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Plant Growth and Climate Change: Urban Trees' Role as a Carbon Sink

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Students struggle to connect small-scale processes like photosynthesis and cellular respiration to large-scale phenomena such as climate change. We developed this exercise for undergraduate introductory biology labs to help students understand how the growth of trees on their campus relates to fluxes in atmospheric carbon. Students apply the scientific process by generating hypotheses about plant growth in urban and forest ecosystems, collecting data on campus trees, and analyzing these data along with a citizen science-generated database of campus trees to determine annual biomass accumulation. They then draw conclusions about variation in tree growth at individual, local, and regional scales.

Keywords: carbon sink, climate change, plant biomass, green roof, urban ecology, urban tree canopy **Link to Supplemental Materials: http://www.ableweb.org/volumes/vol-40/3_Calhoon**

Introduction

We have noticed that students often have trouble connecting processes that happen on the cellular level to large-scale processes occurring at the ecosystem and biosphere level. A connection that is both currently important and that students often have trouble understanding is connecting photosynthesis, plant growth, and global climate change. We initially tried to remedy this shortcoming by writing a lab for Ohio State University's (OSU) upper-level Ecology course in the department of Evolution, Ecology, and Organismal Biology. The lab used a database of tree size measurements that was generated through citizen science on OSU's campus as well as using biomass accumulation equations from an Ecology Letters paper (Anderson *et al.* 2006). This version of the lab was largely based on determining the right equations to use from Anderson *et al.* (2006) and Chojnacky *et al.* (2014) and calculating values from the data, such as growth rates. We wanted to make the lab more suitable to an introductory course, so we considerably reduced the calculations by using Excel to automatically calculate these values. This change allows students to spend significantly more lab time carrying out the scientific method and discussing various topics such as carbon sinks, urban ecology, citizen science, and ecosystem services. In addition, the benefits of this lab include getting students outside where they observe the surrounding environment in a different context, and that it is an inexpensive lab to run.

For set-up, this lab requires only a set of measuring tapes and a computer to run Excel for the calculations. However, substantive advance planning will be needed for a campus without pre-collected citizen science data, as instructors would need to go out at least a year before the first lab to get preliminary data for the tree growth calculations. The lab consists of about 30-45 minutes outside measuring trees and then about an hour inside analyzing data and answering questions.

Student Outline

Name____ Section/TA____

How can urban trees help mitigate global climate change?

Pre-Laboratory Questions

To be completed *prior* to lab on a separate sheet of paper. You must cite your sources of information.
1. What are some advantages of having urban trees, that is, trees present in urban environments? (1 pt.)
2. Define the term ecosystem services. (1 pt.)

Lab Objectives

- Explain connections between cellular energetics (e.g. photosynthesis/cellular respiration) and large-scale ecological phenomena such as global climate change
- Identify and evaluate how human decisions impact life on earth
- Describe some interactions between humans and their environment in the context of urban ecology and ecosystem services
- Apply the scientific method using class-collected data and a citizen science-generated dataset
- Identify advantages and disadvantages of using citizen science
- Develop/interpret/critique quantitative and graphical test results to formulate conclusions about variation in tree growth rates at multiple geographic scales

Introduction

Often in ecology, we feel the need to focus on the "cooler" processes taking place in pristine environments or environments far away, such as tropical rainforests. We can, however, see the same ecological processes and concepts in the world directly around us. The study of urban ecology (the ecology of organisms in cities) is important both because more and more of the surface area of the earth is being taken up by cities and also because the same processes affecting global climate change exist in cities as well as in more pristine environments.

Because the amount of carbon dioxide in the atmosphere is an important factor in the rate of global climate change, ecologists that study global climate change must consider carbon sources and sinks in any model of global climate change. A carbon sink is an environment or group of organisms that absorbs carbon dioxide from the atmosphere and stores it for some period of time. Through the process of photosynthesis, plants take up carbon dioxide (CO_2) from the atmosphere and use that carbon in building plant structures. This is often called carbon sequestration. Much of this carbon ends up stored in plant tissue as biomass. For example, the main component of cell walls of plants is cellulose, a polysaccharide made by covalently linking together many glucose molecules formed during photosynthesis. Therefore, greater amounts of plant growth are associated with greater amounts of carbon storage in plants, reducing the amount of CO_2 staying in the atmosphere. If the amount of carbon stored in plants per year were to equal the amount of CO_2 released in various processes (such as burning of fossil fuels, permafrost melting, and cellular respiration), then the amount of CO_2 in the atmosphere would likely not be increasing. Nonetheless, currently the amount of CO_2 released into the atmosphere is significantly greater than the amount taken up, leading to an increase in total atmospheric CO_2 and subsequent increase in global average temperature.

Methods and Data Collection

Part A: Growth Rates of Urban Trees

1. Based on the above paragraph and the carbon cycle (Figure 1), why are plants, in particular the growth of plants, important to consider when thinking about climate change? (*1 pt.*)

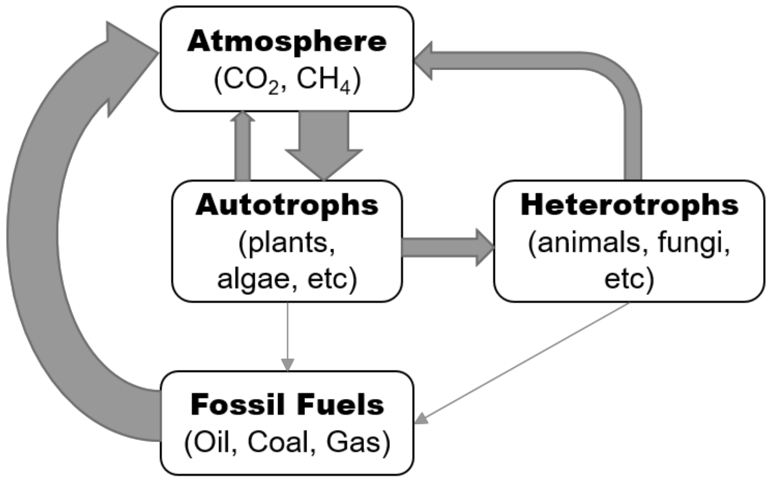

Figure 1. Simplified diagram of the carbon cycle

Different species of trees grow at different rates and, within a species, individual trees will grow at different rates depending on a wide variety of factors.

