TIEE

Teaching Issues and Experiments in Ecology - Volume 19, August 2023

ISSUES: DATA SET

Investigating the Biospheric Carbon Pool in North Central North America

Kellen Calinger

Department of Evolution, Ecology, and Organismal Diversity, The Ohio State University, Columbus, OH 43210

Corresponding author: Kellen Calinger (calinger-yoak.1@osu.edu)

Staghorn sumac budburst: In this image you can see newly emerged leaves and some unburst leaf buds of staghorn sumac, one of the focal species.

TIEE

Teaching Issues and Experiments in Ecology - Volume 19, August 2023

THE ECOLOGICAL QUESTION:
Has the timing of spring leaf out shifted over more than a century of global warming and how will that affect the biospheric carbon sink?

FOUR DIMENSIONAL ECOLOGY EDUCATION (4DEE) FRAMEWORK

- **Core Ecological Concepts:**
  - Organisms
    - Abiotic and biotic features of the environment
  - Ecosystems
    - Energy flow - productivity
  - Biosphere
    - Global climate change
- **Ecology Practices:**
  - Quantitative reasoning and computational thinking
    - Statistics
    - Data skills â€“ data visualization
    - Computer skills: spreadsheets
  - Working collaboratively
- **Human-Environment Interactions:**
  - Human accelerated environmental change
    - Global climate change
- **Cross-cutting Themes:**
  - Pathways & Transformations of Matter and energy
  - Spatial & Temporal
    - Stability & Change

WHAT STUDENTS DO:

1. Use Excel to create line graphs plotting changes in mean monthly temperature over 115 years.
2. Use regression analysis paired with their temperature change figures to calculate both rates of temperature increase and total temperature increase.
3. Analyze correlation coefficients to determine likely temperature drivers of spring leaf phenology.
4. Hypothesize different temperature sensitivity strategies based on the ecological trade-offs of strong vs. weak phenological responsiveness to temperature.
5. Use Excel to create bar graphs depicting mean historic vs. contemporary timing of budburst for four focal species.
6. Use Excel to perform t-tests to determine if spring leaf out time is significantly different between historic and contemporary observation periods.
7. Predict how their observed changes in spring leaf out would affect carbon storage.

STUDENT-ACTIVE APPROACHES:
Think-pair-share, cooperative learning, brainstorming, informal groupwork

STUDENT ASSESSMENTS:
A worksheet that students complete with line graphs, trendlines, calculated rates of temperature change and total temperature change, bar graphs, t-tests, responses to short-answer questions

CLASS TIME:
Roughly 2.5 hours

COURSE CONTEXT:
This investigation has been used in an introductory majors Biology class focused on evolution, ecology, and organismal biology. Most of the students are freshman and sophomores although there are some juniors and seniors.

SOURCES:

Calinger, K and Curtis, P. 2023. A century of climate warming results in growing season extension: Delayed autumn leaf phenology in north central North America. PLoS ONE 18:e0282635. https://doi.org/10.1371/journal.pone.0282635

ACKNOWLEDGEMENTS:
I developed this data set independently using my own published work. This resource was developed to provide students with a laboratory activity to complement our lecture-based discussions of global warming. I had no funding to support this work. We acknowledge Jon Horn and Maggie Wetzel for their helpful comments and suggestions during the development of this resource.

TIEE

Teaching Issues and Experiments in Ecology - Volume 19, August 2023

OVERVIEW OF THE ECOLOGICAL BACKGROUND

The data provided in this activity involves temperature and budburst observations recorded in Wauseon, Ohio, USA, over roughly 130 years. The combination of historic budburst observations prior to major industrialization, modern observations after significant anthropogenic warming, and local temperature data provide a unique opportunity to investigate over a century of warming on a key life event in temperate deciduous forests. These long-term data sets are particularly uncommon in North America. All the data used in this activity is available freely available in Calinger and Curtis (2023).

The temperature data set provides yearly average monthly temperatures for all 12 months from 1892 to 2018. These data are available either via Calinger and Curtis (2023) or directly from the US Historical Climatology Network from which they were originally taken. The budburst data set includes both historic and contemporary observations of the timing of budburst for four focal species. The historic observations were gathered by a local farmer, Thomas Mikesell. Note that not every species has historic observation for every year in the historic period. These data were originally published in full in a 1915 Ohio Meteorological report and are freely available in both the original 1915 publication and in Calinger and Curtis (2023). The contemporary budburst observations were made within roughly 8 km (5 miles) of Mikesell's farmhouse. For the modern observations, I observed multiple individuals of each species in at least two different forest plots. Both the modern and historic budburst observations are reported as the day of year (DOY) of budburst where 1 = January 1 and 365 = December 31.

The data provided in the pre-lab is not associated with the focal question of the main activity as its goal is to provide students with practice making line graphs and bar graphs as well as evaluating trendlines and t-tests.

LEARNING OBJECTIVES:

- Students will evaluate long-term temperature data for an OH site to determine seasonally specific temperature trends from the past 130 years given human-driven global warming.
- Student will use data to form evidence-based conclusions about which seasonal temperatures have been most stable or experienced the most change over the past 130 years.
- Students will select appropriate graphs to visualize their data and complete statistics using data provided in Excel spreadsheets.
- Students will analyze correlation data to determine major (abiotic) climatological drivers of leaf out timing (a biotic variable).
- Students will work together to predict major environmental drivers of key plant life history characteristics and how they will change with climate warming.

- Students will work together to evaluate ecological trade-offs of differing growing season strategies.
- Students will use the photosynthesis equation to make predictions for changing ecosystem productivity given the transformation of inorganic C in CO_2 in the atmosphere to organic C stored in plant tissues.
- Students will calculate average changes in growing season length for 4 temperate, deciduous trees over more than a century of warming.
- Identify appropriate open ecological datasets when addressing a question (optional)

DATA SETS

- Student pre-lab data.xlsx: Student data for pre-lab assignment.
- Faculty pre-lab data.xlsx: Faculty data for pre-lab assignment.
- Student temperature data.xlsx: Student temperature data.
- Faculty temperature data.xlsx: Faculty temperature data.
- Student historic vs modern budburst data.xlsx: Student budburst data.
- Faculty historic vs modern budburst data.xlsx: Faculty budburst data.

