

# Phenology 101 for Educators

## Introduction to Phenology





# Introduction to Phenology

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**HARVARD**  
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**Project BudBurst™**  
Timing is everything!



**SEASON  
SPOTTER**

# Welcome to Plant Phenology 101

How do plants know when to start growing each year? Do trees use calendars to leaf out? Do wildflowers check their cell phones to see when to bloom? Of course not – plants don't have calendars or watches, but they do take cues from their environment (such as changes in day length, amount of rain and snowfall, or increasing/decreasing temperatures) to move along the annual growth cycle. Noting the timing of when plants change through the seasons is the science known as phenology.

In plants, phenology is the study of the timing of the biological events such as flowering, leafing, and fruiting. Changes in the timing of phases of the plant life cycle, known as phenophases, are directly affected by temperature, rainfall, and day length. Scientists have found that the timing of phenological events of many plant species has been shifting as a result of changing temperatures and rainfall patterns associated with climate change.

How plants react to seasonal change has a big impact on the natural environment. Because plants are at the base of the food chain, anything that affects plants can impact other parts of the ecosystem. And, to scientists, changes in the timing of phenological events can be used as an indicator of changing climates.

## How to Use this Guide

This guide contains a combination of readings, discussions, activities, and a self-assessment.

You will find the necessary background content needed to utilize the suite of ala carte educational resources including hands-on activities and videos.

### Helpful Hints:

- The first instance of each glossary word in the text is italicized.
- Full URL's for links can be found in the Appendix on page 15



## Learning Outcomes

- Be able to describe the science of plant phenology to students (or adult learners)
- Be able to explain how long-term observations of changes in plants may be used to better understand changing climates
- Be able to describe at least 2 phenology related research efforts or projects
- Be able to formulate questions that demonstrate the types of scientific questions that can (and can't) be asked and answered using plant phenology data

## Time Commitment

The anticipated time commitment for completing this unit is, on average, 1.5 – 2.5 hours.

|                    |               |
|--------------------|---------------|
| Readings           | 30 min – 1 hr |
| Research phenology | 30 min        |
| Activities         | 30 min – 1 hr |

## What You'll Do

- ✓ Learn about plant phenology
- ✓ Find plant phenology article(s)
- ✓ Observe the plants around you
- ✓ Gain experience working with plant phenology data



As part of a National Science Foundation Macrosystems Biology grant EF-1065074 to the PhenoCam Network, NEON's Project BudBurst is making these resources freely available for use by educators. Please visit [the PhenoCam website](#) to learn more.

## What is Phenology?

### Phenology Defined

The word *phenology* comes from the Greek words 'phaino' (to appear) and 'logos' (to study)—the science of appearance. The study of phenology has gained increasing attention in recent years as we learn more about climate and environmental change. However, the field of phenology is not new. In plants, the appearance of life cycle events (*phenophases* such as leafing, flowering, and fruiting) has long been of interest to humans as they kept track of natural cycles to determine the best time to plant crops, gather edible fruits and nuts, and plan hunting expeditions. The first written observations of plant phenology were recorded by the Japanese over 1000 years ago. In Northern Europe, records dating back to the 1400s indicate that agriculturists began to make detailed notes tracking the emergence of phenophases in plants.



**Figure 1** - Dr. David Inouye examining wildflowers.

Modern plant phenologists are interested in how changes in the environment can influence the timing of specific life cycle events. Plants use cues in the environment such as variation in day length, temperature, and precipitation to determine when to put out new leaves, open flowers, or ripen fruits. Because these phenophase events are sensitive to small variations in climate, especially temperature, phenologists can use changes in phenophase timing, such as earlier fruiting and flowering, to identify trends and understand how climate may be impacting plants.

### Activity 1

#### What's happening in phenology research today?

Find and read two recent articles (published within in the last two years) on plant phenology.

