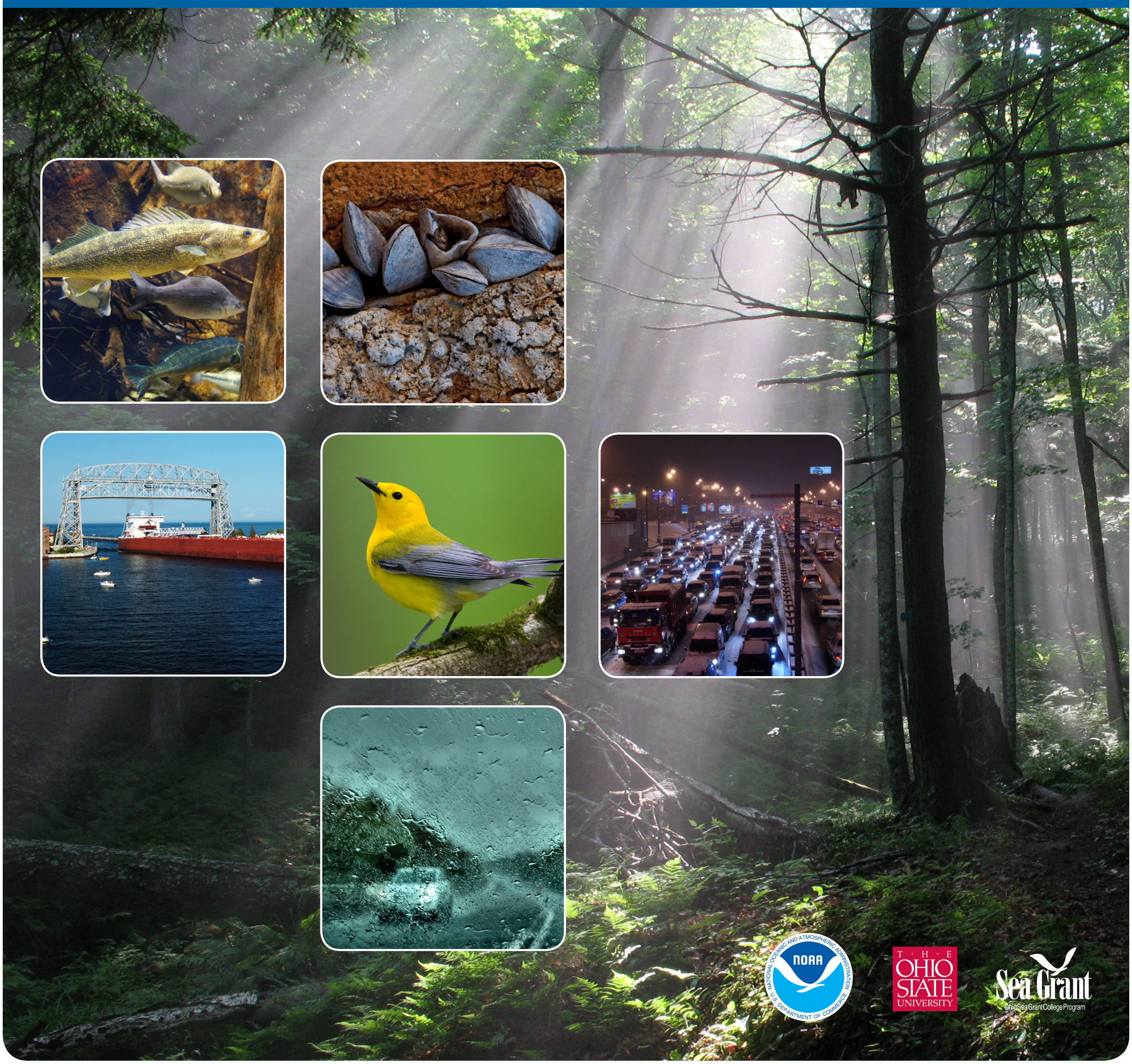
GREAT LAKES CLIMATE CHANGE CURRICULUM

An Earth Systems Education effort of the Ohio Sea Grant College Program and Ohio State University



WATER LEVELS ON THE GREAT LAKES

BACKGROUND

There is something about the movement of waves against the beach, the sight of a sailboat going past, and the ability to plunge in to the water on a hot summer day that attracts people to shorelines. Because of their popularity, coastal areas tend to become highly developed. Property values near lake shores are high. Lakes, however, can be unpredictable because of water level changes and the impact of those changes on waterfront property. Water levels are also important for maintaining healthy wetlands, fisheries and other ecosystems. For an excellent review of Great Lakes water level science and effects on humans, see ***http://www.great-lakes.net/teach/envt/levels/lev_1.html***.

Most scientists agree that climate change will affect the levels of the Great Lakes, in varying ways depending on a number of factors. While sea level is expected to rise, changes in the Great Lakes region are likely to result in lower water levels, though there will be differences from lake to lake. As the science and climate models progress, there are some baseline conditions of hydrology at work in the Great Lakes Basin. This activity deals with those annual, decadal and longer baselines and introduces scenarios that may result from climate change. An optional Extension activity allows students to identify and model management strategies people are using to adapt to lake level changes.

Teacher Activity: How do the levels of the Great Lakes change?

Objectives: In this activity students analyze, interpret and make inferences from web-based data on Great Lakes water levels.

After completing this investigation, students will be able to:

- Interpret graphic information about water level fluctuations in the Great Lakes.
- Examine the relationship between temperature and precipitation and corresponding changes in lake levels.
- Summarize how changing water levels within the Great Lakes region impact ecosystem health and the people who live there.

Materials, per group:

access to Internet
computer with projector
copy of student activity worksheet (1 per person)
heavy duty, bi-level, paint roller tray (1 per class if used for demonstration or 1 per student group)
water

Time required: 1.5 - 2 class periods, more if doing project-based Extension activity.

ALIGNMENT

National Framework for K-12 Science Education:
SEP 4: Analyzing and interpreting data
CC1: Patterns
ESS2: Earth Systems

Great Lakes Literacy Principles:
#1e, g: The Great Lakes, bodies of fresh water with many features, are connected to each other and the world ocean.
#2c: Natural forces formed the Great Lakes; the lakes continue to shape the features of their watershed.
#3e: The Great Lakes influence local and regional climate and weather.

Climate Literacy Principles:
#5b,c,d: Our understanding of the climate system is improved through observations, theoretical studies and modeling.
#7b: Climate change will have consequences for the Earth system and human lives.

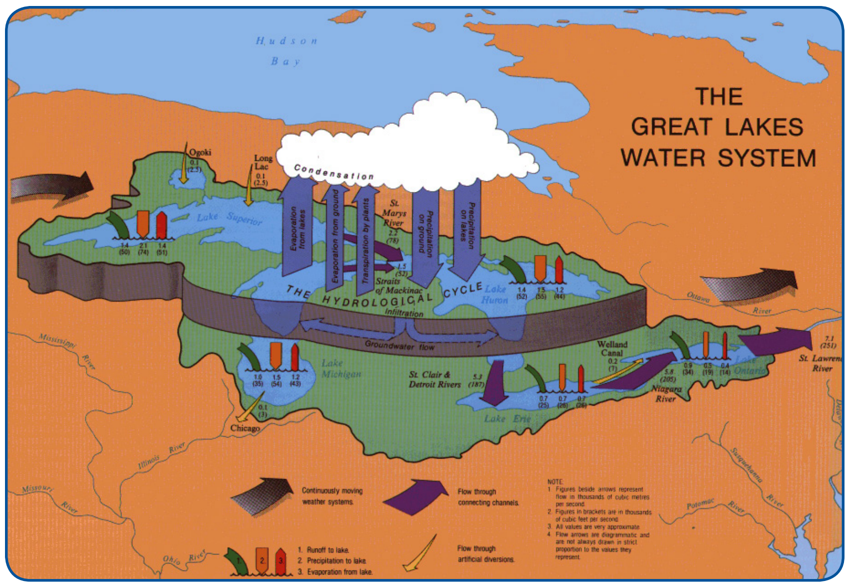
ENGAGE

Show these two images of the same location in the Lake Erie islands (larger images are attached at the end of this lesson). Brainstorm with the class: What determines how much water we see in the Great Lakes today?

[The complex answer depends on how much rain and snow have fallen, how much evaporation has taken place, the season of the year, how much water is moving to the next lake downstream, and how much water is sinking into the ground. What people see as the observed water level is even influenced by which way the wind is blowing!]

EXPLORE

1. Show and discuss the following diagram which summarizes the relative effects of the main factors that affect Great Lakes water supply overall. Review the hydrologic cycle if needed, using the animation at ***http://earthguide.ucsd.edu/earthguide/diagrams/watercycle/***
2. Introduce the idea that water levels vary over time. There are day-to-day, seasonal, and long term cycles. Allow time for students to explore the interactive Great Lakes Water Levels Dashboard at ***http://www.glerl.noaa.gov/data/now/wlevels/dbd/*** before answering questions on their worksheet. If multiple computers are not available for class use, plan to project the web site and allow the class to suggest manipulations of the data. Encourage discussion of trends over short and long periods.



USEPA and Environment Canada, The Great Lakes: An Environmental Atlas and Resource Book. http://www.epa.gov/glnpo/atlas/glat-ch2.html. Accessed May 23, 2012.

> **Teacher's Note:**
> The red line on the graph for each lake is the long-term average water level. Blue horizontal lines are annual or monthly averages depending on the number of years you are viewing. The scale at the bottom of the screen can be expanded to show single years in detail or larger numbers of years. Students will need to use this tool to answer questions.

As they examine water levels over time, students should note that drops and increases in levels are fairly consistent across all lakes, though the magnitude of changes may vary. This is an indicator of the importance of water flow from Lake Superior toward the sea, and a documentation of what the Great Lakes are considered a distinct hydrologic system with its own complex interactions of water, land, ice, air and life!

Annual or seasonal variations in water levels are based mainly on changes in precipitation and runoff to the Great Lakes. Generally, the lowest levels occur in winter when much of the precipitation is locked up in ice and snow on land, and dry winter air masses pass over the lakes enhancing evaporation. Levels are highest in summer after the spring thaw when runoff increases.

The irregular long-term cycles correspond to long-term trends in precipitation and temperature. Highest levels occur during periods of abundant precipitation and lower temperatures that decrease evaporation.

EXPLAIN and EVALUATE

After analyzing how water levels change over time and discussing how the hydrologic cycle moves water between the atmosphere, hydrosphere and solid earth, direct the class to look at factors that determine lake level and consider how climate change might affect water level as well.

3. NOAA's National Climatic Data Center, NCDC, keeps records of climate factors over time. Assign groups of 3-4 students to visit ***http://www.ncdc.noaa.gov/temp-and-precip/time-series/index.php*** to see how temperature and precipitation have changed in the states or region affecting the Great Lakes. Groups may be assigned to separate lakes, or to states comprising major parts of the watershed for one lake. For instance, a group might investigate Lake Michigan's watershed region [East North Central] or examine the surrounding states of WI and MI. A map of the US climate regions is at ***http://www.ncdc.noaa.gov/temp-and-precip/us-climate-regions.php***.

4. Groups should compare temperature and precipitation from the NCDC site with water levels from the GLERL Water Level Dashboard and answer questions on their worksheet. They will discover that while water levels in Lakes Michigan-Huron have gone down over recent years, both temperature and precipitation have increased! Discuss whether this means that temperature is the most powerful force in water level determination, or if other factors are at work.

Answers to Student Worksheet

Part A

1. Lake Huron and Lake Michigan
2. Lake Erie
3. The Welland Canal contains a series of eight locks built to allow ships to pass around Niagara Falls while travelling between Lake Ontario and Lake Erie.
4. The water levels of the lakes is graphed on the dashboard.
5.

Lake	Variation in water level (m)	Rank (greatest variation 1, to least variation 4)
Superior	0.91 m	4
Michigan/Huron	1.51 m	1
Erie	1.23 m	2
Ontario	1.13 m	3

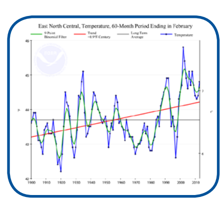
6. Highest water levels in the upper lakes occur in late summer.
   Highest water levels in the lower lakes occur in early summer.
7. Lowest water levels in the upper lakes occur in late winter.
   Lowest water levels in the lower lakes occur in late fall and early winter.
8. Answers will vary but should include factors such as seasonal fluctuations of temperature and precipitation, latitude differences, amount of snow and ice, outflow of water from one lake to another
9. The upper lakes exhibit below average water levels. The lower lakes exhibit average water levels.
10. a. F   b. T   c . T
11. Water levels in Lake Ontario seem less variable and are closer to the expected average than the other lakes.
12. Lake levels seem to be decreasing.
13. The lake levels are predicted to continue dropping.
14. a. Superior has been regulated since 1921 in order to vary the amount of water allocated to hydropower production while at the same time regulating the outflow from Lake Superior to Lakes Michigan/Huron
    b. Ontario has been regulated since 1958 in order to provide of deep-draft navigation through the St. Lawrence, Lake Ontario system; provide hydroelectric power generation; protect shoreline property owners; and improve Montreal Harbor levels.
15. Lake Superior has less seasonal variability; overall lake levels still lower than average
    Lake Ontario has less seasonal variability; overall lake levels near average

Part B

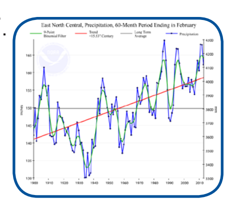
16. a. the temperature trend shows an increase;
    b. the observed individual temperatures fluctuate above and below the trend line

17. a. precipitation trend also indicates an increase;
    b. the observed precipitation levels fluctuate above and below the trend line

16.



17.



18. As precipitation and temperatures increase over Lake Michigan, lake levels continue to decrease. This may indicate that increasing temperatures have a greater impact on overall lake levels than precipitation does, most likely by the mechanism of evaporation and the long term impact of such dryness in the watershed.

EXTEND

Option 1

Climate change is expected to impact the Great Lakes through warmer temperatures year-round, and increased storm activity, sometimes with increased precipitation. The additional heat from both the land and water could result in more evaporation than precipitation. The corresponding drop in water levels may be as much as one meter in the worst case scenarios, but some lakes may even experience a small rise in lake level [Lofgren, et al, 2011]. Regardless of the amount of lake level change, people in the region likely will notice differences in water levels over time.

Use clips of the webinar presented by Dr. Drew Gronewold about why it is important to understand fluctuating lake levels, specifically those of the Great Lakes. See the resources section.

Do the activity "Which Great Lakes factors will increase and which will decrease as a result of climate change?" using a central concept of LAKE LEVEL DROPS ONE METER. Have students think about what will happen to shorelines, shipping, wetlands, swimming beaches, marinas, docks, fish spawning, and other factors that are related to water levels. They may wish to collect photographs or make drawings of the changes they anticipate. Teachers may choose to supplement this activity with *Impacts on Water: Our Region's Vital Resource*, a fact sheet depicting the cascading effects of climate change on water resources in the Great Lakes region (see the resources section).

Option 2

Day-to-day changes are caused by winds that push water onto or away from shore. This is called 'wind set-up' or "surge" and is usually associated with a major lake storm, which may last for hours or days. When wind subsides, water that has been pushed in this way will oscillate back and forth until it reaches equilibrium, in a process known as a 'seiche.' This is often likened to waves in a bathtub. See the Lake Levels webinar (slides 40 and 41) in the resources section for graphic representation of this phenomenon.

Teachers can demonstrate a seiche by using a sturdy, bi-level paint roller tray partially filled with water. Use a small fan to simulate wind moving across a lake during a storm. Try starting from the deep end, then move to the shallow, etc. Discuss any observations as a class. Ask students if a seiche demonstrates a phenomenon of climate or weather? [A seiche is classified as a weather event because of its short-term occurrence.]

REFERENCE

Lofgren, B. M., T.S. Hunter, & J. Wilbarger, 2011. Effects of using air temperature as a proxy for potential evapotranspiration in climate change scenarios of Great Lakes basin hydrology. *Journal of Great Lakes Research* 37: 744–752.

RESOURCES

Background for Great Lakes water levels and their human effects: ***http://www.great-lakes.net/teach/envt/levels/lev_1.html***

Regulation of Great Lakes Water Levels: ***http://www.in.gov/dnr/water/3660.htm***

NOAA's National Climatic Data Center, NCDC, keeps records of climate factors over time:
http://www.ncdc.noaa.gov/temp-and-precip/time-series/index.php

Webinar "*Lake Levels*" by Dr. Drew Gronewold contains GLERL images of lake level changes: see slides 9-13, 19, 74,
http://changingclimate.osu.edu/webinars/archives/2011-05-10/

Extension lesson: Which Great Lakes factors will increase and which will decrease as a result of climate change?
http://changingclimate.osu.edu/assets/docs/2012edu_CurriculaVisualizingV6-Final.pdf

Union of Concerned Scientists' *Impacts on Water: Our Region's Vital Resource* fact sheet:
http://www.ucsusa.org/greatlakes/pdf/glwaterresources.pdf

Information about ships, shipping, and passage through the different levels of the Great Lakes:
http://www.great-lakes.net/teach/business/ship/ship_5.html

Michigan Sea Grant's *Preparing for Variable Lake Levels Fact* Sheet
http://www.miseagrant.umich.edu/downloads/climate/11-700-Preparing-for-Variable-Lake-Levels.pdf

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

Student Activity: How do the levels of the Great Lakes change?

OBJECTIVE

When you finish this lesson you should be able to interpret graphs of how and when water levels change in the Great Lakes, and describe how temperature and precipitation are related to lake level.

Part A: How do the levels of the Great Lakes change?

Just as sea level is expected to rise, most scientists agree that climate change will affect water levels in the Great Lakes. Changes in the region are likely to result in lower water levels, though there will be differences from lake to lake. This lesson is about how lake levels already change through the years and decades.

To begin, here is a profile of the Great Lakes showing how far above sea level they are.

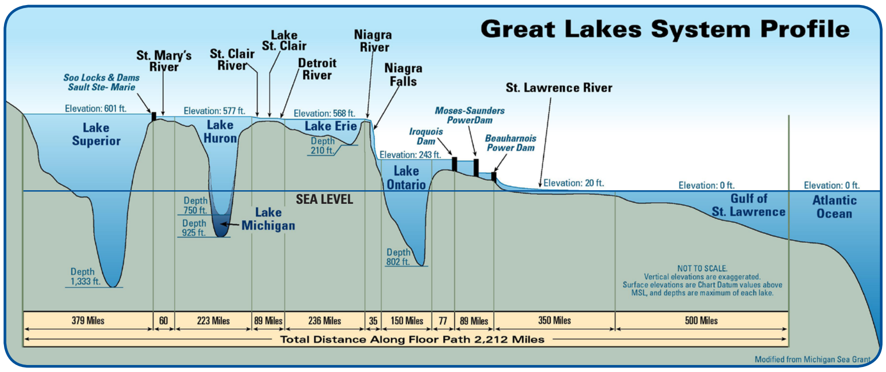


Figure 1. Ohio Department of Natural Resource

1. Based on this diagram, which two lakes are at the same elevation above sea level?

2. Which is the only Great Lake whose floor does not reach sea level? ______________________________

3. The Welland Canal looks like stairs in this diagram! Describe what it really is, with information from ***http://www.great-lakes.net/teach/business/ship/ship_5.html***.

Use the Great Lakes Water Levels Dashboard ***http://www.glerl.noaa.gov/data/now/wlevels/dbd/*** to answer the following questions.

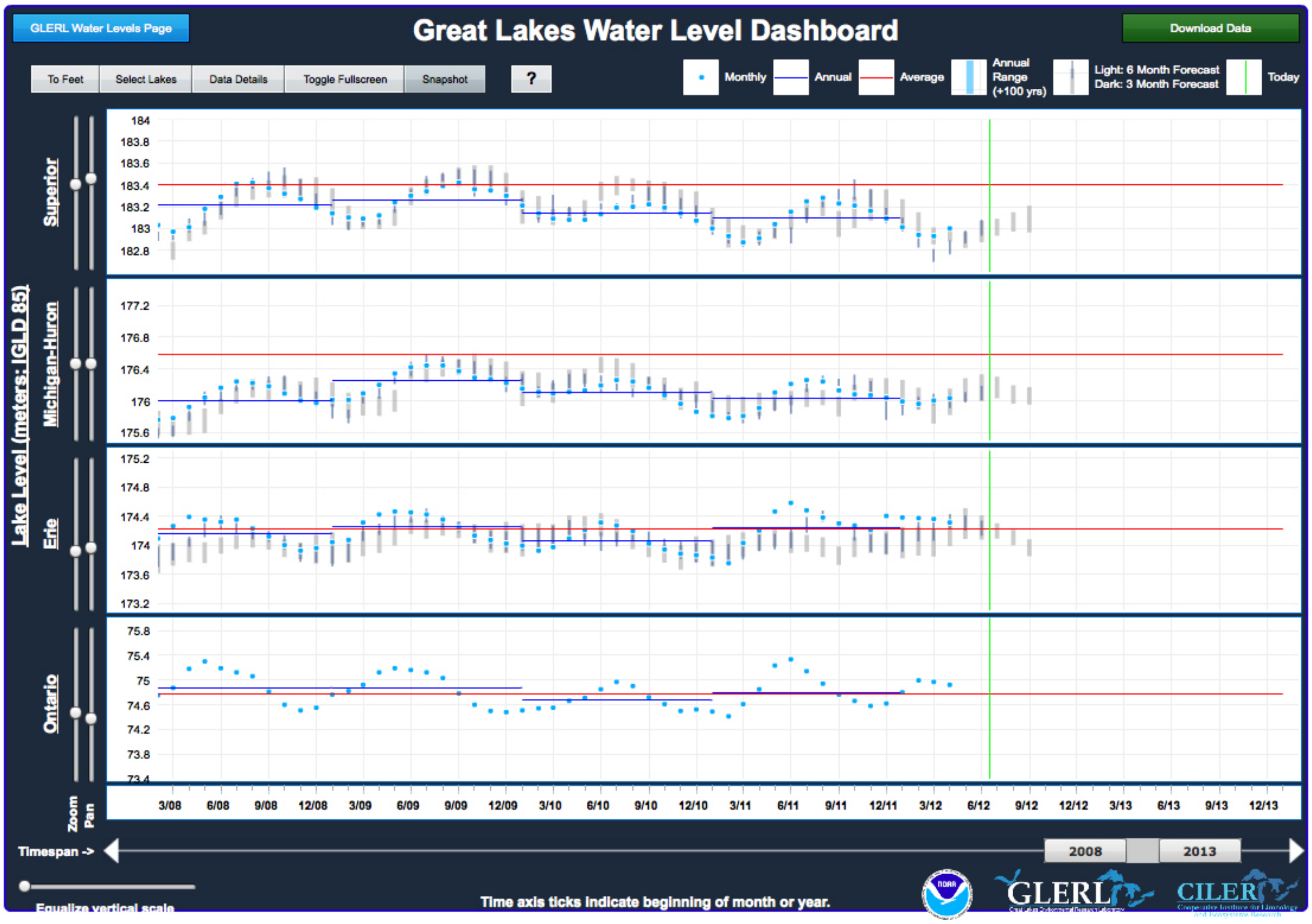
4. What characteristic of the lakes is graphed on the Dashboard?

5. With all the lake graphs in view, determine each lake's variations in water level [from highest to lowest numbers of meters] from 1997 to 2012. Record your data in the table.

Lake	Variation in water level (m)	Rank (greatest variation 1, to least variation 4)
Superior		
Michigan/Huron		
Erie		
Ontario		

Use the sliding scale at the bottom of the Dashboard to focus in on just a few years, so you can see Month/Year on the X-axis. The record for 2008-2012 will look like Figure 2.

Figure 2. Monthly lake level data for the Great Lakes



6. a. During what season of the year did the HIGHEST water level occur in the "Upper Lakes," [Lakes Superior and Michigan/Huron]?

b. What season had the highest water in Lakes Erie and Ontario [the "Lower Lakes," geographically]?

7. a. During what season did the LOWEST water level occur in the Upper Lakes?