STUDENT INSTRUCTIONS

Goals:

- Students will evaluate long-term temperature data for an OH site to determine seasonally specific temperature tends from the past 130 years given human driven global warming.
- Student will use data to form evidence-based conclusions about which seasonal temperatures have been most stable or experienced the most change over the past 130 years.
- Students will select appropriate graphs to visualize their data and complete statistics using data provided in Excel spreadsheets.
- Students will analyze correlation data to determine major (abiotic) climatological drivers of leaf out timing (a biotic variable).
- Students will work together to predict major environmental drivers of key plant life history characteristics and how they will change with climate warming.
- Students will work together to evaluate ecological trade-offs of differing growing season strategies.
- Students will use the photosynthesis equation to make predictions for changing ecosystem productivity given the transformation of inorganic C in CO_2 in the atmosphere to organic C stored in plant tissues.
- Students will calculate average changes in growing season length for 4 temperate, deciduous trees over more than a century of warming.

Introduction:

Human emissions of carbon dioxide (CO_2) to the atmosphere have caused significant global warming. CO_2 and other greenhouse gases trap radiation close to Earth's surface resulting in warming known as the greenhouse effect. In absence of human activities, the greenhouse effect is a natural phenomenon as greenhouse gases like CO_2, methane, and water vapor occur naturally. However, human activities have significantly increased atmospheric levels of greenhouse gases, particularly CO_2 and methane. Increased greenhouse gas concentrations result in more radiation being trapped near Earth's surface. Global temperatures have increased by 0.74°C ± 0.18°C over the past 100 years (1906-2005) with some regions experiencing locally greater warming primarily as a result of increased CO_2 (IPCC 2007).

As temperatures rise, scientists have observed shifts in the timing of key life events (**phenology**) in a wide variety of plant and animal species (Parmesan & Yohe 2003, Menzel et al. 2006; Rosenzweig et al. 2008). Many important life events are phenological events. Phenological events include the time of leaf out in the spring, flowering, mating, hibernation, and migration among many others. Phenology is often strongly driven by temperature. Historically, temperature has been a reliable indicator of optimal growth or reproductive conditions. For example, as temperatures warm in the spring, passing certain temperature thresholds should indicate that dangerous, potentially deadly frosts are over. It should also indicate that daylight hours are long enough for effective photosynthesis and that pollinator species will be active.

However, rapid temperature increase may make temperature an unreliable indicator of these conditions. For example, while average springtime temperature has increased dramatically, severe frosts that kill delicate young leaves are still as likely to occur late in the spring as they were prior to temperature increase. Similarly, pollinators may respond to temperature differently than the plants they pollinate and may not be active when plants flower.

Budburst, or the first emergence of leaves in the spring, is a particularly important phenological event as it marks the beginning of photosynthesis for an ecosystem. Scientists are particularly interested in evaluating the effects of climate warming on budburst timing as it may have significant effects on total carbon (C) storage by the biospheric C pool (see below).

Budburst is a biologically important measurement as it marks the beginning of all energy and carbon gains by plants. Total photosynthetic activity determines the amount of C and energy an individual plant has to dedicate to key life processes like growth and reproduction. Thus, differences in budburst timing responses to warming (aka **budburst strategies**) among species may make some more, or less, competitive in a warming world if their budburst timing allows for a longer total photosynthetic period. For example, imagine that sugar maples advance budburst by 1 week for every 1ºC temperature increase in March while black walnuts only advance budburst for 1 day for the same amount of warming. If March temperatures increase by 3ºC, that would give sugar maples almost 3 extra weeks of photosynthesis over black walnuts! That additional photosynthesis could increase the growth and reproduction of sugar maples over walnuts leading to increased maple populations and decreased walnut populations over time. Alternatively, if sugar maples advance their budburst much more than walnuts with warming, it may put their leaves at greater risk of frost damage resulting in decreased photosynthesis.

The **biospheric C pool** is all C stored in living tissues and the vast majority of this C is stored in plants. As plants photosynthesize, they pull CO_2 from the atmosphere and store this C in their tissues decreasing the total amount of C in the atmosphere. If climate warming changes budburst timing, and thus the start of the active photosynthetic period, this may alter the amount of atmospheric C and thus the rate of global warming.

You will be evaluating temperature change over roughly the past 120 years using data gathered in Wauseon, OH, located in the northwestern portion of the state. We will pair these data with budburst observations made by a famer living in the area between the late 1800's to early 20th century to assess changes in the onset of the growing season in Ohio and make predictions for how these changes may affect C storage by Ohio's forests.

Investigation 1: Historic Temperature Data

You will work in groups to assess temperature change in Wauseon, OH, using data from the U.S. Historical Climatology Network (USHCN). The USHCN has collected temperature data at 26 weather stations throughout Ohio since 1895 with earlier observations at Wauseon recorded by a local farmer, Thomas Mikesell.

1a. Examine the "Student temperature data" file. This table provides mean monthly temperatures in Wauseon from 1892-2018. You will use this data to calculate total temperature change and the rate of temperature change for several months. Given the type of data presented, which figure type would be most appropriate given the information in the pre-lab packet? Once your group has determined the graphing type you think is appropriate, talk with another lab group and compare ideas. Were your ideas similar or different? (Confirm your ideas with your teacher before continuing!)

b. You will produce 4 graphs depicting temperature change over time for the months February, April, July, and December. If we want to determine the rate of temperature change over time and total temperature change in these months, what type of analysis is appropriate given the information in your pre-lab packet? Once your group has determined the analysis type you think is appropriate, talk with another lab group and compare ideas. Were your ideas similar or different? (Confirm your ideas with your teacher before continuing!) Table 1 provides the rates of temperature change and total temperature change for the remaining 8 months.

Table 1

Month	Rate of Temperature Increase (°C/year)	Total Temperature Increase (°C)
January	0.0088	1.12
February		
March	0.0155	1.97
April		
May	0.0095	1.21
June	0.0074	0.94
July		
August	0.00003	0.0038
September	0.0005	0.064
October	0.006	0.76
November	0.0191	2.43
December		

c. Produce the graphs of temperature change over time for February, April, July, and December including any relevant analysis to determine temperature change over time. Remember to include a descriptive title on each graph, label axes, include units, use an appropriate scale for axes, and consistent, readable font size. You will submit the Excel file with the figures.

d. Using your graphs record the rate of change (°C/year; slope) in Table 1.

e. Record the total temperature change (=slope*127years, °C) from 1892-2018 in the table.

2. a. What is the mean annual rate of temperature increase (=(sum of rates from column 2)/12): ____________ (°C/year)

b. What is the mean total temperature increase (=(sum of totals from column 3)/12): _______________(°C)

3. Was warming uniform across the year or did some seasons experience more or less warming? In your answer, provide data to support your conclusions.

4. Considering the timing of budburst, which monthly/seasonal temperatures do you predict will be the strongest drivers of budburst? Support your prediction using logic.

5. Before continuing, compare your answer to question 4 with another group. Record the other group's prediction here.

6. Did your prediction match the other group's prediction? Explain how they were similar or different. If they were different, explain which prediction you think has better support.