2. Make several hypotheses about what factors you think may affect individual tree growth, based on your knowledge of plants. (*1 pt.*)

3. Based on what you think may affect plant growth, predict whether trees in urban environments would grow faster, slower, or at about the same rate as trees in natural forests. Explain your reasoning. (*1 pt.*)

In the next part of the lab, you will go out and collect data on the growth rates of trees around campus. In forestry and ecology, the most commonly used measure of the size of trees is the diameter at breast height (DBH). By comparing DBH of the same individual tree from multiple years, you can estimate the growth rate of that tree. You will collect current DBH for several trees in groups.

The OSU Campus Tree Inventory was started in 2011, and involves staff from the Chadwick Arboretum working with volunteers to map and measure every tree on campus. You can learn more about the tree-mapping project at: http://chadwickarboretum.osu.edu/plant-collections-gardens/trees-our-campus. These trees have been measured multiple times over the years, so you will be able use your measurements and the previous measurements to find the growth rate of the trees.

4. Diameter at breast height (DBH) involves using a tape measure to measure around the tree at approximately chest height. Assuming everyone in the class and previous measurements were taken at the exact chest height of the different people doing the measuring, what potential problem could the measurements have and how would that complicate calculating growth rate? (*0.5 pt.*)

5. What might be one way to correct this potential issue? (*0.5 pt.*)

Your TA will show you where to go on campus to find your trees and will assign you to collect data from a number of individual trees. Once you get to each location, take a second to orient yourself to where your trees are on the maps.
A standard DBH measurement is taken at 1.37 meters from the ground. Note that on some students this will be somewhat below chest height and on others it may be closer to neck or head height. Before taking measurements, you must figure out where this measurement is on you and measure all trees at that height.

You will take the tape measure and measure how far it goes around each tree (i.e. the circumference – a simple equation will tell you the diameter from this measurement). It is important that the tape measure is wrapped tightly around the tree when you take this measurement or you will be overestimating the amount of growth that has happened. Make sure that you are making this measurement at 1.37 meters from the ground and take this measurement to the nearest 0.1 cm, rather than in inches. Record your measurements in the following table:

6. (*1.5 pts.*)

Table 1. Data Sheet for Campus Trees.

Location	Tree (number)	Circumference (cm)

7. Your Lab Instructor will also take you past a green roof on campus. Observe the green roof. Based on your observations, what is a green roof? (*0.5 pts*)

a. Once these measurements are done and you have visited the green roof, you will head back to the lab.
Once back in the lab, put your measurements into the class spreadsheet that will calculate growth rate based on the previous sizes of the same trees. You will be entering the date and the current circumference in columns D and E on Class Data Sheet.
b. Next, click on the tab for the Tree Specific Growth Rate sheet . Note that Column P contains the calculated grams/year of biomass produced by each tree. How was this calculated? First, circumference was converted to DBH. Click on the cell for a single tree in column L and view the function bar (f_x =) at the top of the table. The value that you entered in column K for the current circumference was divided by pi to get DBH in the same units (cm).
c. Current above-ground biomass for each tree was estimated by an equation published by Chojnacky et al. (2014) that takes into account different wood densities specific to different families of trees. For example, maples (F. Aceraceae) have denser wood, as estimated by wood specific gravity, than do willows (F. Salicaceae); therefore, maples generally have more biomass

than do willows at the same DBH. The formula in column M applies a relationship to determine biomass from DBH according to the known specific gravity for the tree families.
d. A formula applied to column N determines the years (and fractions of years) between the date of your measurement and the last time the tree was measured.
e. Then, the difference between the previous biomass estimate and your current biomass estimate (Column O) are used to calculate how much *new* biomass has been produced since the last time the tree was censused.
f. The *new* biomass value is then divided by the number of years to estimate how many grams of tree biomass were produced per year in column P.

8. You collected data from two different locations, each with its own species of tree. Do there appear to be differences in the annual growth rate between the two species? Is this consistent with what you would expect? Why or why not? (*1 pt.*)

Part B: Growth Rates of Trees in Different Parts of the World

In order to determine how much carbon dioxide a tree or forest stores in terms of the amount of space it takes up, we must take the annual tree growth rate estimates we got in the last part of the lab (growth rate was measured in grams per year) and divide by the amount of space the trees occupy (the new measurement will be in grams per year per meter). The lab's spreadsheet will do this calculation for you and we will look at the result in this part of the lab and compare it to growth rates of trees around the world.

Dr. Kristina Anderson and her colleagues calculated the annual growth rate for trees in 64 sites worldwide (see Figure 2).

