



BACKGROUND

When you study a food web in the middle of winter, you find a very different situation than if you look at the same community in the spring. Many organisms including plants and animals exhibit periods of growth and changes in reproductive viability. Insects go through developmental stages that require different food sources in the spring versus the summer. Even mammals change their diets and/or their behavior at different times of the year. These changes are all part species' life cycles, and the study of these changes is called **phenology**.

Humans have paid attention to and recorded data on phenology for centuries because changes in the natural world shape our own lives. Recently there has been an increasing interest in phenology from a scientific perspective. This is because of a growing concern over the impact of climate change on ecology (Fig. 1). The timing of many phenological events are changing with global temperatures and there is concern that species will become mismatched in their phenology. For example, what would happen if hummingbird migration became offset with flowering? If plants leaf out earlier, will the same pests eat their leaves? Will pollinators be there when they flower and if they flower early? These questions, while important, easily become daunting due to the sheer amount of data that we would need to answer them.

Luckily, there is a solution to this problem, and it involves you and anyone who is interested in contributing! Worldwide, there has been a growing effort to collect data on phenology. This data collection does not have to be done by scientists, anyone with a

keen eye and interest in studying the natural world can collect data. Some large efforts like iNaturalist are focused on documenting diversity, while others are focused on phenology like Nature's Notebook. These new resources are helping us compile large datasets of natural observations and improve our understanding of ecology.

Today, you will get a change to explore some of the thousands of data points collected across the nation and get an idea of the power of citizen science.

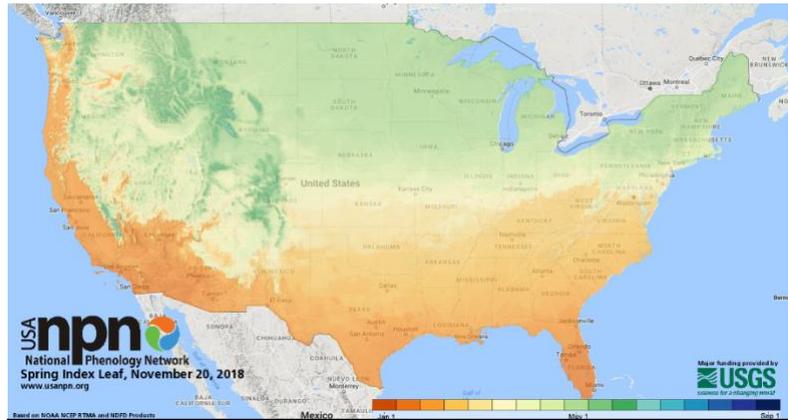


Figure 1. A graph of data on the timing of leaf out in the spring of 2018. Warmer colors indicate earlier leaf out. The timing of leaf out is one thing that is changing as spring temperatures warm.

LEARNING OUTCOMES

By the end of today's lab, you will:

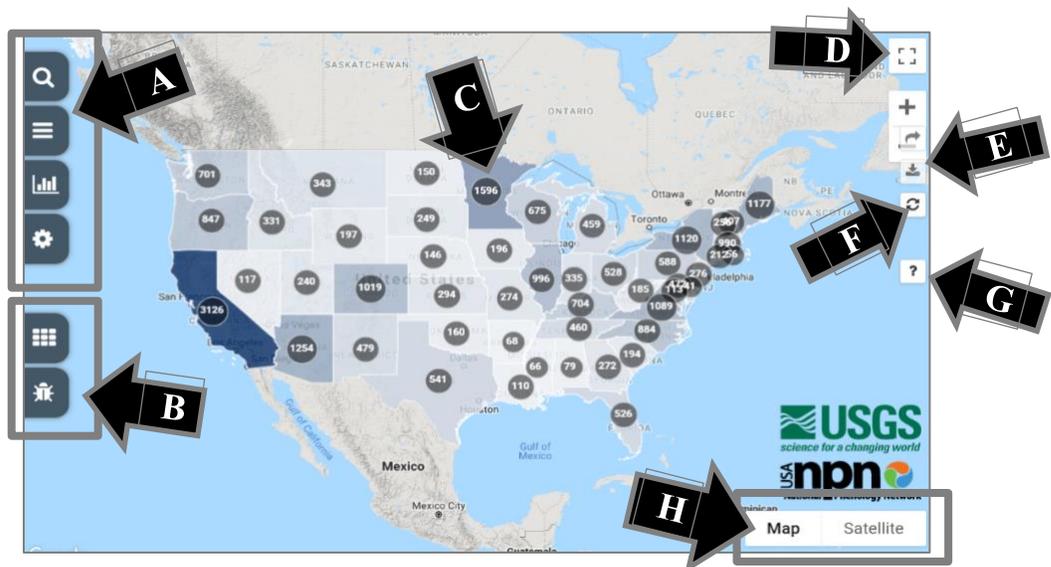
1. Develop and test hypotheses about the relationship between *phenology and climatic conditions* using the NPN visualization tools that develop graphs and models.
2. Examine what *phenological data can tell us about climate change*
3. Analyze data from a large, long-term data set on phenology

