TREES ON THE MOVE: *CAN MAPLES AND BUCKEYES MIGRATE?*

(Background and Teacher Guide)

When we think about changing climates and their impact on biological diversity, we most often think of animals as the types of organisms that are threatened. But plants too will encounter climate changes and have to adapt or perish. Where the vegetation consists of crops that people plant, we can expect that people will just try to plant them elsewhere or find a better crop for the new climate. With forest vegetation, it's a different story. Trees can't migrate very rapidly to the places where climate is favorable! In past ice ages, the changes in climate were slow and some evergreen tree species were able to migrate south in front of the glaciers as they advanced. The climate changes we face with global warming are likely to occur much faster than that, and trees may not be able to "make their move" in time to survive.

This set of 4 lessons for midde and high school focuses on sugar maple and buckeye trees as species that will be affected by climate change.

- The sugar maple is the most important of the maples. It may reach a height of 135 feet (41 meters) and have a trunk diameter of 5 feet (1.5 meters). It has gray bark and dark green leaves. In autumn the leaves turn to beautiful yellow, orange and red. In addition to the maple syrup we get from these trees, the wood of the sugar maple is prized because it is heavy, hard, and takes a fine polish. The wood is used for furniture, flooring and cabinet work. It makes a good fuel wood because it is dense and burns hot for a long time.

- The buckeye is a small deciduous tree in the horse chestnut family. It may reach a height of 60 feet (18 meters), but is usually only half that size, with a diameter of 3-5 feet (1 to 1.5 m). It grows mainly in the Midwest and Great Plains states, especially where the soils are deep, fertile, and more alkaline in pH. Leaves of Ohio Buckeye become very prone to scorching, discoloration, and foliar diseases by mid-summer. Its wood is harvested for pulp today; in the past the lightweight wood was used for furniture, crates, pallets, caskets, and artificial limbs. The seed resembles the eye of a deer, and holding a "buckeye nut" in one's pocket is considered good luck.

The sugar maple leaf is the national emblem of Canada because of the tree's importance to the Canadian economy. Eastern Canadian forests contribute $14 billion to the nation's economy and maple syrup production adds another $36 million. The leaf forms the centerpiece of the Canadian flag (Figure 1).

The buckeye is the state tree of Ohio and the people of Ohio are called Buckeyes. According to the Ohio Department of Natural Resources, "In 1840, Gen. William Henry Harrison was elected President of the United States. During his campaign, buckeye wood cabins and buckeye walking sticks became emblems of Ohio's first citizen to win the highest office in the land. This forever set Ohioans apart as 'Buckeyes.'" Today The Ohio State University claims the buckeye as its symbol as well.

Figure 1: Canadian Flag with Sugar Maple symbol; Logo for The Ohio State University, with Buckeye

This activity set helps students examine the climate niches of the sugar maple *Acer saccharum* and the Ohio buckeye *Aesculus glabra*, and see how some global climate models predict those niches are likely to change. We will observe examples of how plants migrate, and predict some possible impacts on the North American economy and culture as maple and buckeye ranges shift. Finally, examination of research on tree seed germination offers insight on one way temperature affects trees.

ALIGNMENT

National Framework for K-12 Science Education:
CC4: Systems and system models
CC7: Stability and change
Core Idea LS2: Ecosystems: Interactions, Energy and Dynamics
Core Idea LS4: Biological Evolution: Unity and Diversity

Great Lakes Literacy Principles:

3E. The Great Lakes are influenced by larger climate change patterns affecting North America and the world. Climate patterns in the Great Lakes are changing, with warmer and drier conditions predicted.

7A: Exploration and understanding of Great Lakes interactions and links among diverse ecosystems and people are ongoing. Such exploration offers great opportunities for inquiry and investigation.

Climate Literacy Principles:

3A: Individual organisms survive within specific ranges of temperature, precipitation, humidity, and sunlight. Organisms exposed to climate conditions outside their normal range must adapt or migrate, or they will perish.

7E: Ecosystems on land and in the ocean have been and will continue to be disturbed by climate change. Animals, plants, bacteria, and viruses will migrate to new areas with favorable climate conditions. Infectious diseases and certain species will be able to invade areas that they did not previously inhabit.

Lesson overview

Activity A: What do climate models predict about tree ranges?

This lesson introduces examples of how General Circulation Models [GCMs] predict possible scenarios of climate change. Three methods of visualizing change are introduced and students compare how sugar maples and buckeye trees' climate niches are likely to be altered.

Activity B: How can trees migrate?

The seeds of maples and buckeyes are "dispersed" in an outdoor simulation of how far a tree species might be able to spread over several tree generations.

Activity C: How does temperature affect maple seed germination?

Students examine research data on seed germination at different temperatures to infer some of the impacts of temperature on species survival.

Activity D: After the maples, then what?

Students study an outdoor area that has sugar maples and other species. Following research methods of Catherine Keever, they catalog the size and relative abundance of species in the plot and infer what species is likely to succeed if maples disappear.

Original lessons A and B were contributed by Ohio teachers Christina Pryor and Linda Floehr. They were originally published in Ohio Sea Grant's *Great Lakes Instructional Materials for the Changing Earth System [GLIMCES]*, EP-080. Lesson C was contributed by Chicago teacher Lyudamila Shemanyika. Lesson D was developed by Rosanne Fortner and Tony Murphy and was published in NSF's *Activities for the Changing Earth System [ACES]*. All lessons revised in 2012 by Rosanne W. Fortner.

Teacher Activity A: What do climate models predict about tree ranges?

This lesson introduces examples of how General Circulation Models [GCMs] predict possible scenarios of climate change. The lesson may be done as a demonstration with Internet sites projected for discussion; alternatively, if technology is available, small groups can work together to answer the questions.

Objectives: After completing this lesson, students should be able to:

1. Explain what is meant by a plant's climate niche
2. Using maps of climate scenarios, describe how the climate niches of regional trees are likely to be altered by climate change

Materials: Internet access, Student worksheet (one per student or team)

Time required: 1-2 class periods

BACKGROUND

Watch the archived webinar presentation by Steve Matthews, on "Regional Impacts of Climate Change on Forests and Bird Communities" at ***http://changingclimate.osu.edu/webinars/archives/2011-09-29***.

Today's weather map is at ***http://www.hpc.ncep.noaa.gov/dailywxmap/***. At that link it is possible to compare local conditions with national patterns and see how current conditions [weather] compare with longterm averages [climate].

The fundamental niche of a species is the set of environmental conditions within which a species can survive and persist. It includes both physical conditions and ecological relationships. When scientists look at the potential scenarios for climate change, they sometimes focus on just the temperature, precipitation and seasonal characteristics to identify how climate variables impact species' distributions. "A species' niche defined only in terms of climate variables may be termed the climatic niche, which represents the climatic conditions that are suitable for species existence. An approximation of the *climatic niche* may then be mapped in geographical space." [Pearson, 2008]

Climate is the general character of the weather that exists over a particular region of the earth for a long period of time. Unlike the weather, which represents hour-to-hour and day-to-day changes in the atmosphere over a region, climate is the average of all the weather changes over a region for a great many years.

The major factors that are often used to characterize the climate of a region are temperature and precipitation. Because the surface of the earth is not heated evenly, and because land masses, oceans, and polar ice masses are distributed unevenly over the surface of the earth, the climate varies greatly from region to region. The U.S. Department of Agriculture uses temperature [especially the lowest temperature expected] and precipitation to establish planting zones for farmers and gardeners to determine if their area will support certain plants. The maps are printed on seed packets and nursery guides. They are a simple and effective way to look at climate niches for plants!

At the start of 2012 the USDA announced a new planting zone map, updated to reflect warmer conditions throughout the country. The map was last revised in 1990 based on data since 1976. The newest map recognizes that weather conditions in the years from 1990-2012 changed enough that climate niches justified a new map. While the changes in some areas are subtle, the concept of changing this well-recognized map to reflect climate change is huge for demonstrating the impact of the issue. Listen to the NPR story when the map was released: ***http://www.npr.org/2012/02/03/146362934/new-usda-map-may-mean-earlier-planting-in-north***.