7. If your prediction is correct, how will budburst timing have changed in the past 130 years given the temperature data above?

Investigation 2: Temperature and Budburst Relationship

Thomas Mikesell was a farmer in Wauseon, Ohio, and a keen observer of the natural world. Mikesell noted the timing of budburst, flowering, leaf coloration, and leaf fall for roughly 30 tree species from 1893-1912 providing one of the most detailed historic records of plant phenology in all North America. Mikesell's observation days have been translated into a day of year (DOY) format in which each day of the year is assignment a numeric value between 1 and 365 (i.e., Jan. 1 = 1 and Dec. 31 = 365). The mathematical translation of calendar days allows easier statistical interpretation and graphing than the typical month and day reporting of time.

We will use correlation analysis to evaluate the relationship between timing of budburst and monthly temperatures for 4 tree species observed by Mikesell; *Populus deltoides* (cottonwood), *Quercus alba* (white oak), *Rhus typhina* (staghorn sumac), and *Quercus velutina* (black oak). A scientist correlated the DOY of **budburst** for each species versus mean monthly temperatures of the month of budburst and the preceding 11 months. For example, if budburst happened in May on average, the budburst DOY would be correlated with mean monthly temperatures of January-May for the year of budburst and June-December of the year preceding budburst. The correlations allow us to determine which temperatures are most strongly associated with budburst timing based on the strongest, significant relationships between budburst timing and temperature.

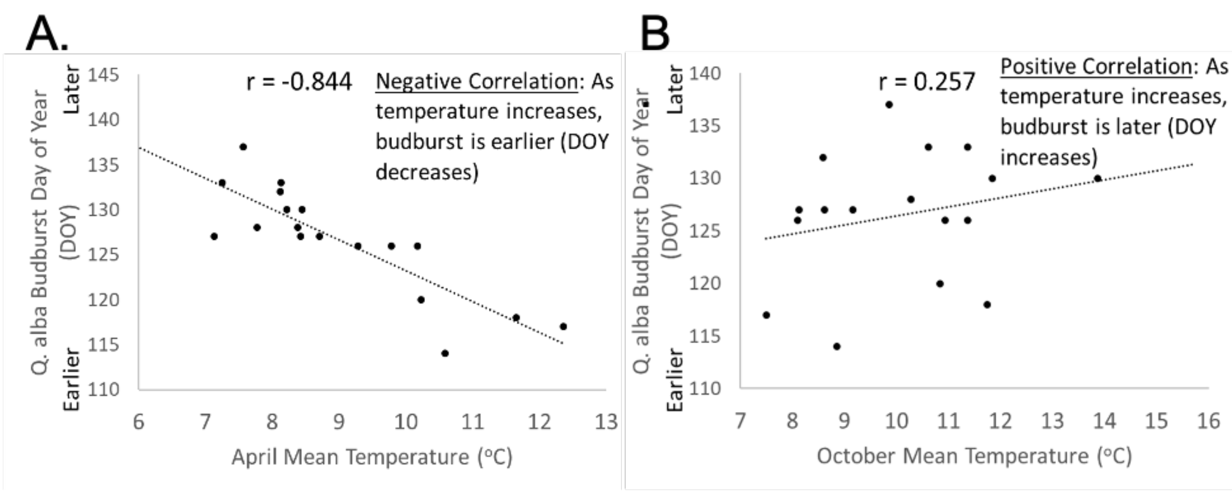

Figure 1. Example correlations between mean monthly temperature and *Q. alba* budburst timing.

Correlation analysis provides information on the strength and direction of the relationship between two variables by providing a number between 1 and -1. The correlation coefficient is negative if one variable increases while the other decreases (Example in Figure 1 A). The correlation coefficient is positive if both variables increase (example in Figure 1 B). In the case of our budburst and temperature correlations, a positive correlation would mean that as temperature increases, the timing of budburst occurs later (as the DOY increases). A negative correlation means that as temperature increases, budburst occurs earlier (DOY decreases).

Correlations also tell us how closely linked two variables are by providing information on the strength of the relationship. If a correlation coefficient is very close to 1 or -1, that shows that the two variables have a strong relationship. Weaker relationships between variables are denoted by coefficients closer to 0.

The table below provides the correlation coefficient for the relationship between budburst of each tree species and monthly temperatures. Significant correlations are in ***bold, italicized*** font. Each

TIEE
Teaching Issues and Experiments in Ecology - Volume 19, August 2023

month has been assigned to its appropriate season using the coding W = Winter, Sp = Spring, Su = Summer, F = Fall.

Table 2

Monthly Temperatures	Black walnut	Cottonwood	White Oak	Staghorn sumac
January (W)	***-0.624***	0.233	-0.352	-0.301
February (W)	-0.130	0.294	-0.106	-0.181
March (Sp)	-0.387	0.207	-0.074	-0.130
April (Sp)	***-0.646***	-0.374	***-0.844***	***-0.759***
May (Sp)	-0.251	-0.041	***-0.481***	***-0.551***
June (Su)	-0.144	-0.446	-0.114	-0.272
July (Su)	-0.242	-0.095	-0.350	-0.180
August (Su)	-0.104	0.021	0.009	-0.173
September (F)	0.269	-0.258	0.164	0.105
October (F)	0.358	-0.062	0.239	0.189
November (F)	***-0.594***	0.051	-0.314	-0.381
December (W)	-0.306	0.245	0.000	-0.066

8. Examine the data provided for white oak. Draw a graph representing the relationship between budburst timing and temperature for April given the correlations provided in the Table 2. You should label your axes for DOY, temperature, and month. Clearly indicate the direction of increase for both temperature and DOY with an arrow on your axes. The exact DOY and temperature values are not important. The line on your figure should clearly reflect the direction of the correlation. Provide a 1 sentence interpretation of the relationship between temperature and budburst timing presented on your graph. **This graph should be drawn by hand as using Excel is not necessary for the skills/content of this question.**

9. Examine the correlations presented in the table. Which months have the strongest relationship with budburst timing and in which season are these months? Which months have the weakest effect on budburst and in which season are these months? (Note the season codes in the table above)

10. Do these correlations support or refute your predictions for which monthly temperatures would be the strongest drivers of budburst? Explain your answer citing specific trends from the data.

11. Define different budburst timing strategies used by each species based on the following criteria: 1. the seasonal temperatures that are the strongest drivers of budburst for a given species; 2. the extent to which budburst advances (strong advancement vs. slight advancement) with increased temperature based on the correlation coefficient.

a. Cottonwood:

b. Staghorn Sumac:

c. Black walnut:

d. White Oak:

12. Species using different budburst strategies will have different interactions with their environment. For example, the delicate, new leaves of different species will experience very different environments if one species strongly advances budburst with warmer April temperatures while the other only weakly advances budburst with warmer June temperatures. Explain the potential ecological trade-offs of each strategy listing pros and cons.