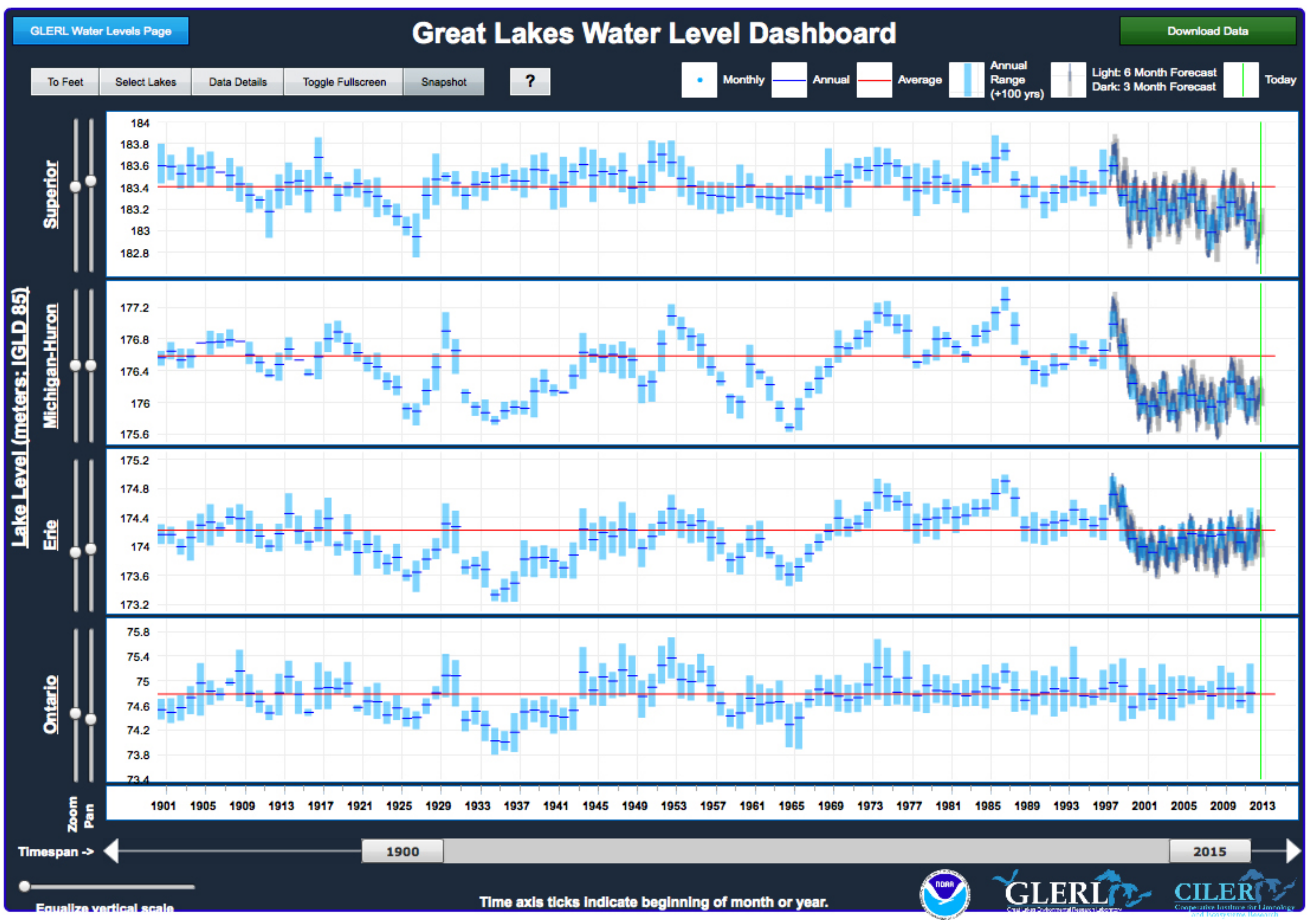
b. What season had the lowest water in the Lower Lakes?

8. What could cause these seasonal differences in water level among the lakes?

9. The red line is the long-term average water level for each lake. Judging from the short period of data in Figure 2, is water level above, below, or about average for the lakes shown?

Now look at a longer period of time using the sliding scale at the bottom of the Dashboard.

Figure 3. Great Lakes water levels since 1900



10. The annual pattern of high and low water you identified above disappears when you look at this scale of data. Practice interpreting data. Put a checkmark next to the statements that are accurate interpretations of the data in Figure 3.
    a. _____ Water levels were below average in Lake Superior in the 1930s.
    b. _____ Water levels were typically above average in all five lakes in the late 1940s and early 1950s.
    c. _____ Lake Superior differed from the other lakes in the 1930s. Its water level were typically above average while the other lakes experienced lower than average water levels.

11. Now examine the Lake Ontario graph. How do water level changes compare with those of the other lakes?

12. Many climate records [for heat, drought, floods, etc.] have been set in the last two decades. Look at the lake level data since 1990. What seems to be the pattern of lake level during the period since 1990?

13. How do the projected lake levels for the next few years compare with the observed pattern of this century?

14. Read about regulation of Lake Ontario and Lake Superior at ***http://www.in.gov/dnr/water/3660.htm***.

    How long have these lakes been regulated: Superior since _______ and Ontario since _______.

    Why are the lake levels regulated?

    Superior:

    Ontario:

15. Mark Figure 3 for the dates of regulation on their respective lakes. How do lake levels vary since regulation began?

    Superior:

    Ontario:

Part B: How do temperature and precipitation relate to water levels?

Use ***http://www.ncdc.noaa.gov/temp-and-precip/time-series/index.php*** to investigate what is happening, or has happened, with two of the factors that influence lake water levels.

16. Use the web choices to plot the temperature for Lake Michigan over the last 60 months, ending with the most recent month.
    This means you will select from the pull-down menus as follows:
    Parameter: Temperature
    Month: February [accept the month on the web page]
    Year: 2013 [accept the year on the web page]
    Filter: 60-month average
    State/Region: East North Central
    Click on PLOT

    a. What is the general trend of the observed temperature over this period?

    b. How does the observed temperature differ from the long-term average for the period?

17. Now change the Parameter to Precipitation and click on PLOT.
    a. What is the general trend of the observed precipitation over this period?

    b. How does the observed precipitation differ from the long-term average for the period?

18. Compare the changes in temperature and precipitation that you have plotted with the change in water level in Lake Michigan over the last century. Which, if either, parameter seems to be related to the water levels you discovered in questions from Part A #13-14?
    How might you explain this?

HOW DO ENERGY USE DECISIONS INFLUENCE GLOBAL CLIMATE CHANGE?
CARS ON TRIAL

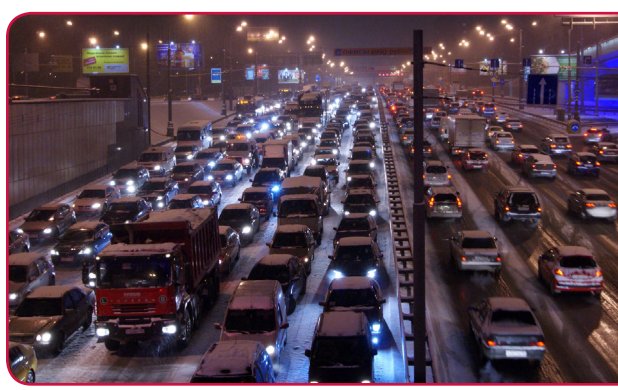
BACKGROUND

This activity encourages discussion about energy use decisions, greenhouse gases, and global warming. In it, a trial is held in which automobiles are accused of emitting a dangerous gas (carbon dioxide) into the atmosphere. The students (jury) must decide how harmful they think automobiles really are and what, if anything, should be done about them.

Carbon dioxide is a greenhouse gas. When it accumulates in the atmosphere, it traps heat from the sun, warming our biosphere like the glass of a greenhouse traps heat in the enclosed space. The Earth's atmosphere is largely composed of nitrogen and oxygen. These molecules are transparent to visible light and infrared radiation while they absorb some ultraviolet wavelengths. Greenhouse gases (carbon dioxide, nitrous oxide, ozone water vapor, and methane) each absorb infrared radiation (heat). If the Earth's atmosphere only contained nitrogen and oxygen, the surface air temperatures would be about negative 18°C. However, the world has a mean surface air temperature of about 15°C because of the presence of the greenhouse gases in the atmosphere. These gases act as a blanket, keeping us warm, just as ozone acts as a shield in the stratosphere, protecting us from ultraviolet rays.

The burning of fossil fuels, such as gasoline, releases carbon dioxide into the atmosphere. Some interesting statements concerning gasoline, cars and CO_2 emissions include the following:

- The U.S. contains about 6 percent of the world's population and owns a quarter of the world's cars. (U.S. Census Bureau, Ward's Auto)
- American cars and trucks cover more than 4.2 trillion miles per year, the equivalent of 45,428 trips from the sun to the earth. (U.S. Dept. of Transportation, Universe Today)
- As of 2009, yearly oil use worldwide averaged 4.3 barrels per person, with the U.S. at 21 barrels per person. Americans use almost 3 times more oil than Europeans on a per-person basis. (Nationmaster)
- Only 4% of Americans use public transportation daily while 88 percent of all trips in the United States are made by car—and many of those cars carry only one person. (American Public Transportation Association)
- "Worldwide, there are over 110 car models that get over 40 miles per gallon, 70% of which are made by U.S. companies. Only three of these vehicles are sold in the United States, however. […] The average gas mileage of cars and light trucks on the road in the United States (both domestic and imported) in 2005 was 19.8 mpg, one of the lowest averages in the more developed nations." (*Environmental Science*)
- Passenger cars account for more than 10 percent of the total carbon dioxide emitted from fossil fuels worldwide, or more than 2.8 billion tons of carbon dioxide annually. (World Energy Council)
- Gasoline consumption in the U.S. has risen 21% between 1980 and 2008, while consumption in European countries has dropped or stayed level. Researchers attribute this pattern to the high gas taxes in Europe, which discourage fuel consumption. (CNN Money)



Sergey Rodovnichenko, via Flickr

Updated from the activity in GLIMCES © The Ohio State University, 1995

Teacher Guide

Objectives: In this activity, students will role play a courtroom trial to discuss energy use as it is related to climate change.
After completing this activity, students will be able to:

- List several pros and cons regarding the use of automobiles in America (or Canada).
- Think critically about the complexity of reducing the amount that Americans (or Canadians) drive cars.
- Describe the basic effects of CO_2 in the atmosphere.

Materials:

- Any props useful for the trial, such as a gavel for the judge, professional clothes for the lawyers, etc.
- Resource materials so that the lawyers and the witnesses can study global warming, carbon dioxide levels, the role of greenhouse gases, the use of automobiles in America, and other related topics
- The prosecution may want materials such as a chart of average world temperatures or a graphic demonstrating how carbon dioxide traps heat

Time required: 1 class period for planning and role research, 1 – 2 class periods for the "trial"

THE CAST INCLUDES

- Bailiff: Strong silent type
- Judge: The teacher is the ideal person for this role to help steer the discussions in productive ways as well as retaining order.
- Prosecuting Lawyer: Opinion is that CO_2 is made by cars; therefore, cars are responsible for global warming.
- Defense Lawyer: Opinion is that automobiles offer benefits to humanity, overriding concerns about CO_2 and global warming.
- Air: Prosecution witness
- Car: Defense witness
- CO_2 Expert: Prosecution witness
- Teenager with License: Defense witness
- Scribe: This person records the decision of the jury, and he or she should be a part of the jury.
- Jury (rest of the class): Determines the verdict

TEACHER'S NOTE

With a large class size, the teacher may opt to have pairs or teams of three students work together to represent the roles of Prosecuting Lawyer, Defense Lawyer, Air, Car, CO_2 Expert and Teenager with License.

ALIGNMENT

National Framework for K-12 Science Education:
SEP7: Engaging in argument from evidence
Core Idea ESS3: Earth and human activity

Great Lakes Literacy Principles:
#6f: The Great Lakes and humans in their watershed are inextricably interconnected.

Climate Literacy Principles:
#6a,c: Human activities are impacting the climate system.

ENGAGE

Project on a screen or provide copies to students of the following image (there is a larger version at the end of this lesson). Facilitate a class discussion about what the cartoon is depicting. Guide students with questions such as: Why is the car on trial? What are the people protesting? Why is the witness wearing a surgical mask?

Dylan Nance, 12th grader at Westerville North High School

EXPLORE

1. Decide who will play which role. Students without specific roles will be part of the jury.
2. Give lawyers and witnesses their cards. They should be made aware of courtroom procedures.
3. Students do internet research to gather facts to support their roles (could be done in class or for homework). So that all students are on task, those who are members of the jury can compile a list of questions they might ask the witnesses.

EXPLAIN

Courtroom Procedure

On the day of the trial . . .

1. The bailiff announces the judge: “All rise, the Honorable Judge ______________ is presiding.”
2. The judge enters, calls the court to order and introduces the case with the following statement: “Today, all of the cars in this nation are on trial. They are accused of emitting harmful CO_2 into the atmosphere, causing global warming.”
3. The judge then introduces the defense and prosecuting lawyers who give their opening statements.
4. Prosecution calls its first witness (the CO_2 expert) to the stand for questions. Following this the defense lawyer may cross examine the witness.
5. The prosecution then gets to call a second witness (the air). Again the defense may cross examine.
6. Next, the defense may call its first witness to the stand (teenage driver). The prosecution may cross examine.
7. Defense may then call their second witness (the car). The prosecution may cross examine.
8. After the lawyers and witnesses have finished, the judge asks the jury if there are any questions.
9. It is now time for the jury to decide the verdict (remedy). The judge should remind them that they must keep the good and safety of society in mind. Is the automobile a menace to society or a useful convenience?
10. Lawyers and witnesses may not interrupt or take part in this discussion. If a clarification of a particular detail is needed, questions may be asked by the jury to the appropriate party.
11. Have one member of the jury write up the conclusions of the jury. Once the jury has agreed on a conclusion, it should be read aloud to the entire courtroom.

EXTEND AND/OR EVALUATE

The following is a list of questions that could be used in a class discussion after the trial has concluded. Alternatively, teachers could assess students by having them write answers to selected questions and requiring them to cite evidence or facts presented at the trial.

- How is carbon dioxide both beneficial and harmful to our atmosphere? [Refer to the background information for an explanation on the role of CO_2 in the atmosphere.]

- Think back to the jury's decision. What factors are barriers to implementing the decision of the jury? How feasible would the jury's decision really be? How many people in the population of your town, state, or country would agree with the jury's decision? [Students should think of how population size, geography, political climate, need for transportation of goods and other factors would affect the decision. They should also incorporate the concept of limited supplies of fossil fuels.]

- How would you best describe an environmentally responsible way to use vehicles (keep in mind that we live on a planet where the population is constantly expanding)? [Students can consider a range of ideas. Ideas should spark discussion. Entertain all ideas equitably.]

- Is it fashionable/popular/cool to use automobiles in an environmentally safe manner? Why or why not? [Students might consider economics of the car industry, status of owning and driving certain kinds of cars, lack of alternative methods of transportation, reasonable price of gas, etc.]

- There has been an increase over the past several years in the percentage of cars that are luxury cars or SUVs (sport utility vehicles). What would make it fashionable to drive an economical or environmentally friendly car? [Earth sense and saving resources might be considered cool or become popular ways of thinking.]

- Brainstorm which things society has at one time esteemed as being "the in things to do" but are generally thought of as in bad taste now because of environmental or health reasons. [These things might include wearing real fur coats, smoking and tanning.]

- Is there a relationship between gas prices and people's willingness to use public transportation? If so, describe it. [According to the American Public Transportation Association, 85 percent of transit agencies reported experiencing capacity constraints during the 2007-2008 gas price spike.]

- How would people's lifestyles change if society started using more public transportation or bicycling to work? [Students might consider changes to personal or family budgets, commuting time, work productivity, availability of free time, etc.]

- How do you envision the way Americans will use cars twenty years from now? [Students can consider a range of ideas. Ideas should spark discussion. Entertain all ideas equitably.]

- On a worldwide level, the United States has significantly more emissions than developing countries. Some people believe that the goal of these countries is to attain the US lifestyle. What would happen if they all did? What would we recommend to them? [Students could create ways of pursuing economic development that are different than what has been done before. Countries could follow a different path.]

- Is a more affluent lifestyle always better? What sorts of lifestyles do you hope to create for yourself some day? Would you prefer a house or a car that is more economical and environmentally friendly over one that is not? What is ideal? [Students could write about or draw their future homes or cars, and then share ideas with the class.]

- Have students investigate the car that they ride in the most. What is its gas mileage? What will happen to it when it is time for it to be discarded? What happens to used oil after it is changed? Why was that particular car purchased? Was the environment one of the buyer's concerns?

Another idea is to have students view *Small-Town Shortage*, a short segment on YouTube showing how a small California town is directly affected by rising gas prices (***http://www.youtube.com/watch?v=hP_C_Sn66yM***). Facilitate a class discussion on the likelihood of these impacts happening in your own town. National Geographic has also produced *Aftermath: World Without Oil*, a three-part program of fictitious accounts of the extreme effects of oil shortages. These are also available on YouTube at ***http://www.youtube.com/watch?v=zyEGnMa9MyM***.

REFERENCES

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

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Cars on Trial Character Cards

You may want to laminate these cards for multiple uses.

JUDGE

The role of the judge is to keep the trial running smoothly and to keep order in the courtroom. The judge may stand at a podium with the courtroom procedures in front of him or her to make sure they are followed. The judge has the ability to make the trial as humorous or as serious as desired.

PROSECUTION LAWYER

It is your job to make sure that the jury understands the serious negative consequences of carbon dioxide emissions, especially at its present rates which are constantly increasing. Your argument is that cars are polluting our air and having serious negative global effects. You think that society must concern itself with the problem soon before more serious damage is done, especially with the ever growing world population. Feel free to state statistics regarding the environmental harm that cars cause in order to impress that point upon the jury. Your opening statement should include the main points that you hope to prove during the trial. You must be ready with good questions to ask of the witnesses.

DEFENSE LAWYER

Your job is to help the jury see how important and beneficial cars are to our society. Your opening statement should include the main points that you hope to prove during the trial. Some arguments you may want to incorporate into your defense are the following:

- You may question the assertion that CO_2 is actually harmful in the atmosphere by claiming that the scientists have greatly exaggerated the consequences of CO_2 emissions in order to scare the public. You also are aware that scientists disagree on the subject of global warming. You want to know how the scientists who argue for global climate change got their data. Claim that no decision should be made until the data are verified and irrefutable.
- The economy of our society depends on cars. The automobile industry employs thousands of people: engineers, designers, mechanics, gas station attendants, factory workers, salespeople, advertisers, etc. We also export a significant number of cars.
- In America we greatly value our freedom to go where we want whenever we want without having to wait for a bus or travel with strangers. This depends on the ongoing use of personal vehicles.
- Ask the jury if they would want to wait for a bus or walk to the subway if any emergency happened. Cars can be lifesavers.
- American life would change dramatically without cars; they have become a symbol of the way we live. We are independent, free and have abundant resources.

Be ready with good questions for each of the witnesses when it is your turn to question them.

Cars on Trial Character Cards

You may want to laminate these cards for multiple uses.

DEFENSE WITNESS – CAR

You are on trial and are being accused of emitting CO_2 into the atmosphere which causes global warming. You must answer any questions truthfully to the best of your ability but one argument you might make on your behalf is that you perform a useful function in society. You can bring up the point (feel free to interrupt the lawyers whenever you want to) that your only purpose on this planet is to serve the public, the very members of the jury, so you are amazed that these same people could be attacking you. You might remind them that you don't drive on icy roads and through potholes for your own good, but that you would rust yourself out driving people anywhere they wanted to go. Has the jury ever noticed how cars are treated in the movies – they're demolished. Remind them that if someone told you to drive over the cliff, you would do it as long as you're able, without even a question. The jury has a lot of nerve to blame you for causing them trouble. You may want to ask the jury how many of them hope to own a vehicle someday. Ask them how many of them rode in a vehicle today and how their parents would get to work without a car. Not only that, but you produce CO_2 which plants need in order to grow and produce oxygen. Feel free to really let the audience know how you feel.

PROSECUTION WITNESS – AIR

You are vehemently against cars. You may want to claim that you are vital to the health of the planet. In fact, you keep the jury (and everyone else) alive from minute to minute, so they ought to be concerned with your health. You feel that automobiles are poisoning you. In some places of this country, people aren't supposed to go outside during certain times of the day because of air pollution. You feel that drastic measures are needed to stop air pollution. You are retaining heat and think that this will have serious negative consequences. None of the jury can afford for things to become worse.

PROSECUTION WITNESS – CO_2 EXPERT

You have an extremely vital role in this trial. You represent the scientific community and present all (or most) of the actual data used in this activity. Your job is to explain how CO_2 works as a greenhouse gas. You need to describe how CO_2 holds in heat, as well as the current levels of CO_2 in the atmosphere and how they are steadily increasing. You could present a chart of global temperatures. The defense lawyers may try to question your authority, so be sure of your facts. Bring in books and notes – you are the educated member in the court. You do not necessarily have an opinion about cars, but rather you just present the facts as you know them.

DEFENSE WITNESS – DRIVING TEENAGER

Your job as a witness is to convince the jury that owning and using a car is a necessity in our society. For instance, you can talk about the job you have delivering pizzas and how you could not imagine doing it without your car. You don't think you could deliver pizzas by bus, subway or bicycle. You also work part-time on the weekends cleaning people's carpets – imagine carrying all those supplies and that equipment around on public transportation. You also go grocery shopping often for your family; without a car you wonder how you would get 10 bags of groceries home. More importantly, you think that cars are fun. Driving is great; you can "blast" your music, you can take your friends wherever you want to go, like to the beach or a park, places off the beaten track. Your car is like your personality. Of course rush hour is bothersome and makes you nauseous, but you think it would be a tragedy to lose any of the freedom that driving gives you.

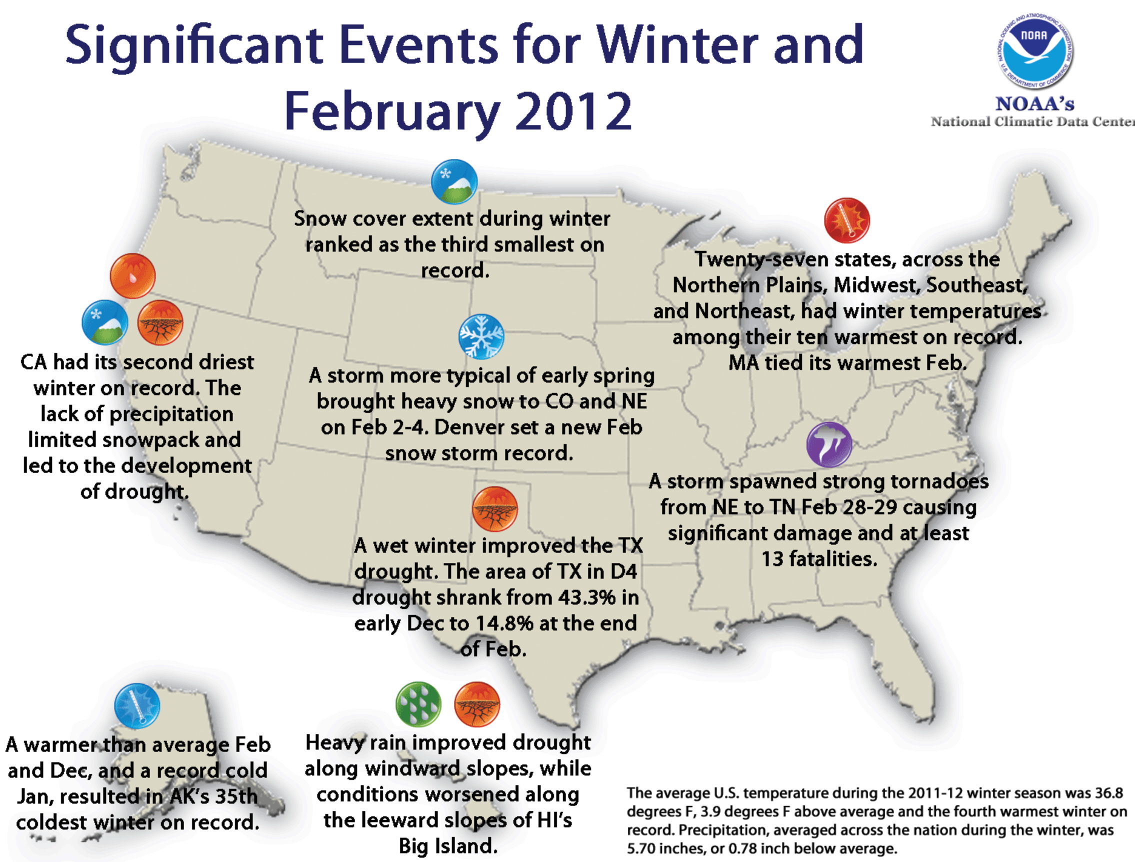
Dylan Nance, 12th grader at Westerville North High School

HOW WILL CLIMATE CHANGE AFFECT A GREAT LAKES STATE?

(Background and Teacher Guide)

According to the National Climatic Data Center, the winter of 2011-12 — collectively December, January and February — was the fourth-warmest for the lower 48 states since record-keeping began more than a century ago. For several days in mid-March, the high temperature in Chicago was 85 °F. Weather extremes were not limited to temperature and heat, however, as the NCDC map indicates. Syracuse, NY, where annual snowfall typically exceeds 115", accumulated only 50.6" in the winter of 2011-12. Of the NCDC's list of Top Snowiest Cities in the U.S., eight are in the Great Lakes region.