ACTIVITY 1: Exploring the USA-NPN’s Visualization Tool

In the USA, the largest network involved in collecting, storing, and sharing phenology data is the USA National Phenology Network (USA-NPN). This network was developed in 2007 and spearheaded an effort to standardize phenology data collection using the app, Nature’s Notebook, and provide resources for the public and researchers interesting in exploring phenology data. One of the tools, NPN developed is the Visualization Tool that we will use in lab. This tool can access all of the data that is in the NPN database and manipulate it based on the species, climatic conditions, and/or regions you are interested in studying. It is a great way to see ecology first-hand through a large dataset collected by scientists and citizen scientist. Some of the datasets that we will look at are large enough that your personal computers would get bogged down if we had to download all the data into an Excel spreadsheet!

PROCEDURE

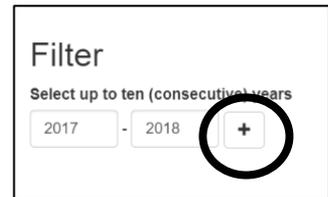
1. Visit the National Phenology Network homepage: <https://www.usanpn.org/>
2. Hover over the “DATA” tab in the banner across the top and select “Visualization Tool” in the drop-down menu.
3. Click anywhere on the map labeled “Go to Visualization Tool.” When you move your mouse over the map, the green overlay changes color.
4. You will see a map of the United States (below) with tool bars along the right- and left-hand sides of the page. We will take some to familiarize ourselves with the various tools and options. The filters and settings you choose will determine which data is displayed on your home map, as well as which data you can use to create graphs and figures.



- A. Use this tool box to select the data you want to view and to create graphs. To open any of these tools, click on the corresponding tab icon. To close the tab, click on the tab icon again. We will explore these tools in greater detail below.

- B. These tools add layers to the map. For example, you can add a map of spring temperature data or first leaf-out dates across the country.
- C. The numbers on the map initially represent the total number of sites where people are observing phenology in each state. Minnesota is one of the leading states! As you select data, these numbers can change to indicate how many data entries match your settings.
- D. Expand the map to full screen. Press "Esc" to exit full screen.
- E. Share your map as a link  or export your map as an image.  (You may need to enable pop-ups to export your map.)
- F. Reset your base map. This returns all your changes to the initial settings.
- G. The question mark button provides links to tutorial videos describing the information included here.
- H. You can toggle between a satellite and a topographic base map.

5. To select the which data you want to explore, click on the **"Filter"** tab in the upper-left-hand side of the page.



6. Select a **time frame** by typing in the dates or using the arrows. Let's start with 2008-2018. Now, click the plus sign next to the years to add this range to your filter.

7. Now you can specify species. Each category has a drop-down menu where you can search and add as many options as you would like. **You can select a species in two different ways.**

- **Select a group of animals or plants** (i.e. deciduous plants); once you have selected the group click outside of drop-down menu. The species list will update in the "Species" drop-down menu. You must now select a species.
- **Select a species;** you can select multiple species. Once you type in all the species, you need to click the plus sign to add the species to your filter. Note that species are listed in order of number of observations.

8. Click "Execute Filter." The numbers on the map will change to reflect the number of observations that meet the requirements of your filter.

9. Your filters will appear in bars across the top of your home map.

10. To further filter the observations by geographic location, click on the **"Boundary Layers"** tab, second from the top along the left-hand menu.



- Pick a boundary layer you'd like to use by clicking on the layer in the left-hand panel. For example, you could choose the "US States" layer, or the USFWS Ecosystem Regions. This will add that layer to your home map. Click the tab to close it.
- You can choose to include any of the outlined regions on the home map by clicking on them. Your selected regions will turn red.
- To deselect a region, right click on the region.



11. Return to your filters and adjust them as need be when you are visualizing the data.

12. Write down what you find. How many data points are there for your species in the region you selected? Is this a well-studied species or not? Share your results with the class.

ACTIVITY 2: How does temperature influence plant phenology?

