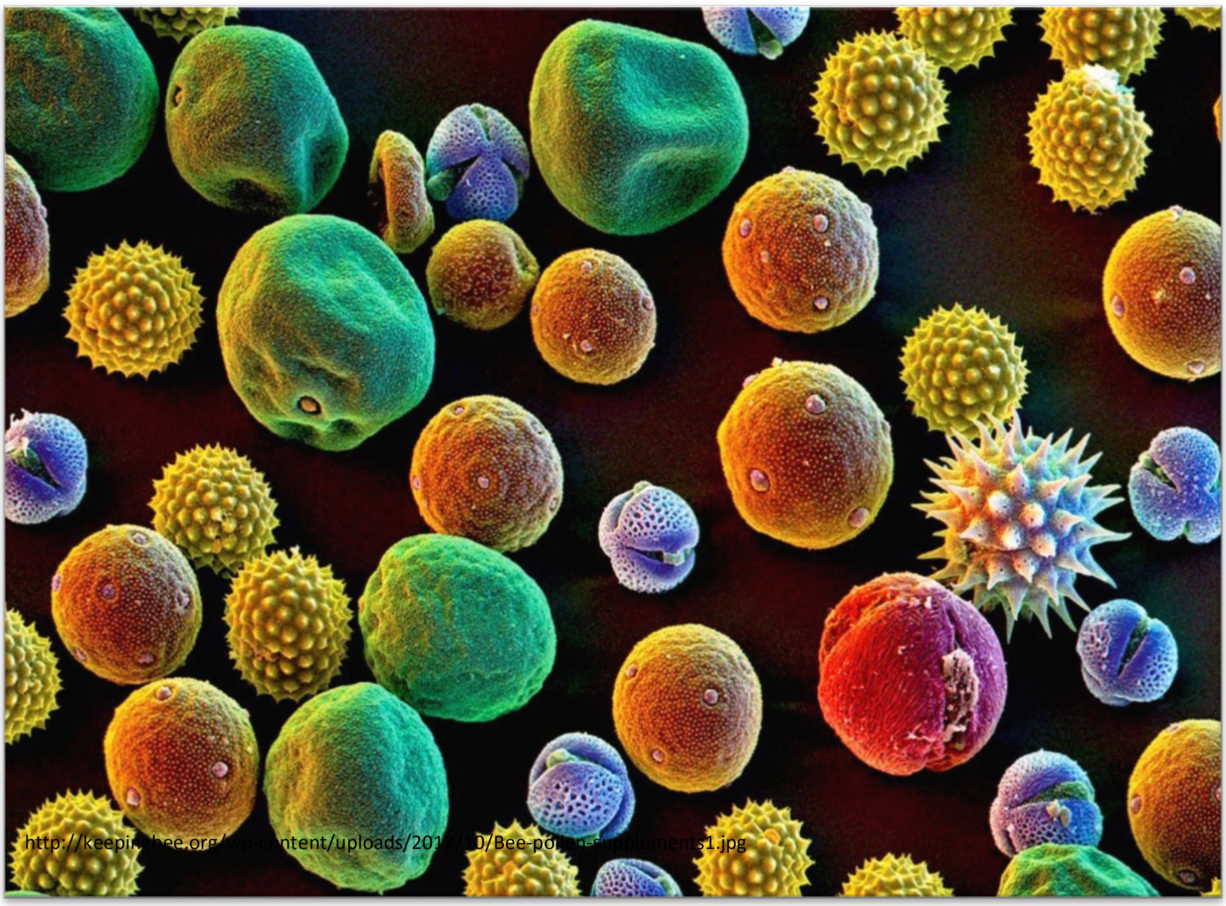
Looking Backward, Looking Forward

Exploring how proxy data provide evidence for past climatic events



http://keepingbee.org/wp-content/uploads/2012/10/Bee-pollen-supplements1.jpg

Maryland Loaner Lab
Teacher Facilitation Guide

TOWSON UNIVERSITY
Center for STEM Excellence

Looking Backward, Looking Forward was developed by the [Towson University Center for STEM Excellence] and [MADE CLEAR]. The activity was adapted from ["Global Climates Past, Present, and Future: Activities for Integrated Science Education."] *S. Henderson, S. Holman, and L. Mortensen (Eds.). EPA Report No. EPA/600/R-93/126, U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC. 25 - 38.*

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For a Microsoft Word version of this document, please email mdll@towson.edu.

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Overview: *Looking Backward, Looking Forward* Activity

The *Looking Backward, Looking Forward* activity engages middle and high school students in three-dimensional learning by challenging them to figure out what Earth's past climate was like through the use of proxy data. Students assume the role of paleoclimatologists (scientists that study past climate) to explore how fossilized pollen found in sediment cores can allow them to infer what the climate in an area was like thousands of years before present. Students actively engage in the scientific practices of analyzing and interpreting data, constructing explanations and engaging in argument from evidence to learn disciplinary core ideas from life and earth space science while making connections to the cross-cutting concept of patterns. Using colored beads to model actual pollen samples found in sediment cores, students collect, analyze, graph and interpret a complex data set. A central part of the activity is having students engage in argument from evidence by constructing, critiquing and revising scientific arguments using the claim-evidence-reasoning framework. Students conclude the activity by comparing past and current rates of climate change.

Learning Goals:

The goal of this lesson is two-fold. First, students will use evidence from a complex data set they collect to develop a scientific argument (a claim, supported by evidence and reasoning) of what Maryland's climate was like and how it has changed over the past 12,500 years. Second, it challenges students to consider how the rapid changes occurring in our current climate contrast to these earlier changes and why current changes in climate are of concern. These lessons are aligned with the Next Generation Science Standards as well as College and Career Ready Standards (see appendix A).

To achieve this overarching goal, students will:

- Use a model of a sediment core containing fossilized pollen to collect pollen proxy data
- Analyze and interpret data derived from an authentic dataset
- Construct and defend a scientific argument to explain how climate in a region has changed over 12,500 years
- Explore how the current rapid rate of climate change is different from past climate change and how today's climate change is affecting organisms and ecosystems

Grade Level and Time Required to Complete

This activity is designed to be used at either the middle or high school level. While the different versions are referred to by grade level, you can choose the version that is most appropriate for your students, regardless of grade level specified. If you would like a Word version of this file so you can adjust the student worksheets to better meet your needs, please email mdll@towson.edu. The following table details how the middle and high school versions differ.

Activity Component	Middle School	High School Version
Model of sediment core	This aspect does not differ between grade level versions.	
Data analysis and interpretation	- You can choose to have students analyze a subset of the 10 taxa. The	You can choose to have your students analyze a more complex data set by including up to 10 taxa
Plant Characteristics Table	This version includes columns that summarize the temperature and moisture requirements of each taxa. Blue Border on cards.	This version does **not** include separate columns that summarize temperature and moisture requirements of each taxa. Red Border on cards.
Constructing a scientific argument	The level of sophistication of the scientific argument will be lower (e.g. fewer pieces of evidence included and less complex reasoning).	The level of sophistication of the scientific argument will be high (e.g. more pieces of evidence included and more complex reasoning).
Rate of climate change	Students will read a short paragraph and answer reflection questions about how the current rate and cause of climate change is differs from past climate change.	Students will be challenged to interpret and analyze data presented in a graph that depict rates of climate change over the past ~22,000 years. Students will answer reflection questions about the graph.
Effect of climate change on ecosystems	This idea is addressed briefly in the reading on rate of climate change	Students watch a short video about effects of climate change on bee pollination and answer reflection questions.

<u>Time Needed</u>: Note that actual time needed may vary depending the on the needs of your students.

Engage	30 minutes
Explore	30 - 40 minutes
Explain	45 – 60 minutes
Elaborate	15 -45 minutes
Evaluate	Throughout the lesson

Materials and Supplies

Below is a table that lists all the materials and supplies needed for this activity. Please note that some of the items (in red) must be supplied by the teacher. The rest are supplied by the Maryland Loaner Lab.

Item	Amount	Supplied by:	Comments	Return Instructions
Binder	1	MDLL	Contains DVD w/videos used in lesson.	Return
Pollen Sample Bags	1 bag	MDLL	Contains 8 Pollen Sample bags: ▪ (2) ~12,500 ybp ▪ (2) ~10,000 ybp ▪ (2) ~3,000 ybp, ▪ (2) ~340 ybp	Return any **unused** bags. Keep, or dispose of any used bags.
White boards/dry erase markers and erasers	1 box, containing (8) of each item	MDLL	1 each/sorting group: ▪ White board ▪ Eraser ▪ Pen	Wipe boards clean and return.
Pie Tins	8	MDLL	1/sorting group; students can dump soil and beads into these trays to facilitate sorting.	Rinse, dry and return.
Bead collection Tray	8	MDLL	1/sorting group	Rinse, dry and return
Plant Characteristics Cards	- (8) Middle School Sets (blue outline) - (8) High school Sets (red outline)	MDLL	1/small group	Return
Jigsaw Information Cards	32	MDLL	4 topics included • (8) Pollen • (8) Sediment • (8) Proxy Data • (8) Plant Communities	Return
CER Rubrics	16	MDLL	1/every 2 students	Return
Bead Color Key	8	MDLL	1/sorting group to help students accurately assign colors.	Return

Soil and measuring cup	1	MDLL	Add ¾ of a cup to each sample bags containing beads.	Return measuring cup and EMPTY bag. Do not return soil.
Temperature change over past 22,000 years Graph Summary Reading - Advanced - Standard	(32) advanced (32) standard	MDLL	For high school version, given to students after they have worked to interpret graph on their own	Return. Wipe clean if students have made any notes using dry erase markers.
Safety goggles/gloves	1/student	Teacher		Teacher provided, do not return.

Teacher background information for the *Looking Backward, Looking Forward* Activity

This activity expands a student's understanding of climate and climate change and explores how scientists are able to infer explanations. The rapidly changing climate we are observing now is affecting the world today and will affect the world in the future. Understanding how scientists study climate, both past and future, is an important educational goal if we want the next generation to be able to make informed decisions about policies that are being proposed to minimize the amount of, and deal with the effects of, global climate change.

An important distinction to make when discussing climate change is the difference between weather and climate. While they are related, they are not the same. Weather is what we experience on a short-term basis (daily, weekly, or monthly). Climate, on the other hand, encompasses a much longer timeframe and refers to the weather conditions, temperature, humidity, precipitation, etc., over a longer period of time, 30 years at a minimum. An easy way to think about it is "*Climate is what you expect, weather is what you get*" or "*Climate determines what is in your clothes closet but weather determines what you wear on any particular day.*" A statement such as 'Climate change and global warming can't be real because this week is cold.' comes from someone who is confusing the terms 'weather' and 'climate'. Weather is a day-to-day phenomenon whereas climate reflects long term averages.

Climate scientists study current climates and past climates. Over the history of Earth, our climate has changed. Scientists can determine how the climate in any one location changed (got warmer or cooler or wetter or dryer) and how rapidly (or slowly) that change occurred. Studying past changes in long-term climate patterns allows scientists to understand what has happened in the past, and develop models to predict what could happen in the future. There are various ways scientists study climate.

Scientists currently use various instruments for studying climate and there are currently thousands of sites around the world where meteorological (i.e., weather) data are collected. But data of the sort needed to study earlier climate didn't exist in those times; accurate data collection didn't begin until the mid-1800's. For information on earlier climates, scientists rely on what is called 'proxy data'.

Climate proxy data are preserved physical characteristics of an environment that scientists can use to infer information about past climate.

Examples of proxy data sources used to infer information about previous climates include ice cores, sediment cores, coral reefs and tree rings. Each of these sources of data contains information that allows scientists to infer specific information about past climatic conditions because these materials contain evidence ('clues') of past climate. One place scientists often look for rich and relevant climate information is in proxy data that reflect past plant communities. Plant communities are sensitive to climatic conditions and different plant communities exist under different climatic conditions; northern boreal forests are quite distinct in terms of species composition from tropical rain forests or savannahs.

There are different sorts of proxy data that scientists use to understand changes in plant communities. Some types of pollen and some types of seeds are very resistant to decay and can be found, intact, in sediments from thousands of years ago. Not all pollen and seed types are preserved, but enough usually are to give us a good measure of what plant community existed around the collection site at various times in the past. Palynologists (scientists who study pollen) study preserved plant pollen to infer past plant communities. By observing different pollen types, we can infer past plant community make-up. Scientists use different techniques to determine how long ago the pollen was deposited and therefore the 'time' (in 'years before present') at which the different pollen samples were deposited in the sediment. In this activity, we will explore palynology, the study of plant pollen, and how it can help scientists understand what the world's climate was like hundreds, or thousands, of years ago.

Pollen is produced by the male reproductive structures of plants and is produced in copious amounts by wind pollinated plants. Many types of pollen grains are highly resistant to decomposition and therefore very well preserved in sediments. In addition, pollen grains have a distinctive 'signature' appearance indicating what type of plant it is from—different types of plants have pollen that look different. While pollen grains are very tiny (typically between 10 – 100 µm) scientists can use microscopes to examine each distinctive pollen grain to identify the types of plant that produced them.

A sediment core is a sample of soil that is often taken from the bottom of a lake or other wet area. Sediment cores can be as long (deep) as 20 meters, and technologies including carbon dating and isotope analysis of the sediment allows scientists to determine dates for the relative layers of the sediment cores; layers at the bottom are older than layers towards the top. When analyzing sediment cores for pollen, scientists will slice the core into thin samples and apply a chemical treatment to isolate the pollen grains from each slice and then use a microscope to identify the types of pollen present in each sample. Abundance of each type of pollen grain can then be compared among the slices taken deeper or shallower (depth represents time), allowing scientists to determine the types of plants present at different times in the past. This allows scientists to reconstruct past plant communities. Because different plant species have different environmental requirements, the pollen data from the sediment cores provide evidence about the climatic conditions at different times in Earth's history at the location where the core was taken.

The patterns in the sediment allow scientists to describe the change in climate as reflected in the plant communities and the time frame over which these major changes occurred. Scientists infer what the climate was like based on the habitat requirements of the plants represented. At any one time, plant communities contain those species that do very well under the current conditions and some plants that can get by but which are living closer to their distribution limit. If a climate changes, which plants are best adapted to the environment also changes and looking back, long after this occurred, we see a change in the community. Those that were once at their edge of their distribution can either become dominant or totally disappear and those that were dominant are no longer abundant. Because of the climate requirements of specific types of plant communities, the fossil pollen reflects both plant community and climate. Since each slice is also dated, it is also clear when these communities existed and how long a period of time was associated with a forest-type transition, i.e., how slowly or rapidly the climate changed.

By understanding the rate at which climate has changed in the past, the importance of the very rapid rate of the current changes we are experiencing becomes clear. In the past, thousands of years might have passed over which a grassland replaced a forest as an area was becoming dryer. The changes in vegetation came about as the biological limits for one type of community were replaced by those of another. Changes in the climate were accompanied by such things as the ability of pollinators to survive, the frequency of natural disasters such as fires or floods, necessity of seeds to withstand drying, or freezing, etc. Different plants use different sorts of environmental clues to 'trigger' their time to produce leaves or flowers or seeds and climate changes can make these clues unreliable for particular plants in particular locations leading to loss of that plant species locally. In the past, one community could replace another because as one was gradually dying out, the second was gradually taking over.

The global climate depends on the Earth's energy balance (how much energy is received at the surface of the Earth and retained, as heat, by the Earth or reflected back into space), and the level of greenhouse gases in the atmosphere are a critical part of that balance. Currently the levels of greenhouse gases are increasing rapidly leading to increased warming of the earth and global climate change. Humans are releasing unprecedented amounts of greenhouse gases into our environment, especially Carbon Dioxide released by the burning of fossil fuels. This change in energy balance is causing global warming; this change in our climate will affect not only humans (through flooding, increased fire and drought, more severe and frequent storms, etc.) but also plants and other animals.

As the climate changes, local ecosystems will no longer be locally adapted, and plants that once thrived in an area may no longer be able to tolerate the new local climate. Animals who rely on predictable food supplies may find that their food sources are no longer available. Plants that depend on animals for pollination or fruit/seed dispersal might disappear if their 'partner' animals can no longer survive. Ecosystems may be affected by invasive species that thrive in these new climates.

We currently depend on plants in many ways and changes in climate, by changing what plants can grow in different regions will also impact our lives. For example, we eat plants and plant products directly (wheat, rice, corn, fruits and vegetables) and the animals we eat depend on the plants we grow to feed them; changes in temperature and rainfall patterns will impact food production and food availability.

Scientists examine past changes in ecosystems associated with changes in climate to understand and predict future consequences of changing climate for our world and in this activity students do something similar. In this activity, students will examine mock sediment core samples (modeled after an authentic data set from the mid-Atlantic region) and quantify different types of pollen present in the different strata, representing different time periods. They will learn about the types of plants that produced the pollen and make inferences about past climatic conditions in the mid-Atlantic region and use this information to infer past changes in climate. Students will come away from this activity understanding how scientists use indirect evidence to infer information about the Earth's history. Students will also compare the time frame and the magnitude of the biological changes they studied in their sample cores to the rates of change the world is currently experiencing.

Common Climate Change Misconceptions related to *Looking Backward, Looking Forward*

There are various misconceptions related to climate change. This webpage addresses many of them.

http://www.skepticalscience.com/climate-change-little-ice-age-medieval-warm-period-intermediate.htm

Preparation Guide: *Looking Backward, Looking Forward*

Each student should receive their own "Student Handout." A template copy of the student handout is provided (Appendix M for middle school and appendix N for high school) and teachers must make their own copies. You might also consider making copies of the Glossary (Appendix B) for the students.

Engage

- PowerPoint (available for download at www.towson.edu/cse on the Maryland Loaner Lab page.
- 1 student packet/student
- Plan groupings for expert and sharing groups (see facilitation guide for details on groups numbers and size)

a) Be prepared to show brief video on earth's changing climate (https://youtu.be/gEFFeAA3MN4).

- Jigsaw Information Cards

Explore

Pollen Count Activity

- PowerPoint
- 1 student packet/student
- Plan groups (see facilitation guide below for details on group numbers and size)
- Prepare the sediment bags by adding ~3/4 cup of soil into each sample bag of beads.
- Each group should receive:
    - (1) bag of sediment with beads
    - (1) sorting tray
    - (1) bead collector tray
    - (1) whiteboard/group
- (1) bead color key per sorting group to be used if students have questions about what color their beads are (e.g. is a bead considered pink or orange).
- Note that we send a maximum of two class sets of beads. This means if you requested for more than two classes, you'll have to have students pour their beads and dirt back into the sample bags for the next class. After the last class sorts the samples, please return the sorted beads to the appropriate containers and dispose of the soil.

Explain

Constructing a Scientific Argument Activity

- PowerPoint
- 1 student packet/student
- 1 laminated copy of CER rubric/ 2 students
- 8 set of Plant Characteristics Cards (1/small group). High school version is bordered in Red, middle school version has blue border.

Elaborate

- PowerPoint
- 1 student packet/student
- High School Only:
    - Climate Change: Past and Present reading (1/student), 32 laminated copies provided (advanced or standard levels, Appendix H and I)
    - Prepare to show video on effects on climate change on pollinators (http://www.smithsonianmag.com/smart-news/how-climate-change-messing-bees-ability-pollinate-180956523/?no-ist) available online or on DVD provided.

Evaluate

- Student packets can be used to formatively and summatively assess student learning.