We have heard the reports about sea levels rising, glaciers melting and the consequences of climate change to animals, like polar bears, in the Arctic. For climate change to be relevant to students, they need examples of change from nearby. What are the consequences of climate change in a Great Lakes state like Ohio?



Activity developed by high school teacher Susan Wasmund for a course on Teaching with Google Earth, Summer 2010. Updated 2012.

Teacher Activity: How will climate change affect a Great Lakes state?

BACKGROUND

To make climate change relevant to students, they need examples of changes that are occurring or are expected in areas and enterprises near them. If it doesn't snow, what happens to winter recreation? If it doesn't rain, what happens to production of corn and dairy products? If the water levels change, will fish be able to find places to spawn? This lesson uses examples of climate change from one Great Lakes state, Ohio, to determine local relevance of climate change. To customize the information for other states, you may wish to use the information at ***http://www.cier.umd.edu/climateadaptation/*** and have tech-savvy students develop a Google Earth tour like this one! The developers of this lesson would be pleased to attach your kmz along with Ohio's!

Objectives: When students have completed this activity, they will

- recognize that global climate change will have consequences for the environment and economy of individual states
- be able to give examples of state issues and the consequences of global climate change

Materials:

Per team of 2-3 students: Student handout, computer with current Google Maps application, Ohio Climate Change Effects Tour.kmz file

Teacher's Note:

Be sure Google Earth's latest version is downloaded to computers in advance [free at ***http://earth.google.com***]. Video tutorials are available on the download site if you need some basic training. Within the application, choose File > Open and navigate to the "Ohio Climate Change Effects Tour.kmz" file included with this lesson. This will insert the file as a "Temporary Place." If you wish to leave the climate change tour in Google Earth for later use, you will get an opportunity to save it within "My Places" when you close the program. To shorten the time needed for the computer part of the lesson, minimize Google Earth on the computers rather than closing it.

Time Required 1 class period, for Google Earth activity, 1 class period for Write Around and wrap-up activity

ALIGNMENT WITH STANDARDS

National Framework for K-12 Science Education:
CC2: Cause and Effect: Progression
CC7: Stability and Change: Progression
Core Idea LS2: Ecosystems dynamics, functioning and resilience
Core Idea ESS3: Human impacts on Earth systems; global climate change

Great Lakes Literacy Principles:
#1E, G, H, I: Changes in water systems, lake levels, stratification, finite resources
#3A, E: The Great Lakes influence weather and climate, and are influenced by larger climate change patterns.
#5F, I: Great Lakes habitats are defined by environmental factors. Life in the Great Lakes has been altered by non-native plant and animal species.
#6A, C, D, E, F: The Great Lakes and humans in their watersheds are inextricably interconnected.
#7C, F: The future sustainability of Great Lakes resources depends on our understanding of resources and their potential and limitations. This requires collaboration among professionals in science, technology, engineering and math, as well as public outreach and education.
#8A, D, E, F: The Great Lakes are socially, economically and environmentally significant to the region, the nation and the planet.

Climate Literacy Principles:
#2D: The abundance of CO_2 is increased through deforestation and the burning of fossil fuels as well as through other processes.
#3A, D: Life on Earth depends on, is shaped by, and affects climate.
#6C: Human activities are impacting the climate system.
#7B, C, E, F: Climate change will have consequences for the Earth system and human lives.

ENGAGE

Ask students to brainstorm some climate change impacts. Typically these will include sea level rise, polar bear impacts, melting ice sheets, warmer temperatures. For each item on the list, check whether it is a local, state, national or regional impact. Chances are most impacts will be global or national, rather than something that might be expected in Ohio! Challenge students to think about Ohio impacts during the lesson to come.

EXPLORE

Students use Google Earth to learn how climate change affects Ohio industries, animals and people, following the steps below. The lesson can be altered to other states by anyone with appropriate technology skills.

1. Open Google Earth.
2. Open "*Ohio Climate Change Effects Tour.kmz*". It should open with the state of Ohio framed on the screen.
3. In the Places menu on the left side of the screen, students click on Placemark A. The map will fly to that area. Still in the Places menu, they click on the blue title for that placemark. In each placemark, students should read the information, look at the image and answer the question. They will probably need to click on the links in the placemarks to help find the answer.
4. Students visit all 14 locations and answer questions on the student handout.

EXPLAIN

The next part of this activity is called Write Around. In groups of 5, students complete the Introductory Phrase as a sentence. When students appear to have a sentence written, direct them to pass their paper to the left. They read the complete first sentence and add another complete sentence to strengthen the topic sentence. Watch for completion, then direct students pass that paper to the left and continue the process until they have their own paper. Depending on class maturity and attention span, you may be able to let the groups continue at their own pace. Finally, each is to write a concluding sentence to complete her/his original idea.

EXTEND

Discuss with the students the kinds of things people in Ohio could do to deal with [or prevent] the changes that are occurring in various industries or with climate in general. For instance, farmers could change to drought-resistant crops; individuals could limit their driving to prevent CO_2 from entering the atmosphere. With various suggestions, discuss the costs and benefits of the action. Maintain a focus on using science as the basis for responding to the issues.

EVALUATE

Students may be assessed on the completion of the answers to 14 questions on the tour and subjectively on their Write Around activity.

ADDITIONAL RESOURCES

Climate Change Outreach Team, The Ohio State University and partners. Archived webinars and resources for learning about climate change impacts in the Great Lakes region. ***http://changingclimate.osu.edu/***

Economic Impacts of Climate Change on Ohio, CIER - University of Maryland, July 2008. ***http://www.cier.umd.edu/climateadaptation*** Clickable map leads to information on other states.

Effects of global warming on the state of Ohio. ***www.e2.org/ext/document.jsp?docId=5410***

Climate change health threats in Ohio. ***http://www.nrdc.org/health/climate/oh.asp***

Climate change myths and misconceptions. ***http://www.newscientist.com/article/dn11462-climate-change-a-guide-for-the-perplexed.html***

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

Activity developed by high school teacher Susan Wasmund for a course on Teaching with Google Earth, Summer 2010. Updated 2012.

Name ______________________________ Period ___________

Student Activity: How will climate change affect a Great Lakes state?

In this lesson you will use a Google Earth tour of Ohio with Placemarks identifying environmental and economic issues of climate change in Ohio.

1. Open Google Earth.
2. Open the Ohio Climate Change Effects tour. Be sure the state of Ohio is framed on your screen.
3. In the Places menu on the left side of the screen, click on Placemark A. The map will fly to that area. Still in the Places menu, click on the blue title for that placemark. Read the information, look at the image and answer the question. You may need to click on a link to help you find the answer.

Record your answers in the following spaces.

A. Northwest Ohio [precipitation, flooding]

B. Farming

C. Reservoirs and drinking water

D. Dairy products

E. Shipping

F. Sediments and pollution

G. Wildlife

H. Invasive species

I. Forestry

J. Human health

K. Energy

L. Forest fires

M. State budgets

N. Fishing

Name ______________________________ Period __________

Write Around

1. In a group of five students, complete the Introductory Phrase as a sentence. When directed, you will pass your paper to the left. Read the complete first sentence. Add another complete sentence to strengthen the topic sentence. When done, pass that paper to the left and continue the process until you have your own paper. Write a concluding sentence to complete your original idea.
2. As a group, discuss your papers.
3. Write several sentences about what could be done to help our state and planet.

Climate change will affect me by:

1. ____
____
____

2. ____
____
____

3. ____
____
____

4. ____
____
____

5. ____
____
____

6. ____
____
____

This is what could be done:

REFERENCE

National Climatic Data Center, national climate report by month [url for February 2012]: ***http://www.ncdc.noaa.gov/sotc/national/2012/2***

GREENHOUSE GASES

BACKGROUND

The Earth's climate depends on the amount of solar radiation received and the atmospheric abundance of clouds and greenhouse gases. The main greenhouse gases are carbon dioxide, methane, chlorofluorocarbons, nitrous oxide, water vapor, and ozone. Much of the high-energy, short-wavelength radiation from the sun passes through the Earth's atmosphere and hits the surface of the Earth. The energy that is not reflected off the surface is absorbed and re-radiated into the atmosphere, where much of it is absorbed by the greenhouse gases. This is known as the greenhouse effect. Certain gases have been increasing in concentration in the atmosphere on a timeline concurrent with increasing global temperature.

Teacher Activity: How do greenhouse gases affect heat absorption?

Objectives: Students simulate a portion of the greenhouse system using carbon dioxide.

After completing this investigation, students will be able to:

- Describe the components of the greenhouse effect.
- Explain the effect of carbon dioxide on the absorption of heat in the atmosphere.

Materials, per group:

2 clear, empty, 1-liter plastic bottles
CO_2 cartridge with piercer*
2 thermometers
infrared radiation source (heat lamp)
2 #4 rubber stoppers with 1 hole in each, or modeling clay or silly putty
2 sheets of white paper
transparent or masking tape and marker
parafilm or stopper grease
thin book, sponge or piece of wood
glycerine, petroleum jelly or other lubricant
graph paper
meter stick

*CO_2 cartridges can be purchased online or at sporting goods stores. 12 gram, threaded cartridges were used in this investigation. An inflator, often carried by cyclists, was used to pierce the cartridge.

Time required: 1 class period for experiment; 1 class period for questions and class discussion

ALIGNMENT

National Framework for K-12 Science Education:

SEP 2: Developing and using models
SEP 3: Planning and carrying out investigations
SEP 4: Analyzing and interpreting data
CC2: Cause and effect: Mechanism and explanation
CC 4: Systems and system models
Core Idea ESS3: Global Climate Change

Great Lakes Literacy Principles:

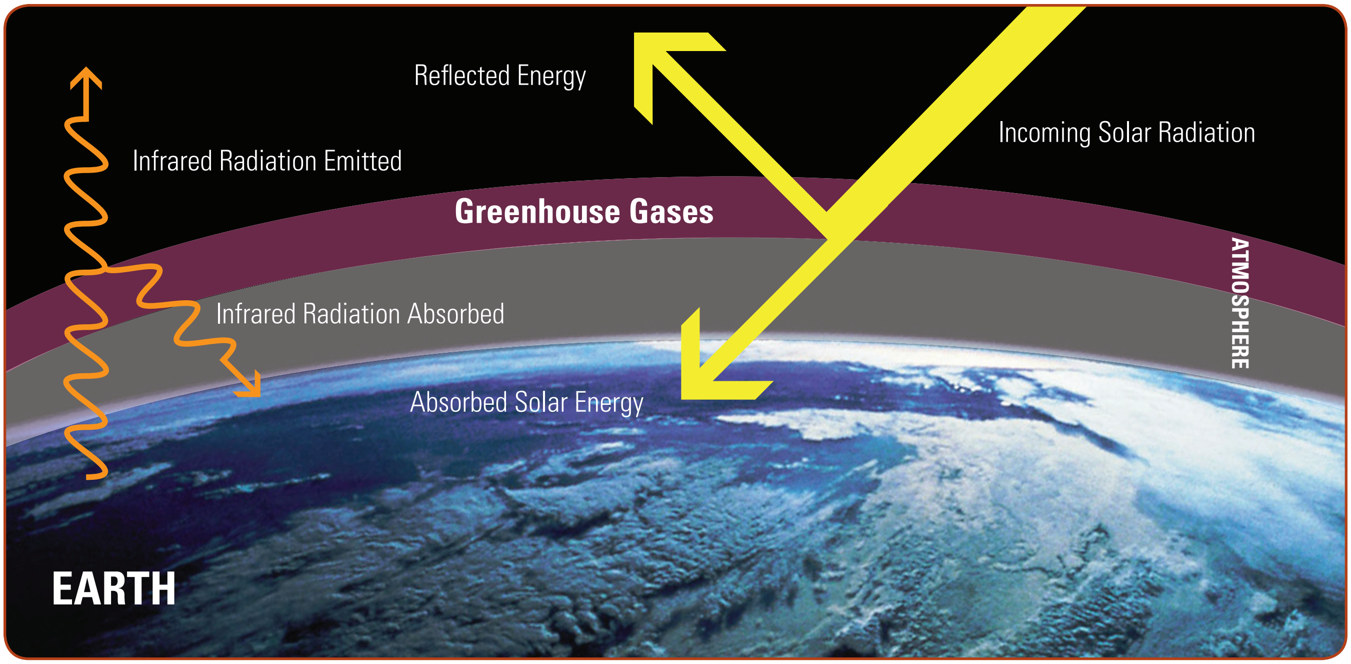
#3e: The Great Lakes influence local and regional weather and climate.

Climate Literacy Principles:

#1a: The sun is the primary source of energy for Earth's climate system.
#2d: Climate is regulated by complex interactions among components of the Earth system.

ENGAGE

Show students the following diagram that is a part of their worksheet. Have them attempt to place the labels on the appropriate arrows on their own, before sharing the answers with them.



EXPLORE

Teacher's Notes:

Before the activity begins, the apparatus should be assembled by the teacher. Lubricate the bottom 1/3 of each thermometer with glycerine or petroleum jelly. Hold one of the thermometers with several layers of paper towels and gently push the thermometer through the hole in one of the rubber stoppers. Push until about 10 cm of the thermometer has passed through the other end of the stopper. Make sure that you push the bulb end of the thermometer toward the small end of the stopper and through the opening. Repeat with the other thermometer and rubber stopper. Wipe off any excess lubricant. Alternately, students can use modeling clay to seal the thermometer assembly to the bottle.

The investigation can be done outside on a sunny day instead of using heat lamps. In this case, steps 7 – 9 in the procedure and questions 1, 6 and 8 on the student worksheet may not be applicable.

1. Provide each group of students with the thermometer/stopper apparatus, 2 bottles, 2 CO_2 cartridges, and remaining supplies.

2. Students follow instructions on their paper to set up an investigation modeling the effects of having carbon dioxide in the atmosphere. They collect and graph data before returning to a class discussion.

CAUTION:
DO NOT FORCE THE THERMOMETER THROUGH THE HOLE.

THE THERMOMETER MAY BREAK AND CAUSE INJURIES.

STRESS SAFETY:

STUDENTS AND TEACHERS SHOULD WEAR GOGGLES WHEN WORKING WITH CO_2 CARTRIDGES.

EXPLAIN

Teachers should facilitate a class discussion while students write answers to the questions on their papers.
A simple animation of the greenhouse effect can be found at ***http://earthguide.ucsd.edu/earthguide/diagrams/greenhouse***.

Answers to Student Worksheet

1. Heat from Earth's surface.
2. The atmosphere.
3. To reduce the direct warming of the bulbs by the heat source.
4. The bottle containing CO_2 should have felt warmer.
5. The bottle containing CO_2 should, because CO_2 absorbs infrared radiation more effectively than air. The CO_2 line should have a steeper slope than the AIR line.
6. Refer to the slopes of the lines. The temperature of the CO_2 should increase faster. Both lines flatten out as the system approaches equilibrium.
7. Four times – inverse square law. They should both increase.
8. The temperature of the CO_2 should increase faster than the temperature of the air.
9. Possibly not. The temperature of the CO_2 is likely to increase faster than the temperature of the air. After a certain time, both lines should flatten out.
10. Thermal equilibrium means heat is no longer moving between two regions, thus temperature remains constant. The temperature in the bottles no longer increases.
11. Global warming appears to be occurring, which suggests that the atmosphere is not in thermal equilibrium.
12. Greenhouse gases transmit short-wave radiation from the sun, but absorb long-wave radiation from the Earth. These gases absorb thermal radiation, thereby trapping it in the atmosphere.
13. Answers should address how increased amounts of greenhouse gases cause warming of the Earth's atmosphere.
14. Variables include, but are not restricted to: the strength of the heat source; the opacity of the plastic bottles; the distance between the bottles and the heat source; the concentrations of gases in the bottles; and the types of gases in the bottles.
15. Based solely on the factors listed, the temperature should be expected to increase.

EXTEND

Have students choose a variable other than the distance between the infrared heat source and the bottles (i.e., the strength of the heat source; the opacity of the plastic bottles; the concentrations of gases in the bottles; and the types of gases in the bottles), and describe how they would repeat the activity to determine how that variable affects the temperature in the bottles.
If N_2O is available, have students conduct the same investigation for comparison purposes.

Venus is a planet whose orbit around the sun is closest to Earth's orbit. It has experienced greenhouse warming for many thousands of years and has a mean surface temperature of 464°C. Research how Venus' atmosphere formed. Could this happen to Earth if the gas composition of the atmosphere alters? Support your answer with evidence.

EVALUATE

Sample evaluation tasks:

Water vapor is actually the most abundant greenhouse gas. Assume you conduct the same investigation, but replace the CO_2 bottle with a WATER VAPOR bottle in which you used a mister to add moisture to the inside of the bottle. Predict how temperature would change in the WATER VAPOR bottle. Construct a graph to show the general trend in data (from both bottles) you would expect to see. Explain whether the results of this experiment would be similar to or different from the results of your original investigation.

Create a concept map illustrating the process of heat absorption in the atmosphere and the consequences that it could produce on the various Earth systems and human society.

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Please call 614.292.8949 for more information.

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Student Activity: How do greenhouse gases affect heat absorption?

BACKGROUND

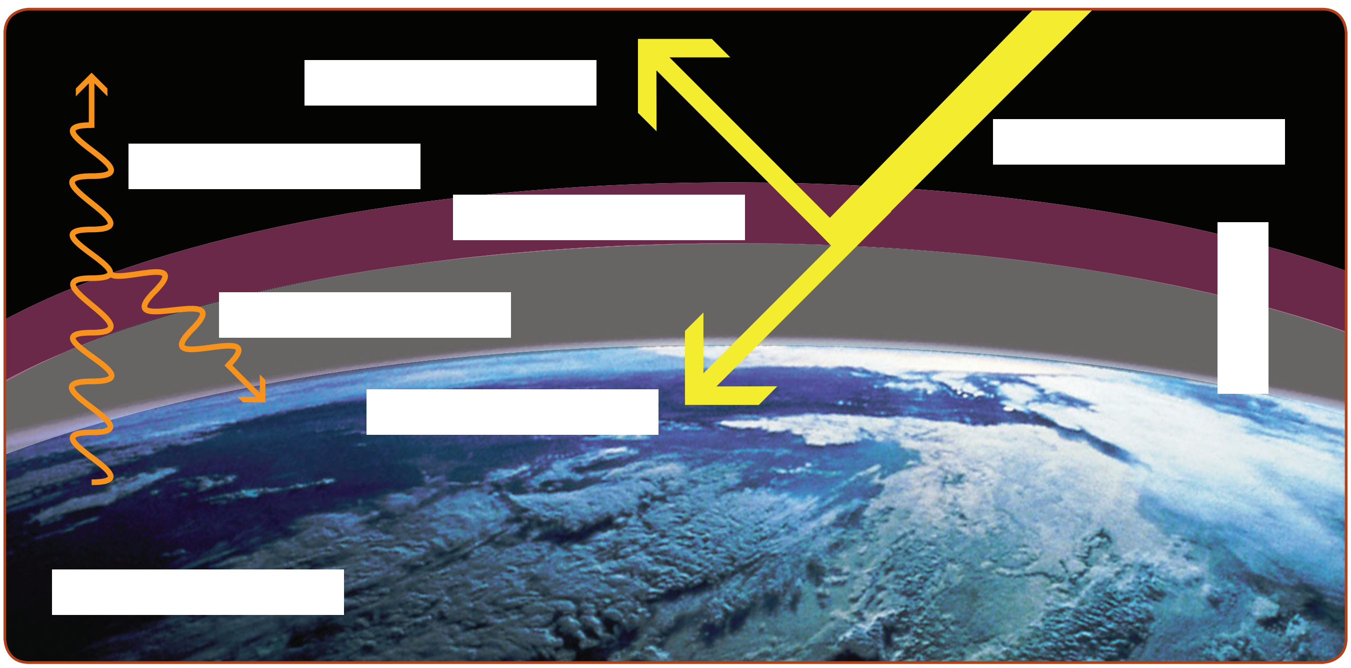
The Earth's climate depends on the amount of solar radiation received and the atmospheric abundance of clouds and greenhouse gases. The main greenhouse gases are carbon dioxide, methane, chlorofluorocarbons, nitrous oxide, water vapor, and ozone. Much of the high-energy, short-wavelength radiation from the sun passes through the Earth's atmosphere and hits the surface of the Earth. The energy that is not reflected off the surface is absorbed and re-radiated into the atmosphere, where much of it is absorbed by the greenhouse gases. This is known as the greenhouse effect.

BACKGROUND

Use the following terms to label the diagram below.

incoming solar radiation **Earth** **atmosphere** **absorbed energy** **reflected energy**

infrared radiation absorbed **infrared radiation emitted**



PROCEDURE

1. Obtain 2 1-liter bottles, stopper-thermometer assemblies and a CO_2 cartridge, as well as the other necessary materials, from your teacher.
2. Tape a small piece of white paper over one side of the bulb of each thermometer. The purpose of this paper is to shield the bulbs from the heat source. Make sure you affix the paper so that you can read the scale accurately.
3. Hold one of the 1-liter bottles with the mouth upward. Using the inflator, pierce 1 CO_2 cartridge and "pour" the CO_2 from the cartridge into the bottle. One student should use their hand to make a seal around the mouth of the bottle while another student "pours" the CO_2 into the bottle. Make sure to empty the cartridge completely.
4. Stopper the bottle containing CO_2 with one of the thermometer/stopper assemblies. Seal it with stopper grease or parafilm. Stopper the other 1-liter bottle in the same way. This bottle will have air in it.
5. Label the first bottle "CO_2" and the second bottle "Air."
6. Lay the two bottles down on their sides together on a white piece of paper. Support the necks of the two bottles with a thin book, sponge or piece of wood. It is important that the pieces of paper you taped to the bulbs of the thermometers are on top and will shield the bulbs from the infrared heat source. Make sure that you can read the scale of each thermometer without moving the bottles.
7. Place the infrared heat source 0.5 m above the two bottles. Make sure that both bottles are equidistant from the heat source.
8. Record the temperatures in each bottle before adding the heat lamp. Then turn on the infrared source and record the temperatures in the two bottles at 2-minute intervals for a total of 16 minutes. (You should have 8 readings in addition to your original reading.)
9. At the end of 16 minutes, lower the infrared source to 0.25 m above the bottles and continue to record the temperatures in the two bottles at 2-minute intervals for another 16 minutes. (You should have 16 readings in addition to your original reading.)
10. After you have completed recording the temperatures for a total of 32 minutes, turn off the infrared heat source and feel the two bottles to see if you can detect a difference in temperature.
11. Construct a line graph to show how the temperatures in the two bottles changed over time. Be sure to add a title to your graph and label the lines to indicate which line represents the "Air" bottle and which line represents the "CO_2" bottle.

