Instructor's notes: Phenological trends and climate change in MN

This module is designed for an introductory level course and can be used in majors or non-majors courses. The exercise assumes no prior knowledge of spreadsheet manipulation, work with large data sets, or extensive climate change knowledge. The module was designed for a biology major's introductory course that had covered the basics of climate change and reading figures. The students had not worked with any datasets and had not created any figures. We used the module to focus on the impact of climate change on biological systems.

The short pre-class homework assignment is meant to get students thinking about what phenology is, where the data come from, and what information is contained in the data sets. It also gives students a chance to manipulate spreadsheets at their own pace before working with them in class. If you are teaching a longer class period or lab (90-120 min), you could introduce the data set the same day and may not need the pre-class assignment (the handout can stand alone from the pre homework). If you are using the module for an online course, a hybrid course, or shorter class periods (50-60 min), you may need to use two class periods, one class for Activities A and B and the second class for reiteration of the results from the elm regression and then completion, reporting and discussion of results from Activity C.

The COVID 19 pandemic changed the initial offering of this exercise to on online synchronous and asynchronous activity. All of our students had access to some sort of computer, but software packages varied. The exercise is functional for those students on a PC or Mac and for those using Excel or Google Sheets. If your institution has a set of laptops/desktops available for classroom use, you could use those computers to ensure all students have access to the same software editions. If students have access to Excel, they will get the broadest exposure to the statistical practice (i.e. running the regression).

Before you start the in-class activity, it is wise to have students check for and download the necessary software add-ons (see Activity B and C prep). Attention to this step before class starts will allow more time to work on the concepts in class. We have also found that students need to open Excel as the desktop application, ***not*** as Excel in a browser. Some of the functions this module requires will not work in the browser version and students will get frustrated with Excel.

The data are used with permission from the Minnesota Phenology Network (MNPH 2020). I thank the Minnesota Phenology Network for supplying data. I also thank all of the volunteer participants who gathered data for the project. The full dataset (MNPN Master Dataset Phenology 2018) can be downloaded from the EDDIE module website. To offer the students the maximum amount of choice with respect to species and date, you can use the whole Excel file. Alternatively, you can tailor the dataset to your class' needs (e.g. select only plants, only species with 30 years of data, etc.). You can share the full data set with students via your schools learning platform or through a Google Drive and Google Sheets (G Sheets). If you are working off-line (or have students who are) and do not have access to the DNR website, all the data you will need for Activities A and B is included in the "Am elm data for off-line work" Excel file.

The Minnesota Climate Trends data (DNR 2020) is county, timescale (e.g. month to multiple months), and time frame (ending month and year span) specific.

Paragraphs in the rest of this document that start with a number correspond to the numbered activity in the student handout. Slide number indications are approximations, some material my flow over/between slides.

Pre-Homework

The homework assignment can be passed out one to several days before you utilize the activity in class. Feel free to add points to the questions if points motivate your students to complete homework.

Questions 1-4 are based on the MN Phenological Network website. Any student with an internet connection should be able to complete these questions.

Slide 2

1. What is phenology?
   [study of repeating events in the lifecycle of organisms, patterns are often tied to seasons and climate]

2. When did the MN Phenological Network get its start?
   [2010 – recent compared to many databases!]

3. Where does the data in the data base come from?
   [some archival data base, but mostly citizen scientists]

Students may be able to pick up a working definition of phenophase from the website, but they may also need to look up a definition to give them a better feel for the term. The term is used on the website and in the handout so it is important students learn the term and do not confuse it with phenology.

4. What are phenophases?
   [phenophases are some stage/phase/event in the cycle of the organism that has an observable start and end point]

Students need to manipulate the "MNPN master data sheet 2018" (Excel or G sheet) and then use it to answer question 6. You can share the full data set with students via your schools learning platform or through Google docs.

The data in the MNPN data sheet are entered chronologically and there are over 54,700 lines of data in the data set, so students will not be able to simply glance at the data and find the entries they want. They will need to use sorting and filtering skills to organize the data. If students do the pre-homework and save their sorted and filtered data sheets, it will save them time during class.