Facilitation Guide: *Looking Backward, Looking Forward*

The following suggests one way to facilitate this activity. If your students already have a strong background on certain concepts, you may choose to skip some of the suggested discussion topics. If much of this information is new to the students, you may choose to spend more time on these discussion topics, and to supplement with other classroom resources. The PowerPoint provided follows the suggested facilitation plan below, but may be modified to fit your students' needs.

Engage

Observation and Inference

a) Show the Far Side cartoon to the students. Ask students to write down three observations of the cartoon. Remind them that observations are what you can detect with your five senses (sight, taste, touch, smell, and hearing).
b) Have students share their observations on the board and collect up to ten different observations on the board.
c) Show and discuss the slide that gives the definitions and examples of observations and inferences.
d) Ask students to write on their papers what each of the examples they came up with were (either observation or inference).
e) Ask students how they think scientists use observation and inference. Typical responses might include 'to learn new things', 'to understand their data', and 'to explain what they see'. Discuss how scientists use observation and inference to understand how the world works and make sense of scientific phenomena.
f) Tell students that they will now using their own skills of observation and inference to answer the scientific question: What has the climate been like in the Anacostia watershed over the past 12,500 years?

Warming Earth Video

b) Show video of the warming Earth (https://youtu.be/gEFFeAA3MN4). Available online or on DVD provided.
c) Have students share their ideas about what the video is showing. Students should eventually conclude that the video is showing the Earth is warming. You can remind students about the difference between weather (short-term) and climate (30+ year weather patterns). Climate is what you expect, weather is what you get!
d) Show climate Headlines PowerPoint slide and discuss how the previous video shows that earth has been warming since 1884. Mention that sounds like a long time, but in terms of Earth's history, it really is a short period of time.
e) Show the next slide and elicit student responses to the question "How do scientists know what the earth was like in the past if they weren't around to see it or if there are no records?" During the discussion, address the idea that scientists make inferences based on observations. In the case of Earth's changing climate, one way to do this is through proxy data. Proxy data for climate are

preserved physical characteristics from an environment that serve as indirect ways of learning about something you cannot directly measure.

f) Have students do a think-pair-share to come up with ideas or examples of proxy data for climate change. After students have had time to discuss with their partners, select students to share their ideas. Typical responses might include 'fossils', 'digging the earth" and 'journals'. After a brief whole class sharing of ideas, introduce them to the various type of proxy data scientists use to learn about climate (tree rings, ice cores, coral and pollen). Tell the students they will be learning more about one of the ways in which scientists can use fossils as indirect data to learn about Earth's past climates.
g) Ask students "Why are data important in science?" Students should understand that data are used by scientists to provide evidence for their explanations and arguments. This question is an important nature of science concept (Appendix A). Explicitly addressing and giving students opportunities to talk about nature of science ideas allows them understand what science is and how it works.

Jigsaw activity with background information

To provide the students with background knowledge and facilitate understanding of how pollen can be used as proxy data, we set the stage for the lesson through a jigsaw activity. A jigsaw activity is designed to allow a class, as whole, to learn about a relatively large amount of material by forming sub-groups who each become 'experts' on distinct pieces of the content being taught. Sharing groups are then formed, which consist of at least one 'expert' from each content area. In these sharing groups, experts share their 'piece of the puzzle' (i.e. the content they learned in their expert group). As a result, all members of the sharing group now understand all the pieces of puzzle.

<u>Expert Groups</u>

a) Divide your students into four expert groups to explore the topics
    1) Pollen
    2) Sediment Cores
    3) Plant Communities and Climate
    4) Proxy Data

   Students should be divided equally among the four topics; we have found that making small sub-groups (3-4 students/group) facilitates all students actively participating in the discussions within these expert groups.
b) Have each student in each expert group read the information card (Appendix C, laminated copies provided). Remember that all students within an expert group will be reading the same card and you will need a minimum of four groups. Have the students discuss within the expert groups the main ideas and address the discussion questions. Encourage the students to take notes in the appropriate section of the 'placemat' graphic organizer on page S-2 of their student handout, as they will need to be ready to share what they learned in their expert groups with the sharing group.

Sharing Groups

a) Once students have explored their 'piece of the puzzle' in their expert groups, direct students to their assigned sharing groups. Sharing groups must include at least four students, as they need to have all four topics represented. Instruct each 'expert' in the sharing group to shares what they have learned about their assigned topic, encouraging group members to take notes in the appropriate areas of the 'placement' graphic organizer.
b) Once all experts have shared their information, the sharing group discusses the question "*How can we infer past climates from the plants that were growing in an area?"* After they discuss, they write their group's answer in the center space of the placemat. If one group is missing an 'expert' you can combine groups, or ask an expert to share with a second group. Their answer should draw on the information from each of the expert group topics.
c) Conclude this part of the activity by having each group share their answers with the whole class, using this opportunity to formatively assess if the students understand the idea of using proxy pollen data to infer past climate conditions or if they need more time exploring the background information.

Explore: Collecting Data

Driving Question and Field Methods Background

a) Introduce students to the driving question of the next activity: **What was the climate like in the Anacostia Watershed over the 12,500 years?**
b) Use the PowerPoint to familiarize students with the location of sampling site, Indian Creek, a tributary of the Anacostia River in Prince George's County, Maryland. Ask students to describe what the climate is like now in that area
c) Discuss with the students how the data that this activity is based were collected. A sediment sample was collected from the Indian Creek River. The sample was brought back to the lab, where thin slices (which yield information from different time periods) were cut from it and chemically treated to enable the scientists to filter out the pollen grains. Scientists then used a microscope to identify a subset of pollen grains from the slices.
d) Discuss how the pollen grains in each slice represent a distinct period of time due to the way that sediment is deposited. Slices from the part of the core that was deepest are the older and slices from the top of the sediment core represent more recent time periods.
e) Explain to the students that they will be using beads as a model to represent the actual data set that was collected from Indian Creek. Each bead represents a different type of pollen grain.

Pollen Data Collection Activity

a) Students should now be arranged small groups. You will need a minimum of four groups and no more than eight. We suggest groups of 3-4. Remind the students they will be collecting data to answer the question: **What was the climate like in the Anacostia watershed over the last 12,500 years?**

b) Each small group will be examining a sample from a sediment core that represents a ‘slice’ in time expressed as ‘ybp’, years before present. If students are not familiar with the term ‘ybp’ you may have to provide some examples so they understand what it means. Their birth date and their age can easily be turned into ybp to help them understand. Each sediment core sample contains ‘pollen grains’ (beads are used as a model for actual pollen grains) from different taxa from a specific depth in a sediment core which reflect distinct time periods. The four time periods that your students will be examining are ~340 ybp, ~3,000 ybp, ~10,000 ybp and ~12,500 ybp. You have been provided with two samples from each time period to accommodate up to eight groups of four. If you have fewer than 32 students, you do not need to analyze all 8 samples, but do make sure to at least analyze one from each time period. If you have more than 32 students you can increase your group size.

c) Instruct each student group to:
   1) Create a data table on their white board to record information on the number and type of pollen grains in their sample.
   2) Find, count and identify the pollen grains in their samples and record information on white board. Students can use a set of *Plant Characteristics Cards* (middle and high school versions provided) or the *Plant Characteristics* table (Appendix D for middle school and Appendix E for high school) in their student packet to identify taxon of plant based on bead color. The *Plant characteristics Cards* and *Plant Characteristics Tables* both contain the same information.
   3) Have them calculate the percentage of each type of pollen in their sample. Challenge the students to figure out how to do this on their own and try not to simply give them the following formula directly. Percentage of each pollen species can be calculated by dividing the number of each pollen type (each color) by the total number of pollen grains counted in their sample. In general, all bags should contain 100 beads, but due to counting error they may differ slightly. Slight differences in number of beads will not affect students’ ability to look for patterns and trends in pollen numbers.
   4) Once they collected their data and determined the percentages, have them fill out the class data table (provided in the PowerPoint or you can display on a whiteboard where all students can access it). Note that each time period should contain the same number of beads, but error in counting the pollen beads (by MDLL staff or your students) might lead to some variation. If more than one group counts the same time period and gets different results suggest they take an average.

General tips for data collection:

- We have provided a bead color key that shows what color each bead is. This will prevent students from misidentifying the beads (e.g. calling a bead purple versus pink).
- If you will be doing this activity with another class, have your students carefully put the soil and the beads back into their sample bags.

- If you will not be using the sample bags again, please instruct the student to place sorted beads into the appropriately labeled containers that you will return with the rest of the kit. The students may dispose of the soil.

Graphing the data

At this point you have an opportunity to allow your students to analyze data from all 10 taxa, or a smaller subset. This can be a useful tool for differentiating this activity. In Appendix F, we have provided suggested subsets of data (4, 5, 8 taxa) you may choose to use. These subsets can reduce the complexity of the analysis, while still showing consistent patterns and trends. If students are using a subset of data, we suggest having them add up the percentages of all the remaining taxa and graph them in a category called 'other'.

Display the whole class data table. Have students copy it onto their own student handout so they can refer to it during data analysis. Instruct each student to create a graph for each time period. Your students may struggle to create their own graphs. This is to be expected. Encourage students to work together and support each other as they create their graphs. The following graphing tips are provided to make comparisons among time periods easier:

- Tell students to arrange the taxa along the x-axis in alphabetical order
- Tell students to include names of all taxa on their x-axis even if they did not count any pollen from that taxa
- Tell the students to use a common scale and same range (0% – 50%) on the y-axis to facilitate comparisons later among samples

While we strongly encourage you to allow your students an opportunity to do as much of the graphing themselves, you may choose to provide more structure (such as pre-labeled axes, legends, etc.) to scaffold the process for some students.

Explain: Analyzing and interpreting the data and constructing a scientific argument

Looking for Patterns

Once the data have been graphed begin a discussion with the students about what they think they will need to do next. They should conclude that they need to look for patterns and trends in their data in order to answer the driving question: *What was the climate in the Anacostia Watershed over the last 12,500 years?*

Have students begin to examine the patterns they see in their data. You can prompt the students by asking "*Did any taxon increase in abundance over time?*" "*Did any decrease?*" "*Do some taxa appear and then disappear over time?*" What type of climate does each taxon do best in? You can chose to allow the students to work individually or in small groups to look for patterns, or scaffold the process by examining one or two taxa in a whole class discussion and then continuing with individual or small group work.

During this process you will also want to draw your students' attention to the *Plant Characteristics Cards* (you are provided with 8 sets) or *the Plant Characteristics Table* in their student packet (and in Appendix D and E). Each contain the same information and describe the preferred climate of each species. Note that the cards for middle school (blue border) have a section that highlights the preferred temperature and moisture requirements of each taxa; the cards for high school (red border) also has this information, but it is in embedded in the written description, thereby making it a bit more challenging for students to determine. The information on both sets of cards will allow the students to infer what the climate was like, based on the proxy data (pollen grains represented by plastic beads) they collected and identified. You can remind them of the information they learned during the jigsaw activity about how plant communities can inform us about an area's climate. The students should soon begin to find common patterns, such as the abundance of birch, fir and spruce (taxa that grow in cold and moist climate) all decreasing over the past 12,500 years.

Constructing a Scientific Argument using the Claim-Evidence-Reasoning Framework

This activity uses the claim-evidence-reasoning (CER) framework to help students construct their arguments. If you and/or your students are not familiar with the Claim-Evidence-Reasoning Framework, you will need to introduce it (see Appendix G for more information on the CER Framework and a CER assessment rubric).

Students can begin by making a claim that answers the driving question based on their review of their data, and then provide their evidence and reasoning to support their claim. Or they may begin by listing the evidence and reasoning, and conclude by filling in their claim. Note that students commonly conflate evidence and reasoning so we encourage you to have students share examples as they are constructing their scientific arguments to evaluate and discuss as a class what might be appropriate evidence and reasoning.

Sharing the CER rubric (provided as laminated sheets for students) with your students at this point will help them understand what to include in their scientific argument. You can choose to have students work independently on their drafts of scientific arguments, or encourage them to work in pairs or small groups as they construct their arguments.

Scientific Argument Peer Review

Once your students have a draft of their scientific argument, have them share their draft with a classmate (if they have been working in groups, it is preferably to have them pick a peer review partner they have not been working with) and have them give and receive feedback using a CER rubric. Providing and receiving critiques on scientific arguments is an important part of engaging in argument from evidence and it is very likely your students will find this challenging. You can scaffold this process by providing guidance on how to use the provide rubric to assess the different aspects of the scientific argument they are critiquing. For example, you could have a class discussion about what is appropriate and sufficient evidence, how they might assess accuracy of interpretation and what relevant reasoning might be. Appendix J provides sample examples of evidence and reasoning.

Have students then incorporate peer review feedback into their final scientific explanation about what the climate was like in the region over the past 12,500 years. This scientific explanation can be used to evaluate student understanding of how scientists use proxy data to infer past climates. Appendix K provides example scientific explanations.

At the end of this part of the activity, ask students to draw on their experiences with this activity and consider the following questions to address the nature of science learning outcomes (see Appendix A)

> *"An important aspect of science is identifying and explaining patterns in nature. Explain why this is important for scientists to do, using an example from your climate investigation."*
> Answer: Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation. By studying these patterns, scientists can understand how the natural world works. By understanding past patterns of climate change, scientists are able to develop a better understanding of current causes of climate change.
> *"Does all science require controlled experiments? Provide specific examples from this activity to support your answer."*
> Answer: Not all scientific knowledge comes from controlled experiments. For example, in astronomy scientists cannot manipulate planets or star but they are still able to make observations and inferences and learn about how the universe works. In the work we have been doing with pollen and climate, we did not create a controlled experiment. Rather, we made observations and inferences of data from different time periods to infer what past climates were like.

Elaborate: Past versus Present Changes in Earth's Climate

Finally, it is important to be aware that after spending time exploring how climates have changed in the past, students may leave this activity with the misconception that there is no need to be concerned about current climate change because climates have changed in the past. While Earth's climate has always been changing, the changes we see in our current climate are occurring at a very rapid rate. Scientists' understanding of past climatic variation, made possible by the use of indirect data from pollen and other proxy data sources such as ice cores, tree rings and coral reefs provide a foundation of knowledge that helps them understand how today's climate change differs from climate change in the past. Today's extremely rapid rate of climate change is different than in the past because it is being caused by human's releasing CO_2 into the atmosphere. You can read more about the myth that we do not need to be concerned about climate change because it has happened before by visiting the Skeptical Science website www.skepticalscience.com.

In this final part of the activity, students explore why current rates of climate change are occurring and why a rapidly changing climate is of concern. This part of the lesson is critical as it provides an opportunity to address the pervasive misconception that because climate has changed in the past, we do not need to be concerned about current climate changes in climate. Note that we have suggested two different ways to engage students in exploring the idea of rates of climate change, one for middle school and one for high school. You may choose whichever version best fits your students' needs, regardless of grade level. There is also a useful video on the Skeptical Science website (www.skepticalscience.com) you may choose to show your students about how we know the current changes in Earth's temperature are due to human's use of fossil fuels and not due to other natural events that have caused temperatures to change in the past.

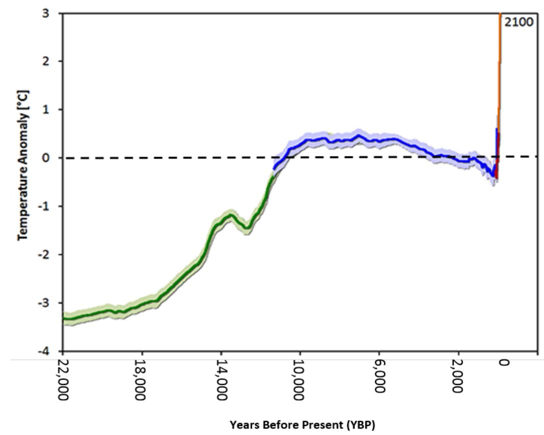
Middle School:

a. Have students read the passage "Climate Change Past and Present" on page S-7 of their student handouts.
b. Encourage students to discuss what they have read in small groups and answers the discussion questions that following the reading.

After students have read the passage and have had time to discuss the ideas with each other ask the students how they would respond if they heard someone say "*I heard that the climate has changed before and this current climate change we are talking about is just like that. So we don't have to be worried. It's the same thing."* There is a space in their student handouts for them to write their own answer. Students should come to the conclusion that the climate has always been changing but the changes we are seeing in recent times are much faster than we have seen in the past. We also know that the increased release of carbon dioxide gas into the atmosphere caused by human's use of fossil fuels is what is causing current climate change. We should be concerned because the current rapid rate of climate change is affecting weather patterns severity of weather events and the type of food that farmers produce. These are harmful to humans.

High School

Divide students into small groups and ask them to interpret the graph of temperature anomaly versus time (ybp), pictured to the right and in student handouts in *Climate Change: Past and Present* section. They may struggle at this point, but encourage them to try to make sense of the information presented. Tell them to start a list of questions they have about the graph. For example, they may wonder what temperature anomaly means, what each of the colored lines means, etc. Reassure them that it is okay if they don't fully understand the graphic at this point. A full explanation of the graph is presented in Appendix H (advanced level) and Appendix I (standard level). You, the teacher, may want to read this prior to class so you have good understanding of what the graph means and to help you to answer some of the questions the students may have about the graph. A copy of Appendix H or I will be shared with the students *after* they have worked on interpreting the graph for themselves (see below).



This figure, often referred to as the 'wheelchair' because of its shape, was created by Jos Hagelaars. The colors on the graph represent the sources of the data, with the orange line representing predicted increases in temperature. Modified from image accessed at https://ourchangingclimate.wordpress.com/2013/03/19/the-two-epochs-of-marcott/.

After students have had a chance to examine and begin interpreting the graph, begin a whole-class discussion about what students think the graphic is showing.

Once you have solicited a number of ideas, ask the students what questions they have that will help them interpret the graph. Remember, at this point you're not meant to explain the graph to your students, only answer some of their questions to help them interpret the graph.

Give students more time in their groups to interpret the graph after having their questions answered. Once they have had time to interpret and analyze on their own, pass out the narrative in Appendix H (advanced reading) or Appendix I (standard reading) and have students answer the following questions.

a. Describe the rate of change in temperature over the past ~22,000 years and compare it to the rate of change in the 200 years since the industrial revolution.
b. Why has the Earth's temperature increased so dramatically in the last 200 years?
c. Given that the Earth's climate has always been changing (consider the data you analyzed about the last 12,500 years), why is there so much concern about current climate change?

Finally, your students will consider how changing climate can affect different species differently. Have students view this 5 minutes video on effects of climate change on bee pollination:

http://www.smithsonianmag.com/smart-news/how-climate-change-messing-bees-ability-pollinate-180956523/?no-ist. Have students answer the Student Questions about this video on their handout.

a. What are the reasons for bees declining?
b. What is phenology? Provide a specific example of phenology.
c. How are plant phenology, pollination and climate change related?
d. What experiment are the researchers in this video conducting?
e. What might happen to our native plants and our agriculture plants if the climate continues to change at its current rapid pace?

Evaluate

Evaluation opportunities are provided throughout the activity. Opportunities for formative assessment include student responses during small and large group discussions and written responses on student handouts. The peer review session is an excellent opportunity for students provide formative assessment to their peers. You can use the final student arguments to summatively assess student learning. Answers to the questions asked on the student handouts can be found in Appendix K.