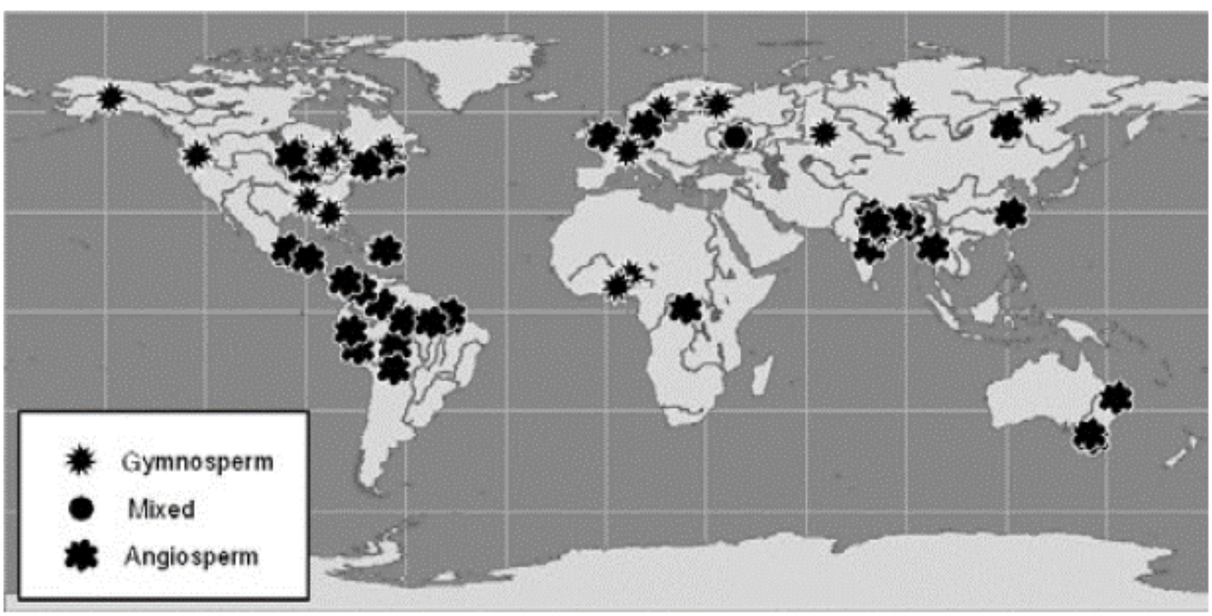

Figure 2. Sites used to calculate annual growth rates. Reprinted with permission from Anderson et al. (2006). © Blackwell Publishing Ltd/CNRS.

Figure 3 below shows the calculated annual growth rates for the sites shown in Figure 2. Note how the annual growth rate changes with increasing distance from the equator (latitude at the equator = 0).

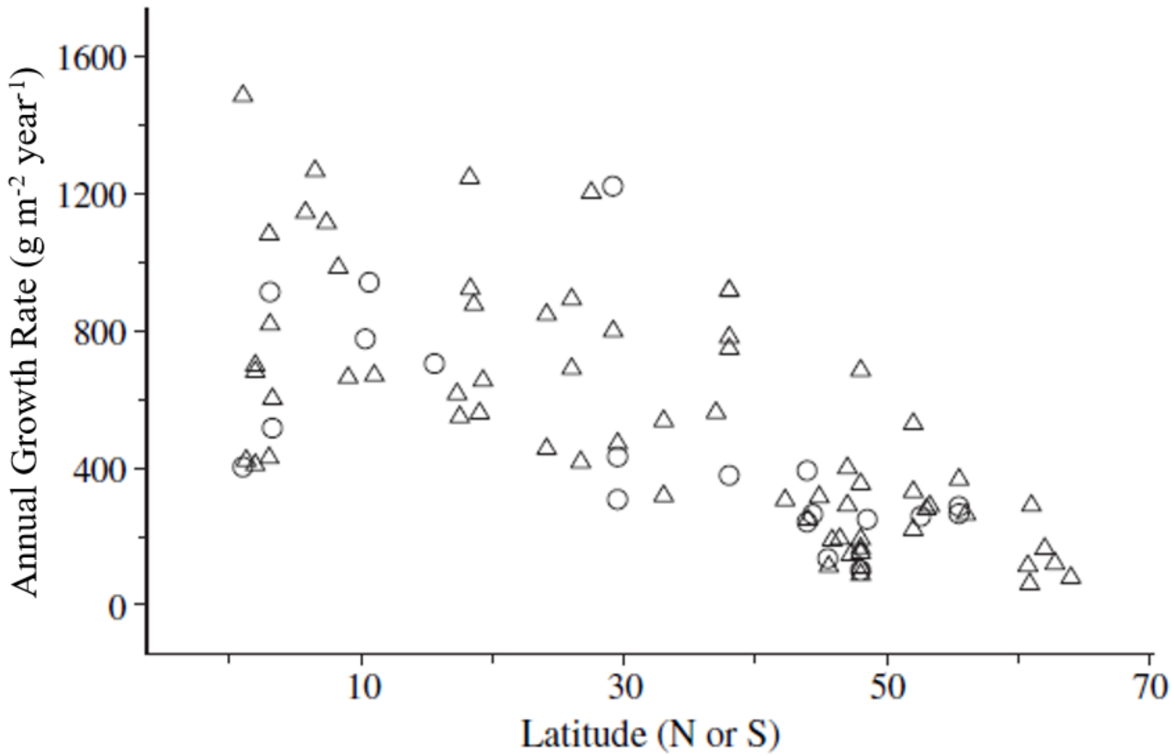

Figure 3. Variation in annual growth rate with increasing distance from the equator. Southern hemisphere sites are marked with circles, and Northern hemisphere sites are marked with triangles. Reprinted with permission from Anderson et al. (2006). © Blackwell Publishing Ltd/CNRS.

1. The higher the latitude, the closer the location is to the poles. The lower the latitude, the closer the location is to the equator. Based on Figure 3, do trees in tropical areas tend to grow faster or slower than trees in more temperate areas? Why do you think that is? (*1 pt.*)

2. The latitude of Columbus, Ohio is approximately 40 (degrees North of the equator). Using the average growth rate of trees from your lab section, plot the estimated annual growth rate for Columbus on Figure 3 above. You may have to extend the y-axis to fit your data on the graph (*1 pt.*)

3. Refer back to Figure 3. Based on this figure, do the urban trees that you sampled seem to have a higher growth rate, lower growth rate, or very similar growth rate to a growth rate you would expect for forest trees in Ohio, based on the growth rates of other forest trees at similar latitudes? Does this align with your original prediction? If it does not align, hypothesize why not. (*1.5 pts.*)

Part C: Trees and Global Climate Change

Ohio is approximately 28.69 million acres in total land area; 7.9 million acres are currently forested. Based on these numbers and our own data for urban trees, we can estimate how much carbon dioxide would be taken in by Ohio's forests per year, if they grow at the same rate as urban trees.