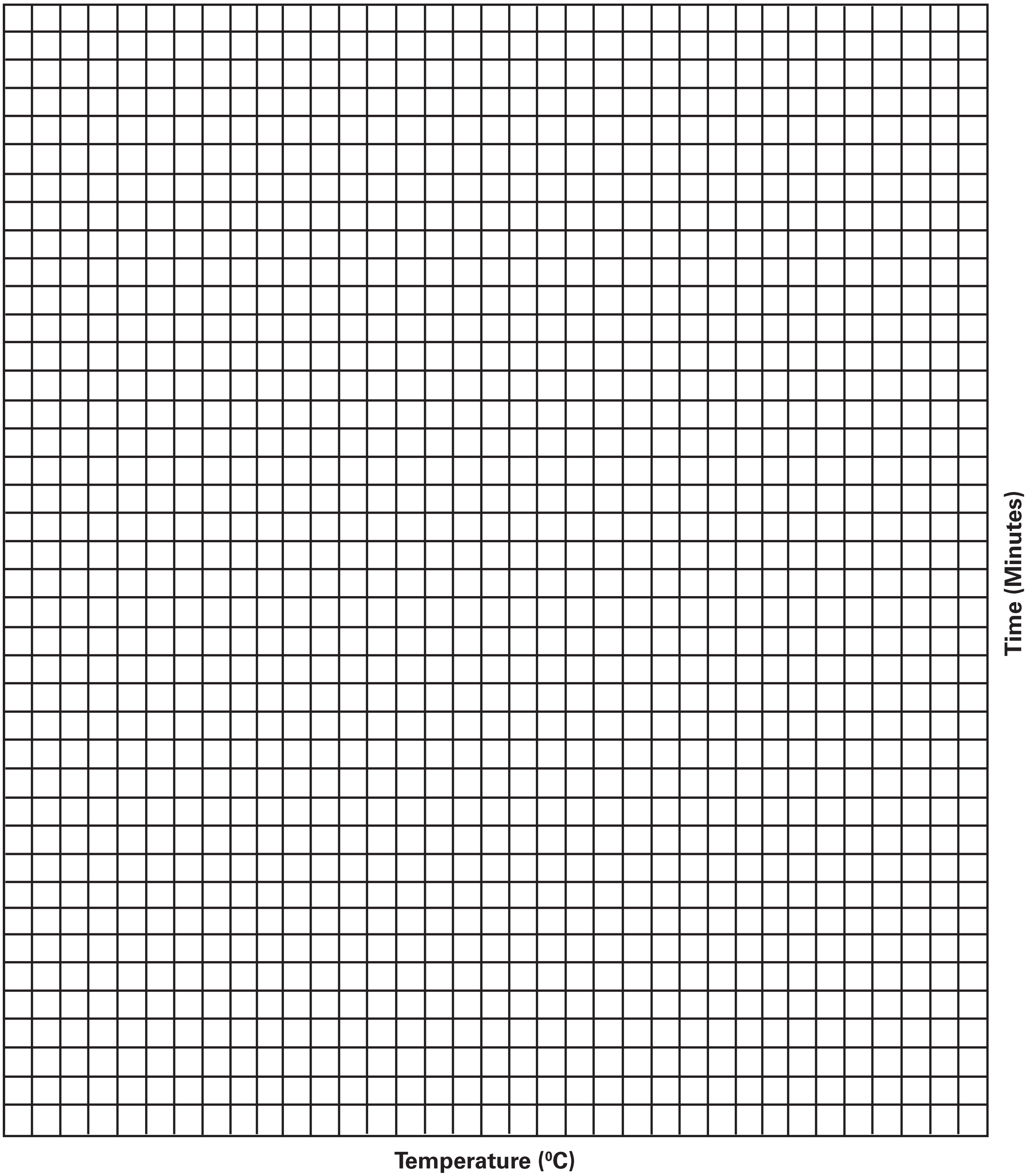
DATA

Heat lamp 0.5 m from bottles

Time (min)	0	2	4	6	8	10	12	14	16
AIR Temp (°C)									
CO_2 Temp (°C)									

Heat lamp 0.25 m from bottles

Time (min)	18	20	22	24	26	28	30	32
AIR Temp (°C)								
CO_2 Temp (°C)								


Time (Minutes)
Temperature (^0C)

QUESTIONS

1. What part of the greenhouse effect system does the infrared source represent?

2. What part of the greenhouse effect system is being represented by the 1-liter bottles?

3. Why was it necessary to shade the bulbs of the thermometers with pieces of white paper?

4. When the heating of the bottles was completed, which bottle felt warmer?

5. In which bottle did the temperature increase faster? How does your graph illustrate this idea?

6. Was the rate of temperature increase for each bottle the same throughout the first 16 minutes? Explain why or why not. Keep in mind what the different parts of the apparatus represent.

7. How many times more heat energy was striking the two bottles after you lowered the infrared source to 0.25 m? How did this affect the temperatures in the two bottles?

8. Was the rate of temperature increase for each bottle the same during the second 16 minutes? Explain why or why not. Keep in mind what the different parts of the apparatus represent.

9. Is the pattern of change of temperature in each bottle the same? Explain why or why not.

10. What is meant by thermal equilibrium? How would you know when the apparatus is in thermal equilibrium?

11. Is Earth's atmosphere in thermal equilibrium at present? Explain.

12. Explain how the presence of CO_2 and other "greenhouse" gases in the atmosphere affects the heating of the atmosphere from an infrared source.

13. Explain fully how this activity relates to the greenhouse effect in Earth's atmosphere.

14. In this activity, what variables help to determine the temperature of the gases in the bottles?

15. If human activity continues to add CO_2 and other greenhouse gases to Earth's atmosphere through burning of fossil fuels, deforestation, and other practices, predict how the average temperature of the atmosphere will change in the future.

This activity was adapted from the Great Lakes Instructional Materials for the Changing Earth System (GLIMCES), 1995.

CLIMATE CHANGE AND AQUATIC INVADERS

What do scientists know about aquatic nuisance species of the Great Lakes and effects that climate change will have on them?

(Background and Teacher Guide)

The Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 defines an **aquatic nuisance species (ANS)** as a nonindigenous species that "threatens the diversity or abundance of native species or the ecological stability of infested waters, or commercial, agricultural, aquacultural or recreational activities dependent on such waters." A **nonindigenous species** is an organism (plant, animal, microbe) found living beyond its historic native range, which is usually taken as the area where it evolved to its present form.

Since the early 1800s, some 184 species of aquatic plants, algae, fish worms, mollusks, and other organisms have invaded the Great Lakes. Likewise, some North American species such as the green sunfish (*Lepomis cyanellus Rafinesque*) have migrated westward and have become pests in Europe. Biologists worry about these intrusions, because each new species in the Great Lakes alters the region's ecosystem. Any environment has a fixed amount of energy that must be divided among all the species present. When a nonindigenous species invades an ecosystem, it often has no enemies. This allows the species to increase rapidly, displacing native organisms by filling their niches. This change allows the once biodiversified region to lose some of its genetic diversity.

It is estimated that 24 of the 175 species of fish in the Great Lakes are nonnative species that were introduced accidentally or intentionally. Eighty-six aquatic nuisance species are plants, although plants have received less attention as invaders. How these non-native species get into the region varies, but many have been shipped in unintentionally.

When ships are not loaded with cargo, they take on ballast to balance and stabilize them as they travel. The use of water as a ballast material has replaced the use of sand and stones. Ballast tanks are filled with water from the harbor where ships are loaded and then dumped, along with any aquatic organisms present, when ships reach their destination. It is estimated that in the history of the Great Lakes, 34% of aquatic nuisance species entered in solid ballast and 56% through ballast water. As shipping times between continents becomes shorter, the threat of introducing live aquatic nuisance species becomes greater.

The United States and Canada have requested that all ships entering the Great Lakes discharge their water ballast while still in the ocean, replacing it with salt water in order to reduce the introduction of new aquatic nuisance species. About 90% of the ships currently comply with the request.

Invasive Species in this Activity

Alewife (*Alosa pseudoharengus*)
Asian Carp (*Ctenopharyngodon idella* or
Hypophthalmichthys molitrix or
Hypopthalmichthys nobilis)
Eurasian Water Milfoil (*Myriophyllum spicatum*)
Purple Loosestrife (*Lythrum salicaria*)
Quagga Mussel (*Dreissena rostriformis*)
Sea Lamprey (*Petromyzon marinus*)
Round Goby (*Neogobius melanostomus*)
White Perch (*Monrone americana*)

Teacher Activity: What do scientists know about aquatic nuisance species of the Great Lakes and effects that climate change will have on them?

Objectives: Students manipulate cards to identify aquatic nuisance species and explain the effects of global climate change on these species. After completing this investigation, students will be able to:

- Name and visually recognize some nonindigenous and invasive species of the Great Lakes.
- Locate on a world map the origins of the Great Lakes aquatic nuisance species.
- Explain the ways in which aquatic nuisance species are introduced into the Great Lakes.
- Explain the impacts of aquatic nuisance species on the Great Lakes ecosystem.
- Analyze the effects of global climate change on aquatic nuisance species of the Great Lakes.

Materials, per group:

Printed copies (or the accompanying electronic version to be projected) of *What's wrong with this picture?* Copies can be requested from Illinois-Indiana Sea Grant at ***http://www.iisgcp.org/catalog/ed/7way.htm***.

Printed copies of or computer access to ANS fact sheets

- Alewife - ***http://www.in.gov/dnr/files/ALEWIFE.pdf***
- Asian Carp - ***http://www.paseagrant.org/wp-content/uploads/2012/07/Asiancarp2012reduced-1.pdf***
- Eurasian Watermilfoil - ***http://www.paseagrant.org/wp-content/uploads/2012/09/EWM2012trialreduced.pdf***
- Purple Loosestrife - ***http://www.paseagrant.org/wp-content/uploads/2012/09/loosestrife2012red.pdf***
- Quagga Mussel - ***http://www.paseagrant.org/wp-content/uploads/2012/09/ZebraQuaggaFactsheet2012reduced.pdf***
- Round Goby - ***http://www.paseagrant.org/wp-content/uploads/2012/09/roundgoby2012reduced.pdf***
- Sea Lamprey - ***http://www.seagrant.umn.edu/downloads/x106.pdf***
- White Perch - ***http://www.in.gov/dnr/files/WHITE_PERCH.pdf***
  (This is a longer document. It is sufficient to print pages 1 - 3 to conserve paper.)

Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS) ***http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html*** This website allows students to search for all ANS in this activity. Note that information on Asian carp can be accessed though the watch list and not the main search engine.

Printed copies of or computer access to ANS background information sheet *NOAA research targets Aquatic Nuisance Species in the Great Lakes* ***http://www.glerl.noaa.gov/pubs/brochures/ANS.pdf***

Copies of the included 32 information cards should be made for each group of students. Each of the four card categories (ANS picture, introduction, ecosystem impact, climate change effects) should be copied onto a different color of paper or cardstock. Cards can be laminated for repeated use.

Time required: 1 class period for reading ANS fact sheets and answering preliminary questions (or this could be done for homework)
1 class period for jigsaw and matching cards

ALIGNMENT

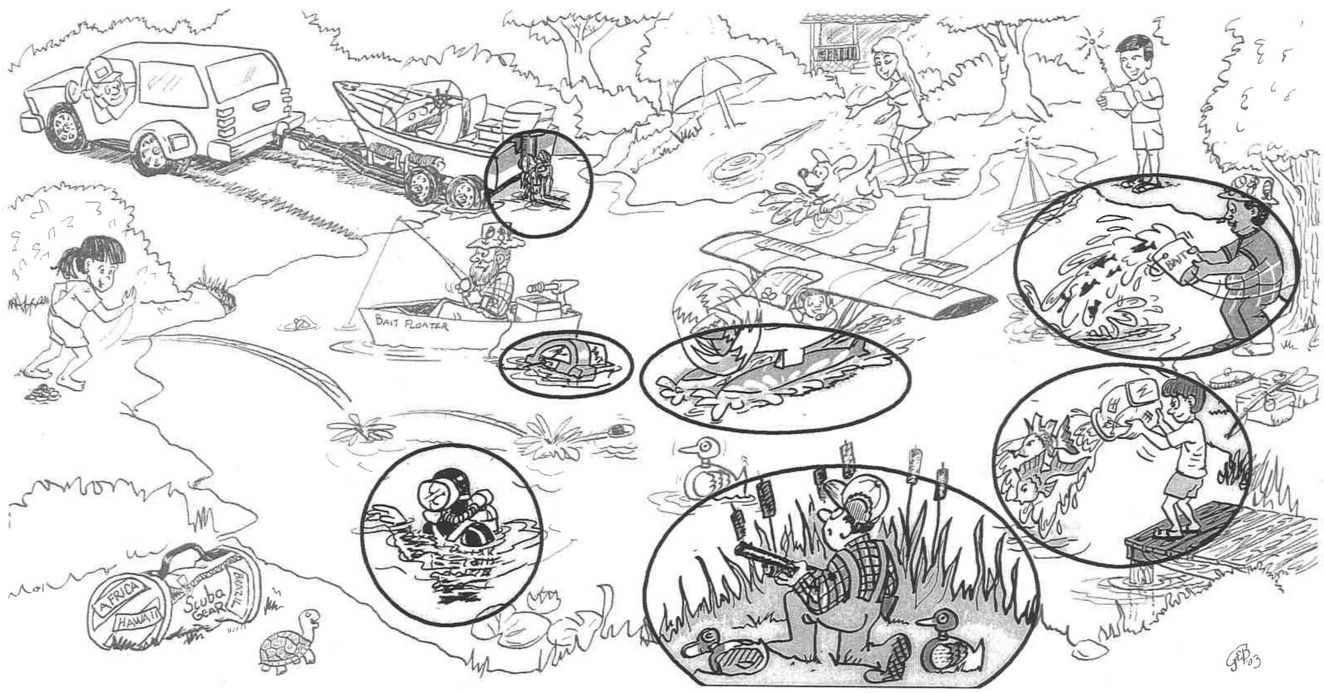
National Framework for K-12 Science Education:
CC 2: Cause and effect: Mechanism and explanation
CC 7: Stability and change
Core Idea LS 2: Ecosystems: Interactions, Energy and Dynamics
Core Idea LS 4: Biological Evolution: Unity and Diversity

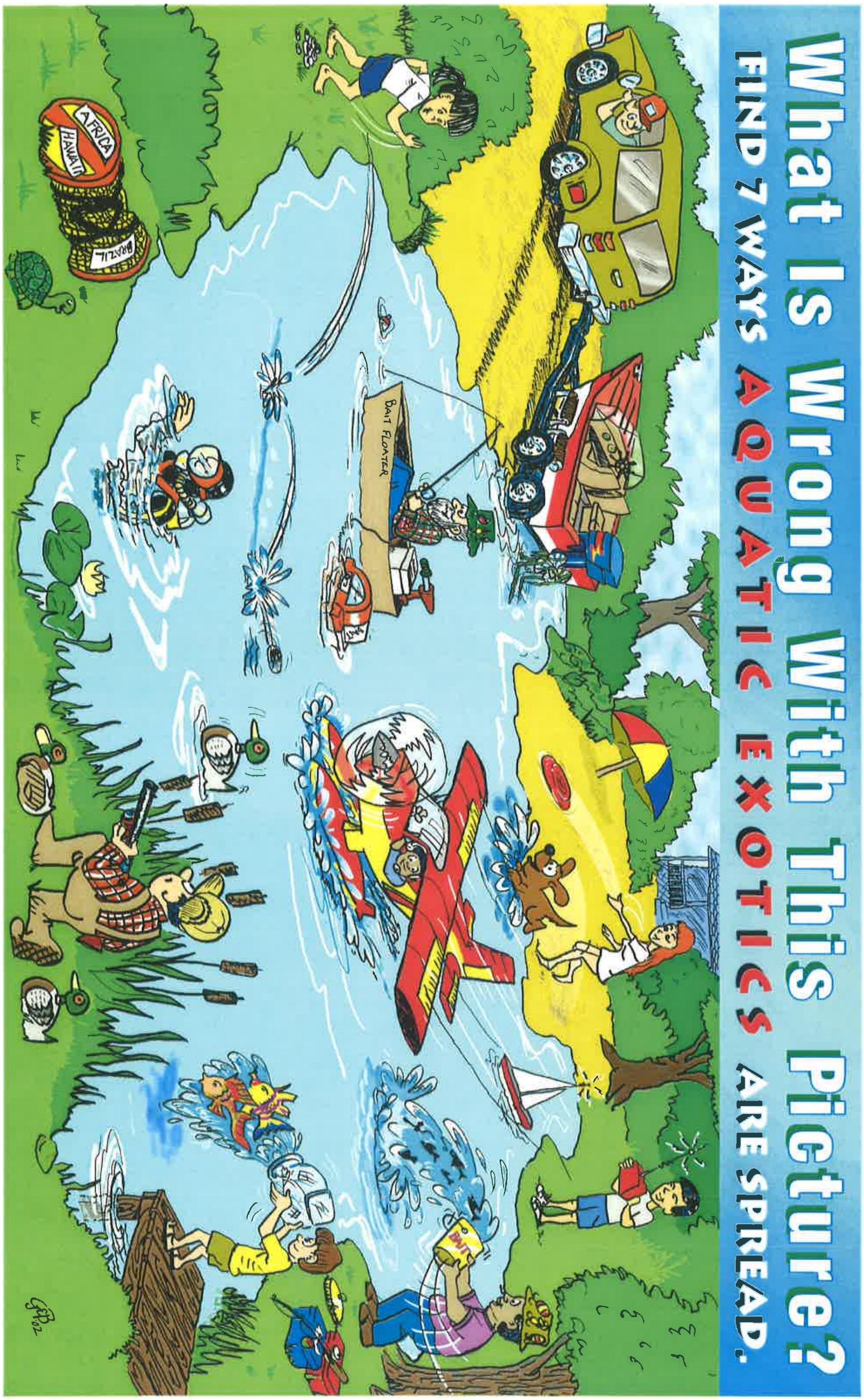
Great Lakes Literacy Principles:
#5i: The Great Lakes support a broad diversity of life and ecosystems.
#8d: The Great Lakes are socially, economically and environmentally significant to the region, nation and planet.

Climate Literacy Principles:
#3a: Life on Earth depends on, is shaped by and affects climate.

ENGAGE

Show students the image "What is wrong with this picture?" Have students identify at least seven ways aquatic nuisance species are spread. [The answer key is included below, but all reasonable suggestions should be entertained.]

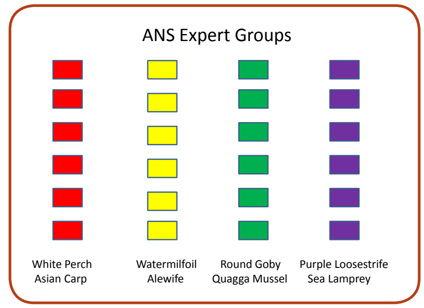


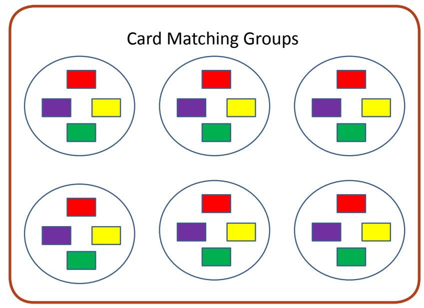

What Is Wrong With This Picture?
FIND 7 WAYS AQUATIC EXOTICS ARE SPREAD.
AFRICA
HAWAII
BRAZIL
BAIT FLOATER
BAIT

EXPLORE

This lesson begins with a teaching strategy called a jigsaw. In a jigsaw, students are first assigned an expert group (small group) and then reorganized into different groups (larger group) that will contain at least one member from every expert group.

1. Divide the class into eight groups and assign each group an aquatic nuisance species to read about and then answer background questions. The students in each aquatic nuisance species group will become experts on the particular species assigned to them.





Teacher's Notes:

If the class is small (or if you prefer smaller groups than described in step 2 below), divide students into four groups; each group is now responsible for answering background questions and becoming experts on two aquatic nuisance species.

This task could be done by students individually as homework so that they come prepared to class the next day. Alternatively, expert groups could use class time to work together to answer the background questions before reorganizing groups.

Answers to student questions in Part 1:

Chart:	All nonindigenous species are invasive species. DISAGREE
	An alien species is the same thing as an exotic species. AGREE
	A nonindigenous species is native to an area. DISAGREE
	All nuisance species are invasive species. AGREE
	All invasive species are nonindigenous. AGREE

1. Answers will vary.
2. A nonindigenous species "threatens the diversity or abundance of native species or the ecological stability of infested waters, or commercial, agricultural, aquacultural or recreational activities dependent on such waters."
3. ballast water of cargo ships; travel through man-made canals as new connecting waterways; unintentional dumping of bait or aquaria organisms; transfer of ANS on boats between bodies of water; intentional introduction by humans because they wanted a particular organism in the ecosystem
4. Dreissenids filter the water and can decimate the spring phytoplankton bloom making less food available to organisms at higher levels in a food web. The filtering increases water clarity and alters nutrient cycling.

EXPLAIN

2. Reorganize students so that each group contains at least one expert on each aquatic nuisance species. These new groups should have at least eight students in them. Students should have their completed worksheets with them.
3. Give each group a complete set of 32 shuffled cards.
4. Beginning with the picture of the aquatic nuisance species, each group should match the cards to determine which introduction, ecosystem impact and global change card goes with each nonindigenous species. For each picture, there should be one matching card of each other color.
5. When group members agree that they have matched the cards to the best of their ability, they may check their answers on the answer sheet. **Answers to card matching:** 1BUd, 2HWh, 3CSe, 4AZb, 5GYf, 6DVc, 7FXg, 8ETa
6. Facilitate a whole class discussion where groups share their findings about how aquatic nuisance species may be affected by climate change.

EXTEND

1. Have students draw a humorous cartoon or write a song or poem depicting the problem of aquatic nuisance species. (Example: A zebra mussel looking for a place to attach on an already-overcrowded lake bottom, a white perch nudging out a yellow perch, purple loosestrife choking other plants, etc.)

2. Have students explore *Nab the Aquatic Invader* (***http://www.iisgcp.org/NabInvader/great_lakes.html***), an interactive website where students acts as private investigators to help other detectives "book the bad guys." Students read ANS profile sheets, uncover more clues by solving the case files on each species, and collect evidence and background information to help "book a bad guy."

EVALUATE

1. Why should people be concerned about nonindigenous species? [Non-native species threaten to change present ecosystems, often in unpredictable ways. Because nonindigenous species frequently do not have predators, they often have the ability to disrupt the existing ecological balance and dominate an area. Consider the effects of European humans after their introduction to North America. Consider other species humans have displaced.]

2. How can the transfer of aquatic nuisance species be controlled or stopped in the Great Lakes or elsewhere in the world? Draft a piece of legislation that could be enacted to stop non-native species from invading the Great Lakes. [Ballast water is critical to the spread of aquatic nuisance species. Rules on ballast dumping are crucial to limit the spread of aquatic nuisance species.]

3. Explain what effects global warming may have on any of the aquatic nuisance species discussed – which species will benefit by the change and which will be negatively impacted? [Most aquatic nuisance species will be able to adapt to warmer water temperatures, higher precipitation and lower lake levels. They will likely outcompete native species as the climate changes.

4. Identify as many Great Lakes jobs as possible that are impacted by aquatic nuisance species. (Some impacts may be positive, that is, new jobs may be created by the newcomers.) [Increased numbers of researchers are needed to study the potential impact and spread of the aquatic nuisance species. There could be new public water systems and industry jobs to keep pipes clean. Fishers will be affected because the type and quality of catch (fish size and health) will be different. Beach cleaners would be needed to get rid of dead fish and boat cleaners will be in great demand to protect boats from aquatic nuisance species (potentially by developing and applying special toxic paints that will prevent quagga mussels in particular from adhering to boat hulls). Recreation facilities will most likely also experience some increased business because of the added water clarity that quagga mussels cause by filtering water, but may also lose some business because of decreased fishing opportunities. Park systems and gardeners must be concerned because aquatic nuisance species will compete with the native vegetation and wildlife.]

ADDITIONAL RESOURCES

Archived Webinar - Climate Change & Invaders: Sources of Uncertainty in Managing the Great Lakes Region
http://changingclimate.osu.edu/webinars/archives/2012-03-20/

NOAA research targets Aquatic Nuisance Species in the Great Lakes
http://www.glerl.noaa.gov/pubs/brochures/ANS.pdf

Ballast Water and Aquatic Nuisance Species Introduction to the Great Lakes (no longer available online)

Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS) ***http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html***
This website allows students to search for all ANS in this activity. Note that information on Asian carp can be accessed though the watch list and not the main search engine.

Nab the Aquatic Invader interactive student website ***http://www.iisgcp.org/NabInvader/great_lakes.html***

REFERENCES

NOAA research targets Aquatic Nuisance Species in the Great Lakes.
http://www.glerl.noaa.gov/pubs/brochures/ANS.pdf

What's wrong with this picture? ***http://www.iisgcp.org/catalog/ed/7way.htm***

Updated from the activity in *GLIMCES* © The Ohio State University, 1995

Student Activity: What do scientists know about aquatic nuisance species of the Great Lakes and effects that climate change will have on them?

Your task is to become an expert on an aquatic nuisance species (ANS). Completing the questions below will prepare you for your next group task.

PART 1

Before you go any further, place a check mark in the correct box on the LEFT to show if you agree or disagree with the sentence.

BEFORE READING		STATEMENT	AFTER READING	
Agree	Disagree		Agree	Disagree
		All nonindigenous species are invasive species.		
		An alien species is the same thing as an exotic species.		
		A nonindigenous species is native to an area.		
		All nuisance species are invasive species.		
		All invasive species are nonindigenous.		

Your teacher will provide background information on aquatic nuisance species, or you can access it electronically at the site listed below:
NOAA research targets Aquatic Nuisance Species in the Great Lakes
http://www.glerl.noaa.gov/pubs/brochures/ANS.pdf

After reading the fact sheet above, place a check mark in the correct box on the right to show if you agree or disagree with the sentence.

1. For how many statements did you change your check marks? ________ / 5

2. Write your own definition for an aquatic nuisance species:

3. Briefly describe four ways in which aquatic nuisance species might enter the Great Lakes watershed.
    a.

    b.

    c.

    d.

4. Describe how zebra and quagga mussels have impacted lake food webs and ecology.

PART 2

Your teacher will provide a fact sheet on your assigned ANS, or you can access it electronically at the site listed below:

Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS)
http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html

Note that information on Asian carp can be accessed though the watch list and not the main search engine.