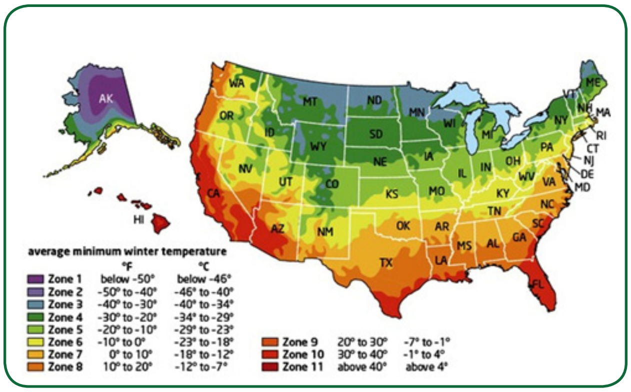

Figure 1a: USDA Planting Zone Map 1990

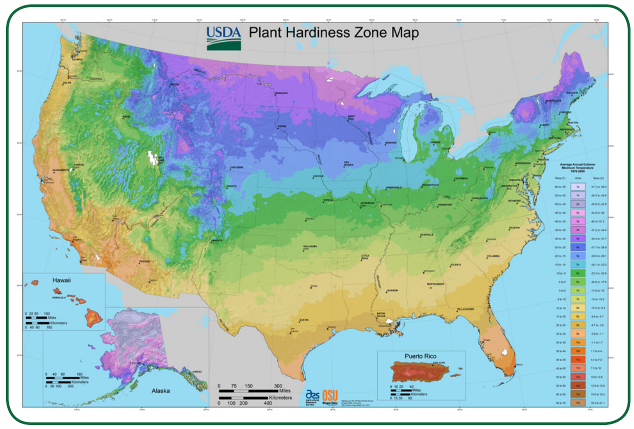

Figure 1b: Planting Zone Map, revised 2012

Not all plants are planted, however, and changes are occurring over larger scales of location and time than the planting map indicates! Scientists have been trying to understand climate by studying current records of events and by examining the geologic records. The importance of understanding and predicting future climates has intensified as the amount of carbon dioxide in the atmosphere has increased. Since there are so many physical processes responsible for the structure and variation of climate, scientists have constructed mathematical models to predict future climates.

The most frequently reported climate change possibilities are based on General Circulation Models (GCMs) that combine atmosphere as well as ocean characteristics: GFDL (Geophysical Fluid Dynamics Laboratory – NOAA), HadCM3 (Hadley Center in the United Kingdom), and PCM (the National Center for Atmospheric Research's Parallel Climate Model). From these models, it is possible to calculate the impact of the global climate change on Earth conditions. Impacts are reported as "scenarios," which are not predictions, but plausible representations of the potential future, based on a specific set of assumptions. Scenarios may be used to identify possible effects of climate change and to evaluate responses to those effects. By analyzing many scenarios, scientists may be able to determine the direction and relative size of change. A "High" scenario is the worst case, with accelerated greenhouse gas emissions and feedback that enhances warming; a "Low" scenario might occur if all nations began immediately to take steps to lower the rates of change. There is also a "business as usual" scenario that presumes continuation of present trends. All the models currently in use predict a regional Great Lakes climate that is warmer and drier than today's.

Procedure: As a demonstration or with students working in teams on computers, examine a sequence of maps as learners consider whether important trees like sugar maples and buckeyes can survive climate change.

ENGAGE

Show Figure 1 on Page 1 and ask students to explain why these images are important in the Great Lakes region. Share the information from the Background section on the role of sugar maples and buckeyes in regional culture. Students may have experience to share about maple sugaring or collecting buckeyes.

EXPLORE

1. Each tree species has a certain climate niche, the region where temperature, rainfall and seasonality are optimum for growth. These are included in maps of climate ZONES for all kinds of plants, such as those in Figure 2. We use the maps most commonly for deciding when to plant in the garden, but they work for trees too. Students should note which climate zones include most of the Great Lakes region. Open a discussion about what would happen to the plants in nature as the climate zones shift with global climate change. Which way would the zones likely move? Could plants be left behind when their zone is shifted?

Figure 2: Climatic regions of North America.
Source: ***http://printable-maps.blogspot.com/2008/09/climate-maps-united-states-and-canada.html***

EXPLAIN

2. Sugar maple trees and Ohio buckeye trees are currently found in areas as shown in Figure 3. The blue line is the climate niche or potential range for the species, and the dots show current densities of trees. Have students identify the climate zones and make a list of the states where most of the maples and buckeyes are found. Discuss what would happen to the trees if the current climate zones shifted northward as climate models suggest.

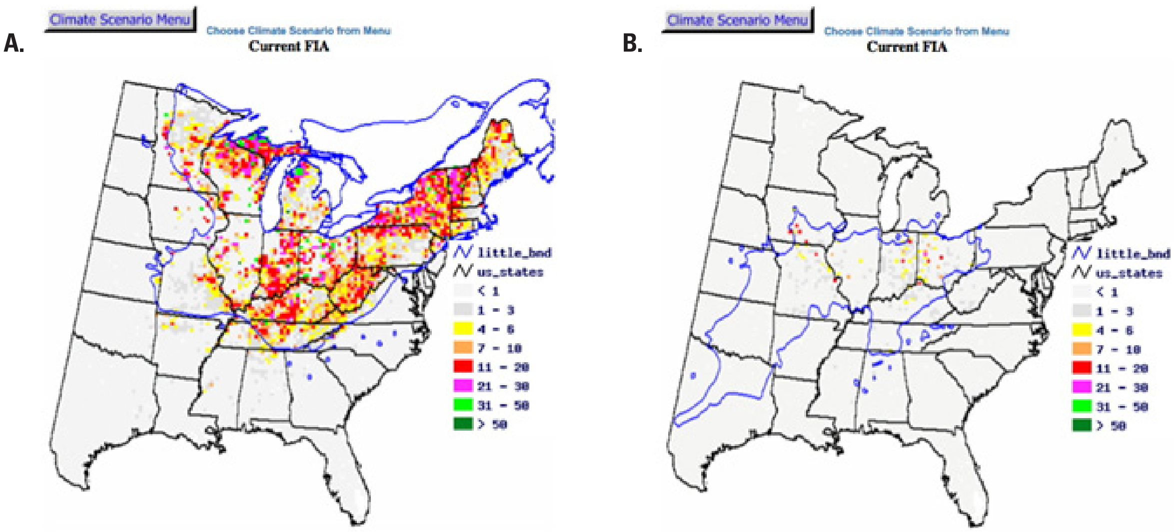

Figure 3: Current climate niche of sugar maples [A] and buckeyes [B].
Source: ***http://nrs.fs.fed.us/atlas/tree/tree_atlas.html***

3. Check your prediction by visiting ***http://nrs.fs.fed.us/atlas/tree/tree_atlas.html***. In the US Forest Service Tree Atlas you can select the trees, then click on "Abundance Change Maps" to see how their potential suitable habitat is likely to change. At the web site, click on "Climate Scenario Menu" and see how the different models predict where the trees will grow and how abundant they will be. Compare the averages for the three highest and three lowest models. Are sugar maples and buckeyes in danger of disappearing in your state, according to the models?

4. Visit the Union of Concerned Scientists' web site on Great Lakes impacts of climate change, ***http://www.ucsusa.org/greatlakes/winmigrating/glwinmig_intro.html***, for another way of illustrating what the models show. Read the summary of Great Lakes changes that are expected, then click on your state's name and watch the changes for winter and summer conditions. Note that the changes are based on temperature and precipitation. For some states, changes in the likelihood of extreme events are also projected. These "migrating climate" maps are based on mid-range scenarios, not the worst that might happen. Have students report the changes on their worksheet.

5. Have students record the winter and summer changes for two of the states listed in #2, in a chart on their worksheet. Discuss with students how different the winter and summer scenarios are, and lead them to think of why the models might be showing these differences.