Appendix A: NGSS Connections-

Middle School NGSS

www.nextgenscience.org

Performance Expectations: Students' ability to complete the following performance expectations will be supported by participation in this activity.

MS-ESS2-2: Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales

MS-ESS3-5: Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.

MS-LS2-4: Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations

MS-LS2-5: Evaluate competing design solutions for maintaining biodiversity and ecosystem services.

Dimension	**Name or *NGSS* code/citation**	**Matching student task or question taken directly from the activity**
Science and Engineering Practice	Analyzing and Interpreting Data • Analyze and interpret data to provide evidence for phenomena.	Students will analyze and interpret patterns of pollen frequency to make a claim, supported by evidence and reasoning, about what a region's past climate was like. Students will compare patterns of fossilized pollen from different time periods (up to 12,500 ybp), noting similarities and differences in claims about inferred past climates.
	Constructing Explanations • Construct an explanation that includes qualitative or quantitative relationships between variables that predicts and/or describes phenomena. • Construct a scientific explanation based on valid and reliable evidence obtained from sources (including students' own experiments) and the assumption that	Students will construct a scientific explanation about how the climate has changed over the past 12,500 years. Their explanation will include a claim, evidence to support their claim and reasoning that connects the evidence to the claim.

	theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. • Apply scientific reasoning to show why the data or evidence is adequate of the explanation or conclusion.	
	Engaging in Argument from Evidence • -Respectfully provide and receive critiques about one's explanations, procedures, models, and questions by citing relevant evidence and posing and responding to questions that elicit pertinent elaboration and detail. • Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon.	Students will critique their peer's scientific arguments on Earth's past climates. Students will present oral arguments to their peers to support their claims and will challenge their peer's claims that lack adequate evidence and/or appropriate reasoning during the peer review process.
	Obtaining, Evaluating, and Communicating Information - Compare, integrate and evaluate scientific and/or technical information presented in different formats (e.g., visually, quantitatively) as well as in order to address a scientific question.	Students will use scientific ideas and reasoning presented in the "Plant Taxa Characteristics Tables" to analyze and interpret the pollen frequency data they have collected in order to construct scientific arguments.
Disciplinary Core Ideas	ESS2.A: Earth's Materials and Systems • The energy that flows and matter that cycles produce chemical and physical changes in Earth's materials and living organisms. The planet's systems interact over scales that range from microscopic to global in size, and they operate over fractions of a second to billions of years. These interactions have shaped Earth's history and will determine its future.	Students will explore fluctuating climatic conditions as they answer the question "*What was the climate like in the Anacostia watershed in the past 12,500 years?*" As a result, they will understand that scientists are able to learn about climatic conditions from thousands of years ago by utilizing fossil records.

	ESS3.C: Human Impacts on Earth Systems • Typically as human populations increase, so do the negative impacts on Earth, unless the activities and technologies are engineered otherwise.	Students will explore how the rapid rate of climate change due to human activity might affect biomes and ecosystems.
	ESS3.D: Global Climate Change • Global climate models are often used to understand the process of climate change because these changes are complex and can occur slowly over Earth's history. Though the magnitudes of humans' impacts are greater than they have ever been, so too are human's abilities to model, predict, and mange current and future impacts.	In the extension part of the activity, students will discuss how recent increases in Earth's temperature are due to humans releasing unprecedented amounts of greenhouse gases and how understanding past climates help scientists build models that predict future climate conditions. They are asked *"Why is our climate changing? What are the effects of the rapid rates of climate change we are currently experiencing?*
	LS2.C: Ecosystem Dynamics, Functioning, and Resilience • Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations.	Students will explore how ecosystems and individual species are affected by, and respond to, changes in climate. Students are asked *"How can scientists infer an area's climate from the type of plants in the area?* Students will respond to the prompt*: I heard that the climate has changed before and this current climate change we are talking about is just like that. So we don't have to be worried. It's the same thing.*
	LS4.D: Biodiversity and Humans • Changes in biodiversity can influence humans' resources, such as food, energy, and medicines, as well as ecosystem services that humans rely on- for example water purification and recycling.	Students will explore how humans are impacting global climate due to increased consumption of fossil fuels.
Crosscutting Concepts	Patterns • Students recognize that macroscopic patterns are related to the nature of microscopic and atomic-level structure. They identify patterns in rates of change	Students will examine patterns in data showing frequency of different taxa of pollen collected to construct scientific arguments of past climatic events. Students are asked to

	and other numerical relationships that provide information about natural and human designed systems. They use patterns to identify cause and effect relationships, and use graphs and charts to identify patterns in data.	look for patterns in their data and use them to infer past climate.

Nature of Science	
NOS Category/Learning Outcome	How Nature of Science ideas are explicitly addressed in Activity
Scientific Investigations Use a Variety of Methods • Science investigations use a variety of methods and tools to make measurements and observations.	Asking the following reflective questions will allow students to explore the idea that not all scientific data come from controlled experiments. *"Does all science require controlled experiments? Provide specific examples from this activity to support your answer."*
Scientific Knowledge is Based on Empirical Evidence • Science knowledge is based upon logical and conceptual connections between evidence and explanations.	Asking students *"Why are data important in science?"* will allow students to explicitly reflect on the empirical nature of scientific inquiry and the role of data in constructing arguments and explanations.
Scientific Knowledge Assumes an Order and Consistency in Natural Systems • Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation.	Asking students the following reflective question allows them to consider the idea that scientists search for patterns to help construct explanations. *"An important aspect of science is identifying and explaining patterns in nature. Explain why this is important for scientists to do, using an example from your climate investigation."*

Connections to Common Core State Standards	
English Language Arts/Literacy RST.6-8.1 RST.6-8.6 RST.6-8.7 RST.6-8.8	 RST.6-8.9 WHST.6-8.1 WHST.6-8.2 WHST.6-8.9

High School NGSS

Performance Expectations: Students' ability to complete the following performance expectations will be supported by participation in this activity. **HS-ESS2-4:** Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes. **HS-ESS3-4**: Evaluate or refine a technological solution that reduces impacts human activities on natural systems. **HS-ESS3-5:** Analyze geoscience data and the results from climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth's systems. **HS-LS2-7:** Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity. **HS-LS4-4:** Construct an explanation based on evidence for how natural selection leads to adaptation of populations.		
Dimension	**Name and NGSS code/citation**	**Specific Connections to Classroom Activity**
Practices	Analyzing and Interpreting Data • Analyze data using tools, technologies, and/or models (e.g., computational mathematical) in order to make valid and reliable scientific claims.	Students will analyze and interpret patterns of pollen frequency to make a claim, supported by evidence and reasoning, about what a region's past climate was like. Students will compare patterns of fossilized pollen from different time periods (up to 12,500 ybp), noting similarities and differences in claims about inferred past climates.
	Constructing Explanations • Construct and revise an explanation based on valid and reliable evidence obtained from sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.	Students will construct a scientific explanation about how the climate has changed over the past 12,500 years. Their explanation will include a claim, evidence to support their claim and reasoning that connects the evidence to the claim.
	Engaging in Argument from Evidence • Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence, challenging ideas and conclusions, responding thoughtfully to diverse	Students will compare and critique each other's scientific arguments about Earth's past climates. Students will critique their peer's scientific arguments on Earth's past climates.

	perspectives and determining additional information required to resolve contradictions. - Make and defend a claim based on evidence about the natural world.	Students will present oral arguments to peers to support their claims and will challenge peer's claims that lack adequate evidence and/or appropriate reasoning.
	Obtaining, Evaluating, and Communicating Information • Compare, integrate and evaluate scientific and/or technical information presented in different formats (e.g., visually, quantitatively) as well as in order to address a scientific question.	Students will use scientific ideas and reasoning presented in the "Plant Taxa Characteristics Tables" to analyze and interpret the pollen frequency data they have collected in order to construct scientific arguments. Students will analyze and interpret a complex graph on rates of climate change.
Disciplinary Core Ideas	ESS2.A: Earth Materials and Systems • The geologic record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities.	Students will explore fluctuating climatic conditions as they answer the question "*What was the climate like in the Anacostia watershed in the past 12,500 years?"* As a result, they will understand that scientists are able to learn about climatic conditions from thousands of years ago by utilizing fossil records.
	ESS3.C: Human Impacts on Earth Systems • The sustainability of human societies and the biodiversity that support them require responsible management of natural resources.	Students will explore how the rapid rate of climate change due to human activity might affect biomes and ecosystems.
	ESS3.D: Global Climate Change • Global climate models are often used to understand the process of climate change because these changes are complex and can occur solely over Earth's history. Though the magnitudes of humans' impacts are greater than they have ever been, so too are human's abilities to model, predict, and mange current and future impacts.	Students will discuss how recent increases in Earth's temperature are due to humans releasing unprecedented amounts of greenhouse gases and how understanding past climates help scientists build models that predict future climate conditions.
	LS2.C: Ecosystem Dynamics, Functioning, and Resilience	Students will explore how biomes, ecosystems and individual species are affected by, and respond to, changes in climate.

	• A complex set of interactions within an ecosystem can keep its number and types of organisms relatively constant over long periods of time under stable conditions. • Anthropogenic changes (induced by human activity) in the environment- including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change- can disrupt an ecosystem and threaten the survival of some species.	
	LS4.D: Biodiversity and Humans • Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. These problems have the potential to cause a major wave of biological extinctions—as many species or populations of a given species, unable to survive in changed environments, die out—and the effects may be harmful to humans and other living things. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth.	Students will explore possible effects of a changing climate on present-day ecosystems and resources in the elaboration activity exploring how changing climate is affecting pollinators.
Crosscutting Concepts	Patterns • Students observe patterns in systems at different scales and cite patterns as empirical evidence for causality in supporting their explanations of phenomena. They recognize classifications or explanations used at one scale may not be useful or need revision using a different scale; thus requiring improved investigations and experiments. They use mathematical representations to identify certain patterns.	Students will examine patterns in data showing frequency of different taxa of pollen collected to construct scientific arguments of past climatic events.
	Cause and Effect • Students understand that empirical evidence is required to differentiate between cause and correlation and to make	Students will explore how climate can affect species composition of ecosystems and they will use patterns

	claims about specific causes and effects. They suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They also propose causal relationships by examining what is known about smaller scale mechanisms within the system. They recognize changes in systems may have various causes that may not have equal effects.	of frequency of fossilized pollen to infer past climatic conditions.
	Scale, proportion and Quantity • Students understand the significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. They recognize patterns observable at one scale may not be observable or exist at other scales, and some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly. Students use orders of magnitude to understand how a model at one scale relates to a model at another scale.	Students will explore that changes in ecosystems happen over such vast amounts of time and cannot always be observed directly by humans and must be examined using proxy (indirect) data.
	Stability and change • Students understand much of science deals with constructing explanations of how things change and how they remain stable. They quantify and model changes in systems over very short or very long periods of time.	Students will explore paleoclimatologists construct explanations about Earth's past climates by using proxy data that spans thousands of years.

Nature of Science	
NOS Category/Learning Outcome	How Nature of Science ideas are explicitly addressed in Activity
Scientific Investigations Use a Variety of Methods • Science investigations use a variety of methods and tools to make measurements and observations.	Asking the following reflective questions will allow students to explore the idea that not all scientific data come from controlled experiments. *"Does all science require controlled experiments? Provide specific examples from this activity to support your answer."*
Scientific Knowledge is Based on Empirical Evidence • Science knowledge is based upon logical and conceptual connections between evidence and explanations.	Asking students *"Why are data important in science?"* will allow students to explicitly reflect on the empirical nature of scientific inquiry and the role of data in constructing arguments and explanations.

Scientific Knowledge Assumes an Order and Consistency in Natural Systems • Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation.	Asking students the following reflective question allows them to consider the idea that scientists search for patterns to help construct explanations. *"An important aspect of science is identifying and explaining patterns in nature. Explain why this is important for scientists to do, using an example from your climate investigation."*

Connections to Common Core State Standards

English Language Arts/Literacy

RST.9-10.1	RST.9-10.10	RST.11-12.1	RST.11-12.9
RST.9-10.3	RST.9-10.10	RST.11-12.3	RST.11-12.10
RST.9-10.4	WHST.9-10.1	RST.11-12.4	WHST.11-12.1
RST.9-10.8	WHST.9-10.4	RST.11-12.8	WHST.11-12.4

Appendix B: Glossary

Alpine biome	A biome with cold climate, found at high altitude and characterized by lack of trees and dwarf shrubs.
Argument (scientific)	A scientific justification for a claim based on evidence and reasoning.
Biome	A term used to describe an area's climate and ecosystem. There are many different types of biomes, including taiga or boreal, temperate deciduous, tundra, desert.
Boreal biome	A biome, also known as Taiga that is characterized by coniferous forests with abundant fir and spruce trees.
Carbon-14 Dating	Method for determining age of an object containing organic material by using the properties of radiocarbon (14C), a radioactive isotope of carbon.
Claim	A conclusion, based on evidence and reasoning.
Climate	The weather conditions (such as amount of rainfall and temperature) based on over 30 year averages.
Deciduous	A tree or shrub that loses its leaves annually.
Ecosystem	The web of all living organisms and their physical environments in one area. All the organisms in an ecosystem are connected in some way.
Evergreen	A plant that retains green leaves throughout the year.
Evidence	Empirical data that can be used to support a claim.
Fossil	The remains or impression of a prehistoric organism preserved in petrified form or as a mold or cast in rock.
Herbaceous	A plant type that has little or no woody tissue (a soft stem) with a single growing season (such as an herb).
Indirect data	Data that are inferred from another source.
Inference	A conclusion based on an observation.
Observation	Something that is detectable by one of the five senses, including sight, sound, smell, touch and taste.
Paleoclimatologist	A scientist who studies past climates.
Pollen	The male gamete of seed-bearing plants that is often dispersed by wind or animals. A pollen grain is so small it cannot clearly be seen without the aid of a microscope.
Proxy data	A type of indirect data.
Reasoning	Scientific facts, theories and laws that connect evidence to a claim in a scientific explanation.
Sediment Core	A sample of soil that is collected using a cylindrical, hollow metal tube. The sediment at the bottom of the core sample is older than the sediment at the top. Sediment cores often contain fossils, including plant pollen and seeds, as well as other types of organisms.

Taxon (plural is Taxa)	A unit of biological classification or a group of related species. "Canids" or dogs for example is a taxon which can include wolves as well as house pets and coyotes.
Temperate forest biome	A biome with moderate temperatures (not too extreme). Characterized by deciduous trees and four (winter, spring, summer, fall) seasons
Taiga biome	A cold biome that is characterized by the presence of conifers such as fir and spruce, see 'boreal' above. It is a wet biome.
Tundra	A type of biome where tree growth is hindered by low temperatures and short growing seasons.
Weather	The state of the atmosphere (wind, temperature, moisture, etc.) in the short term (minutes – months).
ybp (years before present)	The number of years before present. Scientists often use this term with talking about events that have happened thousands and millions of years ago on Earth. It is similar although not identical to time noted as BC and AD.

Appendix C: Background Research Cards for Jigsaw Activity

The Background Research Resources cards begin on next page. This page intentionally left blank.

Laminated copies of the Background Research Cards are provided in the MDLL kit.

What are sediment cores and how are they used by scientists?

Scientists are often curious about what things were like a long time in the past and what types of organisms lived then. One way scientists examine what the Earth was like millions of years ago is by using fossils. Fossils are the remains of things that were once living. We often think of dinosaurs and bones when we think of fossils. But fossils can come from dead insects and even from plants!

Figure 1. An example of a sediment core that was taken from the bottom of a lake in Alaska. Image: http://www.washington.edu/news/files/2013/01/CoreCrop.jpg

Fossils in Sediment Cores

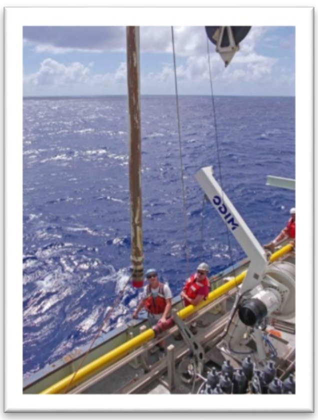


Figure 2. Example of a sediment coring machine collecting sediment cores from the bottom of the sea. https://researcherridge2014.wordpress.com

One place that scientists often look for fossils is in samples of soil or dirt. The picture in Figure 1 shows a sediment core that was drilled from the bottom of a lake. The picture in Figure 2 shows a long tube on a boat that is being used to drill for sample cores in the ocean bottom. Sediment cores don't always come from underwater. You can drill a sediment core in land not covered by water, such as in a forest or a field. Sediment cores can contain clues, in the form of fossils that allow scientists to figure out what the Earth was like millions of years ago. As time goes by, things (pieces of plants like seeds, leaves and pollen, dead insects, etc.) float to the bottom and are covered by sediment (bits of soil and debris that wash into the water) and some of them become fossils. Every year, new things float to the bottom, covering up what was there already and these get covered by

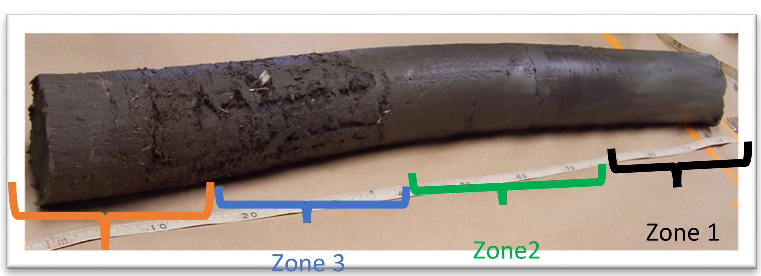


Figure 3. This sediment core was sampled from a bog in the Anacostia watershed in Maryland. The zones represent different time periods. Zone 4 is 0 – ~3,500 ybp (years before present), Zone 3 is ~3,400 – ~6,100 ybp, Zone 2 is ~6,100 – ~10, 700 ybp and Zone 1 is ~ 10,700 - ~12,500 ybp.

new sediment. In this way, layers of sediment form that contain a record of many of the plants and animals that were once found in and around the sample site.

How do scientists determine age of sediment cores?

The oldest samples in a sediment core are from the deepest part of a core, those furthers away from the surface. Each layer closer to the surface of the core represents a more recent time period. Scientists can use a special test, which is called Carbon-14 dating, to determine how many thousands of years ago different layers of the sample were laid down. Look at the picture of the sediment core in Figure 3. This core is about 1.2 meters long and contains sediment that is as old as 12,500 years!

How do scientists examine a sediment core?

Scientists carefully study the sediment core by examining thin slices of the core looking for fossils and other clues to learn about what the Earth used to be like. Each thin slice represents a different period of time. They sort the fossils into categories. With very small fossils, such as pollen, scientists must use microscopes to help them identify what they are.

Discussion Questions for your group:

1. What is a sediment core and where does it come from? Sediment cores are samples of soil, mud, etc. that are taken out of the ground. They can be taken from under bodies of water, such as lakes or oceans, or they can be dug from dry land. Often big machines are used to get sediment cores that can be very long and deep.

2. If you dug a sediment core from your backyard, which part of the core would have soil that had been there the longest? What tests do scientists do to determine how old a sediment core sample is?

The part of the core that is closest to the surface is the youngest. It contains soil and other debris (often insects, pieces of plants, pollen) that recently ended up in that sample. The deepest part of the core contains soil and dirt and other debris that has been there longer. Scientists use a test called carbon-14 dating to determine the age of a sediment core sample.