1. What is the ANS's scientific name?

2. Circle any words that describe how the ANS might be classified.

    vertebrate   invertebrate   plant   animal   crustacean   mollusk   fish

3. Write a brief physical description of the ANS.

4. Where was the ANS originally found? What is its native range?

5. How was the ANS introduced into the Great Lakes?

6. In which Great Lakes is the ANS currently found? (circle)

   Erie Huron Michigan Ontario Superior

7. How is the ANS currently impacting the Great Lakes ecosystem? What specific organisms is it affecting?

8. How might warmer water temperatures in the Great Lakes affect this ANS?

9. How might lower water levels in the Great Lakes affect this ANS?

INVADER #2
Sea Lamprey (*Petromyzon marinus*)

INVADER #4
Asian Carp

Wendy S. Smith

INVADER #1
Quagga Mussel (*Dreissena bugensis*)

Pennsylvania Sea Grant

INVADER #3
Round Goby (*Neogobius melanostomus*)

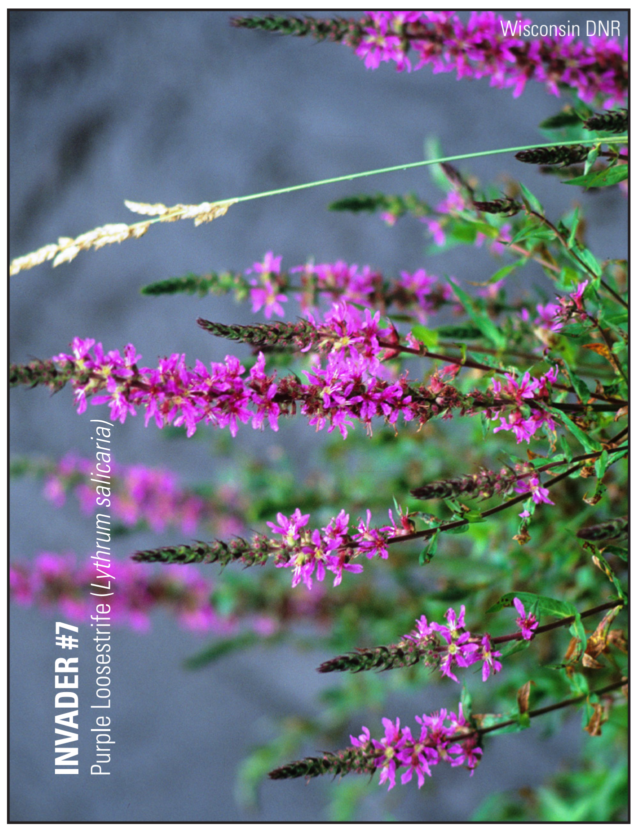
INVADER #6
White Perch (*Monrone americana*)

Chesapeake Bay Program

INVADER #8
Eurasian Water Milfoil (*Myriophyllum spicatum*)

INVADER #5
Alewife (*Alosa pseudoharengus*)

Brian Zimmerman



Wisconsin DNR

INVADER #7
Purple Loosestrife (*Lythrum salicaria*)

INTRODUCTION

Originally, it came from the Caspian Sea region of eastern Europe and western Asia. Canals built during the early 1800s allowed it to spread throughout Europe. First introduction into the Great Lakes was about 1989, when one or more transoceanic ships discharged ballast water into Lake St. Clair. Freshwater ballast from a European port likely contained larvae and possible yearlings. Being a temperate, freshwater species, it found the plankton-rich Lake St. Clair and Lake Erie to its liking.

B

INTRODUCTION

Originally it came from the Atlantic Ocean, the St. Lawrence and Hudson Rivers, and their tributaries for spawning. It swam from Lake Ontario into Lake Erie through the Erie and Welland Canals, gaining entry into the upper Great Lakes by attaching to boat hulls.

H

INTRODUCTION

A native of northern Europe, it made its way into the Great Lakes watershed in 1990. It is believed to have been brought over in fresh water or mud in ballast water of European freighters from eastern Baltic ports. They are currently spreading inland via rivers and canals.

C

INTRODUCTION

This ANS actually consists of a number of species, collectively known by a common name. It was introduced to the United States for aquaculture and fish farming, but is thought to have escaped farm ponds and entered the Mississippi River system and its tributaries as early as the 1970s. This group is currently considered on the cusp of invading the Great Lakes, as they have been found in shipping channels connecting Lake Michigan to the Mississippi River watershed.

A

INTRODUCTION

Coming from the salty Atlantic Coast, this species migrated through water routes, including canals in New York State and the St. Lawrence River. It swam into the upper Great Lakes through the Welland and/or Erie barge canal before 1931.

G

INTRODUCTION

From saltwater areas of the Atlantic coast, this invader moved up the Hudson River and via various canal systems into Lake Ontario and Lake Erie. Because of intentional stocking, it can now be found in all five Great Lakes.

D

INTRODUCTION

This species was intentionally imported from northern Europe over 100 years ago, because its hardiness and beautiful flowers were popular with landscapers, florists, and gardeners.

F

INTRODUCTION

It came from Europe, Asia, and North Africa and was introduced into North America as an aquarium plant. It also spreads when it gets entwined on boats, fishing equipment or waterfowl. It is now found in 37 states and 3 Canadian provinces.

E

ECOSYSTEM IMPACT

Like its better-known cousin, it filters plankton from the water; this allows sunlight to reach greater depths resulting in an overgrowth of aquatic plants. It accumulates on objects such as boat hulls and underwater pipes, clogging valves of both industrial and municipal water intake sources.

U

ECOSYSTEM IMPACT

It destroys valuable fish, especially lake trout, by attaching with its sucker-like mouth to suck out blood and body tissues. It upsets the ecological balance by removing top predators, allowing for explosion of populations of smaller fish such as alewives. It had great economic impact on the commercial fishing industry of the Great Lakes during the 1950s. Current control measures are able to keep populations in check, but the ANS still impacts fish species in the Great Lakes today.

W

ECOSYSTEM IMPACT

This aquatic nuisance species spawns from April to September, longer than many other fish, and producing a large number of offspring quickly. Males ferociously defend the nests, reducing the reproductive success of native species by denying them access to spawning habitat. This fish feeds on the eggs and young of native species, including many important sport fish like yellow perch, damaging an important industry for many Great Lakes states.

The species has also become a primary food source for the previously endangered Lake Erie Watersnake, demonstrating that some invasive species can have a beneficial impact on some areas while acting as a damaging influence in others.

S

ECOSYSTEM IMPACT

This species loves to eat plankton, mussels and snails, and can consume 5-20% of its body weight each day, easily outcompeting native species in the search for food. The fish is also less popular for recreational and sport fishing than the native species it would replace, potentially damaging a Great Lakes fishing industry valued at $7 billion per year.

Z

ECOSYSTEM IMPACT

Feeding primarily on zooplankton, this vertebrate competes for food with juveniles of almost all fish species. Large numbers die off in spring and summer because of electrolyte imbalance from living in fresh water. These die-offs clog municipal and industrial intake pipes and foul beaches. In 1967 bulldozers had to remove 50,000 tons of the rotting fish from the southern shores of Lake Michigan.

Y

ECOSYSTEM IMPACT

This aquatic nuisance species is suspected to be partially responsible for the decline of Lake Erie's yellow perch because of competition for food resources. It is also detrimental to walleye and white bass population because these species' eggs can be a primary food source.

V

ECOSYSTEM IMPACT

It is called "the beautiful killer" because its dense roots choke waterways as it competes with other vegetation. It spreads quickly, crowding out valuable plants that provide food for migrating waterfowl, and destroys habitat for almost all other forms of wetland life.

X

ECOSYSTEM IMPACT

It forms thick mats on the water's surface that choke out native aquatic vegetation. The mats alter the nutrient composition and flow of water, which in turn affects the amount of oxygen available to fish. It also disrupts all forms of water recreation—boating, swimming and fishing—because plants get caught in boat rotors, and swimmers and anglers are blocked from access to the water.

T

EFFECT OF GLOBAL CLIMATE CHANGE

It is very likely that this bivalve will be a permanent part of the Great Lakes environment. It prefers waters with a temperature between 4°C and 20°C, but tolerates temperatures up to 30°C. As global warming increases the temperature of the Great Lakes, it will spread farther north into warmer waters. Because it can grow on both hard and soft substrates, this ANS is likely spread deeper into the lakes as well, tolerating depths of up to 130 meters as well as the lower oxygen conditions present there.

d

EFFECT OF GLOBAL CLIMATE CHANGE

Warmer stream temperatures create a more favorable environment for this parasitic organism, enabling it to spawn successfully at more locations throughout the Great Lakes basin. This could result in a new increase in population that may further upset the ecological balance of the Great Lakes. Their favored prey are cold-water fish, such as lake trout, salmon and rainbow trout, that may migrate to regions where temperatures remain cold—both greater depths and more northern lakes.

h

EFFECT OF GLOBAL CLIMATE CHANGE

Increased summer water temperatures are likely to allow this species to spread farther north into the Great Lakes, and could even help the population grow more quickly. However, the lower oxygen concentrations found in warmer water could limit the fish’s habitat, potentially shifting its range northward instead of spreading out over a wider area.

e

EFFECT OF GLOBAL CLIMATE CHANGE

Because climate change is expected to increase precipitation and severe weather in the Great Lakes region, additional and higher flooding is likely to allow this aquatic nuisance species to cross barriers into the Great Lakes. As higher water temperatures are predicted to decrease available plankton, competition for food will increase, putting native fish at a disadvantage because the species effectively strips the aquatic environment of food sources.

b

EFFECT OF GLOBAL CLIMATE CHANGE

These herring-like fish need deep water with moderate temperature to overwinter. A rise in water temperature would probably result in fewer die-offs and would enable the fish to be more abundant in Lake Superior, where they currently are scarce. This would certainly alter local fisheries, but the specific impacts are not yet clear.

f

EFFECT OF GLOBAL CLIMATE CHANGE

As waters warm, walleye and yellow perch may seek cooler waters in the deeper areas of the Great Lakes, leaving the shallower areas to this competing fish. Without the competition of the other species, this ANS will be able to reproduce into an even larger population, competing with still more species.

c

EFFECT OF GLOBAL CLIMATE CHANGE

As water levels decrease, this aquatic nuisance species will find new wetlands in which to spread, choking out more and more vegetation as it follows the receding waterline.

g

EFFECT OF GLOBAL CLIMATE CHANGE

This plant thrives as waters warm each summer, increasing in volume in relation to the increased water temperature. If this is any indication of its temperature requirements, as waters in the Great Lakes region warm, this species will thrive in the new climate, spreading rapidly to become an even bigger problem.

a

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GLOBAL AND GREAT LAKES CLIMATE CHANGE

(Background and Teacher Guide)

Over the past decades, much attention has been focused on the potential climatic effects of rising levels of atmospheric greenhouse gases, such as carbon dioxide and methane. Human activities as well as natural factors increase the levels of these gases in the atmosphere. A great deal of research has been done regarding the potential global significance of the increased greenhouse gas concentrations. In addition to receiving attention by the scientific community, global temperature fluctuations and other notable climate variations are causing a great deal of concern for average citizens worldwide. Advances in computer and communication technologies have allowed people to access and share large amounts of global climate information. The media have been an important part of this communications revolution, keeping the public informed on environmental issues. The information that we receive, however, can be conflicting and confusing.

Against a backdrop of controversy, government policy makers must decide whether or not to take action to reduce greenhouse gas emissions. Some policy makers argue that scientists do not agree on the problem, and therefore they oppose any specific timetables and actions for combating global climate change. Others call for the establishment of specific targets to cut the production of human-made greenhouse gases. The work of the Intergovernmental Panel on Climate Change [IPCC] supports the conclusion that "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level." Within the instrumental record of global surface temperature, which goes back to 1850, "eleven of the last twelve years (1995-2006) rank among the 12 warmest years" (IPCC 2007). Further, the report cites climate models predicting a global increase in temperature from 1.8 to 4.0 °C by the end of the 21st Century.


Sara Claypool

IPCC, 2007: Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Teacher Activity A: Is the globe warming? Is there evidence in the Great Lakes region?

BACKGROUND

A key to understanding the "global warming" debate is to understand how predictions are made. By recognizing the strengths and weaknesses of predictions based on one data record, for instance in observing temperature trends, the debate over global climate change can become easier to understand. The following activity deals with temperature *anomalies*, or departures from historic normal measures. If anomalies are increasingly positive, it would mean that warming is in progress. How many years does it take to make a trend discernible? Are global trends reflected in the temperatures we experience in the Great Lakes region?

Objectives: In this investigation, groups of students will graph data reflecting temperature anomalies over a short period in the recorded climate history of the world or in part of the Great Lakes region. Using only their own data, they will predict how their actual temperature anomaly trend might continue. That is, with limited data, what do they conclude about the future? As all student groups assemble and observe the trend of the 130-year data set, they may conclude that having a larger dataset offers more confidence in predictions. In addition to the science of the lesson, important conclusions can be drawn about how the construction of a graph scale can influence how the data are interpreted. After completing this investigation, students will be able to:

- Identify a trend in a set of graphic data.
- Evaluate and discuss the difficulties inherent in interpreting and forecasting long- and short-term trends.
- Analyze data, draw conclusions about whether temperature anomalies are evidence of global warming, and defend their conclusions.

Materials:

Copies of Global and Cloquet-Great Lakes Temperature Anomaly Data. Print the two pages on different colors of card stock and laminate for repeated use. Cut apart on lines so each student/group gets one 26-year segment for graphing.	1 per student/group
Graph paper copied from student pages, with origin [0] near the center of the Y axis and an X-axis divided to show actual versus predicted values.	1 sheet per student/group
Colored pencils or markers for making graphs of actual and predicted data.	1 set per student/group
Masking tape for mounting sequential data, for class observation of larger trends.	1 per class

Time required: 1-2 class periods

ALIGNMENT

National Framework for K-12 Science Education:
SEP 2: Analyzing and interpreting data
CC 7: Stability and change
Core Idea ESS2.D: Weather and climate
Core Idea ESS3.D: Global climate change

Great Lakes Literacy Principles:
#3a,b,c,d,e: The Great Lakes influence local and regional weather and climate.
#6c: The Great Lakes and humans in their watersheds are inextricably interconnected.
#7e: Much remains to be learned about the Great Lakes.

Climate Literacy Principles:
#2b,c,e: We increase our understanding of the climate system through observation and modeling.
#5d,e,f: Earth's weather and climate vary over time and space.

ENGAGE

Use a computer projector or smartboard to examine the temperature changes for the state of Wisconsin since 1960 at ***http://climatewisconsin.org/story/temperature-change***. Clicking on the side-by-side maps allows students to see that the temperatures from one decade to the next may not be greatly different, but comparing over longer time periods makes changes clear. The projected changes for decades 2020 and beyond are based on models that use trend analysis, just as students will practice in the activity.

EXPLORE

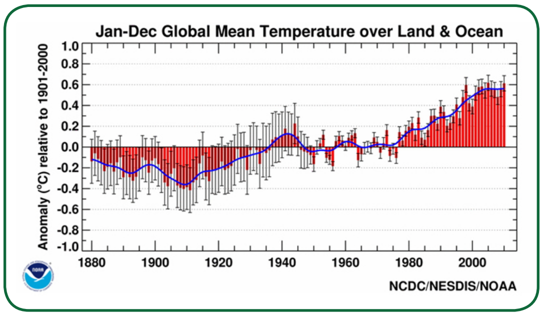
Students follow instructions to graph a segment of the total database and predict the anomalies to come based on the observed trend.

Teacher's Notes:

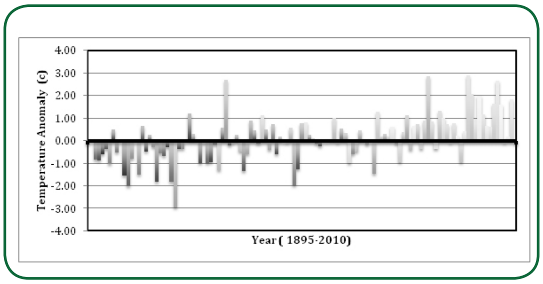
- Graph format: Vertical bar graphs are best for this kind of data, since the anomalies are really not connected across the years as a line graph would indicate. Students can plot increments of 0.2 degree on the Y axis and years on the X axis. They need to count how many years they have, and plan their graph so that the last year on their list is next to the center line on the graph paper. That way their ACTUAL anomalies end just as their PREDICTED anomaly line begins.
- Students typically start from the Y axis to plot the years of data, but it is important to have the LAST year of their actual data be graphed next to the vertical line down the center of the graph.
- Remind students that the numbers are not temperatures, but show how much the average temperature of each year differed from the 20th Century average.
- If modifying the activity for lower-level students, consider modifying the graph paper to have only the number of ACTUAL columns they will plot, and add the vertical scale before giving it to students. You might also provide rulers or another type of straight edge to help students correctly read years and temperature anomalies from the cards.
- If laminating the temperature lists for multiple uses, provide students with wet-erase markers so they can cross off values as they plot them.
- The word *data* is a plural noun. Set an example for student grammar by correctly saying things like "the data are…" or "annual data seem to indicate," or "what do the data show?"

EXPLAIN

Students plot their results and predictions. Call the GLOBAL anomaly plotters to the front in order from earliest year to 2010. As they tape their graphs up for all to see, discuss how the existing numbers result in the predicted values. Fold progressive graphs so that the previous predictions are covered, and the latest prediction builds on a longer trend line. The resulting ACTUAL graph for global anomalies will look like this [without predictions]. The gray bars show the monthly extremes for each year. If you show the graph, point out that recent years have not had the extremes seen in some previous years.



Once the global set has been discussed, call the CLOQUET-GREAT LAKES anomaly plotters up to do the same thing with their graphs. If they used the same scale as for the global graph, the changes will appear large. Discuss why this would be so. [Cloquet data come from only one place, without averaging in the places that are extremely cold or extremely hot.]



Teacher's Notes:

Regional data are not collected separately for the Great Lakes. Instead, long term data from separate sites within states can show how climate change affects local areas. Cloquet [klo-KAY] is a small town in Minnesota, near the western tip of Lake Superior.

This can be a teachable moment for graph scales! The graph shown here for Cloquet has a Y-axis of -3.0 to 3.0, "vertically exaggerating" the differences. Plotting the two data sets on the same axis, one for global and one for Cloquet, would show the true magnitude of the variation in comparison to the globe. Sometimes people who report science choose their graph scales to make a point. They can claim that a trend is "not as great as it was feared," or is "even worse than anyone imagined," just by choosing a different vertical scale. Students should be alert to how data are portrayed in the media, so they can become wise consumers of science information.

The Cloquet data source is the U.S. Historical Climatology Network site at ***http://cdiac.ornl.gov/epubs/ndp/ushcn/ushcn_map_interface.html*** and you can use the site to find the mean annual temperatures of a location near you [not all locations have historical data]. If computers are accessible, student groups can compare several areas to see if temperatures are warming over time across the region. For Cloquet, we requested Monthly Data Download, by year, for all available years. To get the anomaly measure, take the average annual temperature from 1901-2000, and subtract that average from each year's annual temperature.

Answers to Student Worksheet

1. a. In early years the temperatures were below the century average.
   b. Over time, the annual global temperature has been increasing more and more above the century average. Accept various definitions that reference the increases above the average, as shown in the graph.
   c. Generally, people should have more confidence when predictions are based on larger amounts of data. There are some, however, who use the "need more data" cry to prevent action that really should be taken. Students may want to discuss how much is enough data.

2. a. Global warming does appear to be occurring. The trend is not as clear or consistent in the Cloquet-Great Lakes data, but the general pattern is toward higher temperature anomalies.
   b. Students should cite the length of the temperature record as evidence for their decision.
   c. Global data points are much more numerous. Be sure the students are thinking not about how many years are plotted, but how many measurements went into each average yearly number.
   d. Cloquet data do not include temperatures from the equator or the poles, as in global data. Cloquet numbers are only from a single point of latitude and longitude.

3. Answers will vary based on choice of location. Some factors that should be considered include proximity to large bodies of water, altitude of the area, percentage of land covered by urban structures, and such.

4 a. Blue: global temperature anomalies below average; red: global temperature anomalies above average
   b. Blue to red, suggesting a positive (warmer) departure from average global temperatures.
   c. From paragraphs 6 and 7 on the web page: They depict how much various regions of the world have warmed or cooled when compared with a base period of 1951-1980. (The global mean surface air temperature for that period was estimated to be 14°C (57°F), with an uncertainty of several tenths of a degree.) In other words, the maps show how much warmer or colder a region is compared to the norm for that region from 1951-1980. The period of 1951-1980 was chosen largely because the U.S. National Weather Service uses a three-decade period to define "normal" or average temperature. The GISS temperature analysis effort began around 1980, so the most recent 30 years was 1951-1980. It is also a period when many of today's adults grew up, so it is a common reference that many people can remember.
   d. 1880s: colder than average; 1970s: average (because this is considered a baseline temperature); 2000s: warmer than average. Arctic temperatures have undergone more change from average than other parts of the Earth.
   e. The gray patches represent areas where there was no data available at those times. They have decreased in size because more techniques to analyze global temperature data are available now than in the past.

EXTEND

1. Look at graphs of greenhouse gas concentrations over time at ***http://www.ecology.com/2011/11/22/greenhouse-gases-highest/#more-10808***. What relationships do you see between changes in global temperature and the levels of these gases? The IPCC's most recent [2007] assessment of data, including predictions, is at ***http://www.ipcc.ch/publications_and_data/ar4/syr/en/figure-spm-5.html*** and includes an important comparison between greenhouse gas increases and temperature scenarios.
2. Do Internet research on the phenomena of El Niño and La Niña and their effects on global temperature.
3. Have students plot each data set using Excel or similar graphing software. Assign a color to each data set. Have students generate a trend line for their graph. Assuming students have used the same scale, they can print their colored graphs with trend lines and hang them on the board end to end to see the complete data set. Sample graphs employing this technique are included for teachers to use in demonstrations.

EVALUATE Sample evaluation questions

1. Explain what is meant by a temperature anomaly.
   A temperature anomaly is a departure from a normal historic measure.
2. How would you describe the temperature anomalies of the last 10 years compared to the first half of the 20th Century?
   There are greater anomalies in recent years.
3. How does the graph of anomalies in one Great Lakes town compare to that for global anomalies with regard to
   a. Size of temperature anomalies for a given period?
      There are larger anomalies.
   b. Ease of spotting a trend in the temperature record?
      It is more difficult to spot a trend.
4. Why is the data set for a single location so different from that of the globe?
   Fewer data points are averaged into the measure.
5. Is Cloquet's temperature record a sign that global warming is occurring in the Great Lakes region? How is the answer to this question determined?
   It is a sign that the Cloquet area is warming, based on a general upward trend. However, the trend is not as clear as for the globe, and is not adequate for predicting a Great Lakes trend.
6. Discuss the implications of basing conclusions on limited data. Does this mean we should just continue to study climate without making decisions to deal with changing temperatures?
   Discussion should include the idea that we need a reasonable amount of credible scientific study. However, waiting for "enough" data should not prevent actions that would have a beneficial effect regardless of climate change.

ADDITIONAL RESOURCES

Global surface temperature anomalies, explanation and background from NOAA's National Climatic Data Center. Updated May 2011.
http://www.ncdc.noaa.gov/cmb-faq/anomalies.php

An excellent video clip explaining the difference between variations and trends can be found at
http://www.youtube.com/watch?v=e0vj-0imOLw&feature=youtu.be

The IPCC's most recent [2007] assessment of data, including predictions, is at
http://www.ipcc.ch/publications_and_data/ar4/syr/en/figure-spm-5.html

NOAA's State of the Climate Report, updated monthly: ***http://www.ncdc.noaa.gov/sotc/index.php***

Global warming in the Great Lakes, including state scenarios: ***http://www.ucsusa.org/greatlakes/*** Try the Migrating Climates interactive section to see how temperatures and precipitation in specific states will result in a climate more like somewhere else!

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

Original from Katzenberger, J., 1992. Is it getting hot or not? *Ground Truth Studies.* Aspen Global Change Institute, Aspen CO. ***http://www.agci.org/library/publications/about/publication_details.php?recordID=16846*** Updated from the adapted activity in *GLIMCES* © The Ohio State University, 1995.