Plants often serve as a good indicator of climate. In the spring, the emergence of flowers often coincides with warming and in fall leaf drop coincides with shorter days at the end of the year. Not surprisingly, plants also respond to climate change, and warmer spring temperatures are causing earlier leaf emergence across the world (Parmesan and Yohe 2003, Monahan et al. 2016). To help gather more data on phenology, scientists are now turning to large citizen science efforts. Phenology networks have emerged across the world from the USA and Canada to India. However, recording seasonal changes in plants is not a new thing. Many cultures have a long history of nature journaling and in some cases, this had led to exciting, long term datasets (Miller-Rushing et al. 2012). One remarkable dataset is from Kyoto, Japan where the annual cherry blossom festival is timed to match flowering of iconic cherry trees (*Prunus* sp.). Dr. Aono and his colleagues spent years going through old court diaries and documents to compile data on flowering. Now, his dataset is over 1200 years long (Aono and Kazui 2008).

In the USA, one of the longest datasets came out of an early citizen science project to monitor lilacs (*Syringa vulgaris*) developed by Joseph Caprio, a professor at Montana State (Rosemartin et al. 2015). Although a much shorter dataset (about 60 years), it demonstrated how involving the larger community can help scientist gather phenology data. It is estimated that Caprio organized over 2500 volunteers in the western USA, while running his program. Because lilacs are a popular horticultural plant and are not invasive, they have been planted all over the world. They also serve as good indicator species for climate change because they are often reproduced clonally. This means that individuals all over the world can be genetically identical. In fact, there are large efforts, including one by the National Phenology Network to plant genetically similar species in more locations (<https://www.usanpn.org/nn/cloned-lilacs>).

For our first exploration of phenology data, we will look at data from the Common lilac and another popular horticultural plant, Forsythia. We will examine how species' phenology changes with climate and develop hypotheses about how these species' life cycles are altered by climate change.

PROCEDURE

Using the Visualization Tool

1. Before we start analyzing phenology data. Write down how you expect flowering time to relate to temperature. Do you think the warming springs will result in earlier or later flowers?
2. Reset your base map by clicking on the button on  the right side of the screen.
3. Use the filters to select years between 2008 -2018 and the species Common lilac and Forsythia. If you do not remember how to do this, look at the instructions above.

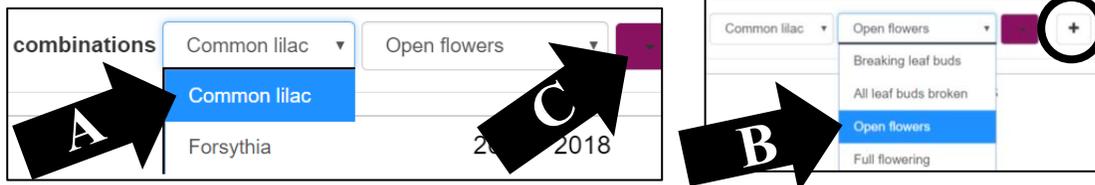
4. Now that you have selected the data you would like to include, you can begin visualizations of the data using the “**Visualizations**” tab on the left-hand side (bar



exploring graph symbol).

5. Within the “Visualizations” tab, select “**Scatter Plots.**”

6. Across the top of the page, you will see drop-down menus with all of the options you selected in your filters.

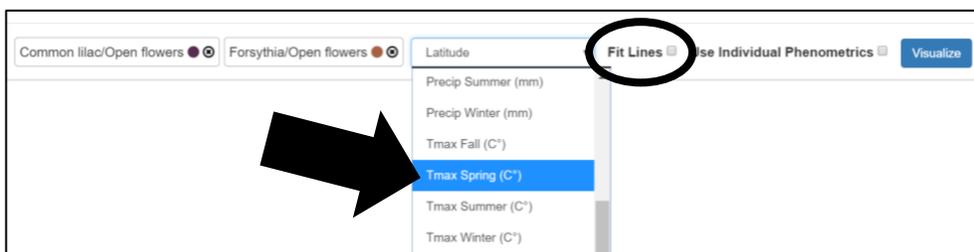


7. Now, we will select parameters. You can select **one species (A)** and **phenophase (B)**

at a time. You can change the **color (C)** displayed in the colored drop-down box.

- Look at the lilac and forsythia keys to see the differences in the phenophases. Notice that the different stages are marked by the percent of the flowers or leaves that are at a particular stage.
- Select open flowers for Common lilac and press the plus sign to add it. This is when you first see flowers open on a plant.
- Repeat this for Forsythia, selecting open flowers.
- In your graph these parameters will be your dependent variables. Which axis will they appear on?