6. Look at the area surrounding the "new position" of the two states whose climate was migrated. Which of the climate zones in Figure 2 includes that new position? Do the average high scenarios in the Tree Atlas web site [the link for Figure 3] look like the new positions will have maples or buckeyes? Could a tree population survive if its summer position was too dry but its winter position was in the same climate belt as before?

EXTEND

7. Have students do internet research to examine how people in the United States and Canada depend on sugar maples and buckeyes. In small groups, they should develop a story about how Canada would be helped or harmed if the sugar maple scenarios became reality. Encourage creativity in their use of information.
8. Have students assume they are Ohio State students [Buckeyes] studying forest management. They trust the models of climate change for their region and see what will happen to the tree that is the school's icon. How could they prepare for the loss of the buckeye trees, or prevent the loss?
9. At the peak of the autumn season in the Northeast and Midwestern sections of North America, a kaleidoscope of colors appears as a result of the pigment changes in the leaves of deciduous trees, particularly in maple leaves. This is truly one of the more spectacular, colorful events in nature. People travel from all across the nation and from around the world to witness this event, generating considerable business in the areas. From the knowledge you have acquired in this activity, suggest how climate change could influence a) the autumn colors and b) this tourist industry.
10. Many people are involved in the production of maple syrup on a local and a commercial basis. Their careers may be seriously affected by any changes the climatologists predict for the future. Note all the possible careers that exist in this industry and careers that will influence the industry, i.e. syrup farmers, laborers, climatologists, food scientists, etc. Each student should select one career and research it, as fully as possible, describing the present status of it and how the future predictions of climate change might influence this.
11. Are there areas in your state, or a nearby state, that have "relic ecosystems" left over from the last glacial cycle? If so, why have they remained? How are they different from the present flora/fauna?

EVALUATE

Examine students' or groups' responses on their worksheets. Answers follow.

1. One map indicates that most of the region is Cold, with the area around Lake Superior being Very Cold. The other classifies the northern part of the region as humid continental climate, with warm summer. The southern part is also humid continental, with a hot summer.

2. As they have already done from 1990 to 2011, climate zones in North America are likely to shift northward with climate change.

3. a. Garden flowers typically could be planted earlier and there might be a longer growing season for them. Some that are on the edge of their planting zone might need additional water and fertilizer if a gardener still wants them, but among flowers there are many options. Most gardeners will change to growing different flowers if their usual choices are stressed by heat or drought.

   b. If vegetable croplands become hotter and their moisture amounts change, some crops might not grow economically. Keeping the same crops in an area might require extra fertilizer and water, stressing the environment and finances. Also, a farmer's equipment and experience may not be the same for a new kind of crop. If cotton were grown in Ohio, it would take very different equipment and strategies to replace corn, for instance.

   c. Forest trees are unable to adapt quickly to changing climates, in general, and most don't have human assistance to deal with the changes. Some trees, such as evergreens grown for Christmas trees, are managed like other crops, so growers may need to choose different species as climate changes. Changing a crop of trees takes far longer than changing a vegetable crop, of course.

4. Maples: NY, WI, VT, MI, OH, IN, WV, KY, PA; Buckeyes: OH, IN, some in KY, TN

5. Students may hypothesize that both species will be lost in their southern range [KY and TN].

6. a. The highest emission models show that these Great Lakes states will lose most Sugar maples: only MN, NY, and the upper peninsula of MI will have high populations of maples.
   Buckeyes are diminished severely throughout the range, but some new ones appear to survive in MN and WI.

   b. Even with the lowest emission scenarios, sugar maples would severely decline in KY, OH, IN, and WV. Buckeyes would decline in their existing range but new ones could survive in IA, southern MN and much of WI.

7. According to the Union of Concerned Scientists, in the Great Lakes region:
    a. Temperatures will increase, with more changes in night than day temperatures; extreme heat more common.
    b. Seasonal rainfall patterns change, with wetter winters, drier summers, somewhat drier overall because evaporation will exceed precipitation.
    c. Frequency of extreme weather events will increase.
    d. Lake effect snow may increase because lakes will remain ice-free longer.
    e. Ice cover will decrease.
    f. Lake levels are likely to fall in most areas of the lakes.

8. An example using Ohio would look like this:

State	2030 Temp °C Su/Wi	2030 Precip % Su/Wi	2095 Temp °C Su/Wi	2095 Precip % Su/Wi	2095 Summer Location	2095 Winter Location
My state						
Ohio	2/ 1-2	-15/10	4-5/3-4	-10 to -15/ 15-20	Arkansas	Eastern Virginia

a. Students will answer either sugar maple or buckeye.

b. Answers will vary depending on the states selected. Students should use the numbers predicted in the charts produced for migrating climates.

c. Answers will vary and should lead to discussion. Accept reasonable answers equitably.

9. a. Answers will vary depending on the states selected. None of the states will remain in the Very Cold zone, and several will move to Humid Subtropical. Accept reasonable answers based on the Migrating Climates model.

b. Some states like WI will remain in their original climate zone for winter but resemble humid subtropical in summer. Most will have the same climate zone for both seasons as judged by this map.

c. This question should generate some discussion. Be accepting of ideas that students can justify with the information given. Summer conditions, being both drier and hotter, are likely to be more stressful for trees than winter ones, but there are likely to be many variations among tree species responses.

d. As in c, there are more factors working than just temperature and precipitation, so students may speculate about variations in impact but a definitive answer would depend on the species.

10. Student summaries may be similar beyond the fact that high-emission models show loss of many sugar maples but possible gain of habitat for small numbers of Ohio buckeye trees. Both trees face changes that will mean dramatic differences in precipitation and temperature. Discussion of what the trees do for people should relate to information at the beginning of the activity.

REFERENCES

Climate Scenario section of the Data Distribution Centre (DDC) of the Intergovernmental Panel on Climate Change (IPCC) ***http://www.ipcc-data.org/ddc_climscen.html***

Prasad, A. M., L. R. Iverson., S. Matthews., M. Peters. 2007-ongoing. A Climate Change Atlas for 134 Forest Tree Species of the Eastern United States [database]. ***http://www.nrs.fs.fed.us/atlas/tree***, Northern Research Station, USDA Forest Service, Delaware, Ohio.

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Pearson, Richard. 2008. Species Distribution Modeling. Online through the American Museum of Natural History, at ***http://biodiversityinformatics.amnh.org/index.php?section_id=104&content_id=296***. Accessed January 14, 2012.

This reference includes discussion of niche definitions in general, how climate niches are determined, and why modeling of species distribution is important. The online page was developed from a synthesis document: Pearson, R.G. 2007. Species' Distribution Modeling for Conservation Educators and Practitioners. Synthesis. American Museum of Natural History. Available at ***http://ncep.amnh.org***.

Pearson, R.G. & Dawson, T.P. (2003) Predicting the impacts of climate change on the distribution of species: Are bioclimate envelope models useful? *Global Ecology and Biogeography*, 12, 361-371.

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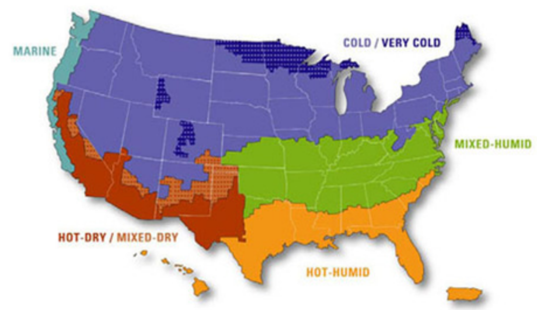
Name ______________________________ Period __________

Student Activity A: What do climate models predict about tree ranges?

Here are two ways to depict climate zones in North America. You may have seen maps of climate zones if your family plants flowers or vegetables. The maps combine seasonal temperatures and precipitation in general across the continent.