When answering this question, consider the environmental pressures of spring (e.g. potential for frost damage, light availability, etc). In what situations would it be **beneficial** to advance budburst and in what situations may it be **detrimental**? (Refer back to the lab introduction to help you brainstorm!)

Strong Advancement with Warming		**Weak/No Advancement with Warming**	
Pro	Con	Pro	Con

Whole class discussion: Take a moment to share your ideas for the pros and cons of strong vs. weak advancement of budburst with warming. It may be helpful to produce a compiled class pro/con table on the board.

13. What additional pros and cons of each strategy were revealed during the class discussion?

14. Given the compiled class pro/con discussion, which strategy (strong vs. weak/no advancement) would you predict to be more beneficial on average as warming continues? Justify your answer.

Investigation 3: Changing Budburst over the past 128 years

Next, we'll assess how much the average timing of budburst for our 4 focal species has changed over the past 128 years. A global change ecologist, Dr. Kellen Calinger, went back to Wauseon a hundred years after Mikesell completed his observations. She selected individuals from the same species Mikesell observed to determine if the average timing of spring leaf out had change. The data in table 3 provides the yearly budburst dates (DOY) for both Mikesell's historic observations and Dr. Calinger's modern observations.

Table 3

Year	Observation Period	White Oak Budburst (DOY)	Staghorn Sumac Budburst (DOY)	Cottonwood Budburst (DOY)	Black Walnut Budburst (DOY)
2010	Modern	104.9	104.8	103.7	108.3
2011	Modern	129.9	131	127.7	127.2
2012	Modern	102.9	95.1	109.4	101.7
2013	Modern	126	126	125.5	124.3
2014	Modern	131.6	126.8	129	120
1883	Historic	128		115	132
1884	Historic	127	126	120	127
1885	Historic	133	141	114	139
1886	Historic	114	113	112	118
1887	Historic	130	128	129	140
1888	Historic	132	141	124	133
1889	Historic	127	121	128	120
1890	Historic	126	132	132	125
1891	Historic	120	113	115	120
1892	Historic	137	133	122	135
1893	Historic	133	132	123	134

1894	Historic	126	132	117	123
1895	Historic	126	122	121	130
1896	Historic	117	111	110	117
1897	Historic	127	124	120	126
1898	Historic	130	128	121	126
1899	Historic	118	117	117	118
1912	Historic	128		117	127

15. Navigate to the Excel file titled "Student Historic vs. Modern budburst timing data." Using these data, you will calculate the average budburst date for each species in the historic (Mean BB Historic) and modern (Mean BB Modern) observation periods. Once you've calculated these averages, determine how much the average timing of budburst has shifted from the historic to modern period for each species (Budburst shift). To calculate how much budburst has shifted in the past 128 years, you should use the following calculation:

Budburst shift = Mean BB Historic – Mean BB Modern

A negative budburst shift means that budburst is ***earlier*** in the modern period than the historic period. Copy your values from Excel to Table 4 below.

Table 4

Species	White Oak	Staghorn Sumac	Cottonwood	Black Walnut
Mean BB Historic				
Mean BB Modern				
Budburst shift				

16. Describe the change in timing of budburst for each of the four species.

17. Consider the temperature trends you found in the first investigation and the correlation coefficients between budburst in each species with monthly temperatures. Do your calculated shifts in budburst over time make sense relative to a. how temperatures have changed in the past 128 years, and b. which monthly temperatures are significantly related to budburst in each species?

Explain for each species including specific information about which months budburst is associated with and how much that month's temperature has changed over time in your answer for each species:

a. Cottonwood:

b. Staghorn Sumac:

c. Black walnut:

d. White Oak:

18. Next you will produce a figure (or figures) depicting the average budburst dates you calculated in question 11 (see table 4 above). Given the type of data present, what kind of figure would be most appropriate from your pre-lab packet? Clearly state the figure type and explain why it is the correct choice. Once your group has determined the figure type you think is appropriate, talk with another lab group and compare ideas. Were your ideas similar or different? (Confirm your ideas with your teacher before continuing!)

19. Copy and paste your figure(s) from Excel showing the modern vs. historic averages for each of the four focal species. Use the instructions in your pre-lab packet and remember to include all components of your chosen figure type as indicated in the packet instructions (error bars, axis labels, etc)!

20. Now that you've produced a graphical display of differences between budburst in the modern vs. historic period, we need to run statistics to determine if the difference is significant or not. Given the type of data and comparison we want to make, which statistic type from your pre-lab packet is most appropriate. Explain your answer. Once your group has determined the analysis type you think is appropriate, talk with another lab group and compare ideas. Were your ideas similar or different? (Confirm your ideas with your teacher before continuing!)

TIEE

Teaching Issues and Experiments in Ecology - Volume 19, August 2023

21. Summarize your statistical comparisons. For each comparison, you should clearly state whether the differences were or were not significant and provide the p-value to support your claim.

Whole Class discussion: Synthesis questions

For this portion of the lab, we'll be comparing your individual predictions for each question with the general consensus of the class. For each question, your lab instructor will tell you when to write your individual prediction on a separate piece of paper. After you've written your prediction, you'll take a few minutes to share out general ideas with the class. If there are differences in your ideas, you'll make note of them in the space provided. Then, your group will devise a consensus on the best predictions given the whole class discussion by revising your original thoughts as needed.

22. Consider the photosynthesis equation you provided in the pre-lab questions. Given the calculated values for budburst shift over the past 127 years, predict how carbon storage in Ohio's forests has changed (increased, decreased, stayed the same) and justify your prediction.

(Note: these patterns of budburst and associated changes in C storage apply to mesic (wet), temperate, deciduous broadleaved forests like those in Ohio. Other forests with different environmental drivers may experience different changes.)

Individual Prediction (copy each group member's individual ideas here after the discussion):

Notes from class discussion:

Revised group consensus prediction:

TIEE

Teaching Issues and Experiments in Ecology - Volume 19, August 2023

23. Each of the four species you evaluated varied in the amount budburst has shifted over the past 127 years. Which species do you predict will benefit most from increased temperatures given these differences? Which species will benefit the least? Justify your answer.

Individual Prediction (copy each group member's individual ideas here after the discussion):

Notes from class discussion:

Revised group consensus prediction:

24. Assume that forests in the northern hemisphere show similar responses to warming as the tree species you've studied in this lab. If warming temperatures result in earlier timing of budburst on average, how will the rate of climate warming be affected? (Hint: Consider the photosynthesis equation in your answer.)