3. What types of clues can be found in sediment cores that help scientists understand what the Earth used to be like?

Soil can contain fossils which help scientists understand what the Earth used to be like based on what lived on it. Fossils can be parts of dead animals, insects and plants.

How do plant communities reflect local climate and changes in climate?

Take a moment and consider the following two locations - Florida and Alaska. Even if you've never been there yourself, you can probable describe what they are like. You might say that Florida is very warm and humid, and that Alaska is very cold. What if you compared a tropical rainforest with a desert? You might describe the rainforest as being very wet and the desert as being very dry. We refer to these differences in temperature and rainfall patterns as different climates. Climate is the expected weather conditions (based on long term averages) for a specific location. Climate includes such things as the average temperature and the amount of rain that falls in an area. Many people confuse climate and weather. Just remember that climate is what you expect, weather is what you get on any particular day!

Climate determines what organisms can survive

Climate affects the types of plants and animals that live in an area. For example, you might expect to see a cactus in a desert environment, but not in a rainforest. That's because cacti (that's the plural of cactus) have special adaptations, such as needle-like leaves and the capacity to store water, that allow them to survive in areas where there is little rainfall. Other types of plants, such as an oak tree, that you might see in your neighborhood, do not have the same adaptions as cacti and can only survive in areas with more available water.

Plants and animals provide clues to help scientists figure out past climate conditions

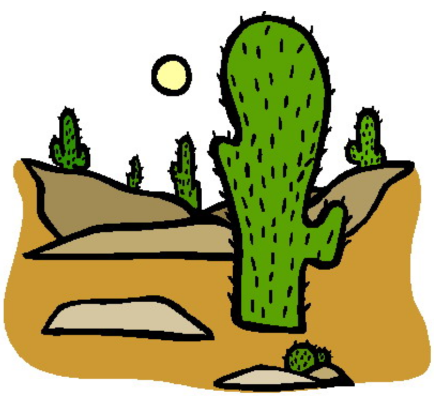
If you know that certain plants only grow in certain conditions (wet or dry, hot or cold) you can guess (infer) what an area's climate is like by what plants are growing there. That's what scientists do to figure out what the climate was like on Earth thousands and even millions of year ago. When scientists use one type of information (like types of plants present) to figure out another piece of information (like what the climate was like) we say they are using indirect, or 'proxy' data; the data about the plants is proxy for climatic conditions. You probably use proxy data all the time, without even realizing it. If you ever been in a neighborhood and see only very large houses with expensive cars, you might say to yourself 'the people who live here have a lot of money'. In this case, you are using the size of the houses and types of cars as indirect evidence (or proxy data) for wealth.

Discussion Questions for your group:

1. How can scientists infer an area's climate from the type of plants in the area? Give an example with you answer.

-Different plants thrive (do best) in different environments. For example, cacti do best in areas with little rain and high temperatures. Most types of Oak trees are found in areas that have more rain than a desert. If scientists find certain plants in certain areas, and they know what type of climate that plant requires, they can infer the climate of that area.

2. Based on what you know about the plants in each picture below, describe what you think the climate would be like in each area.



Picture A

Picture B

3. Define proxy data and give an example of how scientists use it. Proxy data are indirect pieces of evidence that scientists can use to understand the natural world. One example of proxy data can be the use of pollen to infer what plants used to live in an environment.

What is pollen and how is it distributed?

Seeds come from plants and contain genetic information from both male and female parts of the plant. The male part of the plant produces pollen and it combines with the female part of the plant, called an ovule to form a seed.

Pollen is carried by the wind, insects and mammals

Figure 1. Notice the pollen grains from the goldenrod plant sticking to the hair on the honeybee's legs.

Plant populations, like animals, are healthier when individuals mate with unrelated individuals. But plants can't walk around and meet new plants, so how do they manage to mate with unrelated individuals? The trick they use it to produce pollen that is very tiny and it can easily float in the air (as you know if you get hay fever). The wind is one of the ways in which pollen grains move through the environment, although pollen is also moved around on the fur of mammals, and on hair of insects, like honeybees (see Figure 1). A single plant can produce millions and millions of pollen grains that can travel through the environment, carried by the wind, insects and other animals. One pine branch can produce 350 million pollen grains! Because pollen sometimes has to travel far, many plants have evolved to produce pollen with a very tough outer coat which allows it to remain viable (alive) under various environmental conditions.

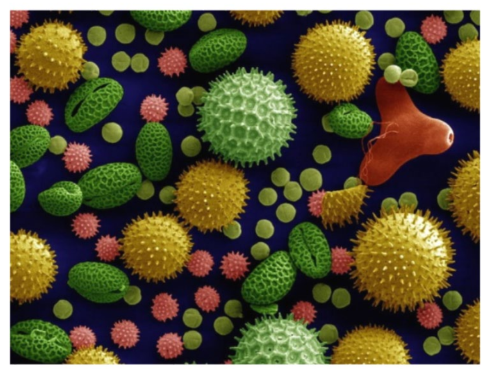


Figure 2. Pollen from a variety of common plants: sunflower, morning glory, hollyhock, lily, primrose, and castor bean. The image is magnified x1000 (1,000 times), so the bean shaped grain in the bottom left corner is about 50 µm long. Image from Dartmouth Electron Microscope Facility, Dartmouth College.

Pollen grains from different plants look different

We call a single piece of pollen a pollen grain, just like we sometimes call a single piece of rice a rice grain. But pollen is much, much smaller than a piece of rice. In fact, it is so small you need a microscope that magnified things over 500 times to be able to see it.

Look at the picture of pollen in Figure 2 that was taken with a very powerful microscope called a scanning electron microscope. What do you see? Did you notice that the pollen grains from different plants look very different? Different plants make different shapes of pollen, and you can tell what type of plant a pollen grain comes from just by looking at its shape and size. For example, the big round green pollen in Figure 2 comes from the Morning Glory plant, while the green football shaped pollen grains are from the Castor Bean plant.

Pollen makes a great fossil

Pollen grains are very tough. They have to be since they sometimes travel long distances. Some are almost indestructible. This means that pieces of pollen from some species can survive in the environment (buried in soil) as fossils for hundreds, even thousands of years! This is because they have a very tough outer coat that protects them from the environment.

Discussion Questions for your group

1. What is pollen and how does it move from place to place?

- Pollen comes from plants and carries male genetic information. It moves around on the wind, as well as on insects and on the fur of mammals.

2. Can pollen be used to identify what types of plants were in an area? If so, explain why. If not, explain why not.

- Yes, pollen can be used to infer what types of plants were in an area. Pollen from different species of plants look different. Therefore, if you find a pollen grain, you can look under a microscope and identify what type of plant it came from. Since pollen travels by wind, insects and mammals you can figure out what types of plants were in the general area by what types of pollen you find.

How are proxy data used to learn about past climate?

Have you ever wondered how scientists learn about what the Earth was like thousands and millions of years ago if they weren't around to observe it directly? Scientists do this by using what they call proxy data. Proxy data are preserved physical characteristics of an environment, and scientists use these data to infer (make a conclusion based on evidence) about what the past climate was like.

Figure 1. Scientists drilling an ice core sample in Antarctica. Photo accessed at

You are familiar with the idea of proxy data (forms of indirect evidence) even if you don't usually call them by that name. If you ride through a neighborhood and see only very large houses with expensive cars you say to yourself 'the people who live here have a lot of money.' You are using the size of the houses and types of cars as proxy data to indicate wealth. There are many examples of types of proxy data that are used to indicate what past climates were like.

Examples of Proxy Data for Climate

There are many different types of proxy data that help scientists figure out what past climates were like.

Ice Core Samples (Figure 1) are samples of ice that are collected from areas such as Antarctica. These ice samples contain valuable information that scientists can use to indirectly study past climates, such as trapped gas or pollen grains.

Tree rings (Figure 2) are also used as an indirect indicator of past climates. Scientists can examine the number and width of the rings, which provides information on how fast the tree grew as well as what the temperature and rainfall was like at the time the tree was growing.

Sediment cores (Figure 3) are long samples of soil that are collected by drilling into the ground, contain many important clues about what the temperature and the climate were like in the past, including pollen fossils.

Figure 2. Rings in a tree trunk. Photo accessed at http://images.inmagine.com/400nwm/iris/imagebrokerrm-

Figure 3. This sediment core sample is about 1.2 meters long and was sampled from the Anacostia watershed in Prince George's County, Maryland. Photo by Dr. G. Brush.

Discussion Questions for your group:

1. Write a definition of proxy data and give a specific example of proxy data used to study past climate.

Proxy data are preserved physical characteristics of an environment. Examples of proxy data used to study past climate include tree rings, ice cores and sediment samples.

2. How are proxy data used by scientists to study past climate?

Students maybe provide some or all of the following information. The gases and pollen samples trapped inside ice cores can provide information about the climate in an area in the past. Tree rings can indicate how fast a tree grew, which can provide information on the climate (temperature and moisture) during the time the tree was alive. Sediment cores contain clues about past climate in the forms of pollen fossils.

Appendix D: Plant Characteristics Table- Middle School

Taxon (bead color)	Temperature	Moisture	Description and Growth requirements
Alder (red)	Tolerant of hot and cold	Along river banks	A small deciduous tree or shrub that can tolerate both temperate (mean temperatures of 50°F, summers hot, winters cold) as well as colder boreal conditions (average temperature about 32°F, summers are very short). Alders are found along river banks and the presence of sufficient local water critical for them.
Birch (white)	Cold	Moist	Birch trees are deciduous and like cold area—many of the current forests of northern Russia are birch forests. In general birches can be found in alpine, boreal climates (cold and moist).
Fir (yellow)	Cold	Moist	An evergreen tree often sold as a Christmas tree. Firs are now naturally found at either very high altitude up on mountains or in the far north at high latitudes where the environment is generally cold and moist.
Hemlock (green)	Cool (not too cold, not too hot)	Moist	Hemlocks are another evergreen tree that does best in moist conditions but needs temperatures that are cool not cold, conditions that are warmer than those found in alpine conditions. Small pockets of hemlock forests exist on the east coast in special spots that are very shaded, moist and usually near rivers.
Oak (black)	Warm (can survive in cold)	Not too wet, not too dry	Oaks are a very common deciduous tree in eastern forests and do best in temperate climates although they can survive in cooler climates. They like mesic [not too wet and not too dry] moisture levels
Pine (brown)	Tolerant of hot and cold	Moist or dry	Pine is an evergreen tree that can tolerate a range of environments. It grows in a cool moist area or a warm dry one. They often occur in forests in low numbers and then expand in number when other species can no longer grow because of a change in the environment.
Ragweed (blue)	Anywhere in temperate zone	Range of moisture levels	The pollen from ragweed, a low growing annual herbaceous plant, is a major cause of hay fever. Ragweed can grow anywhere in the temperate zone and even grows in Canada and Alaska. It can take a range of moisture levels. It is found growing in highly disturbed areas and is associated with agriculture. You do not see it in forests but it is common in abandoned fields, at the edges of farm fields and along roadsides. You find it in places where farms replaced forests.
Sedges (purple)	Cool	Moist	Sedges appear in a quick glance to look 'sort of' like grasses but they have triangular stems not round stems ('sedges have edges'). Fossil pollen from sedges is interpreted to mean cool and wet alpine or boreal habitat. They did best with cool summers, short growing seasons and cold winters.
Spruce (orange)	Cold	Moist	Spruce, also an evergreen tree, is a species that is found in the tundra, a boreal habitat. Boreal habitats are mostly cold and moist with short cool summers and cold long winters.
Viburnum (pink)	Tolerant of hot and cold	Moist	Viburnums are generally forest understory plants that produce large clusters of flowers in mid-spring. While they like full sun they can grow in partial shade. This might explain why we see them commonly in forests with deciduous trees (trees that drop their leaves over winter) so the limbs are bare in early spring and the sun can reach the understory plants.
* A taxon is a group of related species, the plural of taxon is taxa. "Canids" or dogs for example can include wolves as well as house pets and coyotes.			

Appendix E: Plant Characteristics Table- High School

Taxon (bead color)	Description and Growth requirements
Alder (red)	A small deciduous tree or shrub that can tolerate both temperate (mean temperatures of 50°F, summers hot, winters cold) as well as colder boreal conditions (average temperature about 32°F, summers are very short). Alders are found along river banks and the presence of sufficient local water critical for them.
Birch (white)	Birch trees are deciduous and like cold area—many of the current forests of northern Russia are birch forests. In general birches can be found in alpine, boreal climates (cold and moist).
Fir (yellow)	An evergreen tree often sold as a Christmas tree. Firs are now naturally found at either very high altitude up on mountains or in the far north at high latitudes where the environment is generally cold and moist.
Hemlock (green)	Hemlocks are another evergreen tree that does best in moist conditions but needs temperatures that are cool not cold, conditions that are warmer than those found in alpine conditions. Small pockets of hemlock forests exist on the east coast in special spots that are very shaded, moist and usually near rivers.
Oak (black)	Oaks are a very common deciduous tree in eastern forests and do best in temperate climates although they can survive in cooler climates. They like mesic (not too wet and not too dry) moisture levels
Pine (brown)	Pine is an evergreen tree that can tolerate a range of environments. It grows in a cool moist area or a warm dry one. They often occur in forests in low numbers and then expand in number when other species can no longer grow because of a change in the environment.
Ragweed (blue)	The pollen from ragweed, a low growing annual herbaceous plant, is a major cause of hay fever. Ragweed can grow anywhere in the temperate zone and even grows in Canada and Alaska. It can take a range of moisture levels. It is found growing in highly disturbed areas and is associated with agriculture. You do not see it in forests but it is common in abandoned fields, at the edges of farm fields and along roadsides. You find it in places where farms replaced forests.
Sedges (purple)	Sedges appear in a quick glance to look 'sort of' like grasses but they have triangular stems not round stems ('sedges have edges'). Fossil pollen from sedges is interpreted to mean cool and wet alpine or boreal habitat. They did best with cool summers, short growing seasons and cold winters.
Spruce (orange)	Spruce, also an evergreen tree, is a species that is found in the tundra, a boreal habitat. Boreal habitats are mostly cold and moist with short cool summers and cold long winters.
Viburnum (pink)	Viburnums are generally forest understory plants that produce large clusters of flowers in mid-spring. While they like full sun they can grow in partial shade. This might explain why we see them commonly in forests with deciduous trees (trees that drop their leaves over winter) so the limbs are bare in early spring and the sun can reach the understory plants.
* A taxon is a group of related species, the plural of taxon is taxa. "Canids" or dogs for example can include wolves as well as house pets and coyotes.	

Appendix F: Suggested Data Subsets for Differentiation

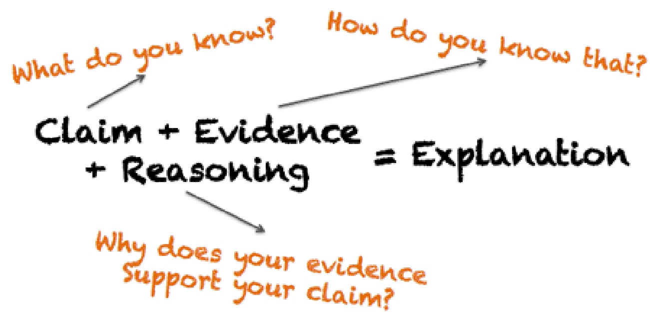
In this activity students are collecting data on the occurrence of up to 10 different pollen taxa. You can choose to have your students use information from all 10 taxa when they construct their scientific argument, or you may choose to direct their attention to fewer taxa. Fewer taxa might be appropriate for students who are not as familiar with constructing scientific arguments or those that might struggle to make sense of multiple pieces of evidence at one time. Below we suggest groupings for using 4, 5, 8 and 10 taxa. We suggest these particular groupings, as each grouping shows similar patterns of climate change. If you choose to have students consider fewer taxa you can discuss how considering more taxa would affect their analysis and interpretation. We suggest including the beads that represent the non-analyzed taxa in the sediment sample bags so that students are aware of the full picture of available evidence. Students can combine the percentages of the non-analyzed samples into a single category labeled 'other'. You can discuss with the students how adding more taxa to the data set might affect interpretation and conclusions.

<u>Suggested Groupings for Differentiated Data Analysis</u>

- 10 Taxa Analysis
  - Alder, Birch, Fir, Hemlock, Oak, Pine, Ragweed, Sedges, Spruce, Viburnum
- 8 Taxa Analysis
  - Birch, Fir, Hemlock, Oaks, Ragweed, Sedges, Spruce and Viburnum
  - Remaining taxa grouped as a category called 'other'
- 5 Taxa Analysis
  - Birch, Fir, Hemlock, Oak and Spruce
  - Remaining taxa grouped as a category called 'other'
- 4 Taxa Analysis
  - Birch, fir, Oak and Spruce
  - Remaining taxa grouped as a category called 'other'

Appendix G: CER Framework Information

Explanations in Science: Claim, Evidence, Reasoning



After students are engaged in an investigation, how can they make sense of their data and construct a scientific explanation in which they justify their claim? One way is to introduce the Claim, Evidence, Reasoning (C-E-R) framework (McNeill and Krajcik, 2011). "An explanation includes a claim that relates how a variable(s) relates to another variable or set of variables. A claim is often made in response to a question and in the process of answering the question, scientists often design *investigations* to generate *data*." Explanations rely on evidence and provide the "how" or "why" phenomena occur (reasoning). *Next Generation Science Standards, Appendix F, page 11.*

Components of an Explanation – What does a good scientific explanation look like?

1. Claim
   - A conclusion that answers the question about a phenomena or a solution to a problem.
   - A statement of what you understand or a conclusion that you have reached from an investigation(s) or text(s) you have read.
2. Evidence
   - Scientific data that supports the student's claim.
   - Must be appropriate and sufficient.
   - Can come from an investigation or other source that may include:
     - Observations
     - Information found in texts
     - Archived data
     - Information from an expert
3. Scientific Reasoning
   - Justification that links the claim and evidence.
   - Shows why the data counts as evidence to support the claim, using appropriate scientific principles.

Scaffold the Process in Your Classroom

- Explicitly define the elements of the C-E-R Framework
- Provide a graphic organizer that explains the parts of the framework
- Connect to everyday examples
- Provide opportunities for oral discourse of claim, evidence and reasoning before writing
- Use teacher questioning or feedback during oral presentation
- Model and critique examples
- Engage students in peer critique
- Provide students with feedback

Student Challenges

- **Using evidence to support their ideas** – Students may tend to rely on their own opinion(s) and have difficulty using sufficient evidence.
- **Explaining why the evidence supports their ideas (justification/reasoning**) – Students may have difficulty articulating this link and/or using scientific principles.
- **Considering multiple explanations or solutions** – Students may have difficulty revising explanations and solutions based on evidence or scientific knowledge.

Claim-Evidence-Reasoning Rubric

The following rubric can be used by both students and teachers to assess their scientific arguments and explanations. Rubric developed and adapted from material at http://slider.gatech.edu/student-edition.