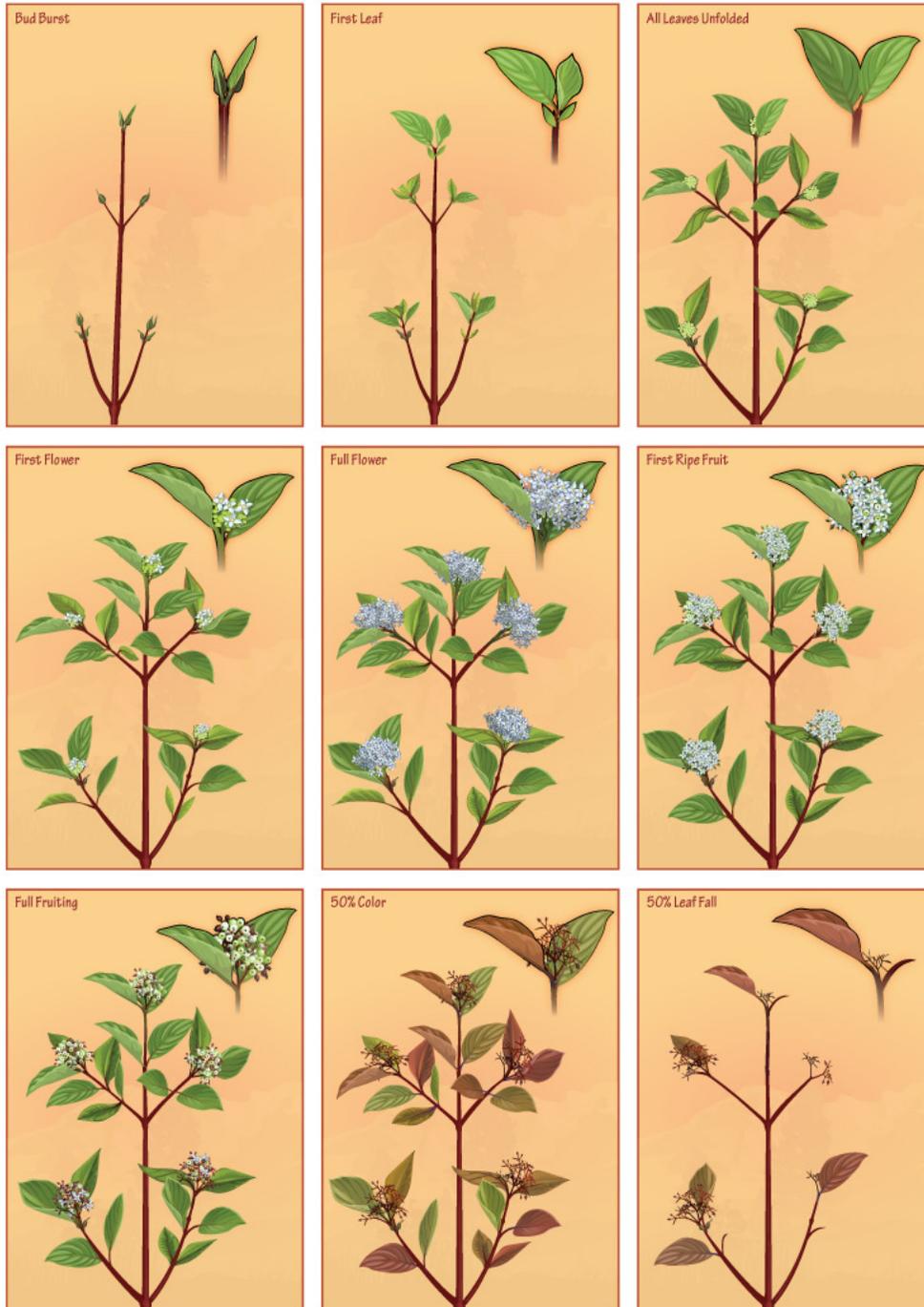
You can find an article by searching an online scientific article database, such as Google Scholar, ScienceDirect or Wiley Online, or going to your local library.

In addition, existing phenological records can be used as “proxy” data to better understand past climates for periods or locations where no instrumental records are available. We know that plant phenophase timing in a given location will vary with temperature. For example, warmer weather leads to earlier fruiting while cooler temperatures cause later fruiting. Knowing how phenophase timing and temperature are related, we can compare historical phenology data with recent plant phenophase observations to reconstruct the missing historic temperature data. This method is not perfect, but along with the use of other indirect measures, it allows a reasonable reconstruction of climate over a long period of time.

When using phenology data to study climate changes, it is important to keep in mind that there is variability in phenophase timing across species and plant groups. In the following sections we will briefly discuss this phenomenon and provide examples of phenophases and their timing in different plant species and groups.