1. The value calculated in the Carbon Accumulation and Uptake spreadsheet is based on the assumption that the average growth rate in forested areas statewide is equal to the growth rate that your class measured for the trees on campus. Do you

think this estimate is too high, too low, or about right? Why? (Consider your prediction from Question A.3., and your answer to Question B.3.). (*1 pt.*)

2. Ohio also has data on the amount of carbon emissions produced by the state. From the Carbon Accumulation and Uptake spreadsheet, what percentage of Ohio's annual carbon emissions are offset by the estimated carbon uptake of Ohio's forested areas, based on your data from urban trees? (The real number would be somewhere between 10 and 20%). Do you think that Ohio should be required to offset its emissions in some way to make that number closer to 100%? Why or why not? (*1.5 pt.*)

Part D. Study Questions

1. The data from previous years was collected by volunteers on their own time, some of whom are scientists, some of whom are not. The collection of data by amateur or nonprofessional scientists is referred to as citizen science. Data similarly collected has been used by scientists in some scientific studies. What do you see as an advantage of citizen science? What might be a disadvantage? (*1 pt.*)

2. By forming a sink for CO_2 and therefore slowing the acceleration of global climate change, forests and urban trees perform an ecosystem service (benefits derived by humans from having functioning ecosystems). Some people have attempted to put monetary values on ecosystem services to help inform lawmakers and other decision-makers. Discuss this - what do you see as advantages to estimating the monetary values of ecosystem services? Do you see any disadvantages to this practice? (*1 pt.*)

3. Green roofs are roofs that have been specifically designed to have plants growing on top of them. Your Lab Instructor took you past a small green roof over a bicycle rack near the lab building. In addition to this green roof on OSU's campus, Howlett Hall also has a green roof. Green roofs are becoming increasingly popular, especially in Europe, where more than 10% of all German houses have green roofs and several cities have required that all new buildings with flat roofs be green roofs. This increasing popularity is because green roofs provide a number of advantages that traditional roofs do not. Besides storing carbon (like urban trees), what might be at least other two ecosystem services provided by green roofs? (*1 pt.*)

4. Besides planting more urban trees and green roofs, what other ways can you think of to increase carbon storage or decrease carbon being released into the atmosphere? (*1 pt.*)

5. Consider what you have learned about ecology in class so far. In what ways do you think urban ecosystems differ from more pristine ecosystems (such as old-growth forests and protected areas)? In what ways do you think they may be similar? (*1 pt.*)

Cited References

Anderson KJ, Allen AP, Gillooly JF, Brown JH. 2006. Temperature-dependence of biomass accumulation rates during secondary succession. Ecology Letters, 9: 673-682.

Chojnacky DC, Heath LS, Jenkins JC. 2014. Updated generalized biomass equations for North American tree species. Forestry, 87:129-151.

Materials

Vinyl measuring tapes - 1 for every two students (Optional more expensive substitution: actual DBH tapes – again, 1 for every two students. If DBH tapes are used, the formulae in the Excel file will need to be changed to reflect that)

Computer with Excel – minimum of 1 in each lab section

Optional: laminated copies of the maps of where trees are located

Notes for the Instructor

Our campus context allowed us to use an existing database with tree species and DBH records for stands of trees grown in monoculture. For campuses lacking these data, instructors would need to select trees, identify species, and measure data one year before implementing the lab for the first time. Alternatively, a first-year iteration of the lab could be adapted to have students collect the first year of tree data. This provides the students an opportunity to contribute to the work of students in subsequent labs. If instructors wish to incorporate student identification of tree species into the lab, it is helpful to identify species in advance so the instructor can provide feedback on student identifications.

The previous and current aboveground biomass estimates (Columns I and M in the large excel spreadsheet in Appendix B) are based on the generalized biomass equation in Chojnacky *et al.* (2014):

$$\ln(\text{biomass in kg}) = \beta_0 + \beta_1 * \ln(\text{diameter in cm})$$

The β_0 and β_1 estimates vary by species and are provided in Table 5 of Chojnacky *et al.* (2014; p. 140). Instructors should enter in the spreadsheet the appropriate β_0 and β_1 estimates for the trees on their campus. For many of the tree families in Table 5 of Chojnacky *et al.* (2014), different estimators are provided for trees with different specific gravities. We recommend that smaller (younger) trees be used in this lab whenever possible, because growth rates will generally be greater in these trees and therefore measured DBH differences from one year to the next will be more pronounced. The specific gravity of younger trees will tend to be small relative to older trees; therefore, the estimators for trees with a lower specific gravity will be the best choices to use in this part of the spreadsheet (Columns D and E in the large excel spreadsheet in Appendix B).

For Part B of the lab, area is incorporated into equations to scale up annual biomass accumulation from specific trees to entire stands of trees. Because the trees we used on our campus were grown in monoculture, we used polygon area estimates of the tree stands based on aerial maps. On other campuses, if trees are not grown in monoculture then the area values would need to be estimated differently, for example by estimating total canopy area. Instructors could assess area prior to running the lab or could incorporate these measurements into the lab itself and have students collect these data.

Questions A8, B2, B3, C1, and C2 incorporate data specific to Ohio State's campus and the state of Ohio, and would need to be altered for other campuses and states. The Division of Forestry or similar agency in your state is a good resource for total land area and forested area estimates.

Anderson *et al.* (2006) used global data from forests in secondary succession to estimate biomass accumulation rates. These estimates are used in Figures 2 and 3 and related questions in the lab activity. This provides an opportunity for instructors to discuss with students the differences between trees in a secondary growth forest and trees in urban landscapes, considering factors like differences in the age of the trees, competition, and resources. Students further explore these differences in question B3 of the lab.