C-E-R Element	Zero (0)	Early (1pt)	Emerging (2pts)	Sophisticated (3pts)
1) Claim	Does not make a claim that responds to the question.	The claim responds to the question, but is inaccurate claim.	Makes an accurate but incomplete claim in response to the question.	Makes an accurate and complete claim in response to the question.
2a) Evidence Use of data	No evidence is provided.	The evidence contains **some** of appropriate data from an observation.	The evidence contains **most** of appropriate data from an observation.	The evidence contains **all** appropriate data from an observation.
2b) Evidence Interpretation of data	Does not interpret any evidence.	Interprets only some data accurately.	Interprets **most** of the data accurately.	Interprets **all** of the data accurately.
3a) Reasoning General Statement	Does not provide any reasoning.	Answers why or how the evidence supports claim with **no relevant** scientific principles (disciplinary core ideas).	Answers why or how the evidence supports claim with **insufficient relevant** scientific principles (disciplinary core ideas).	Answers why or how the evidence supports claim with **sufficient relevant** scientific principles (disciplinary core ideas).
3b) Reasoning Use of pieces of evidence	Uses no evidence or relevant big ideas accurately to explain the relationship between claim and evidence.	Uses **some** piece(s) of evidence and relevant disciplinary core ideas accurately to explain the relationship between claim and evidence.	Uses **most** pieces of evidence and relevant disciplinary core ideas accurately to explain the relationship between claim and evidence.	Uses **all** pieces of evidence and relevant disciplinary core ideas to accurately to explain the relationship between claim and evidence.
4a) Persuasion Complete sentences	**No** sentences are complete**.**	**Only few** sentences are complete.	**Most** sentences are complete.	**All** sentences are complete.
4b) Persuasion Grammatical Choices	**Most** of CER contains many grammatical errors.	CER contains **some** grammatical errors.	CER contains **few** grammatical errors.	CER contains **minimal** grammatical errors.

Resources

McNeill, Katherine L. and J. Krajcik. *Supporting Grade 5-8 Students in Constructing Explanations in Science: The Claim, Evidence, and Reasoning Framework for Talk*: New York, Pearson, 2011. Print.

Sampson, Victor, P. Enderle, L. Gleim, J. Grooms, M. Hester, S. Southerland, K. Wilson. *Argument-Driven Inquiry in Biology: Lab Investigations for Grades 9-12*: Arlington, NSTA Press, 2014. Print.

http://learningcenter.nsta.org/products/symposia_seminars/nsta/files/howdoyouknowthat--helpingstudentswriteaboutclaimsandevidence_12-12-2012.pdf

http://slider.gatech.edu/student-edition

http://www.activatelearning.com/claim-evidence-reasoning/

Appendix H: Advanced Level Reading on graph of temperature versus time

Past and Present Climate: Tying things together

The pollen samples you have been working on represent samples taken during a particular period of time. The earliest samples (12,500 ybp, 10,000 ybp) come from the early part of the Holocene which started 12,000-11,500 years ago and the later samples (3,000 ybp and 340 ybp) come from more recent times, 340 ybp is the late 1700's. The Holocene is the period in which we are living and which is noted for the global retreat of the glaciers. As the glaciers retreated, the temperatures started to warm. The pollen samples represent proxy data reflecting local climatic changes—changes in the vegetation in the area were driven by the changes in climate.

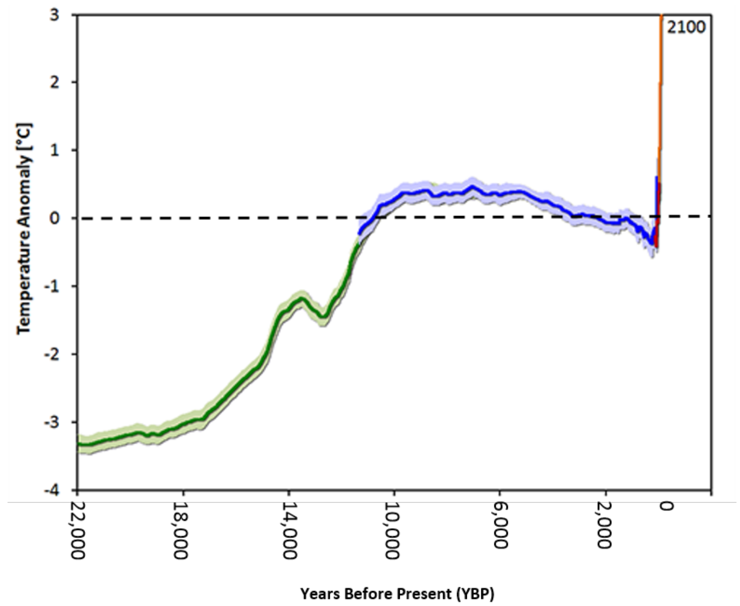


Figure 1: This figure, often referred to as the 'wheelchair' because of its shape, was created by Jos Hagelaars. The colors on the graph represent the sources of the data, with the orange line representing predicted increases in temperature. Modified from image accessed at https://ourchangingclimate.wordpress.com/2013/03/19/the-two-epochs-of-marcott/.

The graph in Figure 1 demonstrates the extent and the rates of the change in temperatures over this period at a more global scale. The primary message from the figure is that the temperature has changed over the 22,000 years represented in the graph but the change was relatively gradual for most of this period—there was a change in one degree Celsius over the 4,000 years between 18,000 and 14,000 ybp. These changes were primarily due warming as the Earth emerged from an ice age. This contrasts markedly with the current (red) and projected (orange line) rates of change since the industrial revolution, where you see the sharp increase at the right side of the graph starting ~200 ybp and projected ~100 years into the future. The recent rapid increase is attributed to the increase in carbon dioxide and other greenhouse gases that humans have been adding to the atmosphere. This increase in greenhouse gases is leading to very rapid warming of the globe.

The Y axis is the amount of the temperature anomaly, but what is a temperature anomaly?

Records of average surface temperature are often presented as anomalies rather than as absolute temperatures. Note that in this graph, the Y axis isn't a measure of temperature per se, it is a measure of the temperature anomaly which is the difference in temperature at a particular time from a long-term average (the 0 point on the axis). For example, if a temperature average is 15°C, and the measured temperature is 17°C, then the temperature anomaly is +2°C (i.e., 17°C -15 C=2°C), the anomaly is positive since the measured temperature is higher than the original. In Figure 1, the temperature at 18,000 year ybp was ~3.2°C cooler than the temperature was ~10,000 ybp and temperature predicted by models for the year 2100, less than 90 years in the future, is expected to be 3°C higher than it is now.

Temperature anomaly data are useful when graphing because they are visual representations of deviations. By using anomalies, changes in different places can be compared easily.

The x axis represents time, but what time period does this graph cover?

Time is referred to as years before present (ybp) and this graph goes back ~22,000 ybp and projects 100 years into the future. The time periods covered by the pollen data in this activity was between ~12,500 and ~340 ybp.

What do the colored lines mean?

The data used in this graph were collected from various sources. The green and blue colored lines represent temperature reconstructions (i.e. proxy data) based on data collected from different sources and published by different people. The red line represents instrumental period data from sea surface and land surface air temperature records. The orange line represents the model average of IPCC (International Panel on Climate Change) *projections* for temperature rise into the year 2100.

Why the rapid increase in temperature

While Earth's climate has always been changing, the changes we see in our current climate are occurring at a very rapid rate (just look at the difference in the slope of the line at the far right and the rest of the graph). The recent spike in temperature, indicted by the red line in the graph, correlates to increases of CO_2 emissions from human-made sources. CO_2 is a greenhouse gas (GHG), which means that it traps heat in the earth's atmosphere. The IPCC 2007 synthesis report states "Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004". Scientists' understanding of past climatic variation, made possible by the use of indirect data from pollen and other proxy data sources such as ice cores, tree rings and coral reefs provide a foundation of knowledge that helps them understand that the extremely rapid rate of climate change that is happening today is caused by human's releasing CO_2 into the atmosphere.

Appendix I: Standard Level Reading on graph of temperature versus time

Past and Present Climate: Connecting 'then' to 'now'

The pollen samples you examined represent proxy data telling you about changes in local climate. The graph in Figure 1 shows how the temperature has changed over the last 22,000 years on a more global scale, as the Earth emerged from the last ice age and glaciers retreated. As the glaciers retreated, the temperature started to warm.

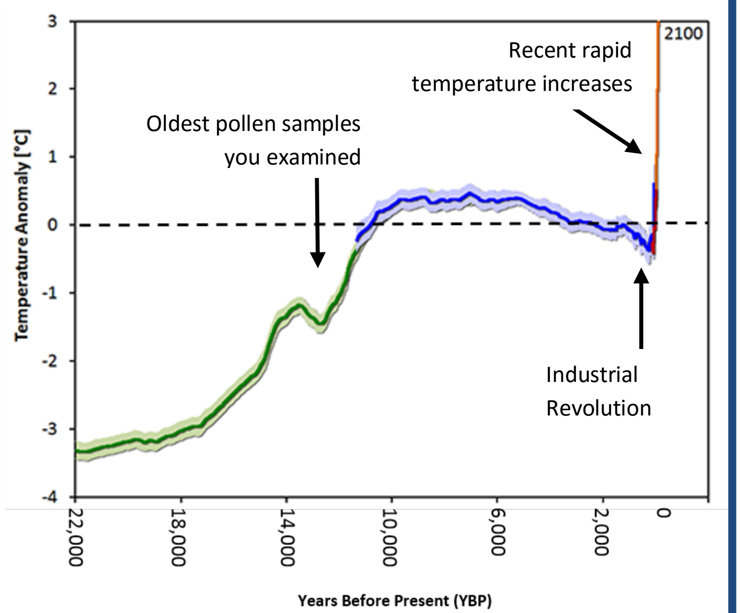


Figure 1: This figure, often referred to as the 'wheelchair' because of its shape, was created by Jos Hagelaars. The colors on the graph represent the sources of the data, with the orange line representing predicted increases in temperature. Modified from image accessed at https://ourchangingclimate.wordpress.com/2013/03/19/the-two-epochs-of-marcott/.

How is the current rate of climate change different from past rates of climate change?

The global temperature change has been relatively gradual for most of the last 22,000 years, with the average temperature increasing a little more than 3 degrees Celsius during this time. But recent climate change and projected future climate change is occurring much faster than in the past. You can see this by the steep rise in the slope of the line that represents current and projected future temperatures (red/orange line at right side of graph). Note that this steep increase starts with the beginning of the industrial revolution, when humans began burning more fossil fuels than they ever had before. Carbon dioxide is released when fossil fuels are burned.

Why is the earth warming so fast now? The recent rapid increase in temperature is attributed to the increase in carbon dioxide and other greenhouse gases that humans have been adding to the atmosphere.

How to read the Graph

- **What do the axes of the graph represent?** The Y axis is the amount the temperature is different from an average. The zero point on the Y axis graph represents the average global temperature from 1961-1990. A point above that line represents a higher temperature and below the line a lower temperature than average. The X axis represents time and is measured in 'years before present' or ybp unless it is years into the future which would be to the right of the 0 year.

- **What do the colored lines in the curve mean?** The data used in this graph were collected from various sources and each color represents a different source of data.

Appendix J: Example Evidence and Reasoning

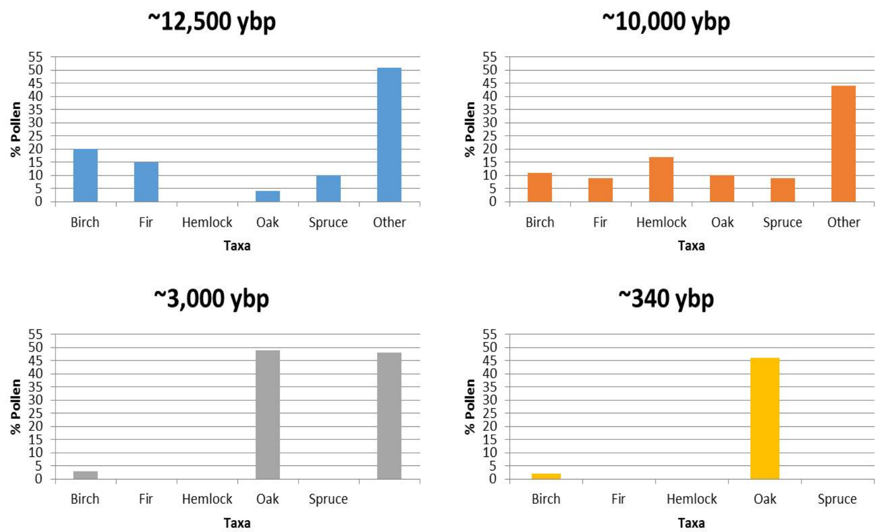


Figure 1. Percentage of pollen from five taxa found in sediment cores samples at ~12,500, ~10,000, ~3,000 and ~340 ybp.

The following Claim, Evidence and Reasoning examples are for an analysis using of five taxa, Birch, Fir, Hemlock, Oak and Spruce.

Example claim: Over the past 12,500 years, the climate changed from one that was cold and wet to one that was warmer and drier.

Example evidence: Students should reference the graphs they created, but also describe in writing the patterns they see in their data.

- Birch is declining, representing 20% of the pollen sampled~12,500 ybp to only 2% of the sampled pollen ~340 ybp (see Figure 1).
- Fir is declining, representing 15% of the pollen sampled~12,500 ybp to being completely absent in samples from ~3,000 and ~340 ybp (see Figure 1).
- Hemlock only appears in sample from ~10,000 ybp, where it represents 17% of the pollen sampled (see Figures 1-4).
- Oak is increasing, representing only 4% of the pollen sampled~12,500 ybp, but representing 46% of the sampled pollen by ~340 ybp (see Figure 1).
- Spruce is declining, representing 10% of the pollen sampled~12,500 ybp to being completely absent in samples from ~3,000 and ~340 ybp (see Figure 1).
- Other (remaining taxa lumped, but not analyzed)

Example reasoning:

- Pollen fossils provide evidence about what plants once lived in an area.
- It is possible to determine the age of pollen fossils found in sediment cores. The oldest pollen is found at the deepest end of the core and the most recent pollen is found at the

surface. More specific dating can be done with techniques such as carbon-14 dating, which provide information on how many years the pollen has been in the sediment.

- Different types of plants can tolerate different climate conditions.
- Birch, Fir, and Spruce do best in cold and moist climates. These taxa decreased over the past 12,500 years, suggesting the climate was becoming warmer and dryer.
- Oak does best in warm climates (although it can survive in cooler climates) and mesic (not too wet, not too dry) climates. Oaks increased over the past 12,500 years, suggesting the climate was becoming warmer and dryer.
- Hemlock prefer cool and moist conditions and appears in the sample representing 10,000 years before present suggesting the climate was cool and moist at that time.
- By knowing what plants were present in past environments (based on pollen fossil evidence) and knowing what climatic (moisture levels and temperature) these plants require we can infer what the climate was like in these past environments.

Appendix K: Example Answers for Student-Constructed Scientific Explanations

The following are example answers you can use to help you assess the student constructed scientific explanations. If your students are new to scientific argumentation or you think they may struggle to incorporate data from so many taxa, you may choose to have your students analyze fewer than all 10 taxa. Below we have provided example answers for groups of 10 taxa, 8 taxa, 5 taxa and 4 taxa. In cases where less than 10 taxa are addressed, the remaining taxa are lumped together as “other”.

Note that these examples are fairly sophisticated and are meant to provide the teacher with a thorough analysis of the data. Depending on their familiarity with constructing scientific arguments, your middle school students may produce arguments that are less sophisticated and/or contain fewer pieces of evidence and reasoning. High school students can be expected to make arguments that are more sophisticated and may use more pieces of evidence and reasoning than middle school students. However, even high school students may not make arguments as sophisticated as the example answers.

Examples begin on next page.

10 Taxa Analysis

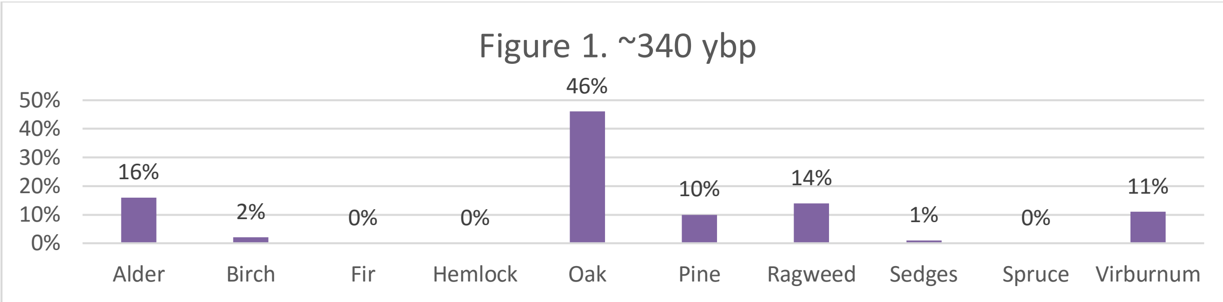
Claim: The climate changed between 12,500 ybp and 340 ybp. The climate was cold and wet at 12,500 ybp (sample 1) and became warmer and drier (but still somewhat moist) over time. At ~340 ybp (sample 4) the region around where the sediment core was samples contained a mixture of forest and disturbed land.

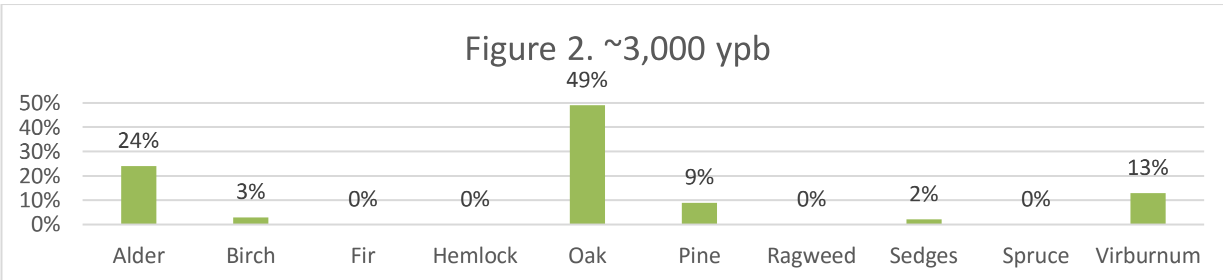
Assessment notes: Note that having only the first sentence in the above paragraph would be considered two pts on line 1 (Claim) of the rubric since it responds to the question, but does not explain how the climate changed.

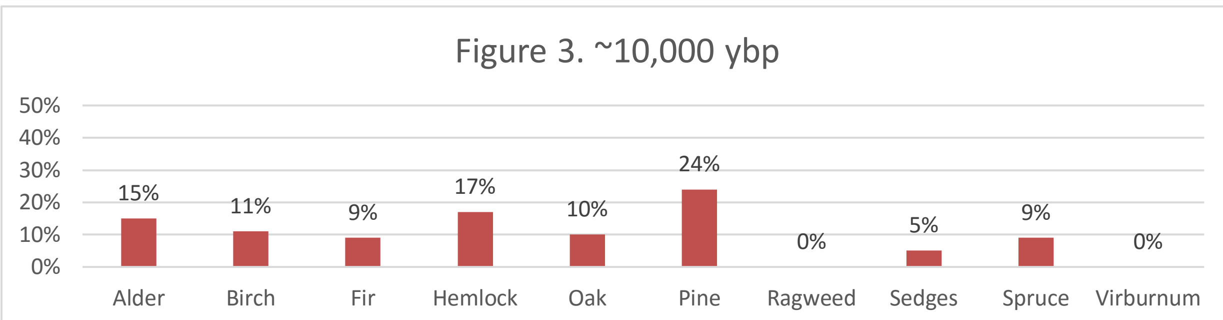
Sentences 2 and 3 above result in a score of three pts on line 1 (Claim) of the rubric since the claim is accurate and complete (tells how the climate changed).