# What is Phenology?

## Phenophases of a Red osier dogwood



**Figure 2** - An example of a Red osier dogwood shrub (*Cornus sericea*) changing through the seasons.

Let's use the graphic of a Red osier dogwood (a *deciduous* shrub) to get a better understanding of what we mean by phenophases. As it emerges from dormancy, the shrub begins to leaf out in the early spring. Flowers appear, and if pollinated, turn to fruit in the fall. As the weather cools and day length shortens, leaves change color and begin to drop. The shrub enters dormancy and in the spring, the cycle begins again.

# What is Phenology?

## Phenophases of a Quaking Aspen Tree

We can use the photos below of a Quaking aspen (*Populus tremuloides*) to provide another example of phenophases in another deciduous plant. The flowers and fruit of the Aspen tree are not nearly as obvious as an Red osier dogwood shrub, but they are equally important to observe. Quaking aspen trees flower before the leaves appear in the spring. Notice in the full flower picture below that there are no green leaves on the branches!



First Leaf



Full Flower



Full Color (Fall)



Full Leaf (at least 95% of all leaves are open)

**Figure 3** - Phenophases of a Quaking aspen (*Populus tremuloides*), clockwise from top left. Please note that the “full leaf” image also has immature fruit present.

# What is Phenology?

## Phenophases of Wildflowers

The examples above have focused on deciduous trees and shrubs. Plants such as wildflowers or grasses or conifers will have different phenophases. For now, let's consider the Common dandelion, a *non-native* wildflower (yes, most of us do think of this plant with the bright yellow flowers to be a weed!). During the course of a year, some wildflowers, like dandelions, will flower and fruit numerous times.



**Figure 4** - This video shows a Common dandelion (*Taraxacum officinale*) progressing through First Flower to Full Flower to First Ripe Fruit. Video produced by Neil Bromhall Copyright 2009. Length of video is 1:23.

Watch the [time lapse video](#) of a dandelion and note the [Project BudBurst](#) phenophase events as they occur:

- First Flower at 0:09
- First Ripe Fruit 0:22 (Note: also End of Flowering)
- Full Fruiting at 0:30
- First Flower at 0:37
- First Flower at 0:52
- Full Fruiting at 1:03

### Activity 2

#### What are plants around you doing?

Find a plant nearby and record observations about its current phenophase. What is it doing (this will vary time of year)? Is it dormant? Are leaves just emerging? Is flowering just starting or ending? In grasses, are the *first flower stalks* visible? Can you see new needles on *conifers*? Or are the cones starting to drop? For more information about observing plants, visit the Project BudBurst website.

## Why Study Phenology?

### Phenophase Timing and the Environment

Let's first think about the timing of plant growth. Most plants produce new growth in the spring which is of critical importance to insects which feed on this foliage. Also during this time, migratory bird species (who eat these insects) return from their southern wintering habitats to nest in the north. These insect-eating migrating birds, such as Warblers, Flycatchers, and Vireos, will visit stopover sites along their migration route to rest and refuel during their trip. They thus rely upon the availability of insects to fuel their migration.

Now, imagine a year during which the weather is unusually warm. Instead of new plant growth emerging in early April, the plants start in early March, and warm temperatures trigger insects to emerge early. While insects can adapt to the changing temperature conditions quickly and emerge when the weather conditions are just right, the birds are more fixed in their migration patterns. Migratory birds may visit their stopover sites during their usual annual migration time periods in search of insects to eat. However, now they find their most critical food to be in short supply. Sadly, many of the birds are left hungry and thus become more susceptible to predation (being eaten by other animals) or starvation.



**Figure 5** - Eastern Meadowlarks rely upon insects as their main food supply in the spring to support their long migration to northern breeding grounds. They also usually arrive at their summer breeding grounds when insects are first active.



**Figure 6** - Left: Columbine (*Aquilegia canadensis*) is a spring blooming and favorite of ruby-throated Hummingbirds who feed on its nectar. Right: A Monarch butterfly feeding on a goldenrod plant (*Solidago canadensis*).