Climatic regions of North America. Source: ***http://printable-maps.blogspot.com/2008/09/climate-maps-united-states-and-canada.html***

1. Describe the climate zones (temperature and precipitation) that include most of the Great Lakes region.

2. How are climate zones likely to shift with global climate change?

3. How might the plants below be affected if the climate zones move? What can be done to save the plants?
   a. garden flowers

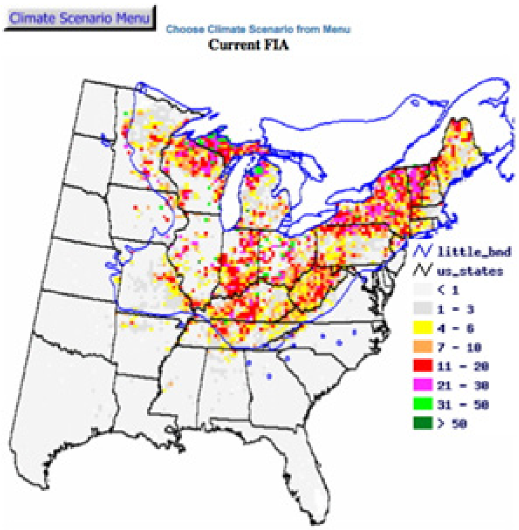
   b. vegetable crops

   c. forest trees

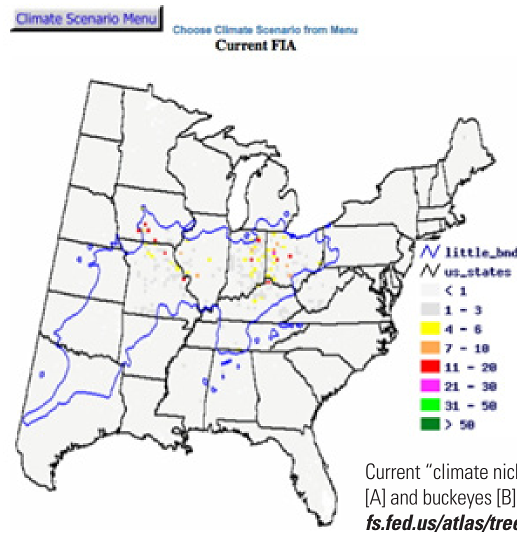
Name ______________________________ Period __________

We will examine how sugar maples and buckeye trees might be affected by climate change. Climate MODELS combine temperatures and precipitation to show possible changes in where trees can live. This is their "climate niche." Look at these models that show where the trees can live now.

A.



B.



Current "climate niche" of sugar maples [A] and buckeyes [B]. Source: ***http://nrs.fs.fed.us/atlas/tree/tree_atlas.html***

4. From the climate niche maps, list the states where MOST of the sugar maples and buckeyes are found today.

   Sugar maples: Buckeye trees:

5. Make a prediction about which states might LOSE a lot of their sugar maples and buckeyes with climate change.

   Sugar maples might be lost in: Buckeye trees might be lost in:

6. Check your prediction by visiting ***http://nrs.fs.fed.us/atlas/tree/tree_atlas.html***. In this US Forest Service Tree Atlas you can select the trees, then click on "Abundance Change Maps" to see how their potential suitable habitat is likely to change. At the web site, click on "Climate Scenario Menu" and see how the different models predict where the trees will grow and how abundant they will be.

   a. Compare the averages for the three highest emission models. These are the most severe climate change predictions.

   Which states will lose the most Sugar maples?___________________________ Buckeyes? ___________________________

   b. Compare the averages for the three lowest emission models. These are the least severe climate change predictions.

   Which states will lose the most Sugar maples?___________________________ Buckeyes? ___________________________

Name ______________________________ Period __________

Another way of looking at climate models is to compare future scenarios with locations that have those conditions of temperature and precipitation today. Visit the Union of Concerned Scientists' web site on Great Lakes impacts of climate change, ***http://www.ucsusa.org/greatlakes/winmigrating/glwinmig_intro.html***.

7. In general, many changes are expected in the Great Lakes climate with global warming over the 21st Century. What is likely to happen to

   a. Temperature

   b. Seasonal rainfall patterns

   c. Frequency of extreme weather events

   d. Lake effect snow

   e. Ice cover

   f. Lake levels

8. Click on your state's name on the left side and watch how the models predict that temperature and precipitation will change the state's climate. Fill in the chart with what the models show.

State	2030 Temp °C Su/Wi	2030 Precip % Su/Wi	2095 Temp °C Su/Wi	2095 Precip % Su/Wi	2095 Summer Location	2095 Winter Location
My state						

Your teacher will assign you to examine either sugar maple or buckeye changes. In the same chart, choose 2 states that you listed in 6a, and add their changes to the chart along with your state. [If your state was listed in 6a, choose two others.] Answer these questions.

   a. Which tree were you assigned? __________________

   b. Compare the states you put into the chart. Which season, summer and winter, had the most dramatic changes in temperature by 2095? ______________ in precipitation? ____________________

   c. Why do you think the seasons were so different in these models?

Name ____________________ Period ________

9. Now look at the 2095 position of the states you tracked. Compare those new positions with the Climate Zone map.

   a. Do models show that either state will change to a different climate zone? __________

   If yes, what new zone will the state[s] resemble?

   b. Will both winter and summer scenarios be in a different climate zone? __________

   c. Do you think that a tree could survive if its summer conditions shifted but its winter ones stayed closer to the original? ________ Discuss the reasons for your answer.

   d. Could a tree survive if its precipitation kept it in the same zone but its temperature changed, or vice versa? ______________ Discuss the reasons for your answer.

10. Collect data from student teams that examined the fate of the other tree. Summarize in a short paragraph the changes that sugar maples and buckeye trees are likely to face with global climate change. Discuss ways that the loss of these trees would affect people in the Great Lakes region, that is, what do the trees do for us?

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Teacher Activity B: How can trees migrate?

The first activity of this set provided the research and modeling basis of the impact of Great Lakes climate change on trees in the region. The maps and resources of Activity A should remain available for reference as the mechanisms of climate impact and response are investigated.

Objective: When students have competed this activity, they should be able to

- explain how plants "migrate"
- describe some obstacles to tree migration.

Materials: Per team of 3-4 students: plastic bag of 30 maple seeds [samaras, familiarly called "helicopters"] or 10-15 buckeye nuts, one meter stick or tape measure, additional graph paper, clipboard or notebook, pencil and magnetic compass. Per class: anemometer and large outdoor space open to the wind.

Time required: One class period plus time for discussion. If the outdoor area is distant from the classroom, the lesson may take one period for data collection and a second period for discussion.

ENGAGE

Pose and discuss the following questions with students: What do you think of when you hear the word "migration?" What does migrate mean? What kind of organisms migrate?

Show some pictures of caribou, salmon, birds, monarchs, etc, and ask additional questions: Why do organisms migrate? Are animals the only organisms that migrate? Do plants migrate? How?

EXPLORE

1. Visit the outdoor area in advance to determine where to place student teams. The locations should be in safe areas with space for seeds to be thrown into the air. A good wind will carry samaras several meters, so be sure to place teams where the longer throws won't lead into unsafe places. Elevated areas will let the buckeyes roll downhill. Parking lots nearby would represent places where seeds might land but not germinate. Creeks or ponds might distribute seeds further or drown them. Such variables encourage students to think about realities of seed success.
2. Divide the class in half and within those groups identify student teams of 3-4. Give half the teams a small plastic bag with about 30 maple samaras and the other half a bag of about 15 buckeyes. [Maple seeds get lost in the grass, so they have to be replaced more often.]
3. Place the teams at spots that were previously chosen. Each team should have a notebook or clipboard with graph paper, a pencil, a magnetic compass and a meter stick or tape measure.
4. If supplies are scarce, have one student measure the wind speed with an anemometer and announce to all for recording on the worksheet. Have each team measure and record the wind direction with a magnetic compass. Teams should place a North arrow on their graph paper, and place a mark in the center to represent the present-day forest (the team's starting position).
5. One member of each team tosses 4-5 seeds [both the samaras and nuts are seeds] high into the air so the wind can catch them. All team members watch where they go. They measure the distance and direction from the starting point to each seed. Based on the first toss, decide as a class how many graph squares will represent one meter, and have teams plot their First Generation [Gen 1] seeds' positions on the graph paper, being sure that the North orientation is observed. It may be helpful to draw a circle that encloses the first generation.
6. The teams will be tossing seeds at least 4 times. After plotting Gen 1, they should send one team member to the spot where each seed landed. From those new locations, each member tosses 3 seeds and the team marks their new positions as Gen 2 on the graph.
7. For the next two tosses, each team should go to the location of a seed that is farthest away from the original "forest," toss 3 more seeds and mark their positions.