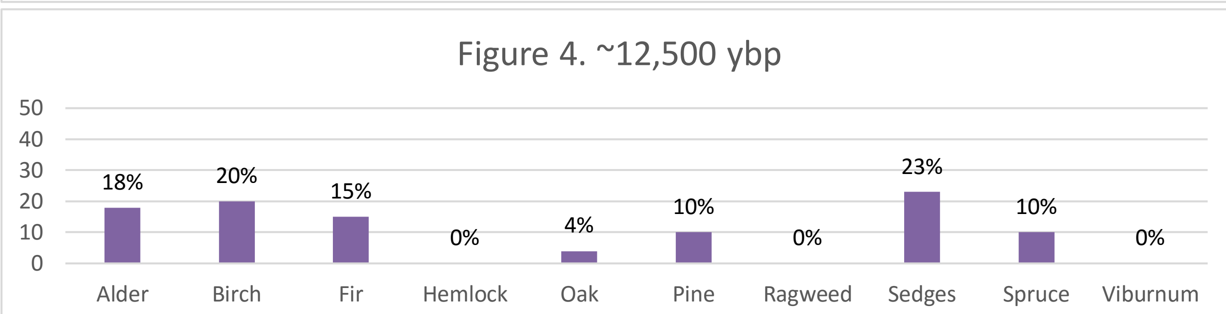
Evidence: (the scientific data you collected that support your claim)

Note in the evidence section, students should only be describing the patterns they see, not explaining the patterns (that is done in the reasoning). We encourage students to not just include their graph in this section, but to also explain in words the patterns the graphs show. This provides the students an opportunity to practice describing the patterns they see, as well as providing the teacher an opportunity to assess if the student is interpreting the patterns appropriately. Students should include all the appropriate data (rubric line 2a) they have collected. This means a sophisticated response on line 2a of the rubric (Evidence: use of data) would include describing the percentages of all plant taxa they identified. If students do not describe all of the plant taxa, they would receive an early or emerging score. However, you may choose to have students provide evidence on only a subset of the data as a way to differentiate the activity.









Alder is present in all samples (Figures 1-4).

Birch, fir and spruce trees and sedges are most abundant in the time period ~12,500 ybp (Figure 4), less abundant in time period ~10,000 ybp (Figure 3) and either at very low numbers or absent in time periods ~3,000 ybp (Figure 2) and ~340 ybp (Figure 1).

Hemlock only appears in the sample from ~10,000 ybp (Figure 3).

There are a few oaks (4%) in the sample from time period ~12,500 ybp (Figure 4) but the abundance of oaks increases in the more recent samples. Oaks are 10% of the sample from

~10,000 ybp (Figure 3) and increase even more in samples from periods ~3,000 (ybp) and ~340 ybp (Figures 2 and 1).

There are some pines (10%) in the sample from time period ~12,500 ybp (Figure 4), more pines (24%) in the sample from ~10,000 ybp (Figure 3) and fewer in samples from periods ~3,000 (ybp) and ~340 ybp (Figures 2 and 1).

Ragweed is only present in the most recent sample from ~340 ybp (Figure 1).

Viburnum only appears in two most recent samples ~3,000 (ybp) and ~340 ybp (Figures 2 and 1).

Reasoning (your explanation for how the evidence supports your claim):
Note the first two paragraphs below address the reasoning general statement (rubric line 3a) since they provide sufficient, relevant scientific principles that connect the evidence and the claim. General statement in the reasoning section should describe the scientific principles and disciplinary core ideas that are necessary to interpret and make sense of the data.

All living organisms, including plants, have certain habitat requirements to grow, survive, and reproduce. Temperature and moisture are two such conditions that can affect which plants can grow, survive and reproduce in any location. Some plants can tolerate a wide range of temperature and moisture conditions, while others can only survive in a narrow range of conditions. If pollen is found in different sediment layers that have been determined to be from a specific time periods, and it is known what types of climatic conditions specific plants can, and cannot survive in, then the climate conditions at a particular time period can be inferred from the types of pollen present (and possibly from the types of pollen that were present in a samples from some period of time but are not present in other samples).

The graphs above provide profiles of pollen from different types of plants from four time periods (~12,500 ybp, ~10,000 ybp, ~3000 ybp and ~340 ybp). The abundance and/or presence of plant taxa change in each sampled time period, providing evidence that climate (long-term temperature and precipitation values) changed throughout the time periods, although not all plants were affected the same way. While a single taxon cannot tell the entire story, each taxon and its pattern over time is a piece of evidence and together they can be used to understand the change in the climate.

The following information addresses reasoning as well, and specifically aligns with line 3b of the rubric- using pieces of evidence. The pieces of evidence in this example include the information that taxon provides with respect to climate conditions (specifically with respect to temperature and moisture).

Alder can survive over a range of temperatures and can grow as long as there is water nearby and it often grows along rivers. Its presence in all time periods examined suggests there has always been enough water in the area sampled for these plants to survive and reproduce. It doesn't tell us as much about the climate as the other taxa. Birch, fir and spruce trees and sedges are typical of 'boreal forests' which are forests that only are found areas that are both very wet and cold. Their decline in the 10,000 ybp sample and further decline or absence in the samples from 3,000 and 340 ybp suggests the climate was coldest and wettest ~12,500 ybp, and became and warmer and dryer in the more recent time periods.

Hemlock does best in cool (but not very cold) and moist climates. Therefore, the presence of hemlock in the sample from ~10,000 ybp provides evidence that the climate at this time was moist and cool. This is idea is supported by the change in fir, spruce, birch and sedges described earlier. The decrease in pollen from plants (they can live but they are getting less dense) which need very cold and wet habitat (fir, birch, spruce and sedges) and the appearance of hemlock that needs cool and wet provides evidence that supports the claim that the climate at ~10,000 ybp was moist and cool, but not too cold. The warming (becoming less cold) that allowed the hemlock to grow also helped the oaks to increase their numbers.

Oak trees are fairly adaptable and can live in places that are not optimal for them. In these samples the oaks increase as the birch, fir, spruce and sedges disappear. Oaks do best in warmer and moist, but not wet, environments. The change in the abundance of oaks, their increase and their remaining high suggests that the area is getting warmer and warmer but staying moist as the percentage of oaks increases and stays high.

Pine can tolerate a range of environments and it is present in all samples. It doesn't tell us as much about the climate as the other taxa.

Ragweed doesn't occur in forests at all as it is a plant that grows on roadsides and in farm fields or places where there is a lot of disturbance. The presence of ragweed only in the most recent sample (~340 ybp) suggests there had been a change in or near the forest and the land is being disturbed (possibly by deforestation and agriculture by humans).

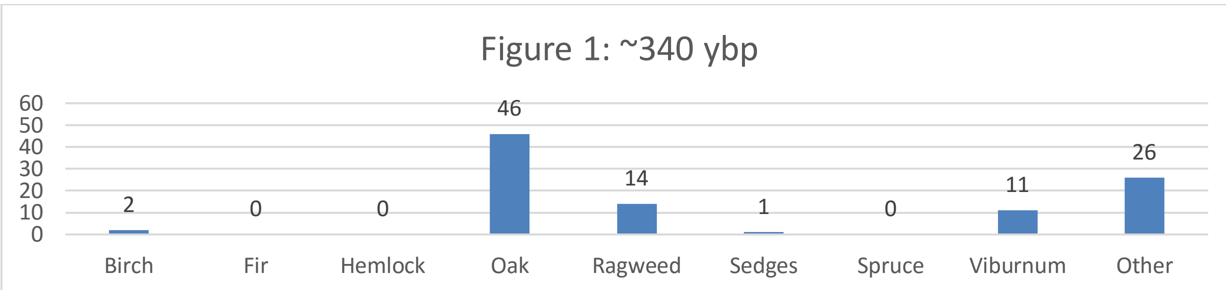
In forests, viburnum usually grows under deciduous trees and oaks are the only deciduous tree ever abundant in this area (based on pollen from the sediment sample) suggesting that during these periods, ~3,000 ybp and ~340 ybp, it was warm enough for there to be lots of deciduous trees and therefore viburnum could also grow.

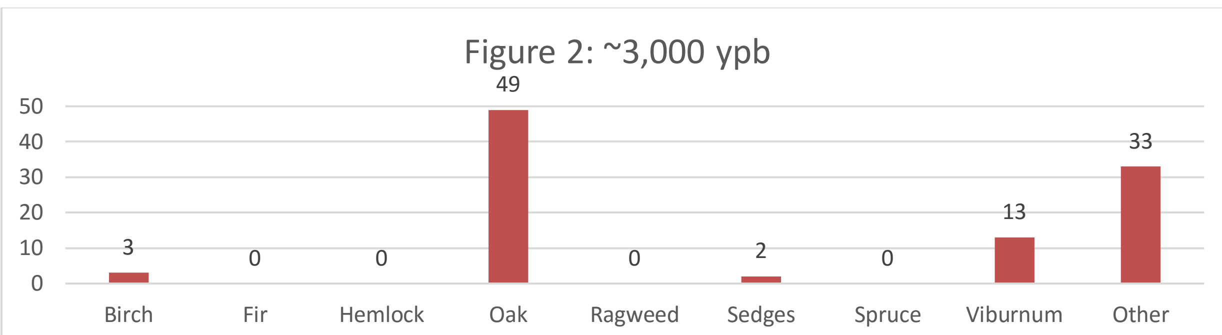
Note that lines regarding Persuasion (lines 4a and 4) of the rubric are addressed throughout the entire student response.

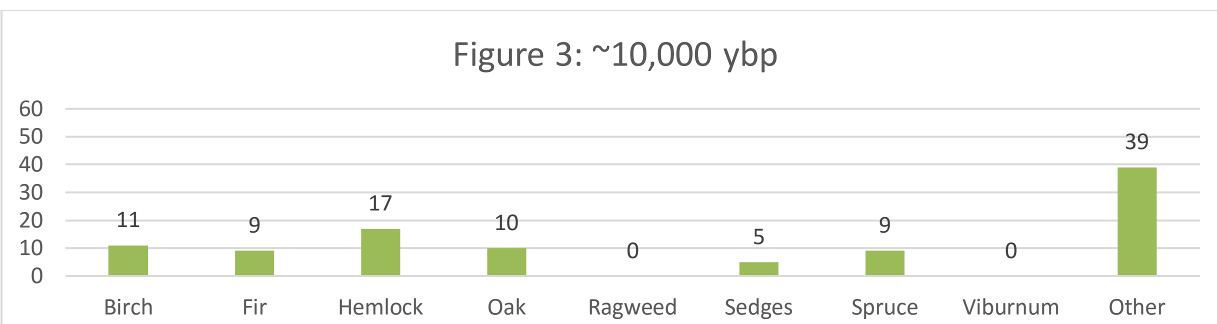
8 Taxa Analysis (Birch, Fir, Hemlock, Oaks, Ragweed, Sedges, Spruce and Viburnum)

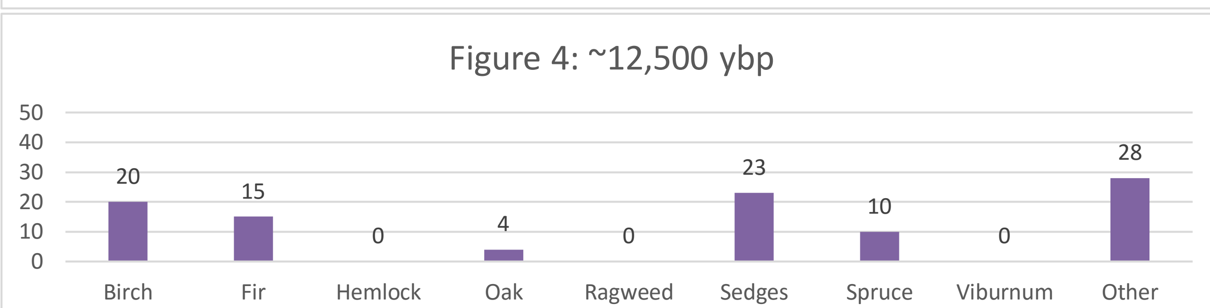
Claim: The climate changed between 12,500 ybp and 340 ybp. The climate was cold and wet at 12,500 ybp and became warmer and drier (but still somewhat moist) over time. At ~340 ybp the region around where the sediment core was samples contained a mixture of forest and disturbed land.

Evidence: (the scientific data you collected that support your claim)









Birch, fir and spruce trees and sedges are most abundant in the time period ~12,500 ybp (Figure 4), less abundant in time period ~10,000 ybp (Figure 3) and either at very low numbers or absent in time periods ~3,000 ybp (Figure 2) and ~340 ybp (Figure 1).

Hemlock only appears in the sample from ~10,000 ybp (Figure 3).

There are a few oaks (4%) in the sample from time period ~12,500 ybp (Figure 4) but the abundance of oaks increases in the more recent samples. Oaks are 10% of the sample from ~10,000 ybp (Figure 3) and increase even more in samples from periods ~3,000 (ybp) and ~340 ybp (Figures 2 and 1).

Ragweed is only present in the most recent sample from ~340 ybp (Figure 1).

Viburnum only appears in two most recent samples ~3,000 (ybp) and ~340 ybp (Figures 2 and 1).

Reasoning (your explanation for how the evidence supports your claim):

All living organisms, including plants, have certain habitat requirements to grow, survive, and reproduce. Temperature and moisture are two such conditions that can affect which plants can grow, survive and reproduce in any location. Some plants can tolerate a wide range of temperature and moisture conditions, while others can only survive in a narrow range of conditions. If pollen is found in different sediment layers that have been determined to be from a specific time periods, and it is known what types of climatic conditions specific plants can, and cannot survive in, then the climate conditions at a particular time period can be inferred from the types of pollen present (and possibly from the types of pollen that were present in a samples from some period of time but are not present in other samples).

The graphs above provide profiles of pollen from different types of plants from four time periods (~12,500 ybp, ~10,000 ybp, ~3000 ybp and ~340 ybp). The abundance and/or presence of plant taxa change in each sampled time period, providing evidence that climate (long term temperature and precipitation values) changed throughout the time periods, although not all plants were affected the same way. While a single taxon cannot tell the entire story, each taxon and its pattern over time is a piece of evidence and together they can be used to understand the change in the climate.

Birch, fir and spruce trees and sedges are typical of ‘boreal forests’ which are forests that only are found areas that are both very wet and cold. Their decline in the 10,000 ybp sample and further decline or absence in the samples from 3,000 and 340 ybp suggests the climate was coldest and wettest ~12,500 ybp, and became and warmer and dryer in the more recent time periods.

Hemlock does best in cool (but not very cold) and moist climates. Therefore, the presence of hemlock in the sample from ~10,000 ybp provides evidence that the climate at this time was moist and cool. This is idea is supported by the change in fir, spruce, birch and sedges described earlier. The decrease in pollen from plants (they can live but they are getting less dense) which need very cold and wet habitat (fir, birch, spruce and sedges) and the appearance of hemlock that needs cool and wet provides evidence that supports the claim that the climate at ~10,000 ybp was moist and cool, but not too cold. The warming (becoming less cold) that allowed the hemlock to grow also helped the oaks to increase their numbers.

Oak trees are fairly adaptable and can live in places that are not optimal for them. In these samples, the oaks increase as the birch, fir, spruce and sedges disappear. Oaks do best in warmer and moist, but not wet, environments. The change in the abundance of oaks, their increase and their remaining high suggests that the area is getting warmer and warmer but staying moist as the percentage of oaks increases and stays high.

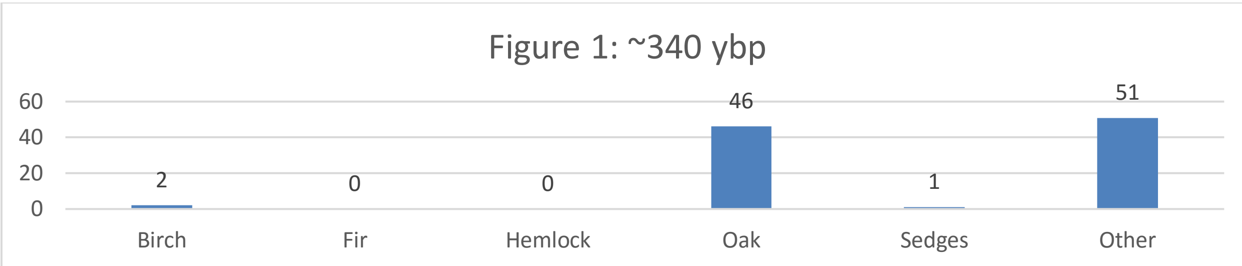
Ragweed doesn't occur in forests at all, as it is a plant that grows on roadsides and in farm fields or places where there is a lot of disturbance. The presence of ragweed only in the most recent sample (~340 ybp) suggests there had been a change in or near the forest and the land is being disturbed (possibly by deforestation and agriculture by humans).

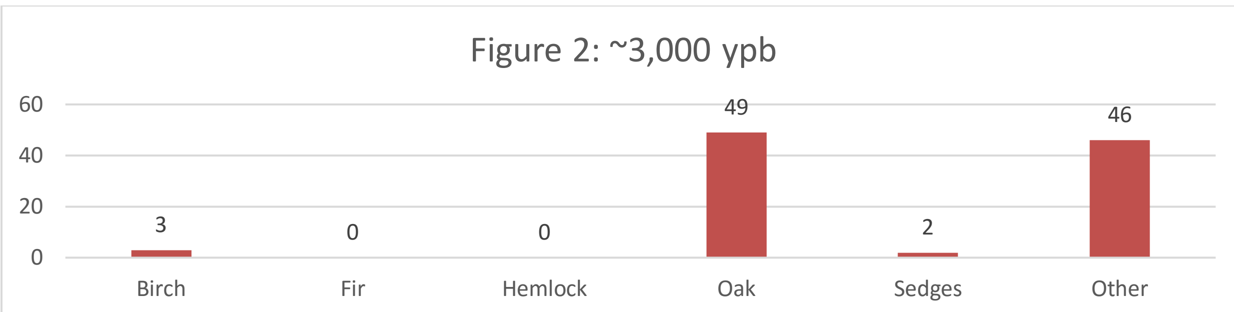
In forests, viburnum usually grows under deciduous trees and oaks are the only deciduous tree ever abundant in this area (based on pollen from the sediment sample) suggesting that during these periods, ~3,000 ybp and ~340 ybp, it was warm enough for there to be lots of deciduous trees and therefore viburnum could also grow.