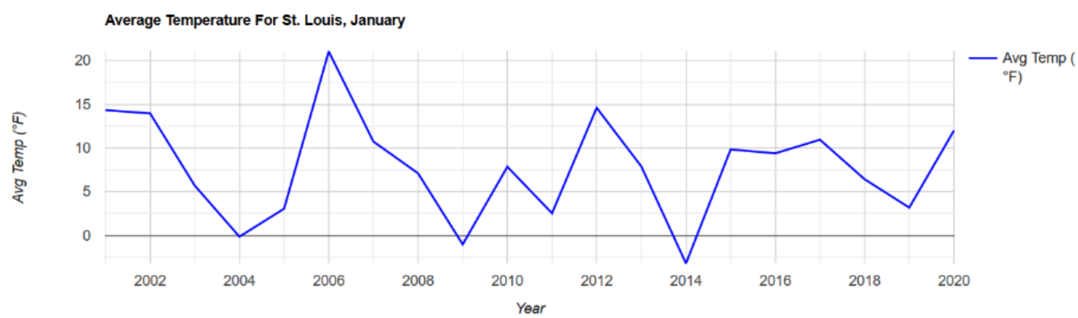
6. There are 17 different "groups" (abiotic, amphibian, arachnid, bird, butterflies, damsel/dragonflies, dragonflies, ferns/mosses/lichens, forbs, grasses, insect, mammal, moth, vegetable, vines, woody, [blank] = fall colors). Students are asked to choose three species from different groups so they have some understanding of how diverse the data are.

Students need to visit the DNR Minnesota Climate Trends website (https://arcgis.dnr.state.mn.us/ewr/climatetrends/) to answer question 7. Unfortunately you cannot request the temperature data in ^oC, so we will continue working in ^oF.

7. Was there ever a year when the average January temperature did not get above 0^oF? (Brrrr!)
[Yes]
If yes, which year(s)? __[2004, 2009, 2014]___

What was the highest average temperature in January during this 19 year period? _[21.05 ^oF]_

What was the lowest average temperature in January during this 19 year period? _[-3.22 ^oF]_



Data from MN DNR Minnesota Climate Trends website for average January temperature in St. Louis Co. from 2001-2020.

If you would like your students to have some additional perspective before the full activity, you could have them read Bradley et al 1999. The paper uses a large data set from Wisconsin, a neighbor of Minnesota, to investigate the relationship between phenophase changes and climate change. If you skip this reading it is fine, your students might then be more surprised by their own results.

Introduction – Phenology trends and climate change in MN

Slide 3 and 4

As you use the Powerpoint slides to introduce American elm to the students, you can either introduce the short list of possible questions regarding elm trees and climate change, ask them to generate a list, or a mix of both.

Activity A – Determine changes in flowering date for American elm in Ramsey Co, MN

Slide 5

1. You can share the full data set with students via your schools learning platform or through Google docs.

2. The data is entered chronologically and there are over 54,700 lines of data in the data set, so students will not be able to simply glance at the data and find the entries they want. They will need to use sorting and filtering skills to find the data for American elm. When sorting, it is important to highlight ALL the rows and ALL the columns so the data stays linked.

3. You can have a discussion about what might be the broadest categories that unify the groups (life form) to more specific (Genus species). At first it may seem like sorting by species (scientific name) would be easiest, but there may be multiple organisms with the same Latin species name (but different genus). As you add levels to the sort activity, the most inclusive group should be listed first and the most selective group should be listed last.

Slide 7

6. Once the elm data are sorted, the phenological events are easier to see. There is no information about Dutch elm disease or water loss so we cannot answer those questions and they would not be appropriate questions to pursue. However, there is information about flowering and leaf color, so both of those would be valid questions to investigate. Some students may return to this question after they finish and answer with the actual data and evidence although that is not necessary. The goal of the question is to get them to consider what they need to answer the questions.