Question A7 and Study Question D3 relate to green roofs. On our campus, students are able to make observations of a green roof and this activity is incorporated into the lab. On campuses where a green roof is not available, instructors could lead a class discussion on green roofs or ask students to research green roofs online.

Other modifications of this lab are possible depending on the trees available for use at other campuses. Additional comparisons that instructors might be able to explore include native versus introduced trees within the same family and urban versus forest trees using data collected on or near campus. In our application of this lab, we chose to focus student work on applying concepts rather than computing estimates; therefore, we automated many of the calculations by incorporating them into a class spreadsheet. Instructors who wish to make the lab more computational could easily modify the lab to have students calculate biomass accumulation estimates.

For sample data and results see Appendix A, for the notes that we give to our lab instructors to help teach the lab, including suggested answers for questions in the Student Outline, see Appendix B, and for a sample map to be given to students when they go out into the field, see Appendix C.

Cited References

Anderson KJ, Allen AP, Gillooly JF, Brown JH. 2006. Temperature-dependence of biomass accumulation rates during secondary succession. Ecology Letters, 9: 673-682.

Chojnacky DC, Heath LS, Jenkins JC. 2014. Updated generalized biomass equations for North American tree species. Forestry, 87:129-151.

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About the Authors

Liz Calhoon has been an Instructor in the Center for Life Sciences Education at Ohio State University since 2016, where she teaches large courses in introductory biology for non-majors.

Corrie Pieterson is an Instructor in the Center for Life Sciences Education at the Ohio State University. She has taught Introductory Biology and upper-division Ecology labs since 2010.

Steve Gougherty is a PhD student at Boston University in the Department of Biology.

Appendix A: Sample Results

Individual Group Data For Biological Sciences				
Sampling Location	**Tree #**	**Family**	**Current Survey Date**	**Current circumference (cm)**
Example	0	Fagaceae	11/17/2015	30.00
Biological Sciences	4	Fagaceae	10/19/2017	45.30
Biological Sciences	5	Fagaceae	10/19/2017	55.40
Biological Sciences	6	Fagaceae	10/19/2017	50.65
Biological Sciences	7	Fagaceae	10/19/2017	30.50
Biological Sciences	8	Fagaceae	10/19/2017	46.20
Biological Sciences	9	Fagaceae	10/19/2017	42.50
Biological Sciences	10	Fagaceae	10/19/2017	40.50
Biological Sciences	11	Fagaceae	10/19/2017	38.55
Biological Sciences	12	Fagaceae	10/19/2017	40.60
Biological Sciences	13	Fagaceae	10/19/2017	41.49
Biological Sciences	14	Fagaceae	10/19/2017	32.60
Biological Sciences	15	Fagaceae	10/19/2017	46.40
Biological Sciences	16	Fagaceae	10/19/2017	29.95
Biological Sciences	17	Fagaceae	10/19/2017	32.50
Biological Sciences	18	Fagaceae	10/19/2017	52.00

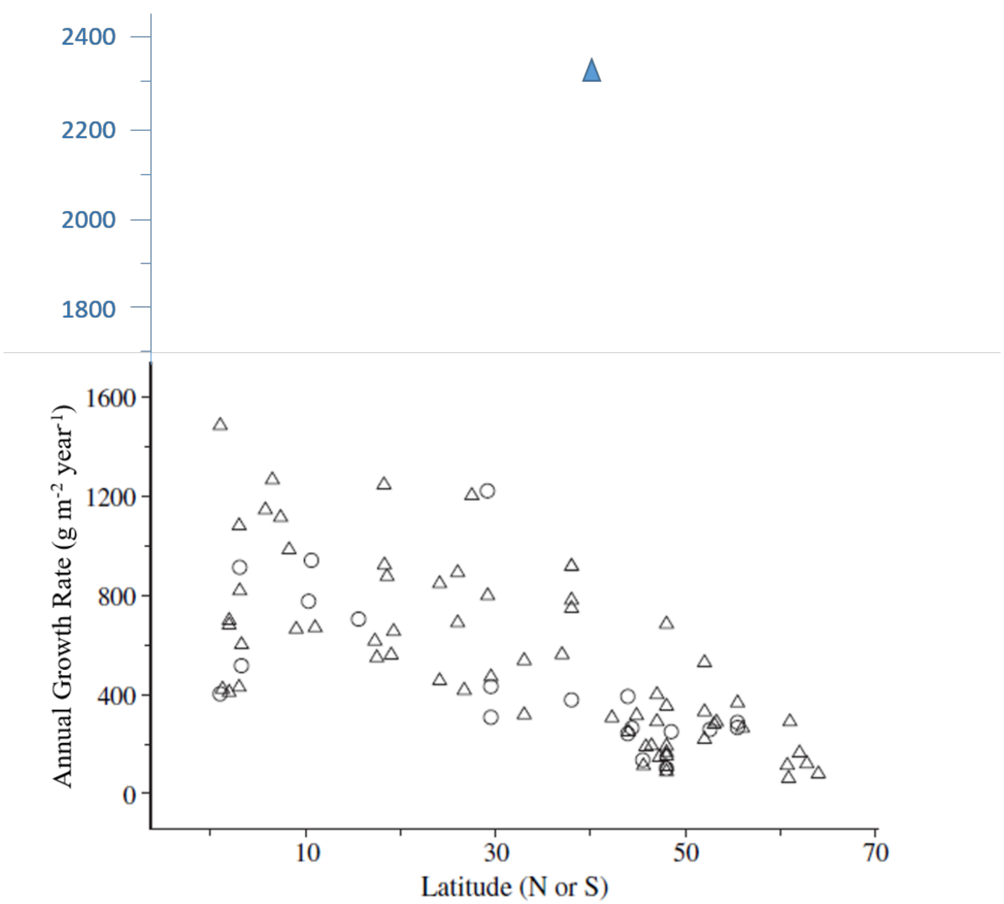
Individual Group Data For Ohio Stadium				
Sampling Location	**Tree #**	**Family**	**Current Survey Date**	**Current circumference (cm)**
Example	0	Fagaceae	11/17/2015	30.00
Ohio Stadium	8	Aceraceae	10/19/2017	50.75
Ohio Stadium	9	Aceraceae	10/19/2017	44.50
Ohio Stadium	10	Aceraceae	10/19/2017	46.60
Ohio Stadium	11	Aceraceae	10/19/2017	38.80
Ohio Stadium	12	Aceraceae	10/19/2017	39.05
Ohio Stadium	13	Aceraceae	10/19/2017	53.00
Ohio Stadium	14	Aceraceae	10/19/2017	51.00
Ohio Stadium	15	Aceraceae	10/19/2017	52.50
Ohio Stadium	16	Aceraceae	10/19/2017	53.90
Ohio Stadium	17	Aceraceae	10/19/2017	44.00
Ohio Stadium	18	Aceraceae	10/19/2017	53.50
Ohio Stadium	19	Aceraceae	10/19/2017	51.50
Ohio Stadium	20	Aceraceae	10/19/2017	60.00
Ohio Stadium	21	Aceraceae	10/19/2017	49.00
Ohio Stadium	22	Aceraceae	10/19/2017	45.50
Ohio Stadium	23	Aceraceae	10/19/2017	39.82