# Why Study Phenology?

## Climate Change and Plant Phenology

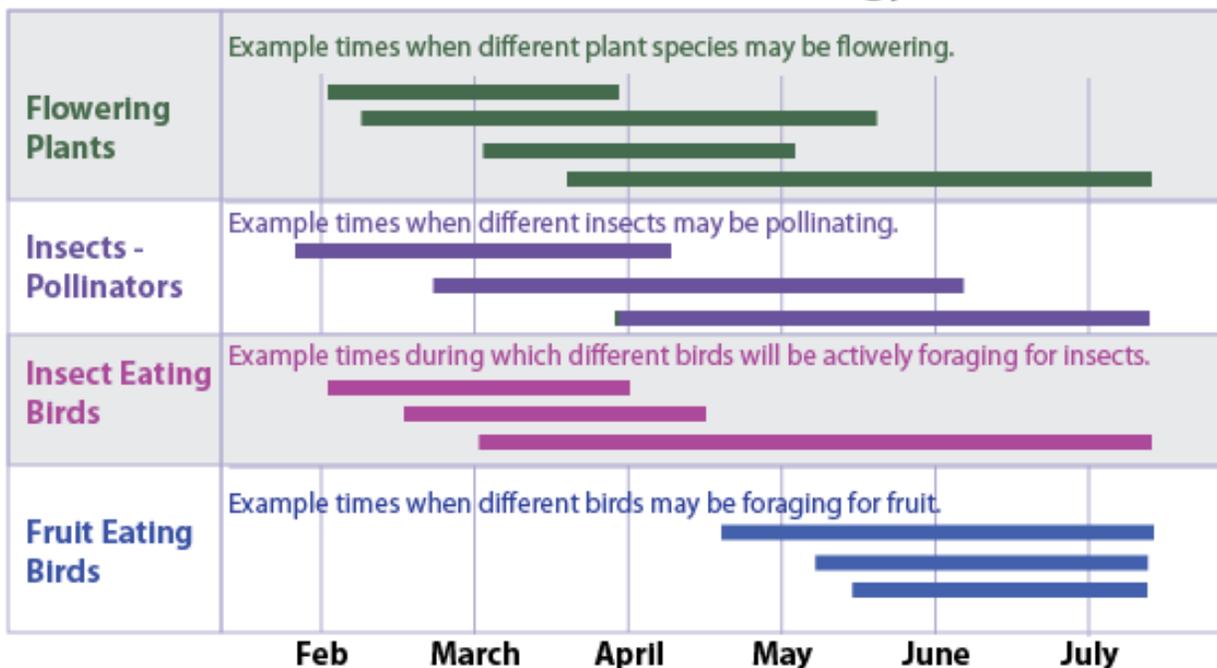
A changing climate associated with a gradual temperature warming may trigger changes in the timing of plant life cycle events (e.g. changes in phenophase timing). This change could impact interactions between different species, ultimately leading to some species becoming more common and others disappearing. A warming climate may not only disrupt the timing of a plant's growth in the spring, but it can also disrupt the life history of other species such as birds, also impacting their reproduction and survival. In ecology it is often stated that "everything is connected." The timing of life events (phenophases) for a species in an ecosystem is often intricately related to phenophases of other species in that ecosystem. It should come as no surprise that if the climate changes quickly, and some species change their timing more quickly than others, these relationships will change, leading to the demise of some species.

So where does plant phenology data fit into this story? Phenology data are integral in tracking changes in plant phenophase timing, which can in turn be used to study broader patterns of impacts on wildlife. This concept of changes in phenophase timing and associated impacts on wildlife is reviewed in greater detail on the [Why Phenology page](#) of the Project BudBurst website.

### Learn and Explore...

[Stenseth & Mysterud's paper](#) provides an example of how changes in plant phenology have been linked to the decline of a migratory bird in Europe. Can you find other articles linking plant phenology to changes in bird migration?

## Timing is Everything! Example Relationships Between Plant and Animal Phenology



**Figure 7** - Example timing of phenology events for plants, insects, insect eating birds, and fruit eating birds. Notice that certain flowering events (green bars) overlap with the timing of certain insects pollinating flowers (purple bars). It is well-known that plants and birds in particular have "co-evolved". It is no accident that flowering, leafing-out, and fruiting corresponds to when these food resources are of the greatest attraction to birds - and when the activity of birds is of the greatest benefit to plant dispersal and/or reproduction.

### Using Phenology Data to Extend Historical Datasets

New phenology data can be used to extend existing historical datasets. The detailed journals of naturalist and writer, Henry David Thoreau, provide a compelling example of the great contributions that volunteers can make to science. They also provide a unique link between current phenology data and historic observations which in turn can be used to make important scientific discoveries.



Figure 8 - A portrait of Henry David Thoreau.