Individual Prediction (copy each group member's individual ideas here after the discussion):

Notes from class discussion:

Revised group consensus prediction:

References:

IPCC, 2014: Summary for Policymakers. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Calinger, K, and Curtis, P. 2023. A century of climate warming results in growing season extension: Delayed autumn leaf phenology in north central North America. PLoS ONE 18:e0282635. https://doi.org/10.1371/journal.pone.0282635

NOTES TO FACULTY

OVERVIEW

The data provided in this activity involves temperature and budburst observations recorded in Wauseon, Ohio, USA, over roughly 130 years. The combination of historic budburst observations prior to major industrialization, modern observations after significant anthropogenic warming, and local temperature data provide a unique opportunity to investigate over a century of warming on a key life event in temperate deciduous forests. These long-term data sets are particularly uncommon in North America. All the data used in this activity is available freely available in Calinger and Curtis (2023).

The temperature data set provides yearly average monthly temperatures for all 12 months from 1892 to 2018. These data are available either via Calinger and Curtis (2023) or directly from the US Historical Climatology Network from which they were originally taken. The budburst data set includes both historic and contemporary observations of the timing of budburst for four focal species. The historic observations were gathered by a local farmer, Thomas Mikesell. Note that not every species has historic observation for every year in the historic period. These data were originally published in full in a 1915 Ohio Meteorological report and are freely available in both the original 1915 publication and in Calinger and Curtis (2023). The contemporary budburst observations were made within roughly 8 km (5 miles) of Mikesell's farmhouse. For the modern observations, I observed multiple individuals of each species in at least two different forest plots. Both the modern and historic budburst observations are reported as the day of year (DOY) of budburst where 1 = January 1 and 365 = December 31.

The data provided in the pre-lab is not associated with the focal question of the main activity as its goal is to provide students with practice making line graphs and bar graphs as well as evaluating trendlines and t-tests.

Prior concepts needed to successfully complete this lab

While the pre-lab and introductory matter in the student lab handout provides all necessary information for completion of this lab activity, student would also benefit from the following content preceding this lab activity:

- Trends in atmospheric CO_2 in the past century
- Sources of anthropogenic CO_2 emissions
- The key reactants and products of photosynthesis
- Major sources and sinks for atmospheric CO_2, especially the biospheric carbon pool as a sink for carbon
- How plants store carbon in their tissues long-term
- Phenology as a concept that applies to all living organisms
- Optimal phenology timing as a key determinant of survival and reproductive success
- Major drivers of plant phenology like temperature and daylength (snow pack melt and water availability for some systems other than the temperate deciduous forest system described here)
- How biologists use statistics to evaluate our data

Running the Class:

i. *General Overview*

I developed this lab to fill a gap in activities dedicated to global warming and the biospheric carbon sink and to complement prior learning from lecture. While the pre-lab activity and introductory matter in the main activity provide sufficient information for students to complete this activity, they would benefit significantly from prior exposure to basic climate concepts in lecture. Specifically, students should understand current observed warming, how human activities result in warming, and how to interpret trends using graphs. Students will also need to understand the photosynthesis equation to understand how shifts in the timing of leaf out may affect the biospheric C sink and therefore atmospheric CO_2 levels.

This lab focuses on data analysis skills as a tool to assess the impacts of warming on budburst timing in four focal species. Specifically, I use a combination of guided and open-ended inquiry to help student select the appropriate figures and statistics to analyze temperature and phenology data. Student then use their own analyses to form evidence-based conclusions about human driven changes in ecosystem processes.

ii. Pre-lab Information and Student Activity

This lab requires the Excel skills needed to produce both line and bar graphs as well as simple linear regression and t-tests, which many students (particularly those early in their college careers) likely will not have encountered. The pre-lab provides in-depth, step-by-step instructions on how to complete these tasks in Excel with screenshots of various Excel interfaces and dialog boxes. I highly recommend assigning this pre-lab as an individual assignment to ensure that all students gain the necessary practice in Excel skills to be successful in this lab. While not always the case, if one student in a group has significant Excel experience, they sometimes take over the bulk of the spreadsheet tasks. Thus, the less practiced students don't gain the experience the lab is designed to provide. By requiring individual pre-lab submissions all students are guaranteed to gain some Excel practice.

Students also would benefit from additional introduction to the following terms/concepts before completing the full lab activity: independent and dependent variables (on which axis each should be plotted, which variable is predicted to drive changes in the other), axis labeling, line graphs vs. bar graphs (which is appropriate for continuous vs. categorical data), the formula of a line (the basics of $y = mx + b$), and use of slopes to calculate rates of change, and t-tests to compare group means.

Discussion of graphs and statistic types can be through a variety of active learning techniques including entire class discussion (particularly useful for smaller classes), using think-pair-share, or "turn to your neighbor" techniques (see http://tiee.esa.org/teach/teach_glossary.html#studentactive for more information on teaching techniques). Student could practice defining the terms listed above in their own words. Another useful activity is to have students find examples of either bar graphs or line graphs and identify the key terms present on their selected figures. Students can then peer-teach each other the information contained on their figures highlighting the relationship (or lack thereof) between the variables present and commenting on significance as indicated on their figures. Student can simply use a web browser and search for the key terms "bar graph" or "line graph" and select one that they find particularly interesting.

iii. General Tips

Students should work in pairs or small groups for the entirety of the lab (please see the *TIEE* link above for additional information on cooperative learning). All students should complete the lab activities in the order presented in their packet because each section builds upon the previous section. For example, students would be unable to consider why a significant, positive correlation

TIEE

Teaching Issues and Experiments in Ecology - Volume 19, August 2023

between budburst and April temperatures is important if they haven't already determined how much April temperatures have increased during the study period. For that reason, I have separated the temperature data file from the historic vs. modern budburst data file. Students should show instructors their completed temperature analysis and predictions from the correlation analysis before moving on to the comparison of historic and modern budburst timing.

iv. Answer Guide for Student Evaluation (Assessable Outcomes: line graphs, bar graphs, temperature change calculations, t-test outputs and interpretation, evaluation of correlation coefficients, short answer responses regarding methods and predictions of change)
The Answer Guide provides a rubric based on a 15-point pre-lab activity and a 32.25-point lab activity. Instructors are encouraged to adapt the rubric based on points that would be appropriate in the context of their courses and reflective of the skills/content that their classes emphasize.

Investigating the Biospheric Carbon Pool in Ohio: Pre-lab (15 points)

Pre-lab. This is an *individual* assignment that must be submitted separately by all students. Please see the "Graphing and Statistics Guide" for detailed instructions on completing all needed figures and statistics for this lab.