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Group Data For Biological Sciences															
Sampling Location	**Tree #**	**Family**	**Family specific B_0**	**Family specific B_1**	**Previous Survey Date**	**Previous DBH (inches)**	**Previous DBH (cm)**	**Previous aboveground biomass estimate (g)**	**Current Survey Date**	**Current circumference (cm)**	**Current DBH (cm)**	**Current aboveground biomass estimate (g)**	**Time between current and previous survey dates (yr)**	**Current - previous aboveground biomass estimate (g)**	**Tree Growth rate (g yr^{-1})**
Example	0	Fagaceae	-2.0705	2.4410	8/16/2012	3.4	8.6	24340.7	1/17/2015	30.0	9.5	31110.2	2.4	6769.6	2795.1
Biological Sciences	4	Fagaceae	-2.0705	2.4410	8/16/2012	3.4	8.6	24340.7	3/30/2016	39.3	12.5	60027.5	3.6	35686.9	9853.0
Biological Sciences	5	Fagaceae	-2.0705	2.4410	8/16/2012	4.2	10.7	40770.3	3/30/2016	49.3	15.7	104709.1	3.6	63938.8	17653.3
Biological Sciences	6	Fagaceae	-2.0705	2.4410	8/16/2012	4.1	10.4	38441.3	3/30/2016	48.1	15.3	98316.2	3.6	59874.9	16531.3
Biological Sciences	7	Fagaceae	-2.0705	2.4410	8/16/2012	3.0	7.6	17932.7	3/30/2016	26.7	8.5	23415.6	3.6	5482.9	1513.8
Biological Sciences	8	Fagaceae	-2.0705	2.4410	8/16/2012	3.5	8.9	26125.4	3/30/2016	44.3	14.1	80544.7	3.6	54419.4	15025.0
Biological Sciences	9	Fagaceae	-2.0705	2.4410	8/16/2012	3.4	8.6	24340.7	3/30/2016	35.9	11.4	48248.5	3.6	23907.9	6600.9
Biological Sciences	10	Fagaceae	-2.0705	2.4410	8/16/2012	3.1	7.9	19427.0	3/30/2016	35.1	11.2	45673.1	3.6	26246.1	7246.5
Biological Sciences	11	Fagaceae	-2.0705	2.4410	8/16/2012	2.9	7.4	16508.4	3/30/2016	35.1	11.2	45673.1	3.6	29164.7	8052.3
Biological Sciences	12	Fagaceae	-2.0705	2.4410	8/16/2012	2.7	6.9	13866.0	3/30/2016	28.7	9.1	27985.1	3.6	14119.1	3898.2
Biological Sciences	13	Fagaceae	-2.0705	2.4410	8/16/2012	3.0	7.6	17932.7	3/30/2016	33.5	10.7	40770.3	3.6	22837.6	6305.4
Biological Sciences	14	Fagaceae	-2.0705	2.4410	8/16/2012	2.6	6.6	12645.7	3/30/2016	28.6	9.1	27657.5	3.6	15011.8	4144.7
Biological Sciences	15	Fagaceae	-2.0705	2.4410	8/16/2012	3.5	8.9	26125.4	3/30/2016	36.4	11.6	50019.0	3.6	23893.7	6597.0
Biological Sciences	16	Fagaceae	-2.0705	2.4410	8/16/2012	2.5	6.4	11491.2	3/30/2016	26.4	8.4	22748.8	3.6	11257.7	3108.2
Biological Sciences	17	Fagaceae	-2.0705	2.4410	8/16/2012	2.4	6.1	10401.3	3/30/2016	34.6	11.0	43937.2	3.6	33535.9	9259.2
Biological Sciences	18	Fagaceae	-2.0705	2.4410	8/16/2012	4.3	10.9	43180.6	3/30/2016	46.2	14.7	89169.2	3.6	45988.6	12697.3

Compiled Class Data	
Average growth rate per square meter across both locations (g m^{-2} yr^{-1})	**2,314.36**

Estimated carbon accumulation in Ohio forested areas	
Acres of forested area in Ohio	7,900,000.00
Total grams of carbon per year accumulated in Ohio's forested areas (assuming 50% of biomass is carbon; g C yr^{-1})	**36,995,190,875,168.90**
	**Note this calculation assumes that the statewide growth rate of Ohio forests is the same as the growth rate of the trees your class

Estimated uptake of Ohio's carbon emissions	
Percent of Ohio's annual carbon emissions offset by forested areas each year (grams of carbon accumulated per year/grams of carbon emitted per year x 100)	60%



Appendix B: Notes given to Lab Instructors at Ohio State University

Overview

The Chadwick Arboretum has volunteers that have mapped out and measured the size and growth of all the trees on campus over several years. This lab takes that data set, has students measure the current size of some specific trees and then relate the growth of these trees to urban ecology, ecosystem services, and global climate change. The lab also introduces students to the use of citizen science data, since the original measurements were taken by volunteers. The tree measurements will take only about 30 minutes, but gets students outside and looking at the trees in a new light.