Excel graph samples provided by Diane Desotelle, Minnesota Sea Grant

GLOBAL ANNUAL TEMPERATURE ANOMALY DATA [^{0}C]

Year	Global Temp Anomaly ^{0}C
1880	-0.14
1881	-0.06
1882	-0.11
1883	-0.15
1884	-0.23
1885	-0.19
1886	-0.16
1887	-0.24
1888	-0.15
1889	-0.10
1890	-0.29
1891	-0.25
1892	-0.29
1893	-0.32
1894	-0.29
1895	-0.21
1896	-0.10
1897	-0.13
1898	-0.25
1899	-0.13
1900	-0.11
1901	-0.16
1902	-0.22
1903	-0.34
1904	-0.38
1905	-0.26

Year	Global Temp Anomaly ^{0}C
1906	-0.20
1907	-0.37
1908	-0.39
1909	-0.40
1910	-0.39
1911	-0.41
1912	-0.34
1913	-0.32
1914	-0.16
1915	-0.08
1916	-0.28
1917	-0.33
1918	-0.22
1919	-0.23
1920	-0.20
1921	-0.14
1922	-0.22
1923	-0.20
1924	-0.18
1925	-0.12
1926	-0.02
1927	-0.10
1928	-0.09
1929	-0.22
1930	-0.03
1931	0.00

Year	Global Temp Anomaly ^{0}C
1932	-0.03
1933	-0.16
1934	-0.03
1935	-0.06
1936	-0.03
1937	0.07
1938	0.10
1939	0.09
1940	0.12
1941	0.18
1942	0.13
1943	0.12
1944	0.23
1945	0.10
1946	-0.03
1947	-0.04
1948	-0.05
1949	-0.08
1950	-0.16
1951	-0.00
1952	0.03
1953	0.12
1954	-0.10
1955	-0.12
1956	-0.18
1957	0.06

Year	Global Temp Anomaly ^{0}C
1958	0.11
1959	0.06
1960	0.01
1961	0.09
1962	0.11
1963	0.13
1964	-0.13
1965	-0.07
1966	-0.01
1967	0.00
1968	-0.01
1969	0.09
1970	0.05
1971	-0.05
1972	0.04
1973	0.16
1974	-0.08
1975	-0.02
1976	-0.11
1977	0.14
1978	0.06
1979	0.16
1980	0.20
1981	0.23
1982	0.12
1983	0.28

Year	Global Temp Anomaly ^{0}C
1984	0.09
1985	0.07
1986	0.16
1987	0.30
1988	0.30
1989	0.22
1990	0.39
1991	0.34
1992	0.20
1993	0.23
1994	0.30
1995	0.41
1996	0.28
1997	0.48
1998	0.60
1999	0.42
2000	0.39
2001	0.52
2002	0.58
2003	0.58
2004	0.54
2005	0.62
2006	0.56
2007	0.55
2008	0.48
2009	0.56
2010	0.61

Teacher: Print and laminate page and cut sections apart. Each student or group should get either one GLOBAL temperature set or one GREAT LAKES set.

Data from ***ftp://ftp.ncdc.noaa.gov/pub/data/anomalies/usingGHCNMv2/***, data set ***annual.land_ocean.90S.90N.df_1901-2000mean.dat***.
Accessed 11/23/11

CLOQUET - GREAT LAKES ANNUAL MEAN TEMPERATURE ANOMALY DATA [^0C]

Year	Cloquet Temp Anomaly ^0C	Year	Cloquet Temp Anomaly ^0C	Year	Cloquet Temp Anomaly ^0C
1895	-0.85	1919	-0.38	1942	0.50
1896	-0.90	1920	0.03	1943	-0.42
1897	-0.62	1921	1.21	1944	0.73
1898	-0.35	1922	0.30	1945	-0.59
1899	-1.04	1923	0.07	1946	0.17
1900	0.50	1924	-0.99	1947	-0.03
1901	-0.52	1925	-0.10	1948	-0.11
1902	-0.05	1926	-0.99	1949	0.56
1903	-1.56	1927	-0.95	1950	-1.97
1904	-2.03	1928	-0.19	1951	-1.27
1905	-0.82	1929	-1.30	1952	0.75
1906	-0.05	1930	0.59	1953	0.82
1907	-1.49	1931	2.71	1954	0.24
1908	0.66	1932	-0.22	1955	0.10
1909	-0.50	1933	-0.08	1956	-0.12
1910	0.25	1934	0.25	1957	-0.25
1911	-0.29	1935	-0.50	1958	0.01
1912	-1.83	1936	-1.36	1959	-0.05
1913	-0.58	1937	-0.61	1960	0.06
1914	-0.69	1938	0.90	1961	1.00
1915	-0.29	1939	0.47	1962	-0.11
1916	-1.82	1940	-0.12	1963	0.55
1917	-2.94	1941	1.13	1964	0.35
1918	-0.37				

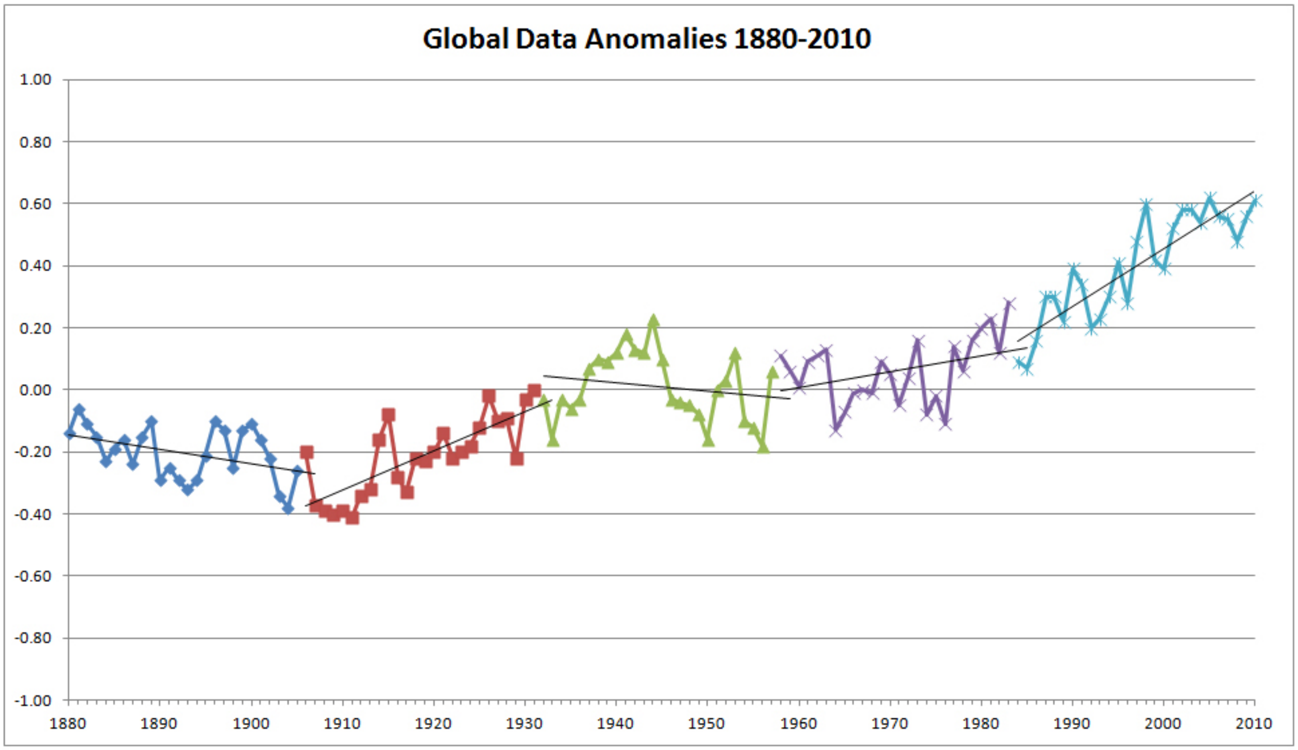
Year	Cloquet Temp Anomaly ^0C	Year	Cloquet Temp Anomaly ^0C
1965	-1.01	1988	0.83
1966	-0.59	1989	-0.35
1967	-0.49	1990	1.33
1968	0.45	1991	0.99
1969	0.07	1992	0.73
1970	-0.19	1993	-0.12
1971	-0.03	1994	0.77
1972	-1.45	1995	0.22
1973	1.27	1996	-0.97
1974	0.16	1997	0.40
1975	0.28	1998	2.90
1976	0.17	1999	2.05
1977	0.61	2000	0.96
1978	-0.14	2001	1.98
1979	-0.97	2002	1.15
1980	0.37	2003	0.65
1981	1.14	2004	0.63
1982	-0.43	2005	1.62
1983	0.63	2006	2.65
1984	0.73	2007	1.57
1985	-0.39	2008	-0.10
1986	0.90	2009	0.18
1987	2.86	2010	1.82

TEACHER: Each student or group should get either one GLOBAL temperature set or one GREAT LAKES set.

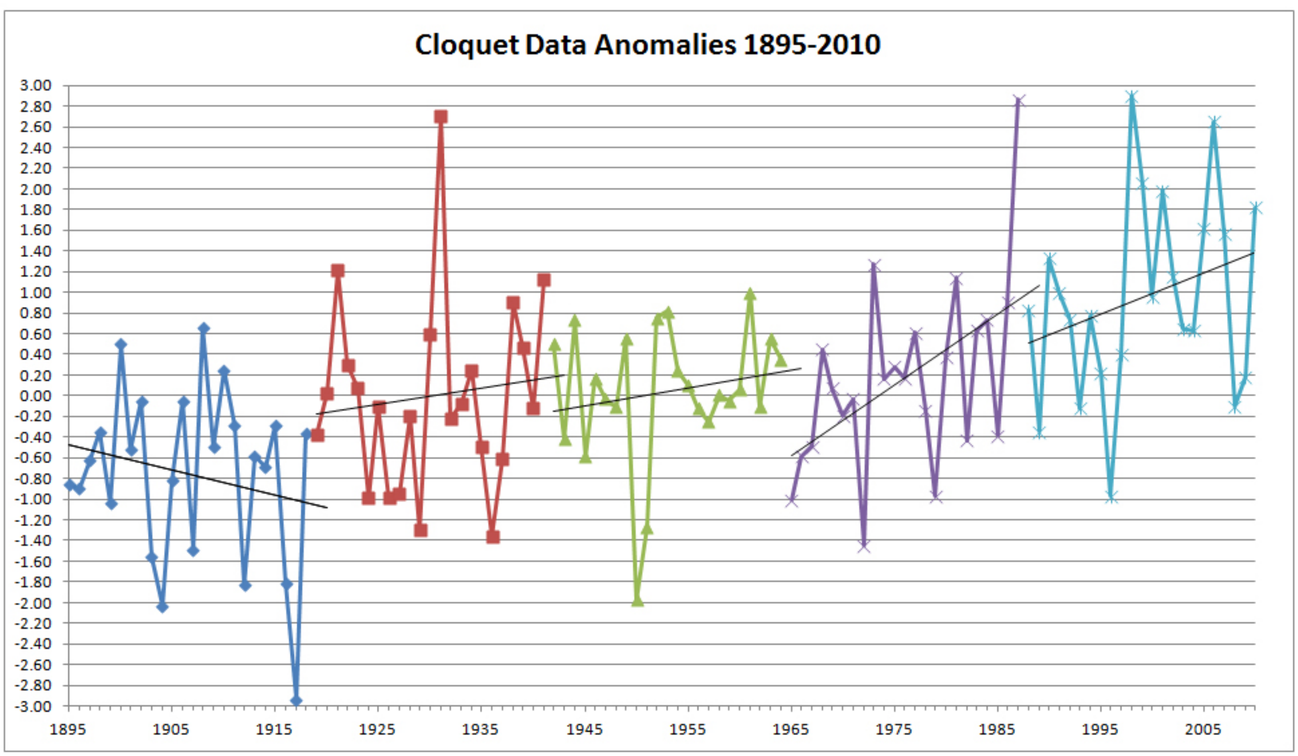
For the Cloquet data, you may wish to use the same Y-axis scale as in the global data, or expand the scale for easy interpretation and graphing.

http://cdiac.ornl.gov/epubs/ndp/ushcn/ushcn_map_interface.html

COMBINED GLOBAL DATA SAMPLE



COMBINED CLOQUET DATA SAMPLE



Graphs provided by Diane Desotelle, Climate Change Adaptation Extension Educator, Minnesota Sea Grant

Student Activity A: Is the globe warming? Is there evidence in the Great Lakes region?

BACKGROUND

A key to understanding the "global warming" debate is to understand how predictions are made. Scientists have been recording temperatures around the world since the 1850s. Based on what they observe, they try to make predictions about the future. This lesson deals with temperature *anomalies*, or differences from the average expected temperature. How many years does it take to make a temperature trend obvious, so we can predict with confidence? Are trends in towns around the Great Lakes similar to those for the globe?

OBJECTIVE

In this investigation, you will graph data on temperature anomalies over a short period in the recorded climate history of the world or in one Great Lakes town (Cloquet, Minnesota). With limited data, what do you conclude about temperatures in the future? How does your prediction improve with more data?

PROCEDURE

Graphing temperature anomalies

From the average yearly temperatures reported by thousands of weather centers, scientists have calculated an average temperature for the 20th Century. Then the National Oceanic and Atmospheric Administration (NOAA, home of the National Weather Service) calculated how each year's average temperature differed from the average for all 100 years. That number is the *temperature anomaly* for the year. If the average temperature for a year was below the century average, the anomaly is negative. If the average for a year is above the century average, the anomaly is positive.

1. You will receive a set of data to plot on a new kind of graph. The data will be either GLOBAL or CLOQUET-GREAT LAKES temperature anomalies for some past years. Use the graph paper provided to plot the data.
    a. Look at the darker lines that cross near the center of the graph. The horizontal line [left to right] represents the global average temperature in the 20th Century. The vertical line [top to bottom] divides the ACTUAL anomalies, the ones on your list, from some PREDICTIONS you make based on what the temperature is doing on your graph.
    b. Count how many years you are graphing, then count backward from the vertical center line so your last year lines up next to the center line. You may have some blank parts of the graph on the left.
    c. This will be a BAR GRAPH, with each year's bar going either up or down from the average line. Do not connect the tops of the bars as if the numbers are on a line graph.

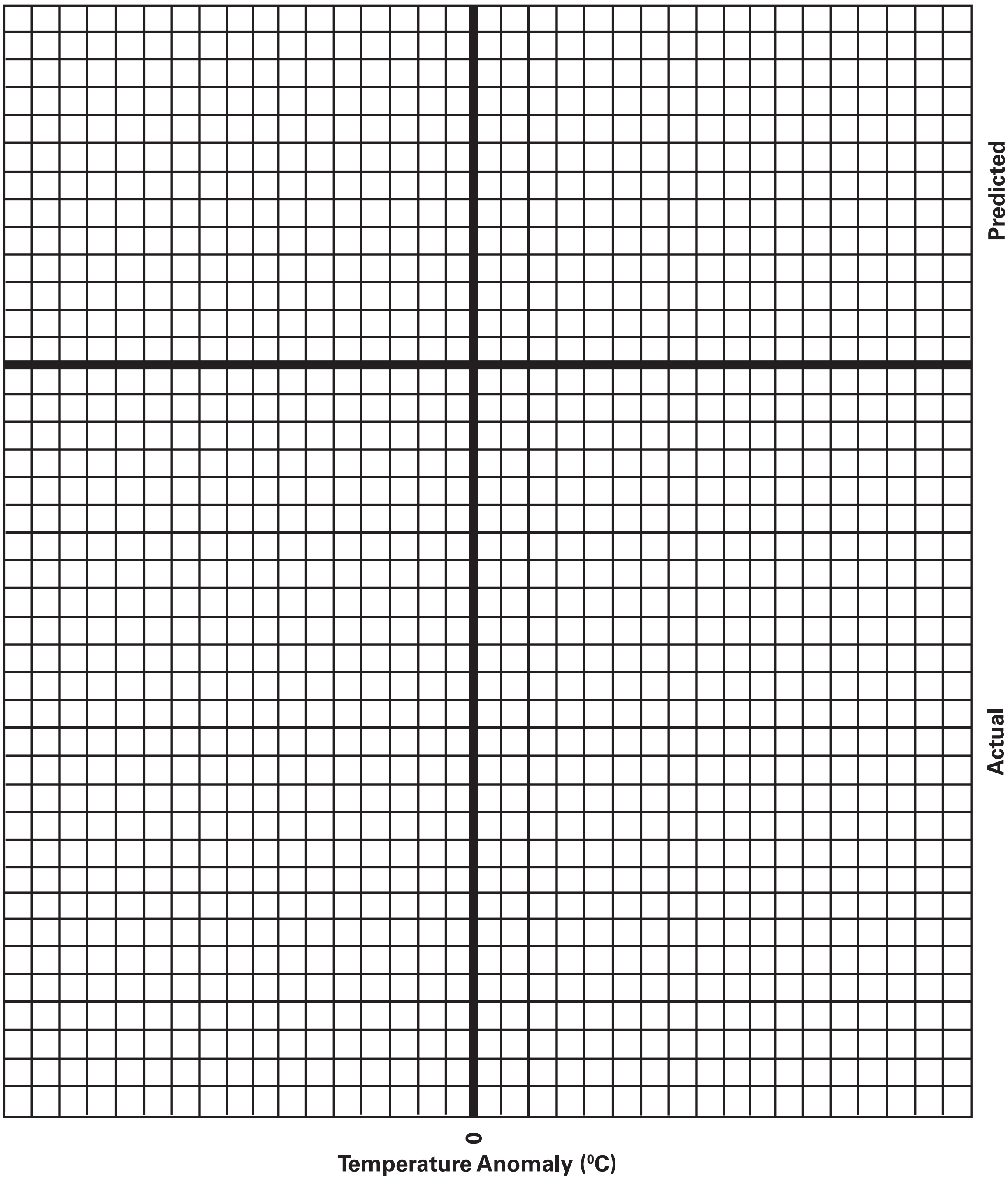
2. After you have made a bar graph of your years of anomalies, look at how the numbers are changing from the first bar to the last one you plotted. Are the numbers going up, down, or what for the period you plotted? Try to identify a *trend* in the data.

3. To the right of the center line, predict how the anomalies will look over the next 25 years, and fill in a sample of how that graph might look.

4. The class will look at each graph in order by years and discuss how predictions were made. Be ready by answering the worksheet questions.

Name ______________________________ Period __________

Graph of Temperature Anomalies Check one: ____GLOBAL ____ GREAT LAKES



Name ______________________________ Period __________

Answer the following questions on this worksheet:

1. Based on the class GLOBAL graphs and predictions, answer the following:
   a. Describe the global temperature anomalies in the early half of the class graph.

   b. Based on the graph, how would you define "global warming"?

   c. Which prediction gives you more confidence – one based on a small amount of data, or one based on more data? Why?

2. Look at the CLOQUET - GREAT LAKES graphs. Describe how the local graph compares to the global graph:
   a. Is global warming occurring in Cloquet, an example of the Great Lakes region? ________ Discuss how the data led to your conclusion.

   b. Assume one of your classmates holds a different opinion of 2a. How will you use data to defend your position?

   c. Consider the geographic area over which the annual averages are collected. Which graph is based on more data, global or Cloquet? _______________

   d. If your class graphed both global and Cloquet anomalies on the same Y-axis scale, why does the local graph have anomalies that are so much different?

Name ______________________________ Period __________

3. If time permits, use the U.S. Historical Climatology Network at ***http://cdiac.ornl.gov/epubs/ndp/ushcn/ushcn_map_interface.html*** to find the mean annual temperatures of other locations in the Great Lakes. Use the software at the web site to plot a graph of annual mean temperatures.
   a. What location did you choose for data from the U.S. Historical Climatology Network? ______________
   b. Does it appear that global warming is occurring there? Describe the graph – does it look more like the global data or the Cloquet data graph?
   c. What factors might affect whether the temperature in a local area is related to global trends?

4. If time permits, watch NASA's animation of global temperature anomalies at ***http://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php***.
   a. What do the red and blue colors represent?
   b. Based on the animation, what is the overall trend in global temperature change?
   c. Click on the dots to see the average temperature anomaly for each decade. Why does it appear that there are few to no global temperature anomalies in the 1950s, 1960s and 1970s?
   d. Describe the temperature anomalies for the Arctic region in the 1880s, 1970s, and 2000s. What do you notice about temperature anomalies in the Arctic compared to other parts of Earth?
   e. What do the gray patches represent? Why does the area of the gray patches decrease throughout the decades?

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***.

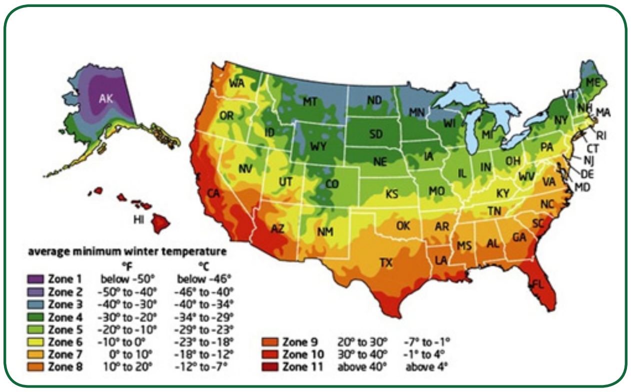


Figure 1a: USDA Planting Zone Map 1990

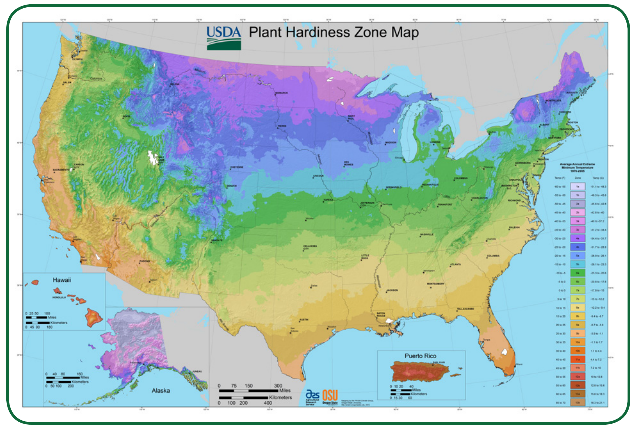


Figure 1b: Planting Zone Map, revised 2012

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?

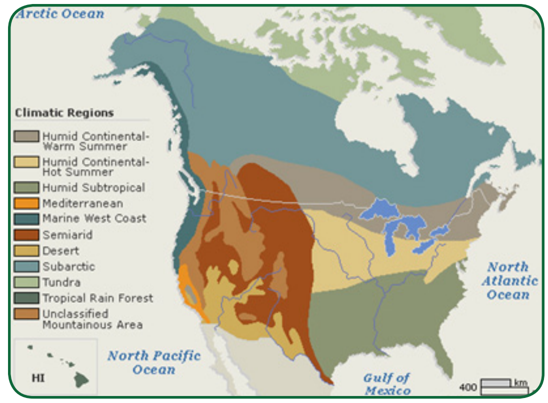
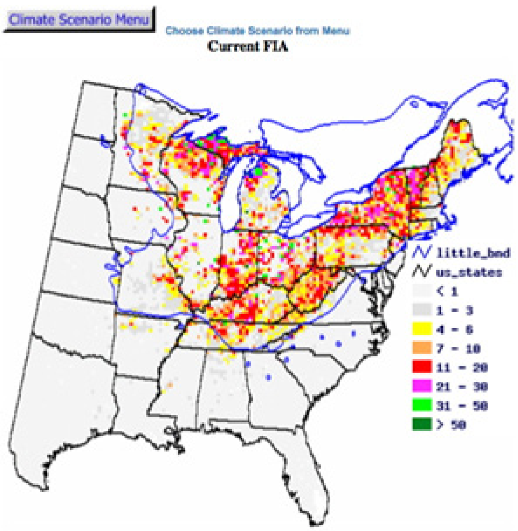


Figure 2: Climatic regions of North America.
Source: ***http://printable-maps.blogspot.com/2008/09/climate-maps-united-states-and-canada.html***

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.

A.



B.

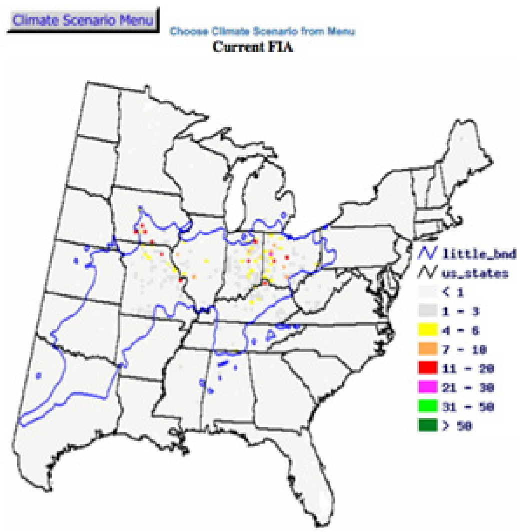


Figure 3: Current climate niche of sugar maples [A] and buckeyes [B].
Source: ***http://nrs.fs.fed.us/atlas/tree/tree_atlas.html***

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

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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.

