your smartphone, record the observation and contribute to the phenological science.

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