Some hints to make things run smoothly:

- There are two locations for surveying the trees in this lab, one outside the Biological Sciences Library, one next to the stadium. Maps should be distributed to the lab detailing the trees to be surveyed. Each tree is numbered within the two locations. You will also travel to see the small green roof on top of a bike rack on W 12th Ave in front of Bradley Hall.
- We will use a spreadsheet to do pre-formulated calculations in the lab. All trees in the spreadsheet for both locations must be surveyed in order for the equations on the excel spreadsheet to calculate. Note that at the Ohio Stadium location, only the maple trees (trees numbered 8-37) need to be assessed. What this means is that you should assign students tree numbers ahead of time for each location. Make sure they realize that it is imperative that they survey the assigned trees or the growth rate calculations will be off.
- The trees in the Biosciences location are all shingle oaks (*Quercus imbricaria*), a native Midwest species used by pioneers to make shingles for their homes. The trees at the Ohio Stadium location are Norway maples (*Acer platanoides*), a non-native plant known to be invasive in many parts of the Midwest. You may want to point this out.
- You will need to give students time to make hypotheses and answer a couple questions before you go out to measure trees
- You will need to make sure that students understand how to measure diameter at breast height (DBH). That is, that they need to measure 1.37 meters from the ground and measure around the tree in centimeters (or convert afterwards, if in inches). There are a couple of large sycamore (*Platanus occidendtalis*) trees along John Herrick Drive that could be good places to have students demonstrate measuring DBH. These two trees and the construction of John Herrick Drive led to the start of the campus tree inventory (more information available at: http://chadwickarboretum.osu.edu/research-and-education/campus-tree-mapping-0)
- If your lab is particularly small and it is taking too long to measure the trees or if there is inclement weather that prevents you from going outside for the lab, there are data from a previous year that can be found in the lab share.
- There are three sheets within the spreadsheet. The first is where you want to input the data. The second has all the things used to make the calculations and shows all the trees' individual growth rates (which will be needed for some of the questions). The last sheet (Carbon accumulation and Uptake) has the average growth rates and all the rest of the numbers needed for answering the questions.

Suggested Key for Lab Answers

Pre-Lab Key

1. What are some advantages of having urban trees, that is, trees present in urban environments? (1 pt.)

   Advantages include: reducing pollution, reducing erosion, conserving energy by providing shade in the summer, reducing noise pollution, increasing wildlife diversity, and many other things

2. Define the term ecosystem services. (1 pt.)

   Ecosystem services are benefits derived by humans of conserving nature / having intact ecosystems
   If humans are not mentioned: -0.5

Lab Key

<u>Part A</u>

1. Based on the above paragraph and the carbon cycle (shown below), why are plants, in particular, plant growth, important to consider when thinking about climate change? (*1 pt.*)

   Give full points for a logical answer that considers how growing plants will pull carbon dioxide out of the atmosphere to build macromolecules (e.g. sugars), reducing total greenhouse gases in the atmosphere.

Give only partial credit for an answer that doesn't specifically mention carbon in some way

2. Make several hypotheses about what factors you think may affect tree growth, based on your knowledge of plants. (Consider especially your knowledge of photosynthesis and the information in the introduction) (*1 pt*.)

Give full points for logical thoughts on what may affect tree growth. Some likely possible answers: carbon dioxide levels, pollution, light/competition with other plants, water availability, temperature, herbivory.

Make sure that they do give at least two hypotheses about things affecting tree growth (half credit for one hypothesis)

3. Based on what you think may affect plant growth, predict whether trees in urban environments would grow faster, slower, or at about the same rate as trees in forests. Explain your reasoning. (*1 pt.*)

Give full points for logically consistent prediction. E.g. Cities have higher carbon dioxide levels so trees in urban areas should have faster growth rates.

4. Diameter at breast height involves using a tape measure to measure around the tree at approximately chest height. Assuming everyone in the class and previous measurements had been taken at the exact chest height of the different people doing the measuring, what potential problem could the measurements have and how would that complicate calculating growth rate? (*0.5 pt.*)

Ideally, they should realize that people are different heights and that measuring at different heights will give different diameters, thus potentially throwing off the growth equations

5. What might be one way to correct this potential issue? (*0.5 pt.*)

Take all measurements at a standardized height

Record your measurements in the following table:

6. (*1.5 pts*.) Students should receive full points for taking measurements of all trees assigned to them

7. Your Lab Instructor will also take you past a green roof on campus. Observe the green roof. Based on your observations, what is a green roof? (*0.5 pts*)

Give full credit for a logical response – likely will say something about it being a roof specifically designed to have plants growing on top of it.

8. You collected data from two different locations, each with its own species of tree. Look at your lab section's data. Do there appear to be differences in the growth rate between the two species? Does this line up with what you would expect? Why or why not? (*1 pt.*)

There will likely be a lot of noise in the data, but one species will also likely have higher average growth rates. Give full credit for fully answering the question with a logically-consistent answer.

Half credit for only answering part of it / lack of logical consistency

Part B

1. The higher the latitude, the closer the location is to the poles. The lower, the latitude, the closer the location is to the equator. Do trees in tropical areas tend to grow faster or slower than trees in more temperate areas? Why do you think that is? (*1 pts.*)

Tropical species grow faster (0.5 pts)

Another 0.5 pt for a logical reason why tropical trees should grow faster – most likely answers include longer growing season, longer hours of sunlight for a greater portion of the year, higher temperature, greater annual rainfall, etc.