Iverson, L. R., A. M. Prasad, S. N. Matthews, and M. Peters. 2008. Estimating potential habitat for 134 eastern US tree species under six climate scenarios. *Forest Ecology and Management*. 254:390-406. ***http://www.treesearch.fs.fed.us/pubs/13412***

The life of a sugar maple tree. Online at ***http://maple.dnr.cornell.edu/pubs/trees.htm***. Accessed January 14, 2012.

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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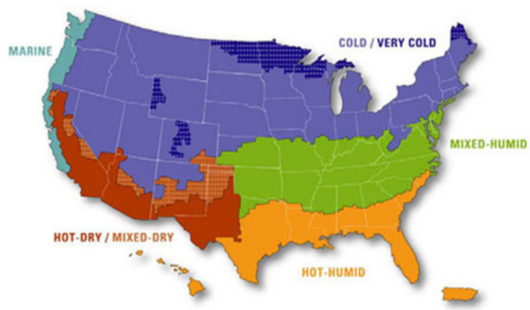
Name ______________________________ Period __________

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

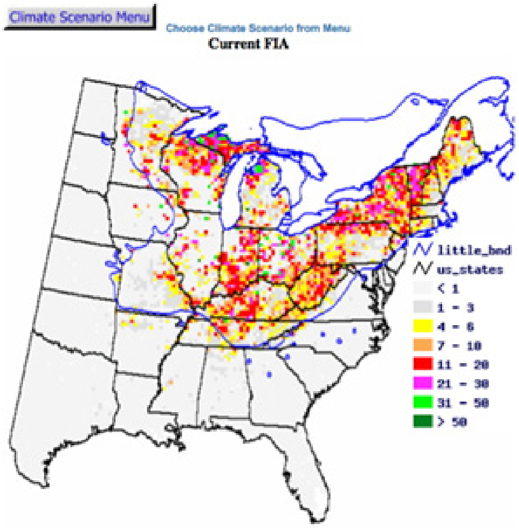
   b. vegetable crops

   c. forest trees

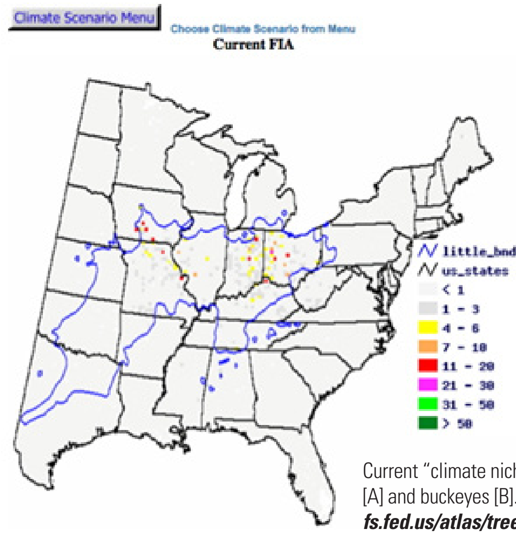
Name ______________________________ Period __________

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

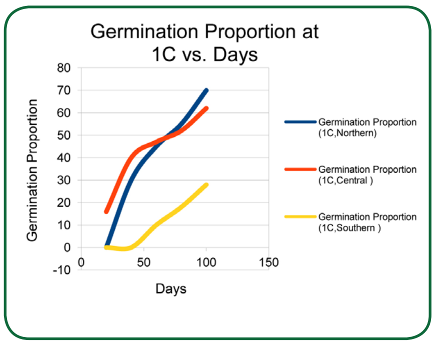
An important part of a scientific paper is the analysis section, where the scientist interprets her findings. Ask students to write an analysis section based on the data presented in this lesson. Depending on the skill level of the students, guiding questions may be used to scaffold this assignment.

EVALUATE

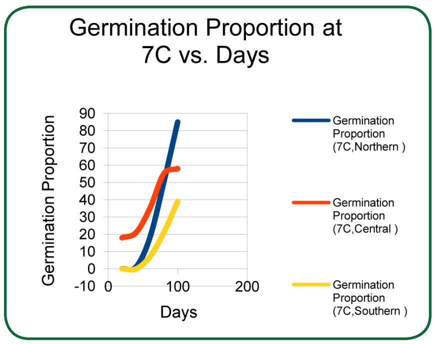
If the emphasis of the lesson was on graphing and data interpretation, give students several line graphs and ask similar questions to those presented here. At least some of the questions should ask students to draw from more than one graph and/or synthesize information from several graphs in a new graph. 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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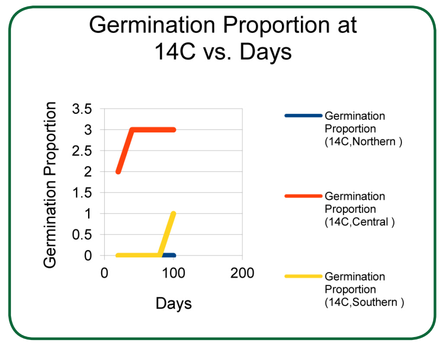


3. Answers will vary based on the student hypothesis. If students hypothesized that seeds from the different areas would be affected differently by the germination temperature experiment, their hypothesis would be supported by the data. They should be encouraged to elaborate on seed responses to different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

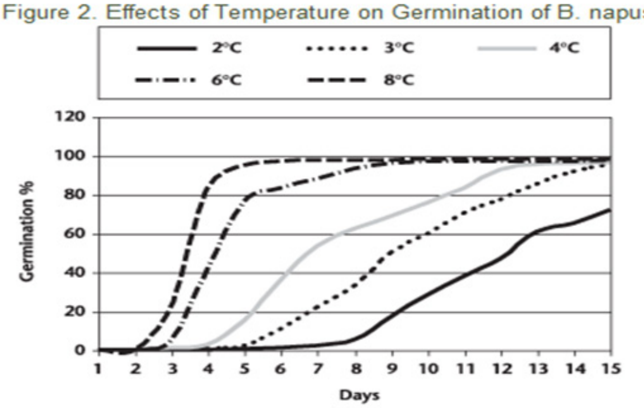
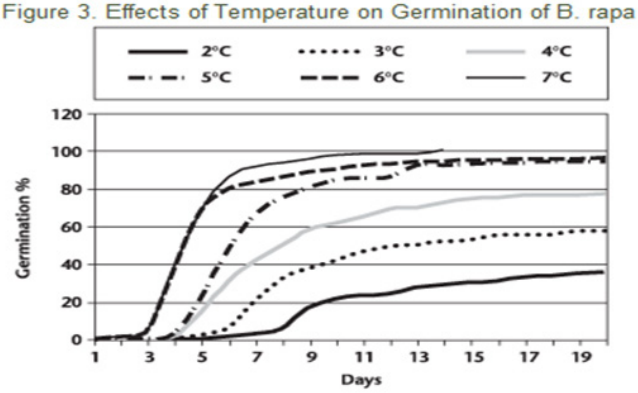


Figure 3. Effects of Temperature on Germination of B. rapa



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 2°C, what proportion of *B. rapa* and *B. napus* seeds germinate?

B. napus:

B. rapa:

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

B. napus:

B. rapa:

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

B. napus:

B. rapa:

5. At 6°C, 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.

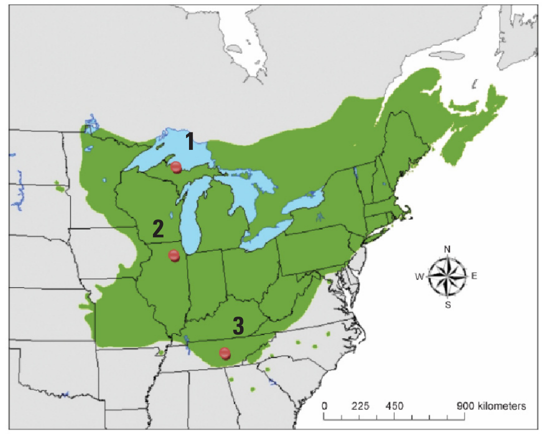

Figure 1: Map of the native range of sugar maples [USGS 1999]. The seed sources were 1) Big Bay, MI, 2) Elburn, IL, and 3) Tennessee.

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.)

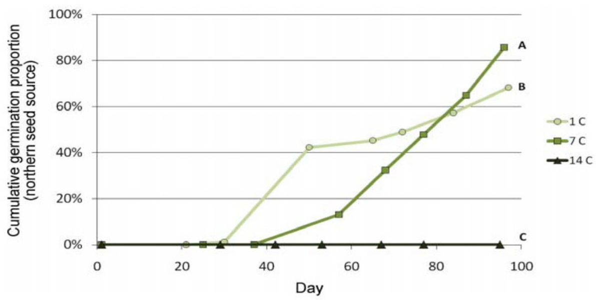


Figure 2: Cumulative germination proportions of all Northern seeds from the three temperature trials. All three lines, A, B, and C, were significantly different from each other.

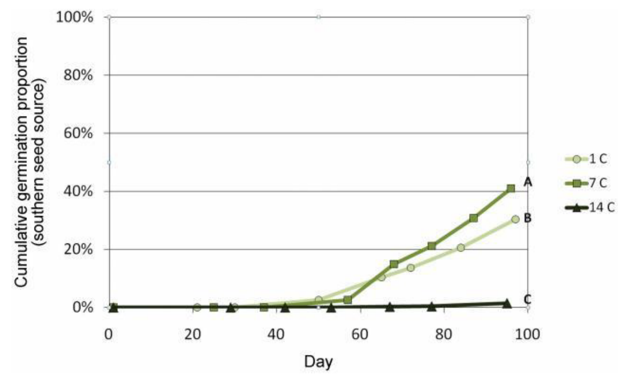


Figure 4: Cumulative germination proportions of all Southern seeds from the three temperature trials. All three lines were significantly different from each other.

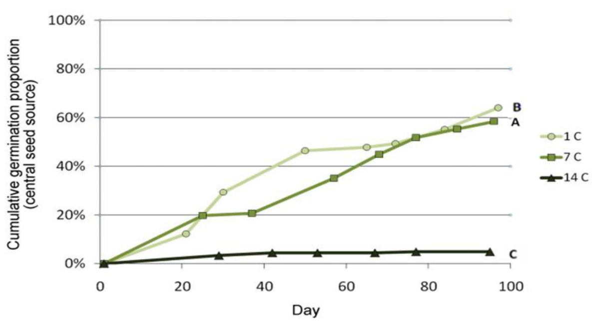


Figure 3: Cumulative germination proportions of all Central seeds from the three temperature trials. Lines A and B are significantly different from Line C, but not significantly different from each other.

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.

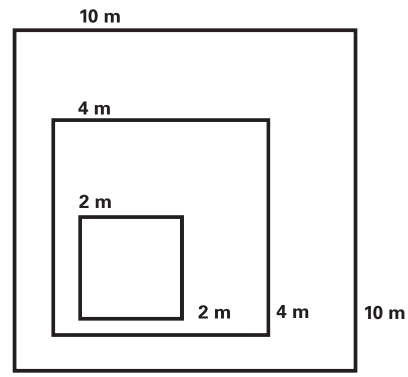
ENGAGE

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:

____
____
____
____
____
____
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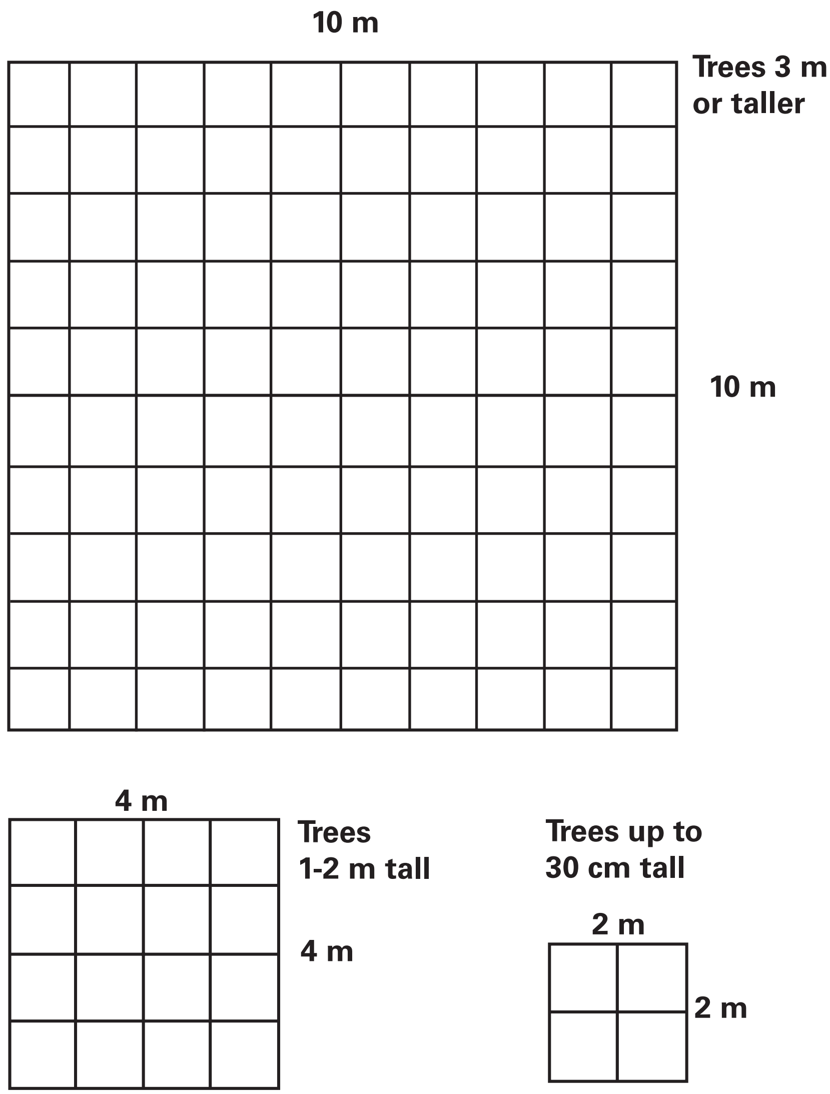
____



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?

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VISUALIZING CHANGES IN THE GREAT LAKES

BACKGROUND
Whenever people talk about the future, they form a mental image of what things will be like. They think about themselves and the things they know about, and in their imagination build a new picture of what they can expect. As we consider the impacts of climate change on the Great Lakes, there are a number of ways of visualizing those changes.

Teacher Activity A: Which Great Lakes factors will increase and which will decrease as a result of climate change?

Objectives: In this activity, students will construct a web of things that may increase or decrease as a result of a changing climate.

After completing this activity, students will be able to:

- List and explain many potential impacts of climate change
- Discuss various interpretations of the possible impacts of climate change

Materials:	Blank wall, bulletin board or a few large tables pushed together	1 per group
	Tape or push pins if using a blank wall or board	50-75 per group
	1 card labeled "INCREASE IN GLOBAL TEMPERATURE"	1 per group
	40 cards labeled "MORE" on one side and "LESS" on the other side	1 set per group
	35-40 scientific and social impact cards (templates included as teacher materials)	1 set per group

Time required: 1 class period

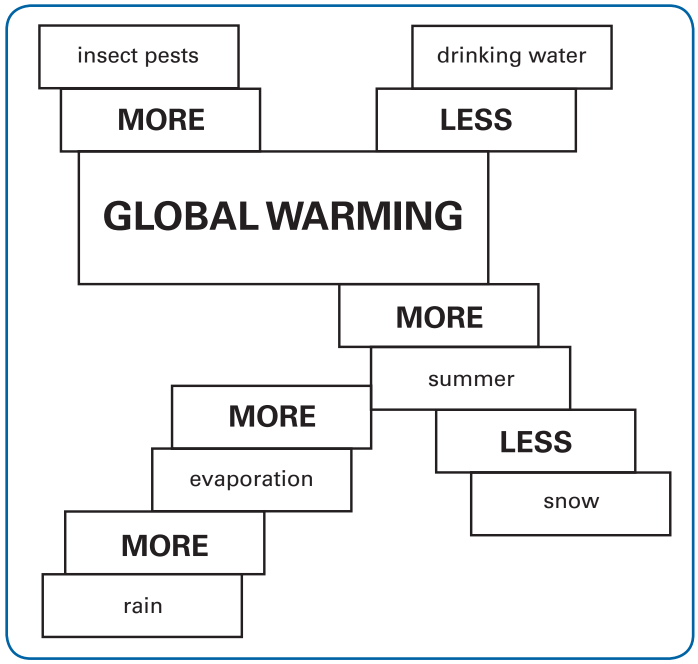
TEACHER'S NOTES
- Because of space, this activity can be done as a whole class or in large groups (i.e., 3 groups of 10 students in a class of 30). If used with small groups, impact cards and MORE/LESS words can be put on 3 X 5 note cards or small pieces of paper. This avoids the problem of students having to wait for their turn at the table/board, and it also results in many different maps that can be compared in group discussion.
- This activity can be used at various stages of a unit. For instance, it can introduce a new topic and relate it to previous ones or it can be a culminating activity to draw all aspects of a study together.
- Use one color paper for the MORE/LESS words and another color for the impact cards.
- While a variety of impact items are provided, feel free to add other scientific and social impacts as appropriate.
- Materials can be laminated for continuous use.

ALIGNMENT
National Framework for K-12 Science Education:
CC2: Cause and effect: Mechanism and explanation
Core Idea ESS2: Earth's systems
Core Idea ESS3: Earth and human activity

Great Lakes Literacy Principles:
#3e: The Great Lakes influence local and regional weather and climate.
#6e: The Great Lakes and humans in their watershed are inextricably interconnected.

Climate Literacy Principles:
#7b,e: Climate change will have consequences for the Earth system and human lives.

This activity can be used at various stages of a unit. For instance, it can introduce a new topic and relate it to previous ones, or it can be a culminating activity to draw all aspects of a study together.



ENGAGE

Pose to and discuss with students the following broad questions: How will things change in the Great Lakes region if the average global temperature increases? How will the various Earth systems (biosphere, hydrosphere, cryosphere, atmosphere, lithosphere) be affected?

EXPLORE

1. Determine whether the activity will be done as a whole class or in large groups.

2. Assemble materials by placing the MORE/LESS cards in a pile and spreading out the impact cards. Place the INCREASE IN GLOBAL TEMPERATURE label in the center of a large table or board.

3. Invite students to come forward one at a time to select an impact card that is a direct result of a previously placed card. They should then select either MORE or LESS as a connector between the two impacts and place them in the web to show a sequence of events. For example, the first student may decide that an INCREASE IN GLOBAL TEMPERATURE (center card) leads to MORE INSECT PESTS or LESS DRINKING WATER. Students must be able to justify the position of the cards they add and their choices of MORE or LESS impact.

EXPLAIN

4. As students use these cards, it will become apparent that there are various interpretations of the impacts. For instance, more weeds and insect pests would probably invade the region, and soil moisture would probably decrease if global warming occurred. However, annual temperatures would be higher and growing seasons longer. The net result could be either more or less crop production. Much would depend on the fertility of northern soils; where and when precipitation falls; and which crops are grown. Lead the class in a discussion of all interpretations.

5. If there are multiple groups completing the activity simultaneously, have groups prepare a written or oral presentation of their maps, analyzing the thinking about interrelationships that produced the array.

EXTEND

This activity, as written, focuses on *global* climate change. Have students consider the scientific and social impacts on a *regional* level (throughout the Great Lakes watershed). How would the organization of the web need to change to represent the impacts of climate change in the Great Lakes? Are there additional impact cards that could be added to the web?

EVALUATE

A suggested way to use this activity is as a pre- and post assessment for a unit on climate change. Have students construct the web prior to any discussion or activities and then again after learning. Students can take a picture of the concept map crated at the beginning of a unit and compare it with the map produced at the end.

Sample evaluation questions

1. Select a chain of at least eight cards. Diagram the chain and give a possible explanation for the links illustrated.

2. List and discuss potential scientific and social factors which may be affected by an increase in global temperature.

    - Accept a large variety of answers for this question. Jobs would be created to help develop new crop seeds that could tolerate warmer, drier conditions. Farmers would need to adjust their crops and farming practices to respond to the changing conditions. Recreation facilities would need to change their structure for the longer summer season, lowered water levels and warmer temperatures. Fishers and manufacturers of fishing gear would need to be flexible because spawning areas for existing fish species may decrease and new species could become abundant. Companies that use toxic chemicals may need to adjust their procedures because increased temperatures and incidence of severe storms would cause airborne pollutants to travel further. The lowered lake and river levels would also greatly impact the shipping industry because boats would either be unable to pass through certain areas or would be required to carry a lighter load. This would have repercussions on the companies that use this method to transport goods.

3. How can the variety of interpretations of global warming impacts lead to uncertainty among policy makers? How do policy makers deal with such dilemmas?

    - Because scientists disagree on what the effects of global warming will be and the severity of these effects, it is not simple for policy makers to make decisions on related issues. They are forced to make difficult decisions based on differing hypothetical projections. The effects of global warming are also not straightforward: agriculture, for instance, in some areas may be improved but in other areas it will be damaged. For most changes, there would also be some groups that will come out the winners and others will be the losers. These uncertainties make decision making difficult.

ADDITIONAL RESOURCES

Union of Concerned Scientists: Great Lakes Communities and Ecosystems at Risk
http://www.ucsusa.org/greatlakes/

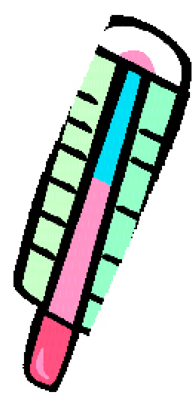
Impacts on Water: Our Nation's Vital Resource (one page handout explaining and illustrating the cascading effects of climate change in the Great Lakes region)
http://www.ucsusa.org/greatlakes/pdf/glwaterresources.pdf

Climate Change in the Great Lakes Region
http://www.great-lakes.net/envt/refs/cchange.html

US Global Change Research Program
http://www.usgcrp.gov/usgcrp/nacc/greatlakes.htm

Updated from the activity in *GLIMCES* © The Ohio State University, 1995, which was adapted from "More or Less" produced by Zero Population Growth.

Increase in global temperature



MORE

LESS

MORE

LESS

LESS

MORE

LESS

MORE

evaporation

snow

drinking water

severe storms

insect pests

flooding

recreation

water pollution

winter

biological diversity

ducks

income

fertilizer use

shoreline development

extinction

lake levels

lakefront property

rain

toxic air pollution

electricity

fear

shipping

disease

soil moisture

pesticide use

people

wetlands

crop production

cooperation

fish

tourism

forests

dredging of waterways

debate

summer

air conditioning

weeds

water diversion

drought

Teacher Activity B: What will people see on the long walk to the water's edge?

The shoreline of the Great Lakes, like the shores of other coasts, is remarkably varied, from sand dunes and beaches to rocky shores, high cliffs, wetlands, and urban waterfronts. A Google image search for a given state (e.g., "Ohio shoreline") will demonstrate this.

Like the shorelines of the world's oceans, Great Lakes shorelines are expected to change dramatically as global climate change impacts the Earth system. Unlike the rising sea levels of the marine coast, however, at least some areas of the Great Lakes are likely to experience dramatically lower water levels.

A complete lesson on Water Levels in the Great Lakes is included in this set. Basically, lake levels rise and fall depending on how much rain and snow falls on the lakes and in their drainage basin, and how much of the water evaporates. The relationship between precipitation and evapotranspiration is good for making predictions on an annual basis, but longer term views are necessary to see what is likely to happen over decades and centuries. Those are considered in the water levels lesson. Regardless, the shoreline of the Great Lakes is likely to look very different in years to come. This lesson invites visualization of how the shore will look in areas where water levels drop, but teachers may also want to consider shoreline impacts where lake levels rise.

What will be exposed as the nearshore waters recede? How far out from shore must we go to get the water depth we need? As water levels drop, the underwater shape of the lake basin (bathymetry) will determine whether a new beach is exposed or higher bluffs. Scientists and regional decision makers are now identifying the kinds of changes this may incur for the region. Examples include positions of marinas and private docks, and the amount of shipping that can go through shallower channels and locks. Cities that get their water supply from the lakes are calculating where new intakes will have to be, and fisheries managers are determining whether lost wetlands could impact the spawning of favorite fish. Many changes may come. We are just beginning to acknowledge the changes and imagine their effects on the life of the region.

ACTIVITY OVERVIEW

In this activity, students examine information about how climate change will likely impact the Great Lakes of North America and assume that they are in a part of the region experiencing a water level decline of over two meters! They listen to [or read] a story in which they imagine that they have spent a lifetime visiting the Great Lakes. With their "memories" and their science information, they describe the changes they have noticed in the Lakes during their lifetime.