EXPLAIN

From their graphs, student teams should be able to get ideas about how fast the tree species might be able to move if the climate in its current zone shifts. The teams should do the following to facilitate discussion:

8. Draw a line on the graph paper that encircles the starting place and all the seeds whose positions you plotted. Describe the area through which the trees migrated: its general shape, direction from the original forest, width and length, orientation with the wind direction or gravity, any overlap with other teams, etc.
9. Discuss and draw on the graph any obstacles that might prevent seed germination. Consider whether the obstacles affect both species in the same way.
10. Display the map of current sugar maple and buckeye locations, Figure 3 of Activity A. If a maple forest or some buckeye trees in this state were migrating poleward through North America from where they are now, what obstacles might be in their path? Could the obstacles stop the migration? Discuss with your team and class.

EXTEND

Lead a student discussion to compare how trees with different types of seeds might survive better under certain conditions. Summarize how plants might be able to move into the areas that climate models predict as their future range.

Lead students to consider whether there are ways to overcome geographic obstacles, either through natural processes or with human assistance. An internet search on managing forests, tree farming, and other human interventions may offer insight. Students should note that given equal stresses, the maples are more abundant than buckeyes and therefore have a higher chance of some “offspring” surviving.

EVALUATE

Examine teams’ responses on their worksheets for efficient teamwork and analysis. Answers follow.

1. Students should fill in the blank with MAPLE or BUCKEYE, and sketch one of the seeds.
2. Hypotheses might mention wind speed, how high the seeds were thrown, how tall the parent tree is, whether there was a chance for them to roll or be carried by water.
3. If only one anemometer is used, wind speed will be the same for all teams. Wind direction is likely to differ somewhat among the teams. Decide what units will be used for recording speed and direction so that consistent information is collected across groups.
4. Answers will vary but should include nearby landmarks, topography, proximity to other teams, and other factors that might influence the seeds’ dispersal.
5. Check to see that the N arrow and starting location are plotted. In some cases, like high winds, it may be more appropriate to put the starting location near the top or a corner of the graph to allow space for recording all generations.
6. Check to see that graph scales are equivalent across groups, and monitor the recording of the “generations” of trees as the lab progresses.
7. Answers will vary but should include the general shape and size of the area of dispersal, topography, obstacles.
8. Seeds need water and suitable substrate for germination, as well as a temperature that is within the climate niche of the species. As the seedling grows, competition with other species for light and moisture may become a limiting factor.
9. Answers will vary. Some seeds may have landed on pavement, in water, on rocks or other locations where germination would be hindered.
10. Answers will vary, but it is likely that on level ground, samaras will disperse further even in a light wind. Students should also think about the number of seeds produced by the tree species. Mature maples produce hundreds more seeds than buckeyes do, so there is a greater likelihood that some will survive to reproduce the next generation.
11. a. Depending on the state’s geographic location, the Great Lakes might be an obstacle for tree migration. Bedrock in the region varies as well as depth of soil, with some substrates more hospitable than others. Student may mention difficulties of seeds surviving in locally known conditions, such as deep forests that could limit light and create competition with other species. In general, answers to this question should reference the factors in #8 as well as larger environmental characteristics of the mid-continent area.

    b. The obstacles certainly could stop or at least stall the migration, but maples with larger numbers and more seeds might have a better chance of surviving into new territory. There may be ways that people can help the species get started in new areas, though. Have students look at internet sites on tree management such as hardwood tree farming.
12. Student summaries should note how tree seeds are dispersed and what obstacles they face, how different species’ success may be based on seed size and shape, and which factors are critical to germination.

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Team member names ____________________________ Period __________

Student Activity B: How can trees migrate?

1. Our team is dispersing _________________ [maple or buckeye] seeds.
   The seeds look like this [sketch in box].

2. We think they will travel farthest if

3. Conditions for dispersal: Wind speed _________ Wind direction _________

4. Description of where our "Parent Tree" is located:

5. Plot on your graph paper:
   a. A small arrow pointing North
   b. a mark in the center to represent the present-day forest (your team's starting position)

6. Generation 1: Toss 4-5 seeds high into the air. Watch where they go. Measure the distance and direction from your starting point to each seed, and plot the seeds' positions on your graph paper. On the graph paper, ______ squares or _____ cm = one meter

Gen 2: Send one team member to the spot where each seed landed. Have each member toss 3 more seeds and mark their new positions on the graph.

Gen 3-4: For the next toss, each team member will go to the location of a seed that is farthest away from the original "forest." Toss 3 more seeds and mark their positions.

Your graph should now show 4 sets of points representing 4 generations of trees. Draw a line on the graph paper that encircles your starting place and all the seeds whose positions you plotted.

7. Describe the area through which your trees migrated: its general shape, direction from the original forest, width and length, obstacles, any overlap with other teams, etc.

8. What conditions are necessary for seed germination?

9. Did each seed get the same chance to germinate? Why or why not?

10. Compare your results with teams that worked with the other type of tree. Which dispersed further? What factors seem to have made a difference in dispersal distance?

11. If a maple forest or some buckeye trees in your state were migrating toward the north from where they are now,
   a. what obstacles might be in their path?
   b. Could the obstacles stop the migration? Discuss with your team and class.

12. It takes a sugar maple about 20 years and a buckeye about 8 years to mature and produce seeds. From your data, calculate how long it could really take these trees to migrate over the distances you found. **Sugar maple**: ___ generations X 20 years = ____ years.
Total distance moved ____ m. Rate of migration = distance divided by years = ______ m/year. **Ohio buckeye**: ___ generations X 8 years = ____ years. Total distance moved ____ m. Rate of migration = distance divided by years = ______ m/year

13. With these rates of migration, hypothesize whether sugar maples and buckeyes will be able to move into their new climate niches quickly enough for some trees to survive in 2030 or 2095. You may need to review the Tree Atlas models in Activity A, #8.

Team member names ______________________________ Period __________

14. Summarize how plants might be able to move into the areas that climate models predict as their future range.

Turn in this worksheet and your graph to complete the lesson.

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Teacher Activity C: How does temperature affect maple seed germination?

Once students have completed Activities A and B of *Trees on the Move*, they should be aware of model predictions for climate change impacts on tree species, and how tree seeds are dispersed into new areas. One of the concepts that emerges from Activity B is that landing on a suitable site does not guarantee a seed will germinate. This lesson looks at temperature as a factor in seed germination.

Objectives: When students have completed this activity, they should be able to

- interpret and manipulate a line graph
- analyze the impact of temperature on seed germination

Materials: copies of this handout, graph paper.

Time required: 1 class period

BACKGROUND

The data in this lesson come from a study by McCarrager, Goldblum and Rig in 2011. The full article addresses many concepts in the *Trees on the Move* lesson set, and reminds us that the science of climate change impacts on a species is complex.
McCarragher, SR, Goldblum, D and Rig, LS. Geographic Variation of Germination, Growth, and Mortality in Sugar Maple (*Acer saccharum*): Common Garden and Reciprocal Dispersal Experiments. *Physical Geography*, 2011, 32, 1, pp. 1–21
(***http://bellwether.metapress.com/content/70150m124tk57486/fulltext.pdf***)

To examine the germination and growing requirements of buckeye trees, visit the Ohio Division of Forestry site, “Growing Buckeye Trees,” at ***http://www.dnr.state.oh.us/tabid/5106/default.aspx***.