Slide 8

7. The climate in Minnesota varies considerably from north to south. The elm flowering data are from Itasca (north) and Ramsey (south) Counties. To eliminate the variability of location, select just the data from Ramsey County. Ramsey is a small (relative to other counties in MN; 170 mi^2) urban county; Ramsey holds the state capitol, St. Paul, numerous suburban cities, developed lakes and small stands of temperate forest. As students select their own phenophase (Activity C) it might be appropriate to use all of the data provided for a phenophase. A discussion about what data is appropriate is warranted.

9. Students do not need any prior knowledge to make a prediction. Asking the students to sketch out the predicted data forces them to think about whether they think the flowering date has stayed the same, gotten earlier, or been delayed. Based on the student’s knowledge about climate

change they may assume it has changed, but are not sure how. When students sketch the data, it also leaves a record that they can use for comparison. Surprises can be impactful.

The figures are intentionally small to force students to estimate and think about the trends; small graphs discourage spending 20 minutes plotting the time and dates on the axes, but encourage a students to sketch predictions or trendlines. Asking students to label axes also encourages estimation of quantity (e.g. does the axes represent 2 days or 25?). If you want students to spend more time on figures, feel free to adjust the size of the figures.

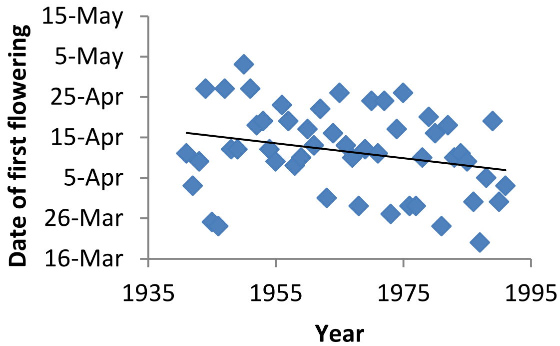


Figure 2. Actual elm flowering date from 1941 -1991 in Ramsey Co, MN.

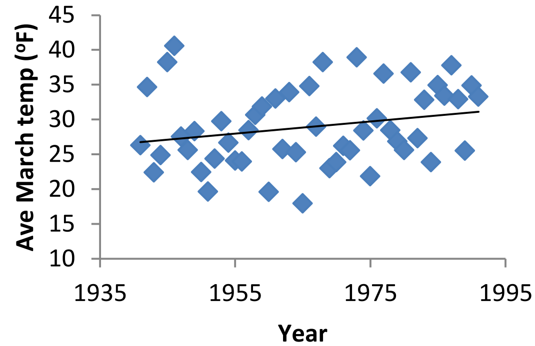


Figure 4. Average March temperature in Ramsey Co. from 1941-1991.

Both Figure 1 and 2 are shown here for ease of comparison (as is done in the student handout). Figure 4 will be completed in step 15 below.

Slide 9

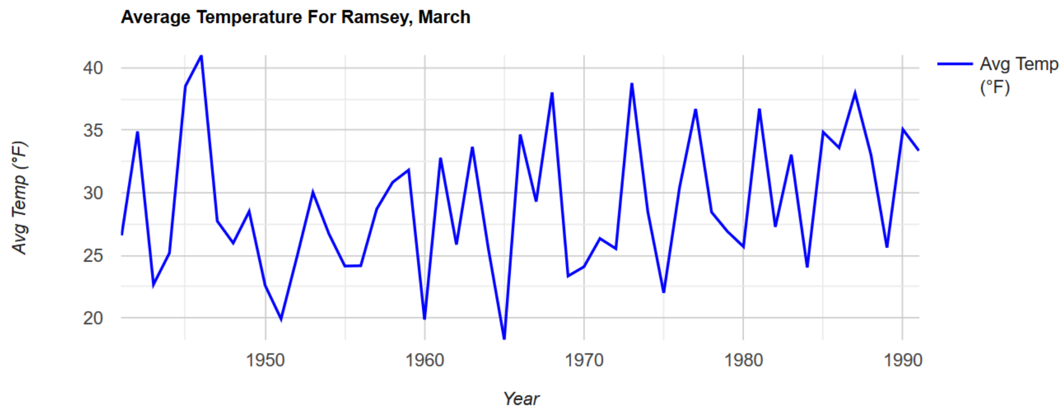
11. The flowering trend is sloped downward so it appears flowering may be happening earlier in the spring. Over the given 50-year period, first flowering date occurs approximately a week earlier.