Include citations for your responses to questions 1-4. Remember to use *reputable, unbiased sources for your information.* Governmental agencies like NASA or NOAA and peer reviewed articles are excellent sources.

1. Provide the photosynthesis equation. Briefly describe where land plants attain each of the reactants and the end point of the products of the reaction (i.e. in the plant, in the soil, in the atmosphere, etc.) Remember to include a citation. (1 point)

$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$ (0.5 points)

Carbon dioxide is taken from the atmosphere and water is absorbed through the soils. (0.25 points)
The sugars are stored in the plant tissues and oxygen is released back to the atmosphere. (0.25 points)

2. Define greenhouse gases and list the major gases associated with global warming. Remember to include a citation. (1 point)

Greenhouse gases are gases present in the atmosphere that trap and re-radiate radiation back to Earth's surface resulting in warming. (0.5 points)

The major greenhouse gases associate with global warming are carbon dioxide and methane. (0.5 points)

3. What human activities release greenhouse gases like CO_2 and methane? What human activities result in most CO_2 emissions? Remember to include a citation. (1 point)

Students may approach this question in a variety of ways depending on how they choose to break down fossil fuel burning. Give partial credit as appropriate.

Fossil fuel burning: may also include details like shipping, air travel, power plants, heating and cooling of homes, etc.

Land-use change: removal of forests, conversion to C intensive practices like cattle farming

Food waste

4. What was the average CO_2 concentration at the beginning of the 1960s? What was the average CO_2 concentration last year? (0.5 points each, 1 point total)

CO_2 concentration in early '60s: ___Roughly 318ppm_____________

CO_2 concentration last year: ____417ppm (for 2022 but value will need to but updated each year______

5. Consider the change in CO_2 concentrations over roughly the past 60 years in your answer to the previous question. Given the greenhouse gas definition your provided in question 2, what is the logical outcome for global temperatures given your reported change in CO_2 concentrations? Explain your answer. (1 point)

CO_2 concentrations have risen by roughly 100 ppm in about 60 years. Since greenhouse gases like CO_2 trap heat close to Earth's surface, more CO_2 should result in increasing temperature.

0.5 points for correctly predicting temperature should increase; 0.5 points for explanation

6. Consider your answer to the first question. If global photosynthesis rates *increased,* would you predict the rate of climate warming to increase, stay the same, or decrease? Explain your prediction. (1 point)

The rate of climate warming should decrease is the rate of photosynthesis increases. (0.5 points)

Since photosynthesis uses carbon dioxide as a reactant, more photosynthesis should draw more carbon dioxide out of the atmosphere. With less carbon dioxide in the atmosphere, the temperature should increase less. (0.5 points)

7. Line graphs and bar graphs are commonly used forms of data presentation and they are appropriate for different types of data. Line graphs are used to depict changes in a **continuous variable** over time. Bar graphs are used when data is **categorical.** Use a reputable source to define each of these variable types and include your citation. (0.5 points each, 1 point total)

Continuous variable: Variables that change along a spectrum and cannot be broken into clearly defined groups.

Categorical variable: Variables that can easily be classified into distinct groups

8. Now we'll practice making line graphs in Excel as you will be making several line graphs and using lines of best fit to interpret trends in data over time. Make a line graph of the data in the table to the right with a trend line and equation of the line. Remember that all graphs must have a descriptive title, axes with labels and units (as appropriate), and reasonably scales axes and font sizes. Follow ***all*** the instructions below to produce a complete graph of the number of red-tailed hawks over time. (Note that the instructions use seagull populations over time but your graph should use the data in the table to the right.)

TIEE

Teaching Issues and Experiments in Ecology - Volume 19, August 2023

Copy your graph below this question prompt. (1.5 points)

Please see the teacher pre-lab data sheet for a completed figure.

a. What is the slope of the line (include units)? (1 point)
___1.55 red-tailed hawks/year___________

b. Describe what this slope tells you about the change in number of hawks over time on average. (1 point)

This slope tells us that the number of hawks in the population increased by 1.55 individuals per year.

9a. Finally, we'll practice making bar graphs in Excel. Using the instructions provided below, make a bar graph comparing mean mosquito populations sizes between two different habitat types (data provided below). Remember that all graphs must have a descriptive title, axes with labels and units (as appropriate), and reasonably scales axes and font sizes. Follow ***all*** the instructions below to produce your graph.

Copy and paste your complete figure below this question prompt. (1.5 point)

Please see the teacher pre-lab data sheet for a completed figure.

b. T-tests are a statistical analysis we use to determine if two groups are different from one another and you will perform several in this lab. Use the instructions at the end of this pre-lab to conduct a t-test using the mosquito data.

Provide the p-value you calculated from your t-test: _____$p = 0.002$____________________ (1 point)

c. Using a reputable source, define what a p-value is using *your own words*. Remember to cite your sources! (1 point)

P-values provide the probability that the relationship between variables or differences between groups is due to random chance. Thus, a low p-value indicates a low probability that the results are due to random chance and a high confidence that the results are actually real. Thus, low p-values (typically below 0.05) indicate significance.

d. Given your p-value for the comparison of mosquito populations in different habitats and the definition of p-values, what can you say about mosquito populations between wetlands and forests. (Hint: are the differences statistically significant? If so, which group mean was larger than the other?) (1 point)

The data shows up that the population size of mosquitoes is statistically significantly higher in wetlands than in forests.

TIEE

Teaching Issues and Experiments in Ecology - Volume 19, August 2023

Investigating the Biospheric Carbon Pool in North Central North America (32.25 points)

Investigation 1: Historic Temperature Data

You will work in groups to assess temperature change in Wauseon, OH, using data from the U.S. Historical Climatology Network (USHCN). The USHCN has collected temperature data at 26 weather stations throughout Ohio since 1895 with earlier observations at Wauseon recorded by a local farmer, Thomas Mikesell.