The lesson includes insight into the nature of science, requiring data interpretation but cautious inferences, and including some information that may not fit the expected results. Some of the best science investigations generate as many questions as they answer!

ENGAGE

To engage students in this lesson, consider students’ background knowledge. If students are unfamiliar with plant reproduction, germinate several seeds before class (peas work well) and pass around the germinated seeds. Conduct a short discussion of plant reproduction and the importance of germination. For students who are familiar with plants and the concepts of germination, hold up a fresh pumpkin seed and a dried pumpkin seed made for eating. Pose the question: “Will both of these seeds germinate?” Students should speculate that perhaps heating will prevent germination, and others may bring up the idea that some plant species such as jack pine trees require a fire to germinate. Regardless of which engagement activity is used, link the activity to the topic of today’s lesson: the possible effects of temperature on seed germination.

EXPLORE

Determine if students will work in small teams or individually, and make enough copies of the worksheet. It may be effective if the same teams from Activity B work together on this lesson, though it only includes maples, not buckeyes.

1. The worksheet has enough information for the lesson. Give students approximately 30 minutes (adjust for skill level and age) to work in groups to interpret the data and make new data representations as well as answer the questions that follow. Circulate, asking probing questions and clarifying anything that prevents students from moving to the next question.

EXPLAIN

2. As a whole class, go over answers to discussion questions, paying special attention to any variability in answers or conflicting responses. Emphasize that germination is only one process required to ensure plant survival, so even though global climate change may not affect germination, it is still a pressing issue for sugar maples and other species. Also highlight the 'nature of science' aspect of this activity: not every analysis will automatically yield the expected result.

EXTEND

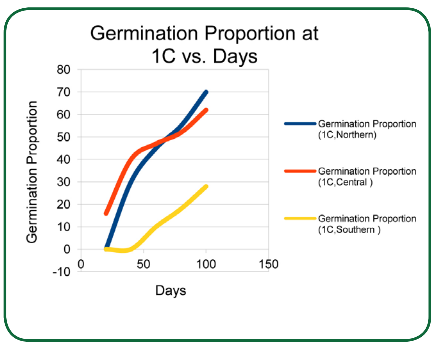
An important part of a scientific paper is the analysis section, where the scientist interprets her findings. Ask students to write an analysis section based on the data presented in this lesson. Depending on the skill level of the students, guiding questions may be used to scaffold this assignment.

EVALUATE

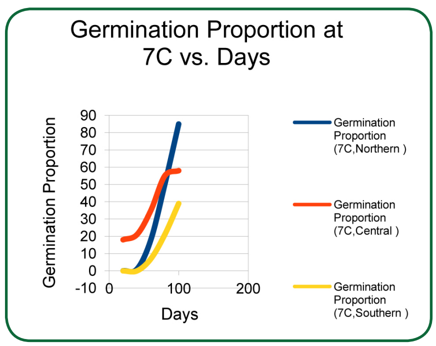
If the emphasis of the lesson was on graphing and data interpretation, give students several line graphs and ask similar questions to those presented here. At least some of the questions should ask students to draw from more than one graph and/or synthesize information from several graphs in a new graph. See the Canola example, from the Canola Council of Canada 2011. Original information at ***http://www.canolacouncil.org/chapter5.aspx***.

Examine students' or groups' responses on their worksheets. Answers follow.

1



2a



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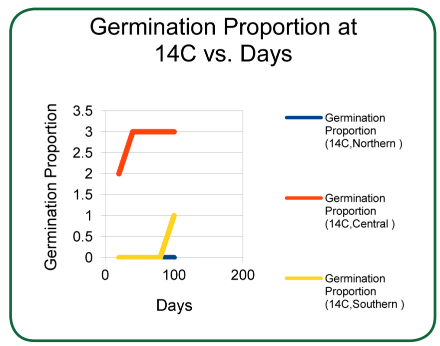


3. Answers will vary based on the student hypothesis. If students hypothesized that seeds from the different areas would be affected differently by the germination temperature experiment, their hypothesis would be supported by the data. They should be encouraged to elaborate on seed responses to different temperatures, especially noting effects of the high temperature.

4. Answers will vary based on the sugar maple dissemination distance. Students should report the distance from the parent maple tree to the farthest 3rd generation tree as their answer. If they studied buckeye dissemination, they should get maple data from another team.

5. The distances recorded in Activity B are much smaller than those of the three seed origins in this lesson, and 3 degrees is a smaller change. Answers will vary for this, but the general answer seems to be "no." Students should see that since the optimal temperature is 1-5 degrees, a shift of 3 degrees could have no effect or little effect. After all, seeds germinated as well or better at 7 degrees as at 1 degree.

6. Students should think about precipitation patterns and moisture needs of growing plants, and the factors in Activity B that could inhibit growth, such as rocky ground, paved streets and such. A 3 degree change might result in lower soil moisture or be accompanied by different rainfall patterns. An extra 3 degrees in the city might be very stressful to plants as heat builds during the days. Any answers here should be accepted if they are reasonable speculations.

SAMPLE ASSESSMENT [canola]

Researchers working in the agricultural industry read the article you studied and want to know if this article might apply to their area of expertise. That is, they wonder, is there an optimal germination temperature for Brassica species, many of which are edible? Does this temperature vary among closely related species? Because they work with plants that produce oil, they test the germination of seeds of *B. napus* and *B. rapa*, both of which can be used to make rapeseed (canola) oil. Their results are below. Study the results, and use them to answer the questions that follow.

Figure 2. Effects of Temperature on Germination of B. napus

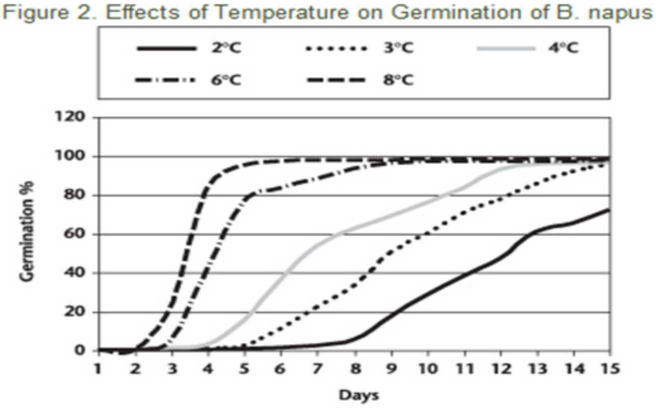
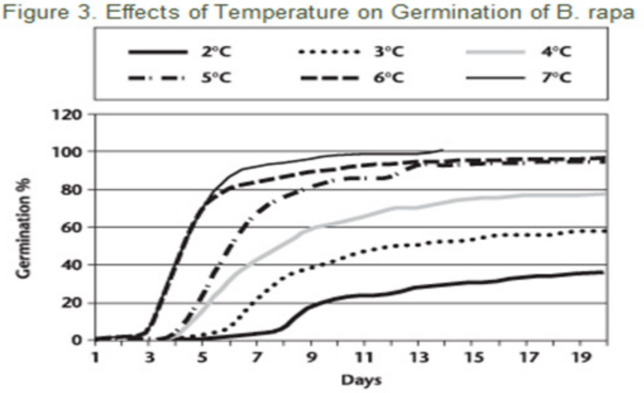


Figure 3. Effects of Temperature on Germination of B. rapa



1. At which temperature did a maximum proportion of *B. rapa* seeds germinate? At which temperature did a maximum proportion of *B. napus* seeds germinate?

B. napus:

B. rapa:

2. At 2ºC, what proportion of *B. rapa* and *B. napus* seeds germinate?

B. napus:

B. rapa:

3. At 3ºC, what proportion of *B. rapa* and *B. napus* seeds germinate?

B. napus:

B. rapa:

4. At 5ºC, what proportion of *B. rapa* and *B. napus* seeds germinate?

B. napus:

B. rapa:

5. At 6ºC, what proportion of *B. rapa* and *B. napus* seeds germinate?

B. napus:

B. rapa:

6. Based on your answers above what is/are the optimal germination temperature/s for *B. rapa* and *B. napus*? Explain.

B. napus:

B. rapa:

Explanation:

7. Based on this study, do closely related species seem to have similar optimal germination temperatures? Explain.

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Name ______________________________ Period __________

Student Activity C: How does temperature affect maple seed germination?