Thoreau kept a daily journal of natural history observations from 1851 to 1858. This journal included first flowering date observations for close to 500 plant species around Walden Pond. Several naturalists continued to make observations in the same general area over several other time periods up until 1993. In 2003 phenology scientists Richard Primack, Abraham Miller-Rushing and their collaborators started collecting the same kind of data that was collected in the past, primarily dates of first flowers, and dates of when trees and shrubs leaf out. In addition to phenophase observations, information was available on the relative abundance of plants around Walden Pond in the mid-19th century that can be compared to plants that are located around Walden Pond today.

In a series of studies summarized by Primack et al. 2012, many important discoveries were made that provide scientists with a rich set of questions and analyses that can be tested with modern plant phenology data. Of particular interest, these studies show that plant species vary widely in their ability to change the dates of their phenophase events as weather and climatic conditions change. Interestingly they found that plants in some families have not changed the dates of phenology as much as others, and that these plants tend to be less common now than they were during Thoreau's time. This suggests that with Project BudBurst data it will be important to see which species are changing their phenology most quickly, and to identify those that are flowering or leafing out on the same dates, regardless of changes in weather or climate. Much could be learned by doing this kind of analysis with Project BudBurst data since it covers the entire country (not just Walden Pond) and also includes a broader range of phenophases than what was originally recorded by Thoreau. This will allow scientists to identify how different regions of the country, and different species are responding to climate change, and also to determine which are the most important species to watch.

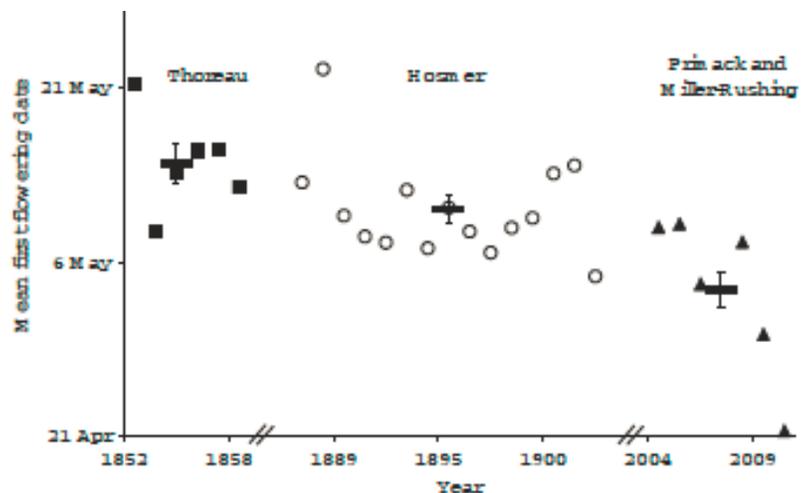


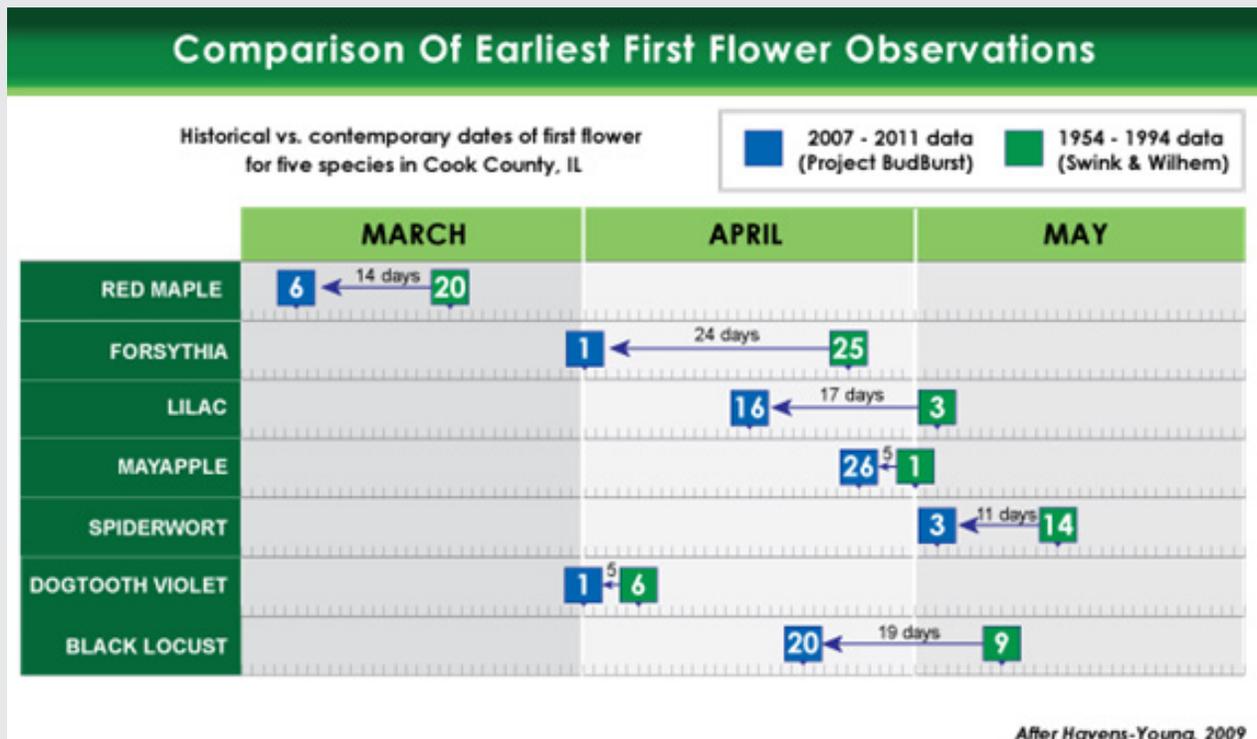
Figure 9 - Notice that Primack and Miller-Rushing's contemporary observations of first flowering times were on average, earlier than Thoreau's historic observations. (Primack et al 2012)