8. Compare these parameters to temperatures by selecting the maximum spring temperature option (Tmax Spring) from the drop-down menu in the middle of the second row (see below). This is now your independent variable. Please check the box next to “**Fit Lines**” and click “**Visualize**”



9. Click the button in the top right to download your figure as an image.



10. Look at the graph. How does flowering time relate to temperature? Does it match your predictions? Do you see the same relationship with both species?

it match your

11. When is the latest you see each species bloom? How do you interpret these late dates of bloom? Is spring temperature relevant to flowering at this time of year?

12. Based on your observation and what you know about climate change, do you expect to see a change in flowering over time?

13. Check your hypothesis by changing your independent variable on the graph to Year and hit **“Visualize”** again.
14. Click the button in the top right to download your figure as an image.
15. Do you see the relationship you expected? Consider why or why not? How long is the dataset? geographic data are you including in your graphs? Close the graph by clicking the X in the right hand corner. What Explain in 1-2 sentences how these different factors might influence the relationship you did or did not see.

16. Because the visualization tool cannot graph longer datasets than 10 years, let’s examine how geography impacts the time of flowering, specifically latitude.
 - Go back to your scatterplots by selecting the **“Visualizations”** tab and **“Scatter Plots.”**
 - This time set up your graph to have the dependent variables: open flowers for Common lilac and open flowers for Forsythia. Make your independent variable Latitude.
 - Explain your results below in 1-2 sentences. Does this help explain your results when you graphed flowering versus year?

17. Click the button in the top right to download your figure as an image.

Asking your own questions about phenology

1. Let us think about the wonderful honey mesquite. Come up with a hypothesis about how you think a specific this plant might respond to climate or latitude. The picture below provides the observed phenology variables you can question.

- Think about:
 - i. Data time frame (2008-2018 vs. compare a dry vs. wet year)
 - ii. Temperature variables such as min temperature
 - iii. What season(s) you would focus on temperature
 - iv. Precipitation, be it total for a year season
 - v. Day length
 - vi. Comparing honey mesquite here or at Santa Rita vs. Tucson proper
 - vii. See other examples on pages 10-

2. Write down your hypothesis below. Be specific area you are curious about with honey mesquite only vs. Tucson and outside of Tucson).

Do you see...	Time:	
Breaking leaf buds	y n ? ____	2017-2018 to
Leaves	y n ? ____	
Increasing leaf size	y n ? ____	vs. max
Colored leaves	y n ? ____	
Falling leaves	y n ? ____	with
Flowers or flower buds	y n ? ____	or for just a
Open flowers	y n ? ____	
Pollen release	y n ? ____	
Fruits	y n ? ____	vs. in Texas
Ripe fruits	y n ? ____	
Recent fruit or seed drop	y n ? ____	12.
Check when data entered online:	<input type="checkbox"/>	about what (i.e. Tucson

Some examples:

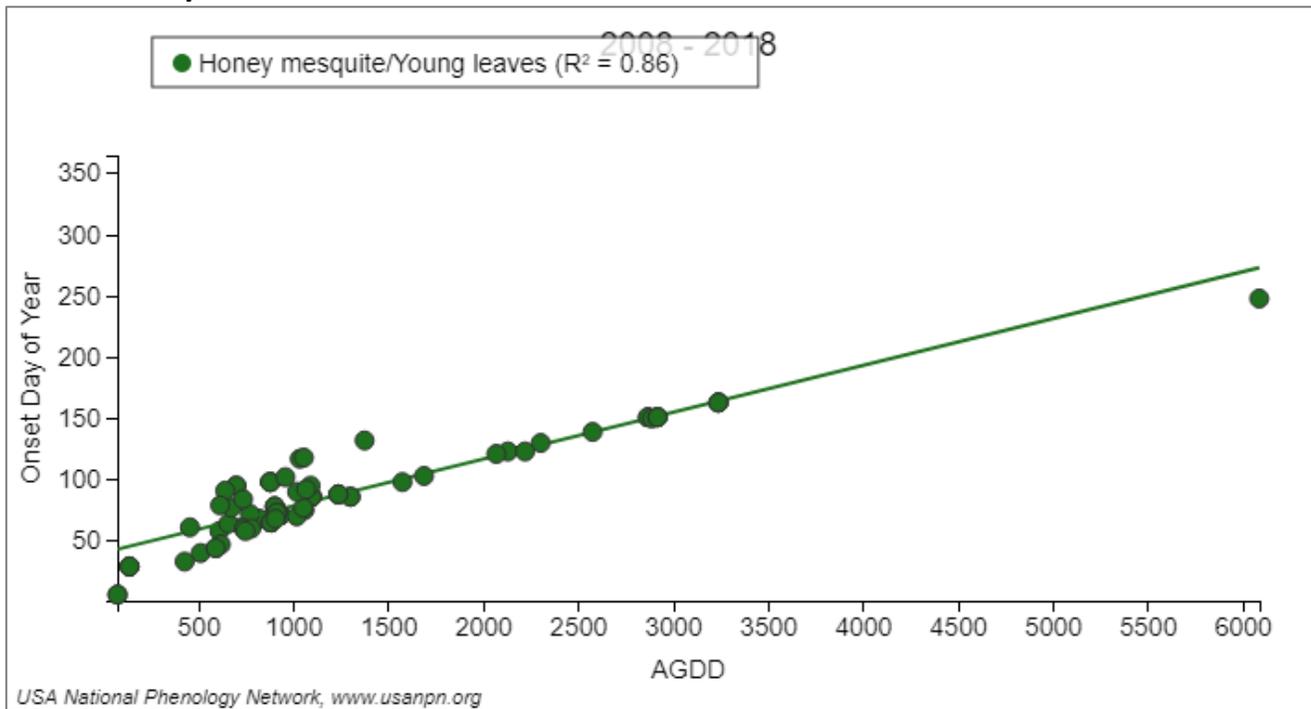


Figure 1: AGDD is Aggregated Growth Degree Day. Essentially, it is the sum of temperature above a certain threshold (here above freezing) throughout the year. Agriculture uses this metric heavily. As perhaps expected, young leaves correlate highly with increasing, accumulated temperature.

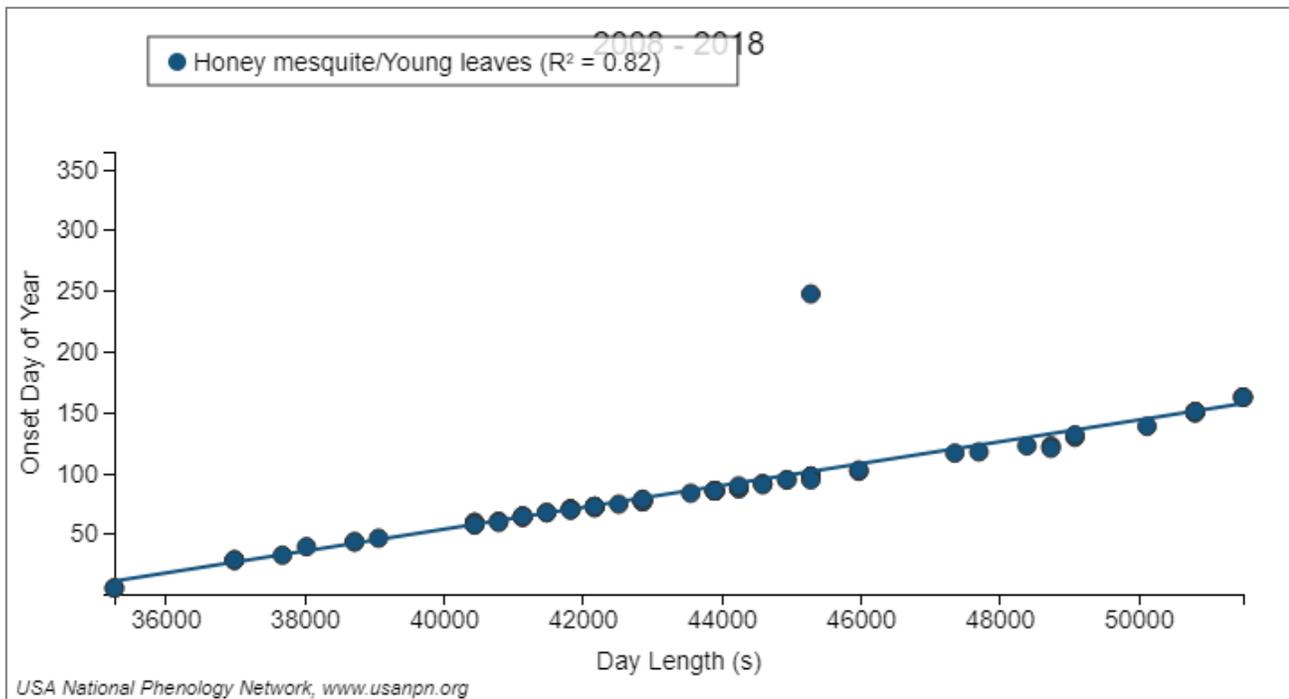


Figure 2: Just like with figure 1, this figure also shows a strong correlation between young leaves and day length instead of AGDD. Why? With this in mind, is figure one sufficient evidence for the claim that global warming is changing mesquite leaf timing, or must more evidence be used?