Some students may look at the scatterplots and suggest there is no trend because the data is “spread all over.” The addition of a trendline helps students visualize the *overall* pattern in the data.

12. The goal of this question is to get students thinking about all the different climate aspects that *might* affect elm flowering date. Students may think of temperature, snowpack, rainfall, light-dark cycle, solar cycle (solar intensity), and others. Some suggestions may not actually affect flowering directly, but that is alright. More advanced students, or those with some botany experience may provide a more refined list.

Slide 10

13. Students know the focus of the day’s work is about climate change, so they may assume that there is a pattern of warming for Ramsey Co. Students may predict that there is a steep positive slope, a rapid temperature rise.



Data from MN DNR Minnesota Climate Trends website for average March temperature in Ramsey Co. from 1941-1991.

Slide 11

15. The temperature data (Fig. 4) shows an increase of a few degrees over the 50 years. Students may predict a large increase in temperature. The phenological changes that happen due to subtle changes in temperature are often surprising.

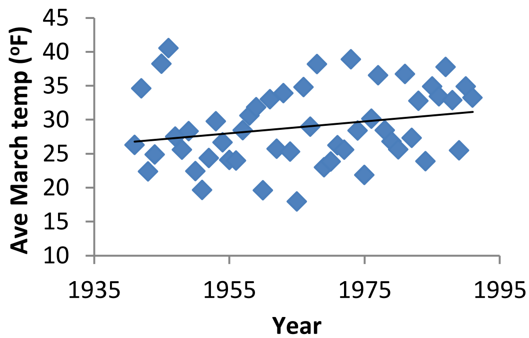


Figure 4. Average March temperature in Ramsey Co. from 1941-1991.

Activity B – Determine significance of changes in flowering date

If your version of Excel does not have the "Data analysis" option under the data tab, you will need to add it. If students have newer computers, this is easy, but a roadblock if you do not know ahead of time. The Data Analysis option may not be available for older Excel versions so the regression statistics are included in the "Am elm data for off-line" sheet which you can choose to share with students who cannot run the regression themselves. To add the Data Analysis tool on a PC, under the "File" tab choose Options; on a Mac OS choose the "Tools" tab. Then select "Add-ins" from the menu, choose "Options" then "Add-ins." Select "Analysis ToolPack" then click "Go." Select Analysis tool pack then OK. The Data Analysis tab will pop up under the "Data" tab.

In G Sheets, select the “Add-on” tab at the top of the sheet and select “Get add-ons.” Search for “XLMiner Analysis ToolPak” in the search box and install that in your google sheet. Follow the prompts and once complete select the “Add-on” tab at the top of the sheet and verify “Linear Regression” is an option. This data analysis option should now be available. During the pandemic we were unable to download this successfully, or find an alternative workaround/explanation. When we tried to download the application, we got the “Sign in with Google temporarily disabled for this app” message. If you run into problems with access to the add-on, you can copy the output from the Excel regression (found on the American elm data sheet) and put it in a G Sheet to share with any students who cannot run the regression themselves in G Sheets.

Slide 13-14

16. If you are working with students new to graphing, you may want to have a discussion about dependent and independent variables. These concepts can be confusing to students and you want to ensure they understand the dependent relationship aspect of the regression. After a slight adjustment in the placement of the data in the spreadsheet, the graphing exercise is a repeat of previously practiced skills.