2. The latitude of Columbus, Ohio is approximately 40 (degrees North of the equator). Using the average growth rate of trees from your section, plot the estimated annual growth rate for Columbus on Figure 2 above. (*1 pt.*)

Full credit for accurately plotting the correct latitude and growth rate on the graph

Half credit for inaccurate plotting of latitude or growth rate

3. Do the urban trees that you sampled seem to have a higher growth rate, lower growth rate, or very similar growth rate to the expected growth rate for forest trees in Ohio? Does this align with your original prediction? If it does not align, hypothesize why not. (*1.5 pts.*)

Should have a much higher growth rate. If they did not originally think that would be the case, they should consider things like decreased competition with other trees, possible caretaking such as watering, fertilizing and removal of pests for trees in managed landscapes, and increased carbon dioxide in cities. If the data do not show this, there was likely some form of experimental error (e.g. measurements done incorrectly). Either way, full points for logical analysis.

Points should be split 0.5 pts for higher/lower/about the same and 1 pt for alignment w/ prediction and reasoning why/why not aligning with original prediction

Part C

1. The value calculated in the spreadsheet is based on the assumption that the average biomass accumulation rate in forested areas statewide is equal to the biomass accumulation rate your class measured for the trees on campus. Do you think this estimate is too high, too low, or about right? Why? (Consider your prediction from Question A3, and your answer to Question B3). (*1 pt.*)

Given that urban trees have a higher growth rate (or should have, barring measurement error) the estimate should be too high. Their answer here will depend on their answer to B3, however.

2. Ohio also has data on the amount of carbon emissions that we, as a state, produce. From the class spreadsheet, what percentage of Ohio's annual carbon emissions are offset by the estimated carbon uptake of Ohio's forested areas? Do you think that Ohio should be required to offset its emissions in some way to make that number closer to 100%? Why or why not? (*1.5 pt.*)

Will likely be 75% or higher. Give 0.5 pts for recording the offset based on their data. Give 0.5 pts for saying yes or no to whether Ohio should offset it emissions. Give the last 0.5 pt for their (logical) argument why/why not.

Part D. Study Questions Key

1. The data from previous years was collected by volunteers on their own time, some of whom are scientists, some of whom are not. The collection of data by amateur or nonprofessional scientists is referred to as citizen science. Data similarly collected has been used by scientists in some scientific studies. What do you see as an advantage of citizen science? What might be a disadvantage? (*1 pt.*)

Full credit for a logical and well thought-out argument for advantages and disadvantages. Possible answers: citizen science is advantageous as it gets citizens involved in science, increases scientific literacy, decreases the price of doing science. The disadvantages include the potential for citizens being less precise in measurements

Half credit for addressing only advantages or disadvantages, or illogical arguments

2. By forming a sink for CO_2 and therefore slowing the acceleration of global climate change, forests and urban trees perform an ecosystem service (benefits derived by humans from having functioning ecosystems). Some people have attempted to put

monetary values on ecosystem services to help inform lawmakers and other decision-makers. Discuss this - what do you see as advantages to putting monetary values on ecosystem services? Do you see any disadvantages to this practice? (*1 pt.*)

Full credit for a logical and well thought-out argument for advantages and disadvantages. Possible answers: allows policymakers to weigh ecological concerns against economic concerns with concrete numbers (advantage), but in doing so some would say that people devalue nature by putting a "price tag" on its value; does not take into account aesthetic value and possible emotional/mental health-related benefits

Half credit for addressing only advantages or disadvantages, or illogical arguments

3. Green roofs are roofs that have been specifically designed to have plants growing on top of them. Your Lab Instructor took you past a small green roof over a bicycle rack near the lab building. In addition to this green roof on OSU's campus, Howlett Hall also has a green roof. Green roofs are becoming increasingly popular, especially in Europe, where more than 10% of all German houses have green roofs and several cities have required that all new buildings with flat roofs be green roofs. This increasing popularity is because green roofs provide a number of advantages that traditional roofs do not. Besides storing carbon (like urban trees), what might be at least other two ecosystem services provided by green roofs? (*1 pt.*)

Full credit for logical answers including: providing heat/sound insulation for buildings, mitigating the effects of heat islands in cities (making cities less likely to be hot in comparison to the countryside), absorbing rainwater (reducing flooding during intense rainstorms), increasing oxygen in the air, potential space for plant food plants, habitat for wildlife, being aesthetically pleasing, etc

4. Besides planting more urban trees and green roofs, what other ways can you think of to increase carbon storage or decrease carbon being released into the atmosphere? (*1 pt.*)

Full credit for logical solutions – preserving forests, increasing power from sun/wind/water, increasing transportation via mass transport and bicycles, increasing efficiency of electronics/vehicles

5. Consider what you have learned about ecology in class so far. In what ways do you think urban ecosystems differ from more pristine ecosystems? In what ways do you think they may be similar? (*1 pt.*)

Full credit for a logical and well thought-out similarities and differences. Example differences: different selective pressures (e.g. more light, more sound, more heat, different toxins/pathogens). Similarities: organisms still interact with each other and their environment, there are still predator/prey relationships, symbiotic relationships, etc.

Half credit for addressing only similarities or differences, or illogical arguments

Appendix C: Sample Map for Student Use in the Field

Mission, Review Process & Disclaimer

The Association for Biology Laboratory Education (ABLE) was founded in 1979 to promote information exchange among university and college educators actively concerned with teaching biology in a laboratory setting. The focus of ABLE is to improve the undergraduate biology laboratory experience by promoting the development and dissemination of interesting, innovative, and reliable laboratory exercises. For more information about ABLE, please visit **http://www.ableweb.org/**.

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