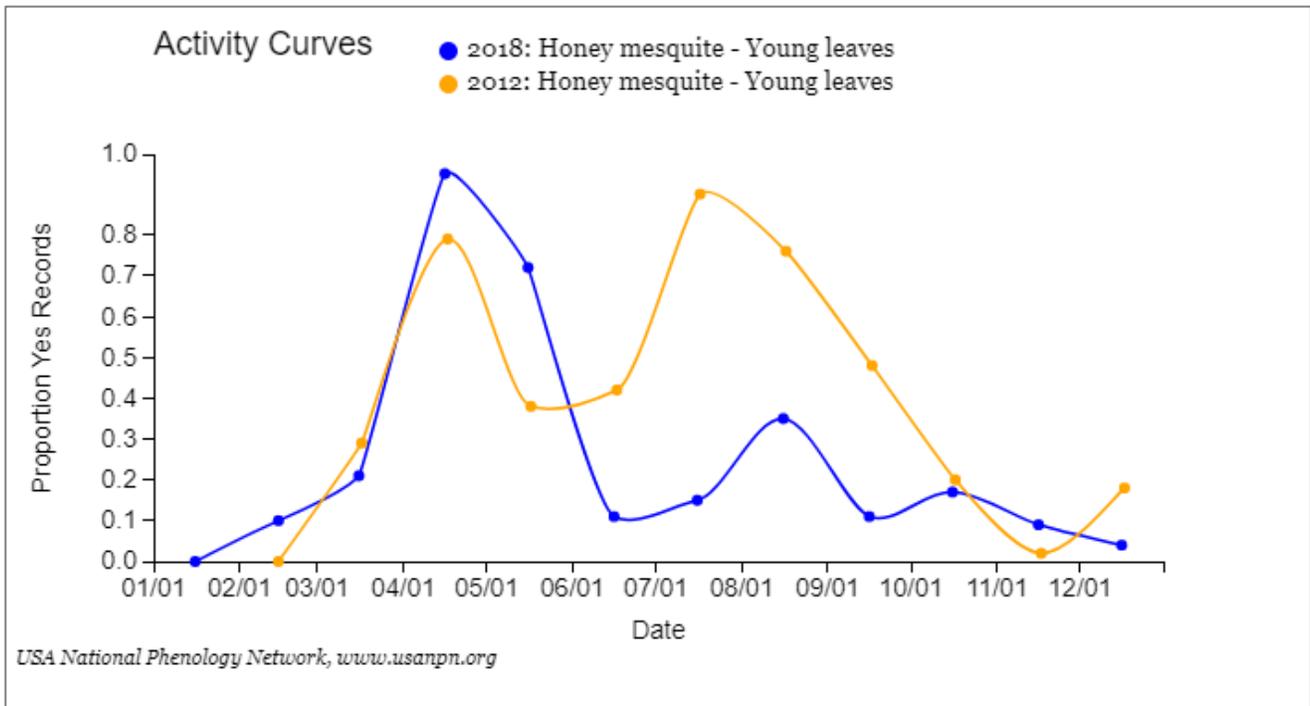


Figure 3: These types of curves are nice to compare different years. In these comparisons, one may encourage students to investigate why these curves are different. Could it be the number of sites (samples) and observations? Could it be due to that year's weather?