1a. Examine the "Student temperature data" file. This table provides mean monthly temperatures in Wauseon from 1892-2018. You will use this data to calculate total temperature change and the rate of temperature change for several months. Given the type of data presented, which figure type would be most appropriate given the information in the pre-lab packet? Once your group has determined the graphing type you think is appropriate, talk with another lab group and compare ideas. Were your ideas similar or different? (Confirm your ideas with your teacher before continuing!) (0.5 points)

Line Graph because we are plotting a continuous variable over time.

b. You will produce 4 graphs depicting temperature change over time for the months February, April, July, and December. If we want to determine the rate of temperature change over time and total temperature change in these months, what type of analysis is appropriate given the information in your pre-lab packet? Once your group has determined the analysis type you think is appropriate, talk with another lab group and compare ideas. Were your ideas similar or different? (Confirm your ideas with your teacher before continuing!) Table 1 provides the rates of temperature change and total temperature change for the remaining 8 months. (0.5 points)

Trendline so we can use the slope to calculate rate of temperature increase. (0.4 points)

Notes from classmate discussion (0.1 points)

c. Produce the graphs of temperature change over time for February, April, July, and December including any relevant analysis to determine temperature change over time. Remember to include a descriptive title on each graph, label axes, include units, use an appropriate scale for axes, and consistent, readable font size. You will submit the Excel file with the figures. (4 points)

One points per figure: Title (0.2 points, axis labels (0.4 points), units (0.2 points), appropriate formatting and readability (0.2 points)

d. Using your graphs record the rate of change (°C/year; slope) in Table 1 (0.2 points each, 0.8 points total)

See values in the table.

e. Record the total temperature change (=slope*127years, °C) from 1892-2018 in the table. (0.2 points each, 0.8 points)
See values in the table.

2. a. What is the mean annual rate of temperature increase (=(sum of rates from column 2)/12):
_______0.01_______ (°C/year) (0.5 points)
b. What is the mean total temperature increase (=(sum of totals from column 3)/12):
__________1.27______(°C) (0.5 points)

3. Was warming uniform across the year or did some seasons experience more or less warming? In your answer, provide data to support your conclusions. (1 point)

Warming was not even—typically winter and spring months showed greater warming. Summer and fall showed moderate to no warming (even with an insignificant negative changes!)

0.5 points for correctly describing trends
0.5 points for referring to data (e.g., using the temperature trends for a couple example months to back up their claims)

4. Considering the timing of budburst, which monthly/seasonal temperatures do you predict will be the strongest drivers of budburst? Support your prediction using logic. (0.5 point)

Spring temperatures is the most reasonable answer but accept any answer supported with logic.

0.5 points for specifying season/month in their prediction
0.5 points for adequate logic in their explanation

5. Before continuing, compare your answer to question 4 with another group. Record the other group's prediction here. (0.25 points)

Full credit for correctly recording another group's prediction

6. Did your prediction match the other group's prediction? Explain how they were similar or different. If they were different, explain which prediction you think has better support. (0.25 points)

Full credit for correctly explaining any differences and justifying which prediction has better support.

7. If your prediction is correct, how will budburst timing have changed in the past 130 years given the temperature data above? (1 point)

Vast majority of students should say that budburst will get earlier—edit your assessment based on their answer to question 4

Investigation 2: Temperature and Budburst Relationship

8. Examine the data provided for white oak. Draw a graph representing the relationship between budburst timing and temperature for April given the correlations provided in the Table 2. You should label your axes for DOY, temperature, and month. Clearly indicate the direction of increase for both temperature and DOY with an arrow on your axes. The exact DOY and temperature values are not important. The line on your figure should clearly reflect the direction of the correlation. Provide a 1 sentence interpretation of the relationship between temperature and budburst timing presented on your graph. **This graph should be drawn by hand as using Excel is not necessary for the skills/content of this question.** (0.9 points)

0.2 points: Figures labeled correctly for DOY (y axis), temperature (x-axis), and the month
0.2 points: the direction of increase for both temperature and DOY is clearly indicated with an arrow on your axes
0.2 points: The line on the figure should clearly reflect the direction of the correlation (positive for Oct. and negative for April)

0.3 points: 1 sentence interpretation of the relationship between temperature and budburst is accurate relative to the correlation provided in the table

9. Examine the correlations presented in the table. Which months have the strongest relationship with budburst timing and in which season are these months? Which months have the weakest effect on budburst and in which season are these months? (Note the season codes in the table above) (0.5 points)

0.25 points: identifies spring temps as having the strongest relationship with budburst
0.25 points-identifies winter and summer as having weaker relationship; identifies fall as having the weakest relationship

10. Do these correlations support or refute your predictions for which monthly temperatures would be the strongest drivers of budburst? Explain your answer citing specific trends from the data. (1 point)

0.25 points: any answer consistent with their previous prediction
0.25 points: cites trends in the data in their answer

11. Define different budburst timing strategies used by each species based on the following criteria: 1. the seasonal temperatures that are the strongest drivers of budburst for a given species; 2. the extent to which budburst advances (strong advancement vs. slight advancement) with increased temperature based on the correlation coefficient. (0.5 points each, 2 points total)

a. Cottonwood: moderate advancement with warmer summers although not significantly correlated

b. Staghorn Sumac: moderate advancement with warmer springs

c. Black walnut: strong advancement with warmer spring and winter

d. White Oak: strong advancement with warmer spring, moderate advancement with warmer winter

12. Species using different budburst strategies will have different interactions with their environment. For example, the delicate, new leaves of different species will experience very different environments if one species strongly advances budburst with warmer April temperatures while the other only weakly advances budburst with warmer June temperatures. Explain the potential ecological trade-offs of each strategy listing pros and cons.

When answering this question, consider the environmental pressures of spring (e.g. potential for frost damage, light availability, etc). In what situations would it be **beneficial** to advance budburst and in what situations may it be **detrimental**? (Refer back to the lab introduction to help you brainstorm!) (2 points)

TIEE

Teaching Issues and Experiments in Ecology - Volume 19, August 2023

Full credit for any reasonable answers with at least one item in each column

Strong Advancement with Warming		Weak/No Advancement with Warming	
Pro	Con	Pro	Con
Longer total growing season	Increased risk of frost damage	No increased risk of frost damage	Light competition may be greater
Reduce early season light competition	Potential increased risk of early season herbivory		Less opportunity for growing season elongation
Greater early season water availability			Shorter duration of ample water supply

Whole class discussion: Take a moment to share your ideas for the pros and cons of strong vs. weak advancement of budburst with warming. It may be helpful to produce a compiled class pro/con table on the board.

13. What additional pros and cons of each strategy were revealed during the class discussion? (0.25 points)

Full credit for correctly documenting items from the class discussion

14. Given the compiled class pro/con discussion, which strategy (strong vs. weak/no advancement) would you predict to be more beneficial on average as warming continues? Justify your answer. (1 point)

Most students will likely say stronger advancement with warming but modify your grading based on answers to the previous two questions. Generally student responses should reflect that earlier timing of budburst with warming will allow plants a longer total time of photosynthesis and thus increase their potential growth and reproduction.