Slide 15-16

17. *A regression primer*

A regression analysis helps us determine if there is a dependent relationship between two variables, in our case if flowering date depends on temperature (independent variable). It can also help us measure the strength of this kind of functional relationship between variables. A linear regression can also be used to predict a value, but that is not the kind of thing we are doing here. We use a regression because we think that temperature (independent) is actually driving the change in flowering date (dependent) unlike a correlation where neither variable is dependent on the other. Regression analysis assumes your data is “normal”, independent, and continuous (or discrete for X).

The regression evaluates the null hypothesis (H_0) that flowering date is independent of average March temperature, or that there is no relationship between the variables, or put another way, the slope of the line is statistically = 0 (H_0: b = 0). The software package will analyze the data for us (as long as we have the data in the correct place), but we need to know how to interpret the output.

Slide 17

- The r^2 value ranges between 0 and 1 and tells you how closely X and Y variables are related. If you multiply the r^2 value by 100, you find the percentage of the variability that the two variables share. For example, if $r^2 = 0.52$, 52% of the variance of Y is “explained” by the X variable. In our phenology language, this means that 52% of the variation in flowering date is explained by average March temperature.
- The r^2 **value = 0.66** for flowering date and average March temperature.

- The test determines the probability (*P*) that the H_0 is true. The lower the probability the more confident you can be that the H_0 is not true, that there is a functional relationship between the variables, or that your slope is not = 0. It is standard in biology to use a P-value of 0.05, or 5%, as a cutoff for rejecting the null hypothesis. In plain English, if you have a P-value lower than 0.05, there is a really good chance that there is a relationship between your two variables (i.e. elm flowering date does depend on March temperature). If you have a P-value above 0.05, then it is most likely that there is no relationship between your two variables (i.e. flowering date does not depend on March temperature).

- The calculated p-value is 3.79×10^{-13}, so you can report this as **p < 0.001**.
- Addition of a trend description plus the supporting statistics (r^2 and p values) to the figure caption encourages students to fully describe the data.

- If you want to extend the exercise and talk about the slope of the line, you can do so. The regression equation Y = a + bX is the description of the relationship in which X is the independent variable, Y is the depending variable, b is the slope of the line that describes the change (increase or decrease) in Y per change (increase) in X, and a is the Y intercept or where the line crosses the Y axis. The regression is testing if the slope of the line is zero or not. If the P-value is < 0.05, you can interpret the slope as significantly different from zero and there is a relationship between temperature and flowering date.

- You can add the line formula to the chart by choosing "more trendline options" from the Chart tools and then check "Display equation on chart," or you can double click on the chart and the Format Chart Area box will appear.
- The equation for the line is y = -1.532x + 42881. (The value looks a little screwy because of the format of the date.) For each 1.5 ^oF average warming, flowering date is on average a day earlier.

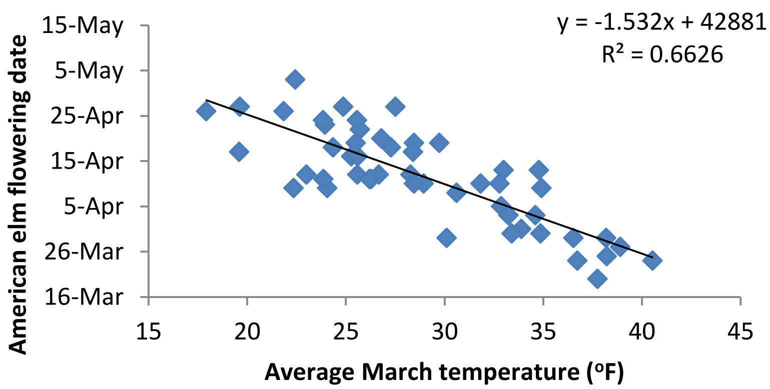


Figure 5. Elm flowering date and average March temperature from 1941 -1991 in Ramsey Co, MN. As average temperature warms, first flowering date occurs earlier ($r^2 = 0.66$, $p < 0.001$).