# Why Study Phenology?

## Activity 3

### Interpreting Historical and Contemporary Phenology Data

In this activity, you will practice interpreting data from a study of phenological change over time. The study took place in the Chicago area where a researcher compared observations of date of first flower for several species growing there over time. A graph showing the study results is presented below.



## Background

The graph above shows change in the timing of first flower events for seven species of plants growing in the Chicago area. Two different datasets were used to create this graph: one dataset comes from Project BudBurst collected between 2007 and 2011 (depicted in blue), and the second dataset comes from a paper by Swink & Wilhem with data collected between 1954 and 1994 (depicted in green). Both datasets contain observations of “date of first flower” for the following species: Red Maple (*Acer rubrum*), Forsythia (*Forsythia xintermedia*), Lilac (*Syringa vulgaris*), Mayapple (*Podophyllum peltatum*), Spiderwort (*Tradescantia ohiensis*), Dogtooth Violet (*Erythronium americanum*), and Black Locust (*Robinia pseudoacacia*). Historical and contemporary averages of “date of first flower” for each species were calculated and plotted on the timeline. Note too that the seven species observed were all located in Cook County, IL.

Activity continued on page 12

# Why Study Phenology?

## Activity 3 (cont.)

### Interpreting Historical and Contemporary Phenology Data

#### Guiding questions

##### *Decoding and describing data*

- 1) From historical data, order the species in terms of which flowers first. Note which species flowered in March, April, and May.
- 2) From contemporary data, order the species in terms of which flowers first. Note which species flowered in March, April, and May
- 3) For Lilac, what was the average date of first flower from historic records, and what was the average date of first flower from contemporary observations? Describe the difference, if any.

##### *Pattern identification*

- 4) Comparing historic data with contemporary data, what do you notice about date of first flower over time? State this as a pattern and cite examples to support your argument.
- 5) Is this pattern consistent between species or is there variation between species?

##### *Reasoning question*

- 6) Based on your knowledge of phenology, climate, and the data provided, suggest a possible explanation for the pattern you identified.

##### *Stretch/extension question*

- 7) In an extensive review article by Walther et al., 2002, the authors found that plants in temperate latitudes worldwide have been advancing their flowering times by about two-three days every 10 years over the past 30 years in response to warmer spring and winter weather. Is this study in the Chicago area (Cook County, IL) consistent with the worldwide pattern identified by Walther and his co-authors?

1. The timing of phenological events such as flowering, leafing, insect emergence, and allergies can impact how plants, animals, and humans are able to thrive in their environments.

True

False

2. Changes in the timing of phases of plant life cycles, phenophases, are directly affected by:

a. Temperature

b. Precipitation

c. Day Length (photoperiod)

d. All of the above

3. Phenology data have been used to extend previously existing, historic observations of phenophase timing.

True

False

4. Which statement best describes phenology?

a. The study of the timing of specific biological events (such as flowering, migration, and reproduction) in relation to changes in season and climate

b. Is one of the oldest branches of environmental science

c. Comes from the Greek words “phaino” (to show or appear) and “logos” (to study).

d. All of the above

5. Some plant species have the ability to change the timing of phenophase events and thus the ability to adapt to changes in climate.