Investigation 3: Changing Budburst over the past 128 years

15. Navigate to the Excel file titled "Student Historic vs. Modern budburst timing data." Using these data, you will calculate the average budburst date for each species in the historic (Mean BB Historic) and modern (Mean BB Modern) observation periods. Once you've calculated these averages, determine how much the average timing of budburst has shifted from the historic to modern period for each species (Budburst shift). To calculate how much budburst has shifted in the past 128 years, you should use the following calculation:

Budburst shift = Mean BB Historic – Mean BB Modern

A negative budburst shift means that budburst is ***earlier*** in the modern period than the historic period. Copy your values from Excel to Table 4 below. (3 points)

Table 4

Species	White Oak	Staghorn Sumac	Cottonwood	Black Walnut
Mean BB Historic	126.61	125.88	119.83	127.22
Mean BB Modern	119.06	116.74	119.06	116.30
Budburst shift	-7.55	-9.14	-0.77	-10.92

16. Describe the change in timing of budburst for each of the four species. (1 point)

Black walnut showed the greatest advancement of budburst by almost 11 days followed by staghorn sumac at just over 9 days.
White oak budburst is roughly a week earlier in the modern period than in the historic period.
Cottonwood showed essentially no change with a difference of less than a day.

17. Consider the temperature trends you found in the first investigation and the correlation coefficients between budburst in each species with monthly temperatures. Do your calculated shifts in budburst over time make sense relative to a. how temperatures have changed in the past 128 years, and b. which monthly temperatures are significantly related to budburst in each species?

Explain for each species including specific information about which months budburst is associated with and how much that month's temperature has changed over time in your answer for each species: (2 points)

a. Cottonwood: Cottonwood budburst timing had the weakest relationship with temperature. It was most closely related to summer temperatures. The lack of advancement from the historic to midterm period is consistent with these findings as summer temperatures have shown the least warming over time.
b. Staghorn Sumac: Sumac budburst timing was significantly correlated with April and May temperatures, both of which have warmed substantially over the past roughly 130 years. Thus, the strong advancement of sumac is consistent with temperature trends and its association with temperature variables.
c. Black walnut: Walnut budburst timing was significantly correlated with January, April, and November temperatures. As all of these predictor variables of show substantial warming over time, that is consistent with the greatest advancement of budburst among the four focal species.

d. White Oak: White Oak budburst timing was significantly correlated with April and May temperatures. As both of these month have shown strong warming trends, the advancement of budburst in this species is consistent with the previous data.

18. Next you will produce a figure (or figures) depicting the average budburst dates you calculated in question 11 (see table 4 above). Given the type of data present, what kind of figure would be most appropriate from your pre-lab packet? Clearly state the figure type and explain why it is the correct choice. Once your group has determined the figure type you think is appropriate, talk with another lab group and compare ideas. Were your ideas similar or different? (Confirm your ideas with your teacher before continuing!) (0.5 points)

Bar graphs are appropriate because we are comparing means among groups (in other words, the data is categorical). (0.4 points)

Comparison with other group's ideas (0.1 points)

19. Copy and paste your figure(s) from Excel showing the modern vs. historic averages for each of the four focal species. Use the instructions in your pre-lab packet and remember to include all components of your chosen figure type as indicated in the packet instructions (error bars, axis labels, etc)! (2 points)

Please see the instructor data file for the figure.

20. Now that you've produced a graphical display of differences between budburst in the modern vs. historic period, we need to run statistics to determine if the difference is significant or not. Given the type of data and comparison we want to make, which statistic type from your pre-lab packet is most appropriate. Explain your answer. Once your group has determined the analysis type you think is appropriate, talk with another lab group and compare ideas. Were your ideas similar or different? (Confirm your ideas with your teacher before continuing!) (0.5 points)

We should use t-tests because we want to determine if two groups are significantly different from each other. (0.4 points)

Comparison with other group's ideas (0.1 points)

21. Summarize your statistical comparisons. For each comparison, you should clearly state whether the differences were or were not significant and provide the p-value to support your claim. (2 points)

Budburst in both white oak and black walnut was significantly earlier in the modern than historic period ($p = 0.041$ and 0.007, respectively. Budburst in staghorn sumac was not significantly earlier although the p-value was only slightly higher than the alpha ($p = 0.06$) suggesting that additional observation years may reveal significant trends. Finally, there was no significant difference in budburst timing for cottonwood ($p = 0.42$)

Whole Class discussion: Synthesis questions

For this portion of the lab, we'll be comparing your individual predictions for each question with the general consensus of the class. For each question, your lab instructor will tell you when to write your individual prediction on a separate piece of paper. After you've written your prediction, you'll take a few minutes to share out general ideas with the class. If there are differences in your ideas, you'll make note of them in the space provided. Then, your group will devise a consensus on the best predictions given the whole class discussion by revising your original thoughts as needed.

22. Consider the photosynthesis equation you provided in the pre-lab questions. Given the calculated values for budburst shift over the past 127 years, predict how carbon storage in Ohio's forests has changed (increased, decreased, stayed the same) and justify your prediction.

(Note: these patterns of budburst and associated changes in C storage apply to mesic (wet), temperate, deciduous broadleaved forests like those in Ohio. Other forests with different environmental drivers may experience different changes.) (1 point total)

Individual Prediction (copy each group member's individual ideas here after the discussion) (0.25 points):

Full credit for copying each student's prediction

Notes from class discussion (0.25 points):

Full credit for notes correctly documenting the class discussion.

Revised group consensus prediction (0.5 points):

0.25 points: States C storage should have increased
0.25 points: Justification—since budburst is earlier there's a longer period for photosynthesis. More photosynthesis = more C stored

23. Each of the four species you evaluated varied in the amount budburst has shifted over the past 127 years. Which species do you predict will benefit most from increased temperatures given these differences? Which species will benefit the least? Justify your answer. (1 point total)

Individual Prediction (copy each group member's individual ideas here after the discussion) (0.25 points):

Full credit for copying each student's prediction

Notes from class discussion (0.25 points):

Full credit for notes correctly documenting the class discussion.

Revised group consensus prediction (0.5 points):

Most will probably say black oak will benefit most and cottonwood will benefit least because they show the greatest and least shift in budburst, respectively.

Any reasonable answer given justification should be given credit.

0.25 points: specifies species that do best vs. worst
0.25 points: provides budburst based justification

24. Assume that forests in the northern hemisphere show similar responses to warming as the tree species you've studied in this lab. If warming temperatures result in earlier timing of budburst on average, how will the rate of climate warming be affected? (Hint: Consider the photosynthesis equation in your answer.) (1 point total)

Individual Prediction (copy each group member's individual ideas here after the discussion) (0.25 points):

Full credit for copying each student's prediction

Notes from class discussion (0.25 points):

Full credit for notes correctly documenting the class discussion.

Revised group consensus prediction (0.5 points):

If forests have earlier budburst and perform more photosynthesis on average as a result, the rate of warming should decrease as more CO_2 is removed from the atmosphere.