Research by McCarragher, Goldblum, & Rig in 2011 examined how germination of sugar maple seeds varied with geography. The study sites on this map are where their seeds were collected, and are referred to as 1) Northern, 2) Central, and 3) Southern samples.

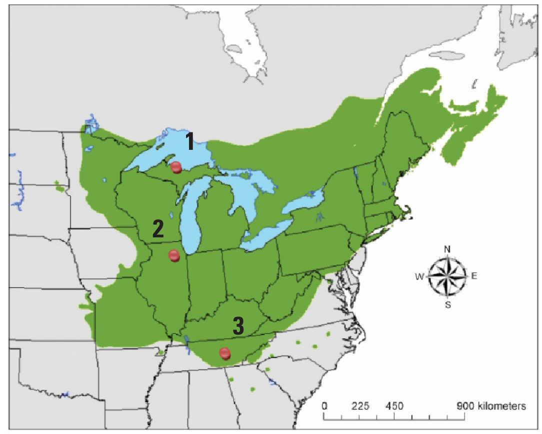

Figure 1: Map of the native range of sugar maples [USGS 1999]. The seed sources were 1) Big Bay, MI, 2) Elburn, IL, and 3) Tennessee.

Hypothesize: Scientists collected sugar maple seeds from the three different sources (see map to the right) and tested their germination at different temperatures. Do you predict that the results varied depending on where the seed was from? Explain.

CONTINUED →

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Name ______________________________ Period __________

Now, examine real data from the scientists, and use them to answer the questions that follow. Seeds were germinated at three different temperatures. (Note: the optimal germination temperature for sugar maple is 1°-5°C). Cumulative germination proportion refers to the percentage of seeds that has germinated as of a specific time.)

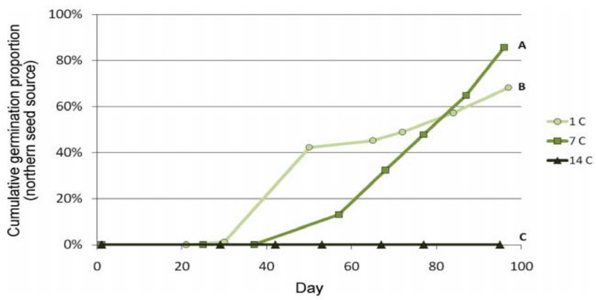


Figure 2: Cumulative germination proportions of all Northern seeds from the three temperature trials. All three lines, A, B, and C, were significantly different from each other.

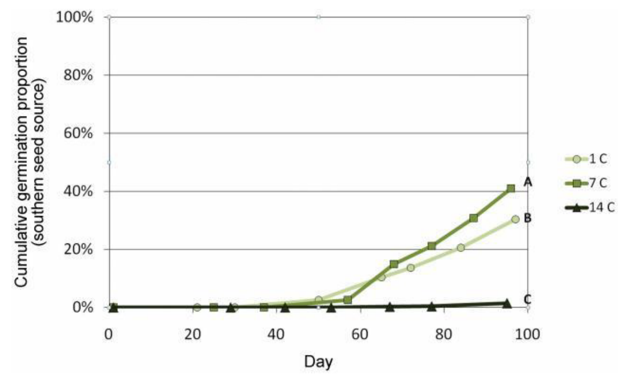


Figure 4: Cumulative germination proportions of all Southern seeds from the three temperature trials. All three lines were significantly different from each other.

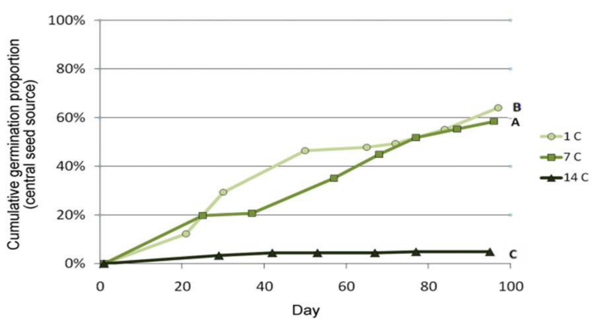


Figure 3: Cumulative germination proportions of all Central seeds from the three temperature trials. Lines A and B are significantly different from Line C, but not significantly different from each other.

1. On a piece of graph paper, graph the cumulative germination proportion of seeds from the three sources at 1°C at 20 days, 40 days, 60 days, 80 days, and 95 days.

2. On a separate piece of graph paper repeat the procedure above for cumulative germination proportion at 7°C and 14°C.

3. Using your three graphs from questions 1 and 2, analyze whether your hypothesis was correct. Explain.

4. Assume it takes 20 years for a sugar maple to become sexually mature and produce seeds. Based on the results of your dispersal experiment [Activity B], how far can a sugar maple migrate in 60 years?

5. Predict what will happen to the southern sugar maple individuals if, in 60 years, they migrate as far as your answer in question 4, and temperature goes up 3°C. Will seed germination be affected? Support your answer using the data provided.

6. What else (besides germination) affects sugar maple survival? Would these factors be affected by a 3 degree temperature increase? Explain.

Teacher Activity D: After the maples, then what?

Once students have learned

- what climate models predict for the new climate niches of tree species [Activity A],
- how and through what distances tree seeds are disseminated [Activity B], and
- how temperature affects tree seed germination [Activity C],

they should be ready to investigate what will happen in a tree's current niche when that tree can no longer survive there.

This activity is patterned after the 1953 classic study done by Catherine Keever, an ecologist with exceptional foresight, when she studied the dominant species remaining after the Chestnut Blight removed chestnut trees from forests of the Blue Ridge Mountains. Students will go out into a maple forest and apply Keever's methods to predict the possible dominant species if the maple trees are removed. They will identify and count trees of different heights in three different size plots, each nested within the next larger one.

NOTE: It is much more common in current science to study climate impacts on an ecosystem level rather than on a species level. In nature "everything is connected," and what happens to one species has direct and indirect effects on many other biological and physical conditions of the environment.

Objectives: At the completion of this activity, the students should be able to

- identify a sugar maple [*Acer saccharum*] tree and associated species of a maple forest,
- explain one way in which ecological studies are done to predict future dominant species in an ecosystem, and
- make a prediction as to the possible dominant species if maples are removed from the forest.

Materials

- a wooded area of any size with maple trees and other species
- 12 pointed stakes or flags to mark plot dimensions
- about 70m rope or twine
- several meter sticks or rope cut to specific lengths for measuring the height of trees
- worksheet, pencil and clipboard
- tree and plant field guides for identifying species

Time Required: one 50-minute class period if the woods are close to the school. If the woods are more distant it may be necessary to lay out the study plots one day and return the next to collect data. If stakes are left overnight, do not leave ropes attached between them.

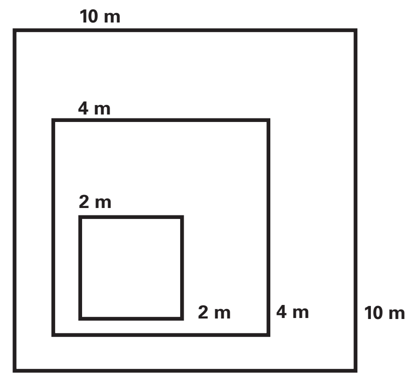
ENGAGE

Focus student attention on the investigation by showing photos of the maple woods that you will study. Have twigs from the main types of trees so they can learn to identify the species quickly in the field. The lesson is easier if leaves are on the trees, but twigs and bark are good for identifying species in the winter. Some distinguishing characteristics of maple twigs are their buds, bud scars, and opposite branching. An excellent website for twig and leaf identification is VTree ID from Virginia Tech ***http://dendro.cnre.vt.edu/dendrology/idit.htm***.