True

False

6. Henry David Thoreau observed and recorded phenophase timing for close to 500 species located around Walden Pond during the middle 19th century.

True

False

### Answer Key

1. True 2. d 3. True 4. d 5. True 6. True



# Introduction to Phenology

## *Review and Glossary*

This background guide introduced you to the science of plant phenology and the importance of observing plants as indicators of changes to climate and the environment. We also overview relationships between phenology data and broader scale issues such as climate change and land use change. These are the types of issues that may be important to present to your learners when using plant phenology data in your educational setting.

We hope this guide got you thinking about the plants that surround you and how observations of the flowering, leafing and fruiting of these plants can contribute to a growing body of important scientific research.



### Next up...

- Explore the supplementary *Introduction to Phenology* resources (Student activities, videos, etc.).
- Get started on the next unit, *Monitoring Phenology*.

# Review and Glossary

## Links from this Unit

PhenoCam Network: <http://phenocam.sr.unh.edu/webcam/about/>

Project BudBurst: <http://www.budburst.org/>

Google Chrome: <https://www.google.com/intl/en/chrome/browser/>

Internet Explorer: <http://windows.microsoft.com/en-us/internet-explorer/download-ie>

Firefox: <http://www.mozilla.org/en-US/firefox/new/>

Science of Phenology on the Project BudBurst website:

<http://budburst.org/science/phenology.php>

Phenology Defined on the Project BudBurst website:

[http://budburst.org/science/phenology\\_defined.php](http://budburst.org/science/phenology_defined.php)

Why Phenology on the Project BudBurst website:

[http://budburst.org/science/phenology\\_whyphenology.php](http://budburst.org/science/phenology_whyphenology.php)

History of Phenology on the Project BudBurst website:

[http://budburst.org/science/phenology\\_history.php](http://budburst.org/science/phenology_history.php)

Phenology Today on the Project BudBurst website:

[http://budburst.org/science/phenology\\_phenologytoday.php](http://budburst.org/science/phenology_phenologytoday.php)

Dandelion Time Lapse Video: <http://www.youtube.com/watch?v=jGItoOY60SA>

Stenseth & Mysterud's paper: <http://www.pnas.org/content/99/21/13379.full>

# Review and Glossary

## Glossary

Definitions of technical terms used in this unit. Glossary definitions have been compiled from the Project BudBurst and USA National Phenology Network websites.

**Bud Burst:** Date when the protective scale coating is shed from the bud exposing tender new growth tissues of one or more flower buds or leaves.

**Conifer:** A tree that bears cones and evergreen needlelike or scalelike leaves.

**Deciduous:** Falling off, as leaves from a tree; not evergreen; not persistent.

**First Flower Stalk:** Date when the first flower stalk is emerging from the stem of the grass and you can see the first flower cluster (spikelet) rising above the leaves of the stem.

**First Leaves:** Date the first leaves are completely unfolded from the bud on at least 3 branches. Leaves need to be opened completely (flat) and the leaf stem or base must be visible (you might need to bend the leaf backwards to see those).

**First Flower:** Date at which the first flowers are completely open. You should see the stamens among the unfolded petals. For herbs (non-woody plants), look for the date when the first flowers of one patch are blooming. For trees or large shrubs you will want to make sure there are blooms on at least three places on the tree or shrub.

**First Ripe Fruit:** Date when the first fruits become fully ripe or seeds drop naturally from the plant on 3 or more branches. Ripening is often indicated by a change to the mature color or by drying and splitting open.

**First Leaf:** 95% of all leaves are open.

**Non-native:** Of or relating to a plant or animal that is not indigenous to a region.

**Phenology:** Recurring plant and animal life cycle stages. It is also the study of these recurring plant and animal life cycle stages, especially their timing and relationships with weather and climate.

**Phenophase:** An observable stage or phase in the annual life cycle of a plant or animal that can be defined by a start and end point. Phenophases generally have a duration of a few days or weeks. Examples include the period over which newly emerging leaves are visible, or the period over which open flowers are present on a plant.

# Phenology 101 for Educators

## Introduction to Phenology