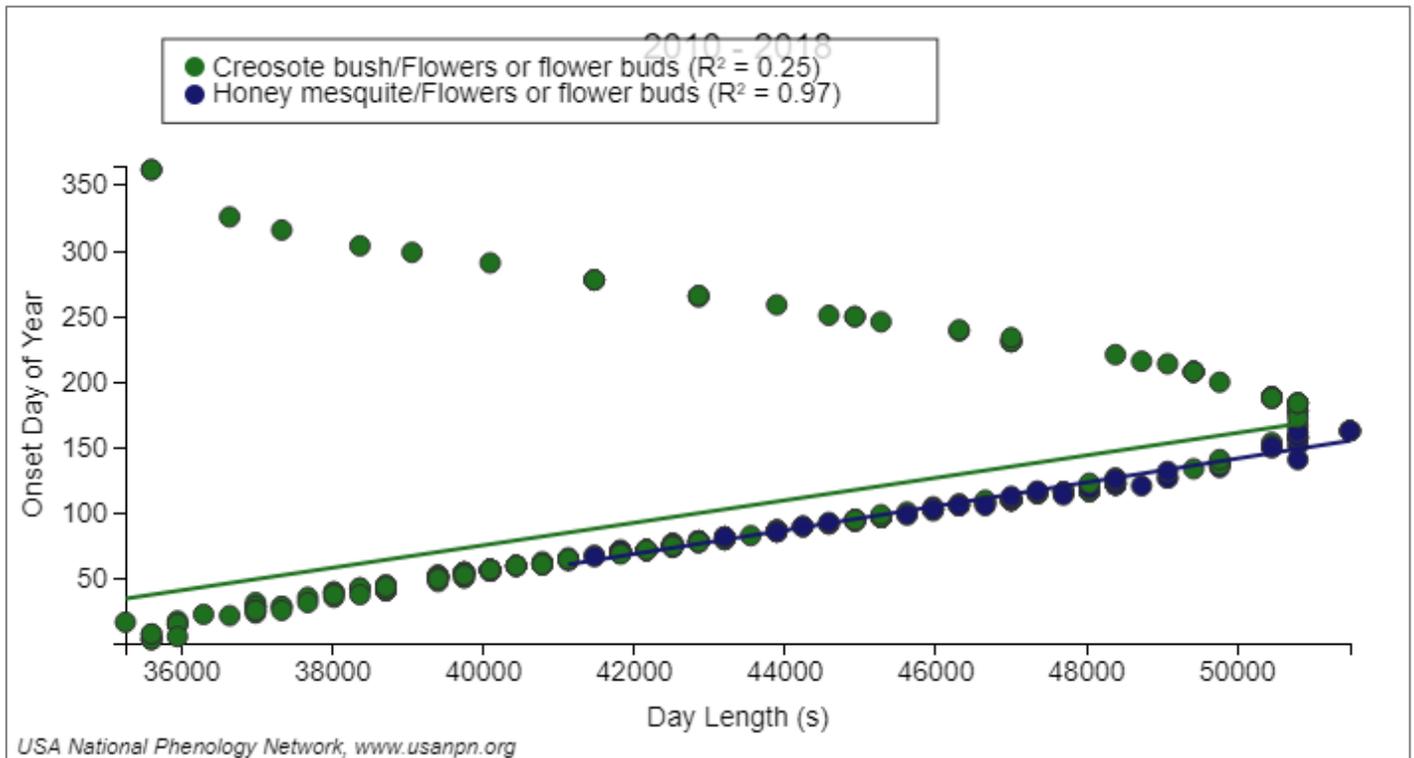


Figure 4: For some flowering plants, day length (technically night length), is the trigger for flowering. For others, it may be precipitation or temperature.