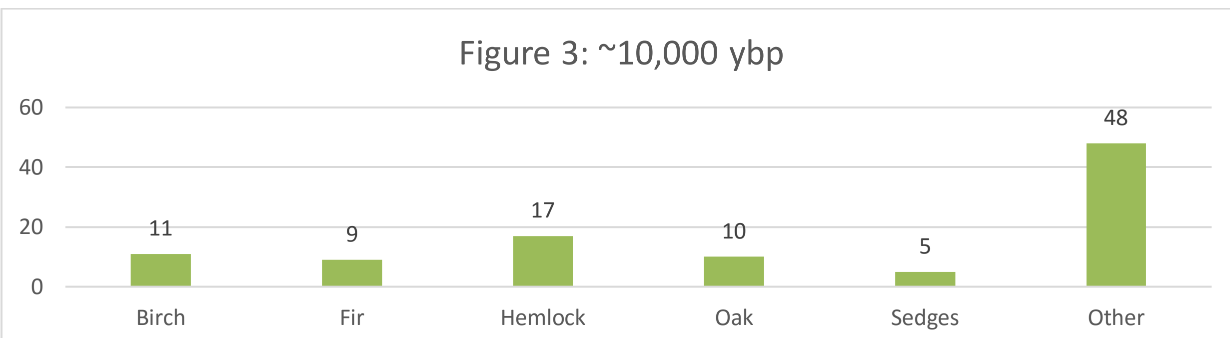
5 Taxa Analysis (Birch, Fir, Hemlock, Oaks and Sedges)

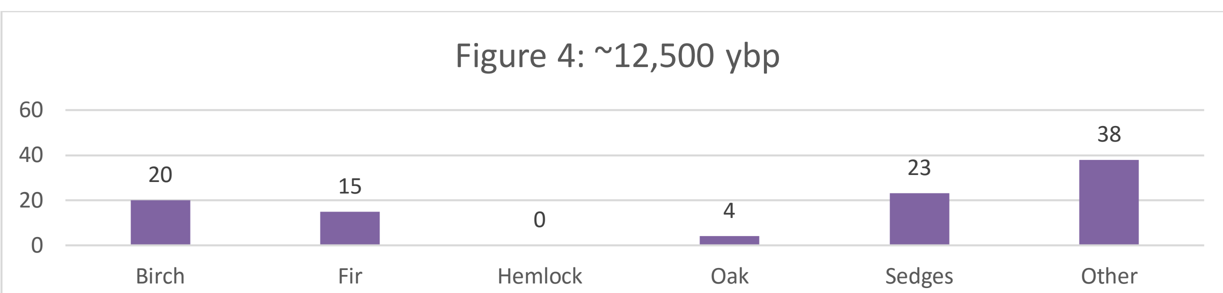
Claim: The climate changed between 12,500 ybp and 340 ybp. The climate was cold and wet at 12,500 ybp and became warmer and drier (but still somewhat moist) over time.

Evidence: (the scientific data you collected that support your claim)









Birch and fir trees and sedges are most abundant in the time period ~12,500 ybp (Figure 4), less abundant in time period ~10,000 ybp (Figure 3) and either at very low numbers or absent in time periods ~3,000 ybp (Figure 2) and ~340 ybp (Figure 1).

Hemlock only appears in the sample from ~10,000 ybp (Figure 3).

There are a few oaks (4%) in the sample from time period ~12,500 ybp (Figure 4) but the abundance of oaks increases in the more recent samples. Oaks are 10% of the sample from ~10,000 ybp (Figure 3) and increase even more in samples from periods ~3,000 (ybp) and ~340 ybp (Figures 2 and 1).

Reasoning (your explanation for how the evidence supports your claim):

All living organisms, including plants, have certain habitat requirements to grow, survive, and reproduce. Temperature and moisture are two such conditions that can affect which plants can grow, survive and reproduce in any location. Some plants can tolerate a wide range of temperature and moisture conditions, while others can only survive in a narrow range of conditions. If pollen is found in different sediment layers that have been determined to be from a specific time periods, and it is known what types of climatic conditions specific plants can, and cannot survive in, then the climate conditions at a particular time period can be inferred from the types of pollen present (and possibly from the types of pollen that were present in a samples from some period of time but are not present in other samples).

The graphs above provide profiles of pollen from different types of plants from four time periods (~12,500 ybp, ~10,000 ybp, ~3000 ybp and ~340 ybp). The abundance and/or presence of plant taxa change in each sampled time period, providing evidence that climate (long-term temperature and precipitation values) changed throughout the time periods, although not all plants were affected the same way. While a single taxon cannot tell the entire story, each taxon and its pattern over time is a piece of evidence and together they can be used to understand the change in the climate.

Birch and fir trees and sedges are typical of 'boreal forests' which are forests that only are found areas that are both very wet and cold. Their decline in the 10,000 ybp sample and further decline or absence in the samples from 3,000 and 340 ybp suggests the climate was coldest and wettest ~12,500 ybp, and became and warmer and dryer in the more recent time periods.

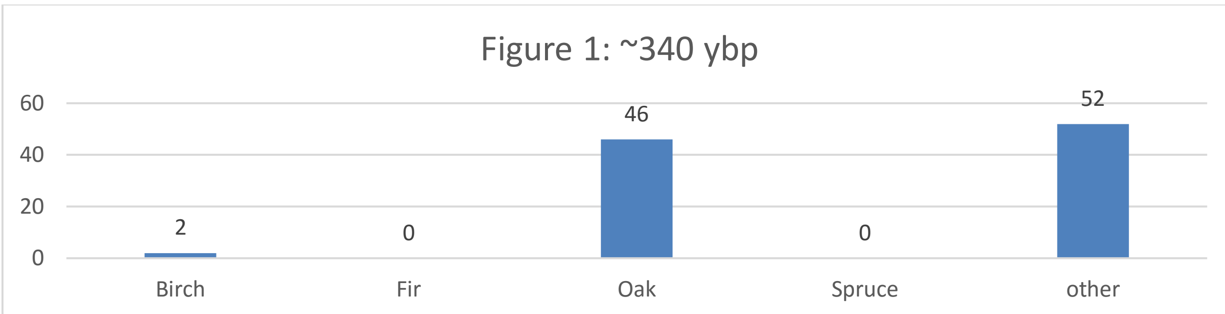
Hemlock does best in cool (but not very cold) and moist climates. Therefore, the presence of hemlock in Sample 2 provides evidence that the climate at this time was moist and cool. This is idea is supported by the change in fir, birch and sedges described earlier. The decrease in pollen from plants (they can live but they are getting less dense) which need very cold and wet habitat (fir, birch and sedges) and the appearance of hemlock that needs cool and wet provides evidence that supports the claim that the climate at ~10,000 ybp was moist and cool, but not too cold. The warming (becoming less cold) that allowed the hemlock to grow also helped the oaks to increase in number.

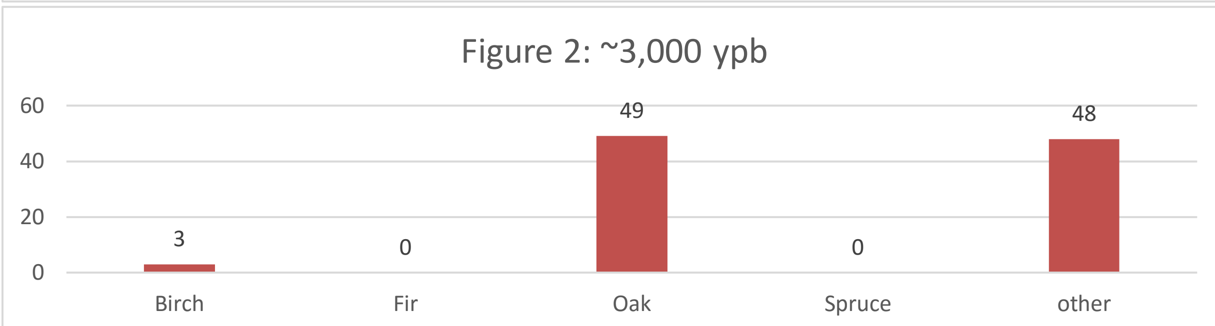
Oak trees are fairly adaptable and can live in places that are not optimal for them. In these samples, the oaks increase as the birch, fir and sedges disappear. Oaks do best in warmer and moist, but not wet, environments. The change in the abundance of oaks, their increase and their remaining high suggests that the area is getting warmer and warmer but staying moist as the percentage of oaks increases and stays high.

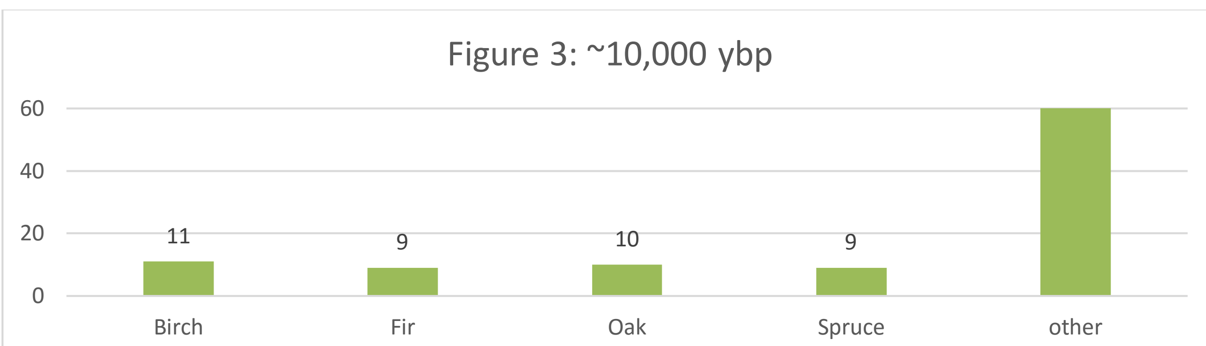
4 Taxa Analysis (Birch, Fir, Oaks and Spruce)

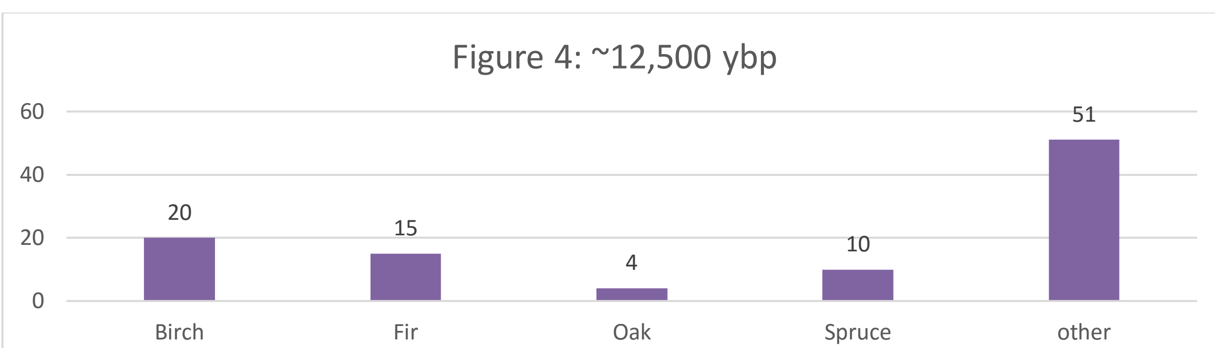
Claim: The climate changed between 12,500 ybp and 340 ybp. The climate was cold and wet at 12,500 ybp (sample 1) and became warmer and drier (but stayed somewhat moist) over time.

Evidence: (the scientific data you collected that support your claim)









Birch, fir and spruce trees are most abundant in the time period ~12,500 ybp (Figure 4), less abundant in time period ~10,000 ybp (Figure 3) and either at very low numbers or absent in time periods ~3,000 ybp (Figure 2) and ~340 ybp (Figure 1).

There are a few oaks (4%) in the sample from time period ~12,500 ybp (Figure 4) but the abundance of oaks increases in the more recent samples. Oaks are 10% of the sample from ~10,000 ybp (Figure 3) and increase even more in samples from periods ~3,000 (ybp) and ~340 ybp (Figures 2 and 1).

Reasoning (your explanation for how the evidence supports your claim):

All living organisms, including plants, have certain habitat requirements to grow, survive, and reproduce. Temperature and moisture are two such conditions that can affect which plants can grow, survive and reproduce in any location. Some plants can tolerate a wide range of temperature and moisture conditions, while others can only survive in a narrow range of conditions. If pollen is found in different sediment layers that have been determined to be from a specific time periods, and it is known what types of climatic conditions specific plants can, and cannot survive in, then the climate conditions at a particular time period can be inferred from the types of pollen present (and possibly from the types of pollen that were present in a samples from some period of time but are not present in other samples).

The graphs above provide profiles of pollen from different types of plants from four time periods (~12,500 ybp, ~10,000 ybp, ~3000 ybp and ~340 ybp). The abundance and/or presence of plant taxa change in each sampled time period, providing evidence that climate (long term temperature and precipitation values) changed throughout the time periods, although not all plants were affected the same way. While a single taxon cannot tell the entire story, each taxon and its pattern over time is a piece of evidence and together they can be used to understand the change in the climate.

Birch, fir and spruce trees are typical of 'boreal forests' which are forests that only are found areas that are both very wet and cold. Their decline in the 10,000 ybp sample and further decline or absence in the samples from 3,000 and 340 ybp suggests the climate was coldest and wettest ~12,500 ybp, and became and warmer and dryer in the more recent time periods.

Oak trees are fairly adaptable and can live in places that are not optimal for them. In these samples the oaks increase as the birch, spruce and fir disappear. Oaks do best in warmer and moist, but not wet, environments. The change in the abundance of oaks, their increase and their remaining high suggests that the area is getting warmer and warmer but staying moist as the percentage of oaks increases and stays high.

Overall, the high abundance of plants that only do well when it is very cold and very wet at the earliest time period and their decrease over time along with the increase in a plant that does best in warmer climates says that in this area the climate change from one that was cold and wet to one that was warmer.

Appendix L. Answers to Questions on Student Handouts (Middle and High School Versions)

1. Write down at least 3 observations about the cartoon.

- *The fish is holding a long object.*
- *There is a hole in the container*
- *The fish's eyes are wide.*
- *Etc.*

There will likely be many students who initially wrote inferences (e.g. the fish is holding a bat, the fish is surprised) instead of observations.

2a. Students will check which of the four topics they have been assigned to read about in the jigsaw.

2b. Students will write notes from each of the Background resource cards in the placemat graphic organizer on page 2 of their handout.

2c. Students will verbally share in their sharing groups what they learned from reading about their topic in their expert groups.

2d. As a group, answer the question in the middle of the paper "*How can we infer past climates from the plants that were growing in an area?"* Remember, you'll need to use information from all the topics to fully answer this question.

Answers should draw on information from each of the expert groups. Students should conclude that scientists can use proxy data as evidence, in the form of pollen, to infer what types of plants used to be in an area. The types of plants present provides information on what the climate used to be like, as plant communities reflect local climate.

3. What does ybp mean?

YBP means "years before present.

4. On your white board, create a table for the data you will be collecting from your sediment sample.

Data tables may vary. Ideally, they should include a place to collect the following information:

- Time period being sampled
- Counts for beads of each color
- Pollen type (based on bead color key)
- Percentage of type of pollen

5. After collecting your data, use the Plant Characteristics table to help you identify the type of plant each pollen grain comes from.

Bead color corresponds to plant type. This information can be found on the *Plant Characteristics Table* (Appendix D and E) and the Plant Characteristics Cards.

6. Calculate the percentage of each type of pollen you collected in your sample and record it on your data table.

Percentage is calculated by dividing the number of each bead color by the total number of beads in sample. Actual answers may vary due to sorting and counting error, but general percentages can be found in table below. General patterns will remain the same, even if students are off by a few percentages.

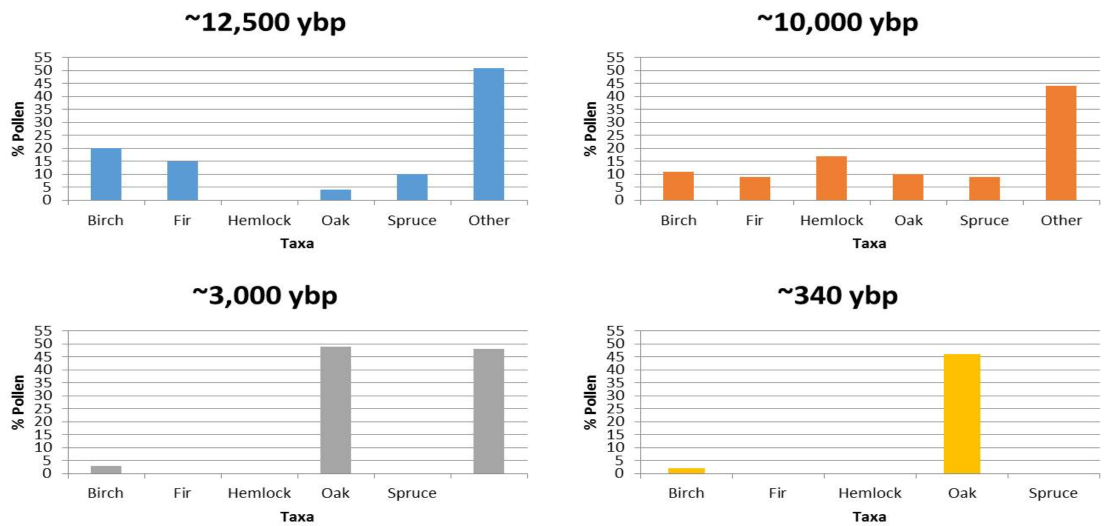
Bead color	Taxa	~12,500 ybp	~10,000 ybp	~3,000 ybp	~340 ybp
red	Alder	18%	15%	24%	16%
white	Birch	20%	11%	3%	2%
yellow	Fir	15%	9%	0%	0%
green	Hemlock	0%	17%	0%	0%
black	Oak	4%	10%	49%	46%
brown	Pine	10%	24%	9%	10%
blue	Ragweed	0%	0%	0%	14%
purple	Sedges	23%	5%	2%	1%
orange	Spruce	10%	9%	0%	0%
pink	Viburnum	0%	0%	13%	11%

7. Copy your data onto the class data table that will be shared with the whole class. Copy the whole class data table below.

We suggest having students copy the class data set into their student packet so they have the information if they need to work on the analysis outside of class time.

8. Graph the Data

Students should create their own graphs in their student packets. Example graphs are shown below.



Percentage of pollen from five taxa found in sediment cores samples at ~12,500, ~10,000, ~3,000 and ~340 ybp.

9. Now that your group has graphs for each time period sampled, it is time to begin analyzing and interpreting the data. First, write the driving question that you are trying to answer below:

What was the climate like in the Anacostia watershed over the past 12,500 years?

10. *Students should be looking at their graphs and using information from the Plant Characteristics Table or Cards as they make sense of the data. They need to eventually come up with a claim that answers the driving questions (What was the climate like in the Anacostia watershed over the past 12,500 years?) and provide evidence and reasoning to support that claim. They can take notes in the CER graphic organizer as they find pieces of evidence and come up with reasoning.*

11. Using your data from the graph and the science ideas you have learned about, write a scientific argument to answer the driving question *What was this climate like in the Anacostia watershed over the past 12,500 years?* Develop your scientific argument by writing you Claim, Evidence and Reasoning in the graphic organizer below.

You can find examples of claims, evidence and reasoning in Appendices G and H.

12. Share your scientific argument with a partner from another group. Each of you will state your claim and explain your evidence and reasoning. Provide feedback on each other's scientific argument. You can use the rubric your teacher will provide to help you evaluate the argument.

Students can use the CER rubric (provided as laminated sheets) to assist in their peer review.

13. After receiving feedback and modifying your scientific argument, write your final scientific explanation for what the climate was like over the past 12,500 years in the space below.

You can find examples of claims, evidence and reasoning in Appendices G and H.

Middle School Version (Answers to high school version below)

14. Students are reading the Climate Change Past and Present passage.

15. Why is our climate changing so quickly now?

Our climate is changing so quickly because humans are releasing large amounts of carbon dioxide in the atmosphere. Carbon dioxide traps heat, which causes our planet to become warmer.