EXPLORE

1. Using stakes and twine, or field flags, mark off three plots in a wooded area containing maple trees. The largest plot should be a 10m x 10m square. Inside it is a 4x4m plot and within that is a 2x2m plot. It does not matter where the inner squares are located as long as they are nested: large, medium, small.

2. In each plot, students will work in small groups to inventory different size trees. Each tree of the specified height must be identified and plotted on a grid sheet. In the 10 x 10 m plot, all trees that are 3m or taller are identified and recorded. In the 4 x 4m plot, trees between 1-2 m tall are identified and recorded, and in the smallest plot any trees 30cm and shorter are identified and recorded. The figure here illustrates one method of recording.



EXPLAIN

3. After all the trees have been identified and recorded in their plots, have the students compare their data from each plot for similar species. This will require combining data from different teams and may work well in a whiteboard discussion.

4. If any one species is found in all plots and all sizes, it is possible that it may become a dominant species of the maple forest. After comparing all the data, students should make a group prediction for the dominant species that would succeed the maples if all maples died out or migrated with climate change.

EXTEND

1. For the species identified as ones that might follow when the maples are gone, have students use the models in the Tree Atlas [***http://nrs.fs.fed.us/atlas/tree/tree_atlas.html***] to see if those surviving species would actually remain in your area.

2. How do the surviving species reproduce? Test some of their seeds to compare with the maples and buckeyes for distances traveled in each generation. Are the new species more likely to be able to migrate?

3. Read about the surviving species and determine their value to humans. Does it appear that the new species will be able to satisfy the same human needs as maples and buckeyes have done? What values do the new species bring?

4. Have students imagine that they are the oldest person in a community, having lived nearly 100 years. The school children contact them and ask about the maple forest they have never seen! Students should write a letter to this class of children, or draw a picture, describing a maple forest, telling of their recollections and experiences in a maple forest when they were young.

5. Today's forest management research looks at more than what other species are present in the environment. Matthews and others [2011] are studying tree species' adaptability to climate change based on 9 biological factors [CO_2/productivity, CO_2/water use efficiency, shade tolerance, edaphic specificity, environmental habitat specificity, dispersal, seedling establishment, vegetative reproduction, and fire regeneration] and 12 ecological disturbances [disease, insect pests, browse, invasive plants, drought, flood, ice, wind, fire topkill, harvest, temperature gradients, pollution]. They have information on the factors from other researchers, and including these factors into predictive models can help make better assessments of what species will survive in place, which can adapt or migrate, and which will fail. Discuss with the students how some of these factors might affect maples or buckeyes in the area where you live.

EVALUATE

Check student work while it is in progress in the field and as predictions emerge in class discussion. Assess their understanding of the entire set of four lessons by class results and with their answers to Review Questions on their worksheet. The Analysis question at the bottom of the grids should reflect the most common species in all plots and sizes.

ANSWERS to Review Questions

1. Have students brainstorm and discuss. Responses should include wildlife habitat needs, human foods, lumber, and ecological factors of the forest.

2. If climate change occurs, the plants will survive only in more favorable geographic locations [as in Activity B]. This change happens slowly.

3. Other tree species that rely on the maple for shade and protection may be lost. Some tree species that can tolerate the new environmental conditions better than the maples will become the dominant species. Humans and other animals that rely on maples must adapt. Students may mention birds, seed-eating foragers, and wildlife that use maples as shelter.

4. The new dominant trees will have to be more tolerant to warmer and drier climate conditions, and possibly a different seasonal pattern of moisture. There is no guarantee that some of these trees are already growing in the sample plot. They may instead move in from other areas.

5. The health of a forest is vital to the whole ecosystem. Global change is likely to change the nature of the present maple forests significantly. It may take a century or more before a stable new forest ecosystem emerges.

REFERENCES

Keever, Catherine. 1953. Present composition of some of the stands of the former oak-chestnut forest in the southern Blue Ridge Mountains. *Ecology* 34(1): 44-45.

Matthews, Stephen N.; Iverson, Louis R.; Prasad, Anantha M.; Peters, Matthew P.; Rodewald, Paul G. 2011. Modifying climate change habitat models using tree species-specific assessments of model uncertainty and life history-factors. *Forest Ecology and Management*. 262: 1460-1472. [Download at ***http://nrs.fs.fed.us/pubs/38643***]

McCormick, J.F and R.B. Platt. 1980. Recovery of an Appalachian forest following the chestnut blight or Catherine Keever – You were right! *The American Midland Naturalist* 104(2): 264-273.

Additional Great Lakes Climate Change lessons are available from Ohio Sea Grant.
Please call 614.292.8949 for more information.

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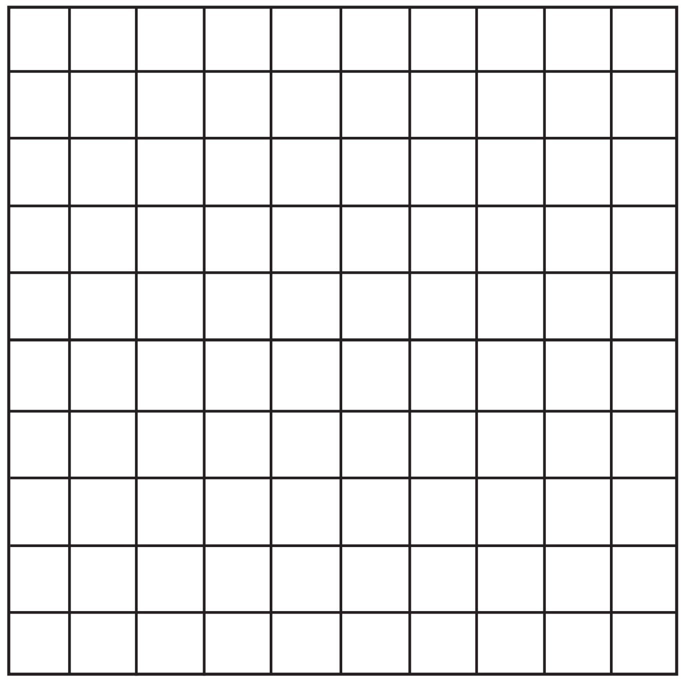
Names ______________________________ Period __________

Student Activity D: After the maples, then what?

On the grid below, record the location of your team's tree species. Collect data from other teams to complete all three grids. Be sure to create a key to the names of species that all teams identified.

KEY:

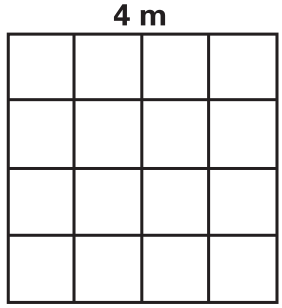
10 m



Trees 3 m or taller

10 m

4 m

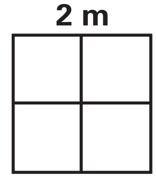


Trees 1-2 m tall

4 m

Trees up to 30 cm tall

2 m



2 m

Names ______________________________ Period __________

Analysis: If any one species is found in all plots and all sizes, it is possible that it may become a dominant species if the maples disappear. What is your prediction for the species that is likely to follow the maples?

Review Questions: Trees on the Move

1. Why are people concerned that sugar maples and other tree species will be lost with global warming?

2. How and why do forests get displaced [migrate]?

3. Predict the impact of maple "migration" on
   a. other trees
   b. wildlife
   c. human communities.

4. What characteristics will "new dominant trees" have compared to those that were displaced?

5. Will global warming damage the overall health of maple forests?

Original lessons A and B were contributed by Ohio teachers Christina Pryor and Linda Floehr. They were originally published in Ohio Sea Grant's *Great Lakes Instructional Materials for the Changing Earth System [GLIMCES]*, EP-080. Lesson C was contributed by Chicago teacher Lyudamila Shemanyika. Lesson D was developed by Rosanne Fortner and Tony Murphy and was published in NSF's *Activities for the Changing Earth System [ACES]*. All lessons revised in 2012 by Rosanne W. Fortner.