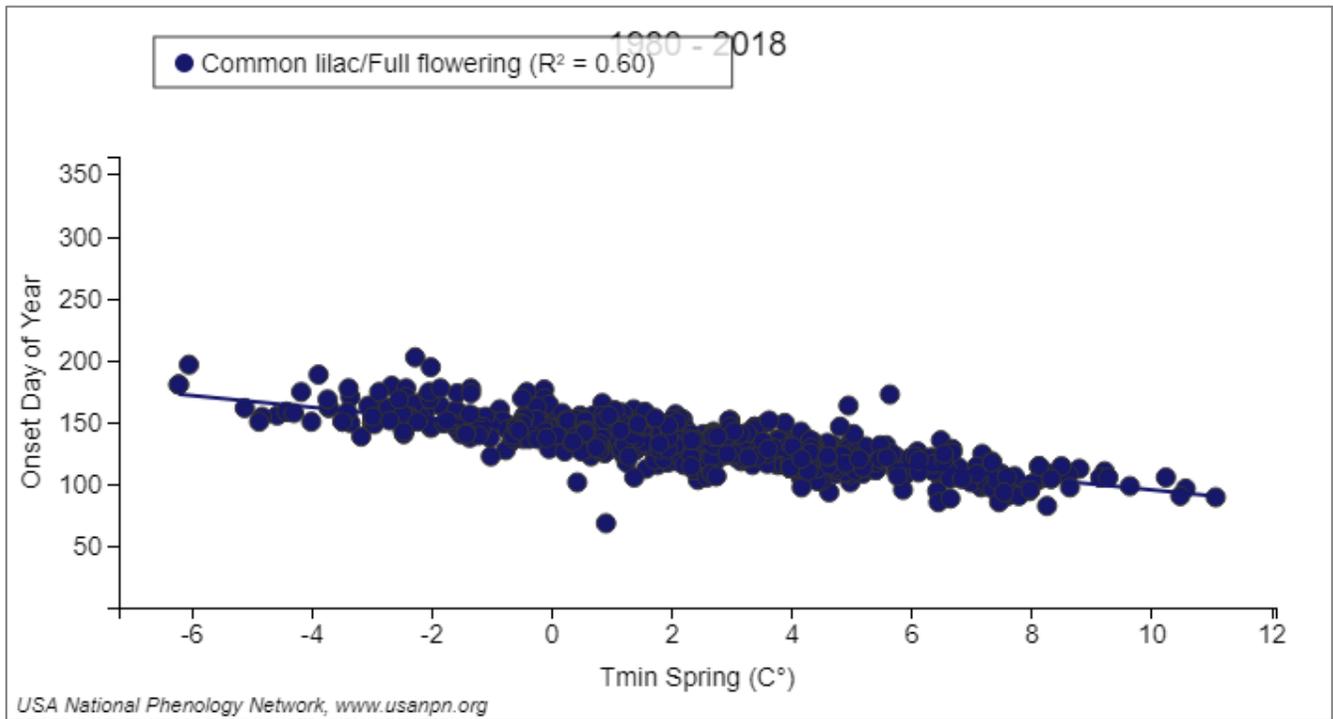


Figure 5: Common lilacs have a very high representation in the U.S. This figure indicates that lilacs seem to flower earlier in the year as the minimum spring temperature increases.

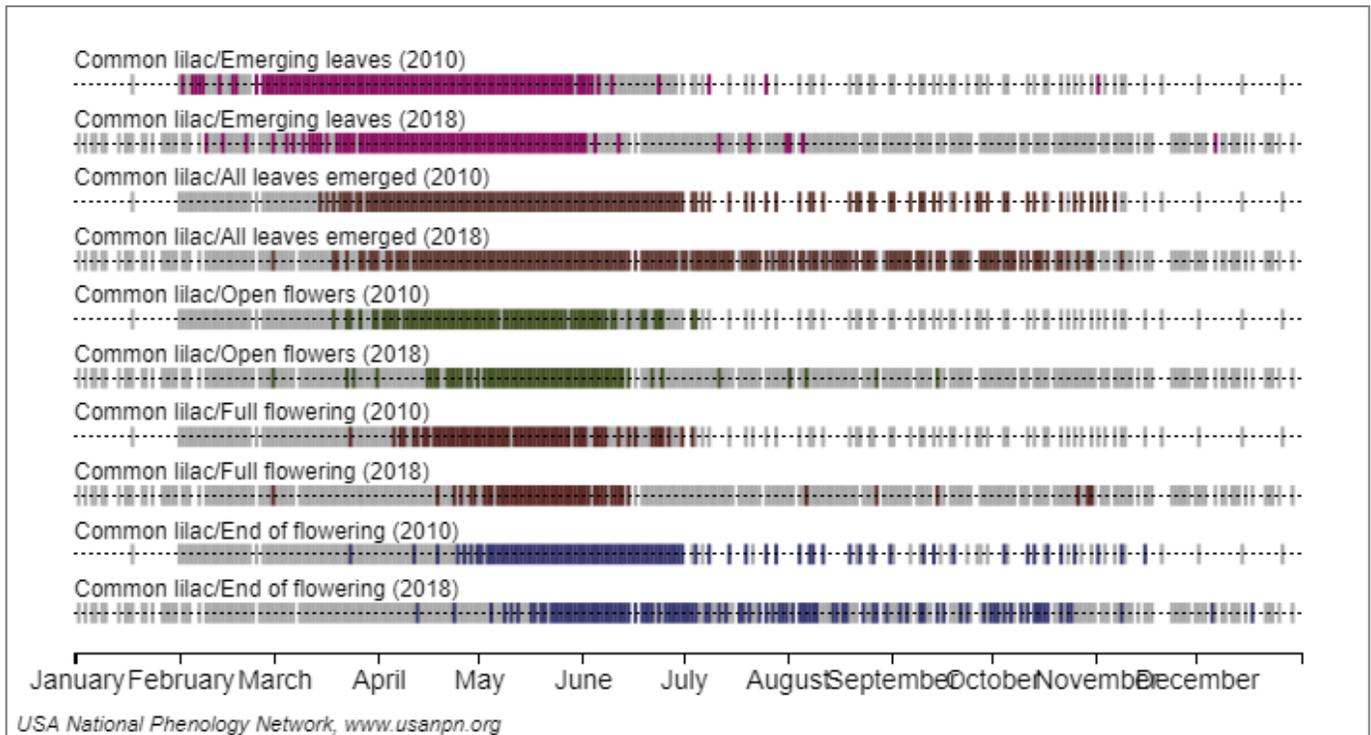


Figure 6: Gray coloring is for "no" data, as in the phenophase, such as flowering, is not occurring.

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Blake Steiner with support from the National Phenology Network.

Works Cited and Further Reading

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