16. What are the effects of the fast rates of climate change we are currently experiencing?

The fast rate at which our climate is changing is causing:

- Increases in extreme weather events like storms and hurricanes
- Changes in the types of plants found in forests
- Changes in the types of food we are able to grow due to changes in climate and presence of pollinators

17. How would you respond if you heard someone say *"I heard that the climate has changed before and this current climate change we are talking about is just like that. So we don't have to be worried. It's the same thing".*

The climate has always been changing but changes we are seeing in recent times are much faster than we have seen in the past. We also know that the increased release of carbon dioxide gas into the atmosphere by humans is what is causing current climate change. We should be concerned because the current rapid rate of climate change is affecting weather patterns and the type of food that farmers produce. These events are harmful to humans.

High School Version

Climate Change: Past and Present.

14. Students are analyzing and interpreting data from the graph depicting temperature anomaly over the past 22,000 years. Students are asked to write down any questions they may have about how to read and interpret the graph.

- *These questions will vary but may include:*
  - *What does temperature anomaly mean? What does temperature anomaly data represent?*
  - *What do the different colored lines refer to?*
  - *Why is the temperature increasing so rapidly in recent time?*

- *You should be able to find most of the answers to the student questions in Appendix H.*

15. Interpretation of graph of temperature anomaly over past 22,000 years.

- *See Appendix H (advanced version) and Appendix I (standard version) for explanation of the graph.*

16. Read the narrative that discusses the graph of temperature change over the past 22,000 years and answer the following questions.

a) Describe the rate of change in temperature over the past ~22,000 years and compare it to the rate of change in the 200 years since the industrial revolution.

The primary message from the figure is that the temperature has changed over the 22,000 years represented in the graph but the change was relatively gradual for most of this period—there was a change in one degree Celsius over the 4,000 years between 18,000 and 14,000 ybp. This contrasts markedly with the current (red) and projected (orange line) rates of change since the industrial revolution (the sharp increase at the right side of the graph starting ~200 ybp and projected ~100 years into the future). The recent rapid increase is attributed to the increase in carbon dioxide and other greenhouse gases that humans have been adding to the atmosphere. This increase in greenhouse gases is leading to very rapid warming of the globe. This most recent change and the projected change in the temperature is occurring at a rate that is much more rapid than changes seen in the past (~3 degrees Celsius over 12,000 years versus 3 degrees Celsius over 200 years).

b) Why has the Earth's temperature increased so dramatically in the last 200 years?

Increased CO_2 emissions from human-made sources. CO_2 is a greenhouse gas, which means it traps heat in the atmosphere. Since humans are emitting more CO_2, more heat is getting trapped and warming the earth globally.

c) Given that the Earth's climate has always been changing (consider the data you analyzed about the last 12,500 years), why is there so much concern about current climate change?

The current rate of change in climate is extremely rapid, much more rapid than the changes we examined in the past 12,500 years. In addition, the changes in our current climate are directly linked to increased greenhouse gas emissions in the atmosphere by humans. Since humans are continuing to emit high levels of greenhouse gases, our climate is only going to continue to warm. Evidence from past climate conditions show that rapidly changing climate can have disastrous effects on species and ecosystems (e.g. mass extinctions).

17. Watch the short video "How climate change is messing with bee's ability to pollinate" and answer the questions below. You may want to read the questions before watching the short video so you have an idea of big ideas to listen for.

a. What are the reasons for bees declining?

Several reasons are listed, including pesticides, human development, disease and climate change.

b. What is phenology? Provide a specific example of phenology.

The timing of when something occurs. For example, the timing of when a plant species typically flowers.

c. How are plant phenology, pollination and climate change related?

Climate change is affecting the timing (phenology) of flowering in plants. A warming climate can mean that plants are able to flower much earlier than normal. Plants rely on pollinators (such as bees and other insects that transfer pollen from one plant to another) to successfully reproduce. If the timing of flowing and availability of pollinators gets mismatched due to changing climates, flowers may not be able to reproduce and bees might lose an important source of food. This is a big problem for both the insects and the plants.

d. What experiment are the researchers in this video conducting?

They are changing the timing of when a plant flowers by removing snow cover, thereby allowing it to flower early. They do not manipulate the timing of the bees. They are then observing how early flowing affects fruit and seed production. They are interested in finding out what affect this might have on the reproduction of flowing plants.

e. What might happen to our native plants and our agriculture plants if the climate continues to change at its current rapid pace?

We may see a decline in native plants and agricultural food plant production due to a decrease in pollination

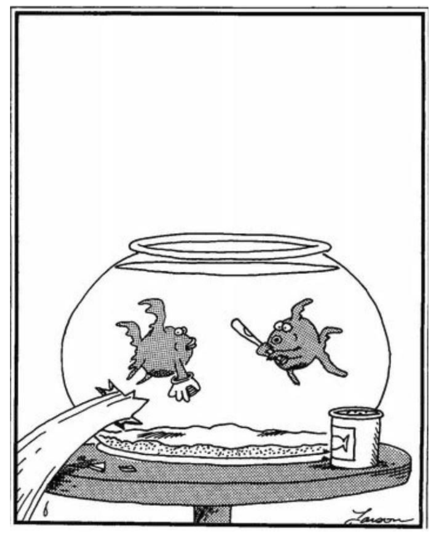
Appendix M. Middle School Student Handouts

Student hand-outs being on next page.

Looking Backward, Looking Forward

Driving Question: What was the climate like in the Anacostia watershed over the past 12,500 years?

Over the next few days, you will be acting as paleoclimatologists (scientists who study past climate) to answer the driving question *What was the climate like in the Anacostia watershed over the past 12,500 years?* In order to answer this question, you will need to work collaboratively, learn some background information, collect data and analyze and interpret the data. You will use everything you learn to write a scientific argument to answer this question.



Observation and Inference

1. Write down at least 3 <u>observations</u> about the cartoon.

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Inferring past climates from the plants that were growing in an area?

2. Jigsaw with Research Information.
   a. Check the topic you are assigned in your research (expert) group
      - ☐ Pollen
      - ☐ Plant Communities
      - ☐ Sediment Cores
      - ☐ Proxy Data

   b. Record your notes in the appropriate section in the diagram on the next page.

   c. Share what you have learned in your expert group with you group members in your sharing group. Take notes about each topic in the diagram on the next page.

   d. As a group, answer the question in the middle of the paper "*How can we infer past climates from the plants that were growing in an area?*" Remember, you'll need to use information from all the topics to fully answer this question.

Pollen

How can we infer past climates from the plants that were growing in an area?

Plant Communities

Sediment Cores

Proxy Data

Driving Question: What was the climate like in the Anacostia Watershed over the 12,500 years?

Collect data: You will work with your "expert group" from yesterday to collect data from one time period

3. Check your time period below you are assigned. What does ybp mean? ___________________

    i. ~12,500 ybp
    ii. ~10,000 ybp
    iii. ~3,000 ybp
    iv. ~340 ybp

4. On your white board, create a table for the data you will be collecting from your sediment sample.

5. After collecting your data, use the Plant Characteristics Cards or the Plant Characteristics table at the back of this packet to help you identify the type of plant each pollen grain comes from.

6. Calculate the percentage of each type of pollen you collected in your sample and record it on your data table.

7. Copy your data onto the class data table that will be shared with the whole class. Copy the whole class data table below.

Driving Question: What was the climate like in the Anacostia watershed over the past 12,500 years?

8. Create a bar graph for each of the time periods you have data. Here are some suggestions for creating your graphs that will make analyzing and interpreting the patterns on the graphs easier.

   a. You should include a category for each type of pollen, even if there were none counted in a sample.
   b. Each graph should use the same scale for percentage of pollen.
   c. Graph the types of pollen in the same order. Consider arranging them alphabetically.
   d. Label your graph appropriately (title, x-axis, y-axis, units).

Analyzing and Interpreting Data

9. Now that your group has graphs for each time period sampled, it is time to begin analyzing and interpreting the data. First, write the driving question that you are trying to answer below:

____

10. Now, you will need to:
    - ☐ Look for patterns in the data. Do percentages of some types of pollen change over time? Do some disappear altogether? Do some appear?
    - ☐ Learn about what climate (temperature and moisture) that each pollen type requires by reading the information on the *Plant Characteristics Cards or Plant Characteristics Table* (found at the end of this packet). Do you notice changes over time in what types of plants are represented?

Construct a Scientific Argument

11. Using your data from the graph and the science ideas you have learned about, write a scientific argument to answer the driving question *What was this climate like in the Anacostia watershed over the past 12,500 years?* Develop your scientific argument by writing you Claim, Evidence and Reasoning in the graphic organizer below.

<table>
<tr><td colspan="2">Claim:</td></tr>
<tr><td>Evidence</td><td>Reasoning:</td></tr>
</table>

Answering the question: ***What was this climate like in the Anacostia watershed region over the past 12,500 years?***

Peer Review of Scientific Argument

12. Share your scientific argument with a partner from another group. Each of you will state your claim and explain your evidence and reasoning. Provide feedback on each other's scientific argument. You can use the rubric your teacher will provide to help you evaluate the argument.
13. After receiving feedback and modifying your scientific argument, write your final scientific explanation for what the climate was like over the past 12,500 years in the space below.

14. Read the following passage and answer the Discussion Questions.

Climate Change Past and Present

Why is current Climate Change a Problem?

You have probably heard that our climate is changing. Maybe you talked about it in school or heard about it on the news or from your friends and family. And you just learned from your investigation that the climate in Maryland has changed over the past 12, 500 years.

So if Earth's climate has changed before, why are we so worried about current changes to climate? There are several very important reasons. First, our climate is changing at an incredibly fast rate, much faster than has happened before. Secondly, people are the cause which means we can do something about it. Humans are releasing large amounts of CO_2 into the atmosphere when we burn fossil fuels which we use to run our cars and to produce electricity to run our homes and factories. Since CO_2 is a greenhouse gas, more CO_2 in the atmosphere means more heat is trapped, causing our planet to warm. Thirdly, we know that changing climates can have all sorts of consequences, including increases in extreme weather events, like hurricanes and tropical storms in addition to changing the types of plants in a forest if the change occurs very, very slowly. Changing climate can also affect how we produce food since plants grow best under certain conditions and climate change will alter the local conditions. For example, changes in climate can affect the presence of pollinators, such as bees, which can in turn affect the types of food that farmers can grow.

What can we all do about Climate Change?

Scientists all over the world are working to address issues of climate change and reducing the amount of carbon dioxide in the atmosphere. Some are studying ways to decrease the amount of carbon humans release into the air (by building hybrid and electric cars, or working to capture wind and solar power). Others are trying to find ways to reduce the amount of CO_2 that is already in the atmosphere (by planting more trees that will absorb carbon dioxide).

You can do your part by reducing your carbon 'footprint'. That is, you can reduce the amount of carbon dioxide you release into the air by saving energy all the time. You can ride your bike instead of asking someone to drive you, support alternative fuel sources such as solar and wind power, you can help recycle items rather than toss them into the trash, you can help plant trees near your home. You can also become a scientist and work with other scientists to solve the problems associated with our changing climate.

Discussion Questions

15. Why is our climate changing so quickly now?

16. What are the effects of the rapid rates of climate change we are currently experiencing?

17. How would you respond if you heard someone say *"I heard that the climate has changed before and this current climate change we are talking about is just like that. So we don't have to be worried. It's the same thing".*

Plant Characteristics Table

Taxon (bead color)	Temperature	Moisture	Description and Growth requirements
Alder (red)	Tolerant of hot and cold	Along river banks	A small deciduous tree or shrub that can tolerate both temperate (mean temperatures of 50°F, summers hot, winters cold) as well as colder boreal conditions (average temperature about 32°F, summers are very short). Alders are found along river banks and the presence of sufficient local water critical for them.
Birch (white)	Cold	Moist	Birch trees are deciduous and like cold area—many of the current forests of northern Russia are birch forests. In general birches can be found in alpine, boreal climates (cold and moist).
Fir (yellow)	Cold	Moist	An evergreen tree often sold as a Christmas tree. Firs are now naturally found at either very high altitude up on mountains or in the far north at high latitudes where the environment is generally cold and moist.
Hemlock (green)	Cool (not too cold, not too hot)	Moist	Hemlocks are another evergreen tree that does best in moist conditions but needs temperatures that are cool not cold, conditions that are warmer than those found in alpine conditions. Small pockets of hemlock forests exist on the east coast in special spots that are very shaded, moist and usually near rivers.
Oak (black)	Warm (can survive in cold)	Not too wet, not too dry	Oaks are a very common deciduous tree in eastern forests and do best in temperate climates although they can survive in cooler climates. They like mesic (not too wet and not too dry) moisture levels
Pine (brown)	Tolerant of hot and cold	Moist or dry	Pine is an evergreen tree that can tolerate a range of environments. It grows in a cool moist area or a warm dry one. They often occur in forests in low numbers and then expand in number when other species can no longer grow because of a change in the environment.
Ragweed (blue)	Anywhere in temperate zone	Range of moisture levels	The pollen from ragweed, a low growing annual herbaceous plant, is a major cause of hay fever. Ragweed can grow anywhere in the temperate zone and even grows in Canada and Alaska. It can take a range of moisture levels. It is found growing in highly disturbed areas and is associated with agriculture. You do not see it in forests but it is common in abandoned fields, at the edges of farm fields and along roadsides. You find it in places where farms replaced forests.
Sedges (purple)	Cool	Moist	Sedges appear in a quick glance to look ‘sort of’ like grasses but they have triangular stems not round stems (‘sedges have edges’). Fossil pollen from sedges is interpreted to mean cool and wet alpine or boreal habitat. They did best with cool summers, short growing seasons and cold winters.
Spruce (orange)	Cold	Moist	Spruce, also an evergreen tree, is a species that is found in the tundra, a boreal habitat. Boreal habitats are mostly cold and moist with short cool summers and cold long winters.
Viburnum (pink)	Tolerant of hot and cold	Moist	Viburnums are generally forest understory plants that produce large clusters of flowers in mid-spring. While they like full sun they can grow in partial shade. This might explain why we see them commonly in forests with deciduous trees (trees that drop their leaves over winter) so the limbs are bare in early spring and the sun can reach the understory plants.
* A taxon is a group of related species, the plural of taxon is taxa. “Canids” or dogs for example can include wolves as well as house pets and coyotes.			

Appendix N. High School Student Handouts

Student hand-outs being on next page.

Looking Backward, Looking Forward

Driving Question: What was the climate like in the Anacostia watershed over the past 12,500 years?

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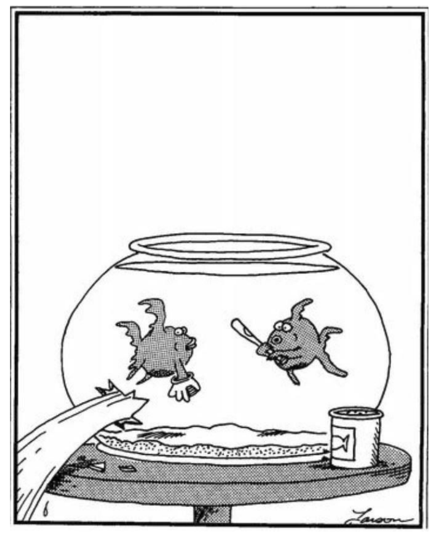

Observation and Inference

1. Write down at least 3 observations about the cartoon.

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Inferring past climates from the plants that were growing in an area?

2. Jigsaw with Research Information.
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   e. Record your notes in the appropriate section in the diagram on the next page.

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   g. As a group, answer the question in the middle of the paper "*How can we infer past climates from the plants that were growing in an area?"* Remember, you'll need to use information from all the topics to fully answer this question.

Pollen

How can we infer past climates from the plants that were growing in an area?

Plant Communities

Sediment Cores

Proxy Data

Driving Question: What was the climate like in the Anacostia Watershed over the 12,500 years?

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Claim:	
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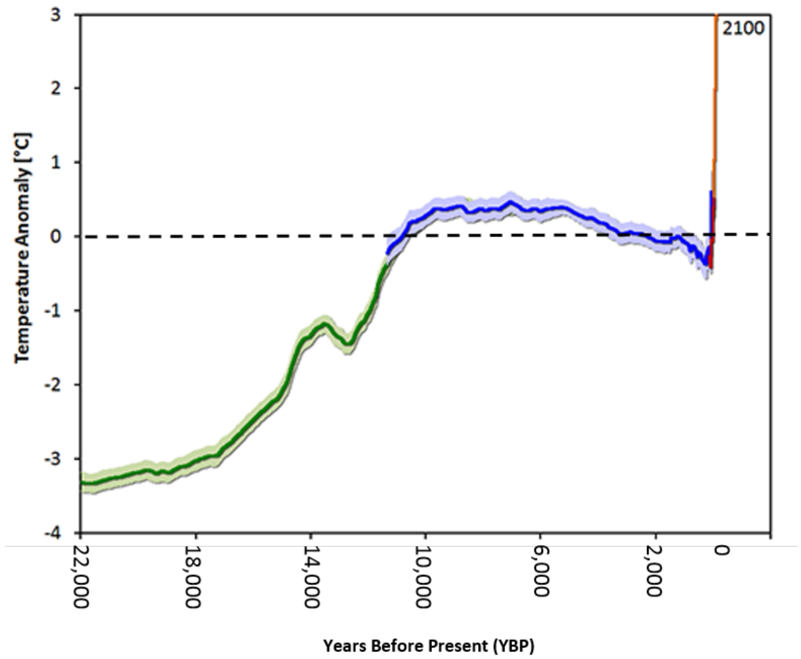
Answering the question: ***What was this climate like in the Anacostia watershed region over the past 12,500 years?***

Peer Review of Scientific Argument

12. Share your scientific argument with a partner from another group. Each of you will state your claim and explain your evidence and reasoning. Provide feedback on each other's scientific argument. You can use the rubric your teacher will provide to help you evaluate the argument.
13. After receiving feedback and modifying your scientific argument, write your final scientific explanation for what the climate was like over the past 12,500 years in the space below.

Climate Change: Past and Present

14. Consider the graph to the right. Using what you know about reading graphs, try to interpret this graph. You may have some questions you need answered about thing you don't understand. That's okay. For now, write those questions down and we'll answer them as a class.



This figure, often referred to as the 'wheelchair' because of its shape, was created by Jos Hagelaars. The colors on the graph represent the three sources of the data. Modified from image accessed at https://ourchangingclimate.wordpress.com/2013/03/19/the-two-epochs-of-marcott/.

   a. Questions we have about the graph:

   b. Now share your questions with the class and write the answers to your questions above.

15. After getting your questions about the graph answered, write your interpretation of the graph below.

16. Read the narrative that discusses the graph and answer the following questions.

    a) Describe the rate of change in temperature over the past ~22,000 years and compare it to the rate of change in the 200 years since the industrial revolution.

    b) Why has the Earth's temperature increased so dramatically in the last 200 years?

    c) Given that the Earth's climate has always been changing (consider the data you analyzed about the last 12,500 years), why is there so much concern about current climate change?

17. Watch the short video “How climate change is messing with bee’s ability to pollinate” and answer the questions below. You may want to read the questions before watching the short video so you have an idea of big ideas to listen for.

a. What are the reasons for bees declining?

b. What is phenology? Provide a specific example of phenology.

c. How are plant phenology, pollination and climate change related?

d. What experiment are the researchers in this video conducting?

e. What might happen to our native plants and our agriculture plants if the climate continues to change at its current rapid pace?

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