18. Temperature in the spring can affect how early the trees start breaking dormancy. A warming climate results in an earlier flowering date for American elm trees in Minnesota. As the average March temperature increases by 10^oF, the flowering date increases by approximately 12 days.

Activity C – Determine a phenophase (“event”) pattern for a Minnesota organism of your choice

Activity C can be used as the student choice part in class or it can be assigned as homework for discussion in the next class period.

Slide 19

19. There are almost endless possibilities for what species and phenophase students choose for Activity C. If they are paralyzed by options, encourage them to start with one of the species they used for their homework assignment. The stipulation of using a species with at least 20 years of data for a particular phenophase, should help narrow the options while also giving students enough data to see any trends. Remind students they need at least 20 data points in 20 years, not just some data over 20 years. Some students may choose a species with, for example, 6 data points over 20 years, but it is hard to see trends with that little data. More data is also better for seeing climate change trends, so if there is more data available, encourage students to use it all.

If you wish, you can have students report their chosen species so you can eliminate repeat species. Restricting the overlap of species may give you greater chance at having some species that speed up, slow down, or stay the same with climate change. In a class of 25 students, we only had one or two repeat species.

20. One of the outcomes of the module is that students should be able to formulate an answerable question from a given data set. If students understand the limits of the data (e.g. no Dutch elm disease or transpiration information), then they should be able to pose their own answerable question with a new species.

21. You may want to remind students that it may be most appropriate to use data from one county (i.e. check the dataset carefully). Additionally, students will want to request the temperature data with the particular timeframe they selected for their phenophase event (step 24).

23. Your students will most likely get some sort of linear function in their data, but if they do not, you can talk about what a different trend (e.g. curvilinear, bimodal, etc.) or no trend might indicate (e.g. timing with photoperiod or precipitation rather than temperature).

24. Sometime students will use the temperature data from the American elm timeframe. You may need to remind them to adjust their climate data “request” from the DNR website.

25. If students struggled with the concepts in Figure 5 (e.g. independent and dependent variables, regression, etc.), you may see troubles in Figure 8. Students who are not clear about the purpose of the regression may plot the variables on the wrong axes or create scatterplots of a single variable (i.e. phenophase or temperature) and time as they did in Figs. 2 and 4.

26. Once working with their own phenophase, students may need help thinking about what the p-value means with respect to their new data. If their p-value is <0.05, then the temperature (independent variable) is actually driving the change in their chosen phenophase (dependent variable) unlike a correlation where there is a relationship, but neither variable is dependent on the other.

27. If you are in a classroom, you can have students sketch their Figure 8 (with supporting caption) on the board so all can see them at once. If you are working online, you can create an editable document on G-Drive where students can paste a copy of their Figure 8. After a given deadline, students can work with that document in real time or you can post a version of it to your LMS.

Slide 20

28. Phenophases that may now occur earlier in the spring are those that are dependent on warmer temperatures. For example, insect hatches, snake activity, or phenophases that dependent on water (e.g. bud break, ice melt, arrival of birds that rely on fish or ice free lakes, amphibian calling) may be affected by warmer temperatures.

Phenophases that may now occur later in autumn are those that are dependent on warmer temperatures. For example, insect activity, snake activity, last migrating individuals seen, and leaf color may be affected by warmer autumn temperatures.

Phenophases that are dependent on the light-dark ratio or are not temperature dependent may not be affected by climate change. For example, some bird arrival/departure, mid to late season flowering, moose antler eruption, etc, may show no change in date.

Citations:

Bradley NL, Leopold AC, Ross J, Huffaker W. 1999. Phenological changes reflect climate change in Wisconsin. Proc. Natl. Acad. Sci. 96: 9701-9704.

Minnesota Department of Natural Resources (DNR). 2020. Minnesota Climate Trends. Accessed [7.10.2020]. Available: https://arcgis.dnr.state.mn.us/ewr/climatetrends/.

Minnesota Phenology Network (MNPN). 2020. Datasets. Accessed: [7.10.2020]. Available: http://mnpn.usanpn.org.