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

- visualize the appearance and condition of a Great Lakes shoreline with climate change;
- write clear, scientifically plausible essays about the changed shoreline; and
- demonstrate appropriate use of science language.

Materials (for any size class):

Individual writing supplies or word processor access
Great Lakes Then and Now Story
Internet access [optional]

Time required: one class period, or as homework

ALIGNMENT

National Framework for K-12 Science Education:
CC7: Stability and Change
Core Idea ESS3: Earth and human activity

Great Lakes Literacy Principles:
#2c: Lake level changes influence the physical features of the Great Lakes coast.
#8a: The Great Lakes are a source of inspiration, recreation, rejuvenation and discovery.

Climate Literacy Principles:
#7b: Climate change will have consequences for the Earth system and human lives.

ENGAGE

Look at various photographs of Great Lakes shorelines at the photo gallery provided by NOAA's Great Lakes Environmental Research Laboratory [GLERL], ***http://www.glerl.noaa.gov/pubs/photogallery/***. Discuss the level of the water in relation to what is shown on the land. How close is the water? What is happening right on the shore?

EXPLORE

Read the personal story on the student worksheet aloud with the class and then allow time for individual students to write about how they visualize the new shoreline, comparing it to what they imagine (or remember). The writing may be assigned for homework to allow for reflection and careful composition.

EXPLAIN

Since this lesson is for imagining, attempts to explain may be conceptual and based on experience, or they may take the form of students doing Internet research about water level impacts on infrastructure and environment. This section of learning should be flexible to allow for student maturity, access to technology, and whether the class has done the Water Levels lesson in advance.

EXTEND

More people are aware of sea-level rise than of lake-level decline, and many credible Internet sites describe the mechanisms and impacts of climate change on the volume of the world ocean. To compare coastal issues, students may want to visualize what a walk to the new seaside would be like. Would it be a longer or shorter walk than before the climate began to change? What shoreline changes are likely to be observed at the students' favorite beach?

EVALUATE

Miller and Calfee (2004) developed a science-writing rubric with useful criteria for many writing experiences. It includes ways to compare science achievement, as well as written expression, and is available at ***http://nsta.org/main/news/stories/science_and_children.php?category_ID=86&news_story_ID=49933***.

Perhaps more important than scoring the writing is to foster visualization. In considering the science and policy of global climate change, few people have stopped to envision how environmental changes, such as less lake water or rising sea level, will affect them personally. While environmental science on the scale of climate change is very abstract, this kind of activity brings to light the personal aspects. Students may be able to relate more to the science if they see that the changes to come are likely to be personal ones as well as those that make headlines. It is valuable to discuss the "Science in Personal and Social Perspectives" as fostered by the National Science Education Standards (NRC 1996) and to consider such lessons as part of science literacy.

REFERENCES

Miller, R., and R. Calfee. 2004. Making thinking visible. *Science and Children* 42 (3): 20–25.

USGCRP. 2003. Internet document from U.S. Global Change Research Program.
http://www.usgcrp.gov/usgcrp/Library/nationalassessment/overviewmidwest.htm

ADDITIONAL INTERNET LINKS TO ENHANCE THIS ACTIVITY INCLUDE

http://www.great-lakes.net/envt/water/levels/hydro.html
This page of the Great Lakes Information Network (GLIN) has current information about water levels and a clickable map of the lakes with recent data on water levels.

http://www.great-lakes.net/teach/envt/levels/lev_1.html
In the education section of GLIN, an online overview of water levels and impacts is presented. The section includes a map of the Great Lakes watershed, with the states and provinces identified.

http://www.usgcrp.gov/usgcrp/nacc/greatlakes.htm
U.S. National Assessment of the Potential Consequences of Climate Variability and Change. Region: Great Lakes. This is a link to the interpretation of climate variables in the region.

http://www.glerl.noaa.gov/seagrant/glwlphotos/Seiche/25October2001/EriePix.html
This page has photo examples of a low-water event in 2001 on Lake Erie.

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

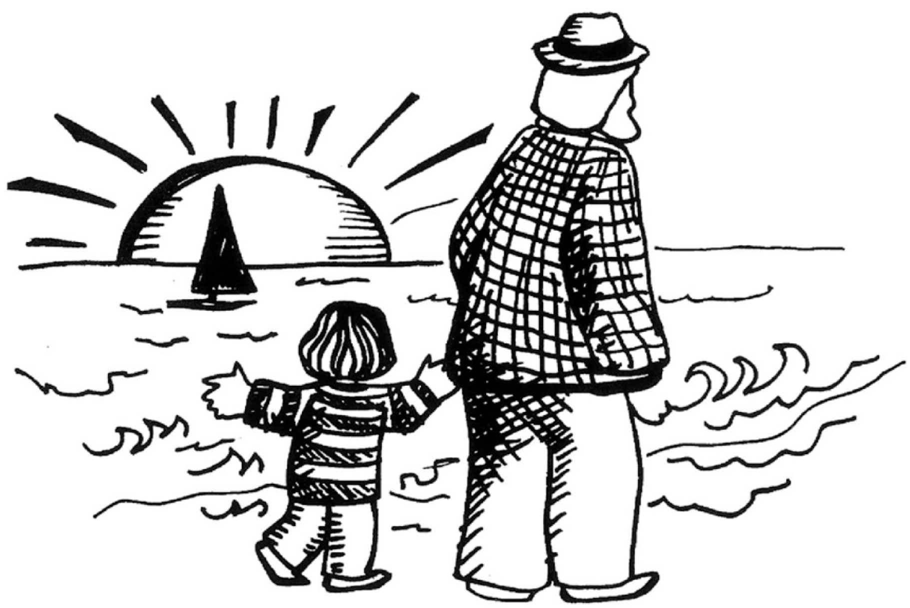
This activity was adapted from the Great Lakes Instructional Materials for the Changing Earth System (GLIMCES), 1995.

Student Activity B: A Long Walk to the Water's Edge

When your grandparents first bought land on the shore of the Great Lakes, it was very beautiful. The forest reached almost to the beach, and ended in some low rolling sand dunes you used to run across with your bare feet flying. From the dunes to the water's edge was barely a skip or two; then your toes could wiggle in the cool water as it swished over the smooth, rounded stones. Along the beach you searched for lucky stones and interesting driftwood to put in the treasure box under your bed.

In the corner of the lot was a low area where some cattails grew, and the water was quiet and warm. Tiny fish swam there, and a green heron came every morning to find a mouthful for breakfast. A big frog once startled you with its lightning leap and a splash into the water when you came too near. It was great then when the water was so close you could hear it from your open window at night, and the beach seemed only a step away. Whatever your grandparents paid for that place, it was worth it.

So now the old place welcomes you back with your own grandchildren. You've told them stories about how it was; the image is so vivid in their minds as they run toward the beach. Follow them. On the porch swing that night, your daughter wants to hear what her children saw, and what YOU saw today.



In the role of the grandparent and then the child, think about how things have changed since the climate got warmer and the water level dropped. Write two stories: one from the perspective of the grandchild and the other from the perspective of the grandparent. She might appreciate a picture, too—your mental photograph of then and now.

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ESTUARY VALUES AND CHANGES

(Background and Teacher Guide)

Along the shores of the Great Lakes are numerous marshes and estuaries. These wetlands support a great diversity of plant and animal life. Abundant aquatic and terrestrial organisms use areas either on a temporary or permanent basis. Unique wetland habitats support a greater variety of plant and animal life than any other area of equal size in the region.

Estuaries are not easily defined. They have traditionally been characterized as the area where fresh water meets the sea and water levels rise and fall with the tides. Estuaries, however, can be more than just an aquatic interface between fresh water and salt water. In a larger meaning, they are the part of the mouth of a stream in which the water level is influenced by the lake or sea into which the stream flows. The chemical contents of the estuary water [salinity or total dissolved solids] are also between those of the stream and the lake or sea. In this case, they occur where rivers meet freshwater lakes. Many different habitats—marshlands, open water, sand beaches, upland forests, even cities and agricultural fields—can merge at these unique areas.

Terrestrial and aquatic vegetation serve several functions in an estuary. Emergent aquatic plants filter out large quantities of nitrogen, phosphorus, pesticides and silt. Subsequently, some of the nutrients and toxins are taken up by the root systems of these aquatic plants. Without estuaries and marshes acting as a natural buffer zone, even greater quantities of pollution would enter the Great Lakes.

Additionally, plants provide a food source for herbivores and detritus feeders (organisms that feed on dead materials), which are the base of the lake food web. The thick layers of foliage in an estuary provide protective breeding and nursery ground for fish and other aquatic animals. Finally estuaries reduce the harmful flooding effects of storms in the Great Lakes watershed by absorbing large quantities of storm water and then slowly releasing the water into the lakes.

Climate change is predicted to increase lake water evaporation and cause lake levels to lower. If this happens, many estuaries could lose their distinct identities. Only those located where the conditions are compatible with the new shorelines will remain.

The following activities explain some of the beneficial environmental functions wetlands contribute and what may happen to some estuaries as climate change occurs.

Additional Resources for Climate Change Impacts on Estuaries

Climate Change and Great Lakes Wetlands (archived webinar)
http://changingclimate.osu.edu/webinars/archives/2011-11-08

EPA - Climate Ready Estuaries
http://epa.gov/cre

Freshwater Estuaries (video)
http://www.youtube.com/watch?v=Eb3B9VaRVHk

What's an Estuary? Now You Know (video, primarily saltwater focus)
http://www.youtube.com/watch?v=XLumSN4G5P4&feature=youtu.be

National Estuarine Research Reserves
http://nerrs.noaa.gov

Old Woman Creek NERR
http://nerrs.noaa.gov/Reserve.aspx?ResID=OWC

Lake Superior NERR:
http://nerrs.noaa.gov/Reserve.aspx?ResID=LKS

Estuaries 101 Curriculum
http://estuaries.gov

Wonders of Wetlands Curriculum
http://wetland.org/education_wow.htm

Teacher Activity A: What is the ecological role of an estuary?

BACKGROUND

To most people, an **estuary** (es-chew-airy) is a place where freshwater meets the sea. In its broader meaning, an estuary is that part of the mouth of a stream in which the water level is influenced by the lake or sea into which the stream flows. The chemical contents of the estuary water [salinity or total dissolved solids] are also between those of the stream and the lake or sea. The Great Lakes have some estuaries. Old Woman Creek on Lake Erie in Ohio and Lake Superior's St. Louis River in Wisconsin and Minnesota have estuaries that have been set aside by the state and federal governments as "state nature preserves" and "national estuarine research reserves." Why should the government bother to preserve estuaries such as Old Woman Creek and the tip of Lake Superior? There are many reasons:

- The estuaries of the world serve as breeding grounds for many important animals that live in deeper waters.
- An estuary has a wide variety of habitats available for wildlife to use as nesting and feeding sites. Thus, estuaries harbor a lot of diversity.
- The sediments and water of an estuary are places where nutrients are recycled and where the basic things needed for life are made available to a wide variety of organisms.
- Estuaries serve as buffer zones to filter pollutants. Runoff from the land is cleansed before it enters a lake or ocean.
- Estuaries also buffer changes in water level. The effects of flooding and water level changes are lessened as water spreads out in the shallow area of the river mouth.
- Estuaries are "endangered ecosystems." Because of their quiet waters and nearness to lakes or oceans, estuaries are often attractive places for marinas, home sites and tourist developments. Few estuaries still exist in their natural conditions.

An estuary contains some areas that are almost always under water, some areas that are almost always dry land, and some areas between these two extremes. Each of these environments has a set of plants that can survive best under the given conditions. Each set of plants has a special role to play in the estuary and contributes to diversity of both plants and animals there.

Objectives: In this investigation, students will examine some of the characteristics of the estuary at Old Woman Creek, near Huron, Ohio.

The things students learn about this estuary will illustrate the importance of estuaries worldwide.

After completing this investigation, students will be able to:

- Describe the methods used by ecologists to sample populations of plant and animal life in aquatic ecosystems.
- Give a general description of the living communities that are found in different depths of water in an estuary.
- Give examples of how plant communities are important to animal life in an estuary.

Materials:	colored pencils	variety of colors per student/group (green, blue, brown, yellow, red)
	rulers	1 set per student/group

Time required: 1-1.5 class periods

ALLIGNMENT

National Framework for K-12 Science Education:
SEP 4: Analyzing and interpreting data
CC 3: Scale, proportion and quantity
CC 7: Stability and change
Core Idea LS 2: Ecosystems: Interactions, Energy and Dynamics

Great Lakes Literacy Principles:
#2c: Natural forces formed the Great Lakes; the lakes continue to shape the features of their watershed.
#5e,f,h: The Great Lakes support a broad diversity of life and ecosystems.
#6: The Great Lakes and humans in their watersheds are inextricably interconnected.

Climate Literacy Principles:
#3a,c: Life on Earth depends on, is shaped by, and affects climate.
#4a: Climate varies over space and time through both natural and mad-made processes.
#7c,e: Climate change will have consequences for the Earth system and human lives.

ENGAGE

Students look at pictures of estuaries across the United States and propose a definition of an estuary based upon characteristics shared by estuaries in the pictures.

Click through various estuaries at ***http://www.nerrs.noaa.gov/ReservesMap.aspx***. Encourage students to look at the Google maps, the photographs and the brief descriptions of each estuary. As a class or in small groups, have students generate a list of characteristics that are common to all estuaries.

Students watch a 3-4 minute video clip introducing wetlands and their components at ***http://www.youtube.com/watch?v=ft_2nj96jLM&feature=related***.

EXPLORE

Students follow instructions to manipulate the map and charts to analyze the vegetation and animals in an estuary.

EXPLAIN

Students answer questions about the types of vegetation and animals in an estuary and their roles in the ecosystem.

Answers to Student Worksheet

1. Marsh, open water and deciduous forest are present within the estuary.
2. Forest plants are rooted in dry soil.
3. Plants could provide nest sites, protection (places to hide), and food for animals.
4. Marsh areas have emergent plants. Some submerged plants are in the open water areas and the marsh.
5. The marsh has the greatest number of animals.
6. Most of the animals are eating or reproducing there.
7. The plants provide food nest sites and protection.
8. Most of the fish listed are plant eaters when they are young. Carp eat plants as adults, too. Songbirds may eat plant seeds.
9. The bottom of the estuary is muddy. This provides the plants with something to hold their roots in place. The plants in the estuary tend to slow down the stream's flow. When water slows down, it cannot carry as much sediment. Much of the stream's load of sediment is, therefore, deposited in the shallow areas where plants are rooted in the water. Pollutants suspended in the water may also be trapped in the estuary this way.
10. An estuary is that part of the mouth of a stream in which the water level is influenced by a lake or ocean into which the stream flows.
11. The water level must have been higher when the picture was taken than when the computer map was made.

EXTEND

Sample extension activities

1. Discuss how the roles of plants might vary in different depths of water in an estuary.
2. Refer to the computer map noting the different types of land uses in the region. What impact could land use have on the estuary? Research examples you can use to support your answer.
3. Look at the map of the Lake Superior National Estuarine Research Reserve at ***http://lsnerr.uwex.edu/maps-data.html***. Compare and contrast the vegetation found at Lake Superior NERR with that found at Old Woman Creek. What land use issues might arise here that would be different from those at Old Woman Creek?

EVALUATE

Sample evaluation questions

1. Define estuary. Where are estuaries found in the Great Lakes? [An estuary is the part of the mouth of a stream in which the water level is infuenced by the lake or sea into which the stream flows. There are many estuaries in the Great Lakes, but Old Woman Creek National Estuarine Research Reserve on Lake Erie and the Lake Superior National Estuarine Research Reserve are recognized nationally.]
2. What are some of the functions served by estuaries that affect an ecosystem? [Estuaries provide breeding, nesting and habitat sites; filter nutrients, sediment and pollutants from water; and lessen the effects of flooding because of water level changes.]
3. Give a general description of the types of plants found in different depths of water in an estuary. [Submerged plants have their roots and leaves under water. Emergent vegetation has roots in water, but leaves and seeds emerge into the air. Some emergent vegetation may float on the surface in deeper water, while be rooted into sediment in shallower waters.]
4. List some ways in which plants are useful to animals in the estuary. Are there ways that animals are useful to plants? [Plants provide a food source for herbivores, omnivores and detritus feeders (organisms that feed on dead materials. The thick layers of foliage in an estuary provide protective breeding and nursery grounds for fish and other aquatic animals. Animal waste, as well as dead and decaying animals are sources of recycled nutrients like nitrogen and phosphorus needed by plants.]
5. Describe a method by which scientists can sample a community. What do you think are the challenges in trying to find a representative sample of all of the organisms in an estuary? [In population sampling, a portion of the organisms in a given area are identified and counted and then an estimate of the total population is made. Satellite imagery and aerial photography can also help scientists determine biodiversity in large areas.]

ADDITIONAL RESOURCES

The Swamp in OSU's Backyard fact sheet: ***http://changingclimate.osu.edu/features/the-swamp/***

Updated from the activity in *ES-EAGLS – Life in the Great Lakes* © The Ohio State University, 1997

Originally modified from OEAGLES EP-016A, "The Estuary: A Special Place." By Rosanne W. Fortner and Ron Mischler

Names ______________________________ Period __________

Student Activity A: What is the ecological role of an estuary?

BACKGROUND

To most people, an **estuary** (es-chew-airy) is a place where freshwater meets the sea. In its broader meaning, an estuary is that part of the mouth of a stream in which the water level is influenced by the lake or sea into which the stream flows. The chemical contents of the estuary water [salinity or total dissolved solids] are also between those of the stream and the lake or sea. The Great Lakes have some estuaries. Old Woman Creek on Lake Erie in Ohio and Lake Superior's St. Louis River in Wisconsin and Minnesota have estuaries that have been set aside by the state and federal governments as "state nature preserves" and "national estuarine research reserves." Why should the government bother to preserve estuaries such as Old Woman Creek and the tip of Lake Superior? There are many reasons:

- The estuaries of the world serve as breeding grounds for many important animals that live in deeper waters.
- An estuary has a wide variety of habitats available for wildlife to use as nesting and feeding sites. Thus, estuaries harbor a lot of diversity.
- The sediments and water of an estuary are places where nutrients are recycled and where the basic things needed for life are made available to a wide variety of organisms.
- Estuaries serve as buffer zones to filter pollutants. Runoff from the land is cleansed before it enters a lake or ocean.
- Estuaries also buffer changes in water level. The effects of flooding and water level changes are lessened as water spreads out in the shallow area of the river mouth.
- Estuaries are "endangered ecosystems." Because of their quiet waters and nearness to lakes or oceans, estuaries are often attractive places for marinas, home sites and tourist developments. Few estuaries still exist in their natural conditions.

An estuary contains some areas that are almost always under water, some areas that are almost always dry land, and some areas between these two extremes. Each of these environments has a set of plants that can survive best under the given conditions. Each set of plants has a special role to play in the estuary and contributes to diversity of both plants and animals there.

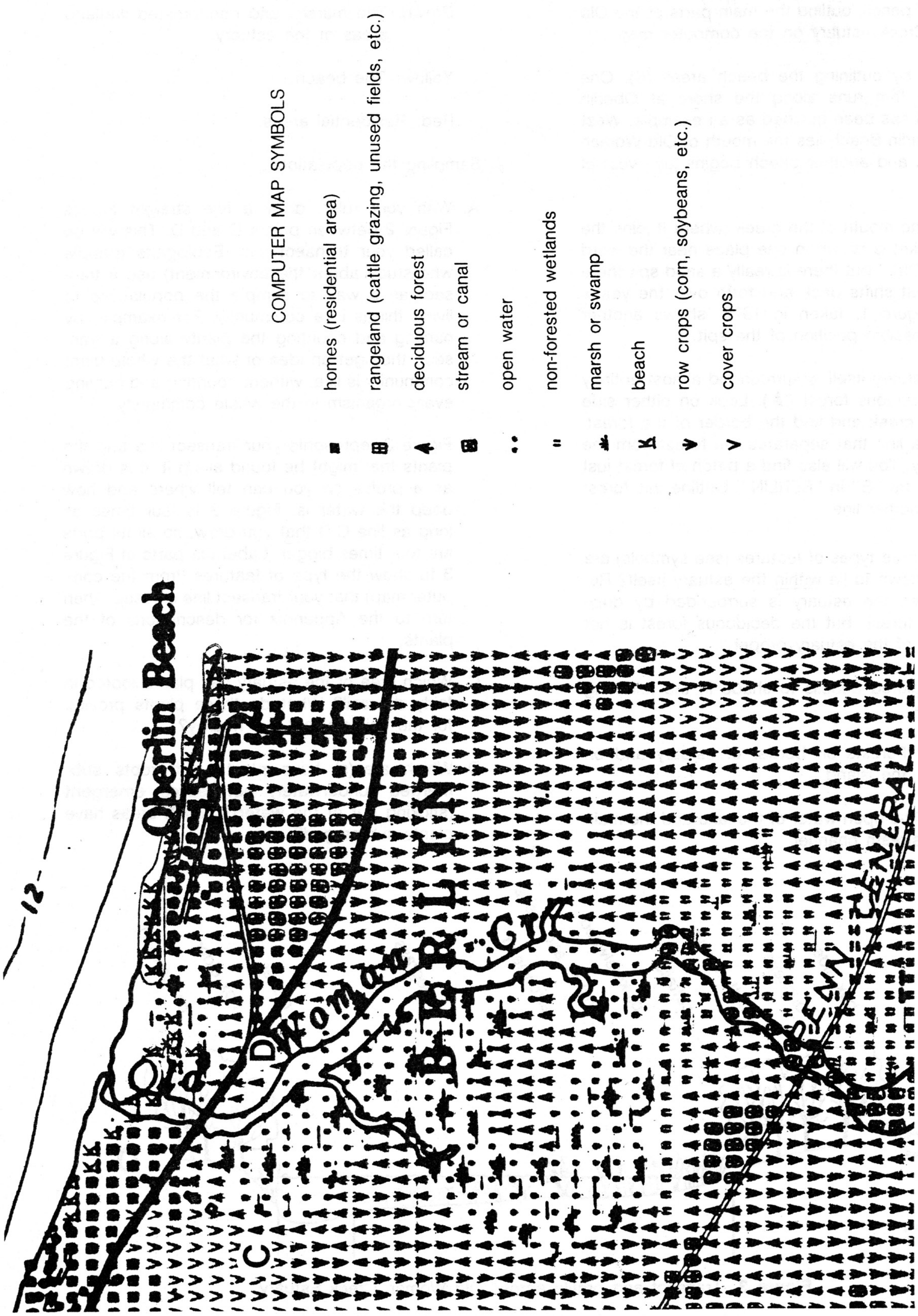
1. Figure 1 is an aerial photograph of the Old Woman Creek estuary, east of Huron, Ohio, on the shoreline of Lake Erie. In this image the opening of the creek is directly in front of the bridge.

Figure 1. Aerial photograph of Old Woman Creek Estuary

2. Figure 2 shows the land use and plant types (called "vegetation") in the same area. Each symbol drawn by the computer stands for the main characteristic of an area equal to about ¼ of an acre. One-quarter of an acre is equal to about 930 square meters, a bit bigger than the average school classroom.

Names ______________________________ Period __________

Figure 2. Computer-generated Map of Old Woman Creek Estuary.



Names ______________________________ Period __________

With your pencil, outline the main parts of the Old Woman Creek estuary on the Figure 2 computer map:

a. Outline the beach area (marked K). One beach that runs along the shore at Oberlin Beach has been outlined as an example. West of Oberlin Beach lies the mouth of Old Woman Creek and another beach begins just west of that. NOTE: The mouth of the creek (where it joins the lake) is drawn in one place near the word "Old," but there is really a sand spit there that shifts back and forth over time. Figure 1, taken at a different time, shows another possible position of the spit.

b. The estuary itself is surrounded almost entirely by deciduous forest (marked with a tree). Look on either side of the creek and find the border of the forest. Draw a line that separates the forest from the estuary. You will also find a patch of forest just below the "B" in BERLIN. Outline this forest with another line.

c. Use colored pencils to shade in the following features:

- Green → forest on border of estuary and on the island
- Blue → the open water of the lake and the main stream channel
- Brown → the marshy and non-forested wetland areas of the estuary
- Yellow → the beach
- Red → residential areas

Sampling the Populations

3. Ecologists use a transect as a way to sample the populations of living things in a community. For example, by naming and counting the plants along a transect, they get an idea of what the whole plant community is like, without counting and naming every organisms in the whole community.

   With your ruler, draw a line straight across Figure 2 between points C and D. This will be called your TRANSECT line.

4. Figure 3 represents your transect line and the plants that might be found along it. It is drawn as a profile so you can tell the location and depth of the water. Figure 3 represents a transect approximately 2.3 times as long as line C-D in Figure 2. That means all its parts are that much bigger.

   Label the parts of Figure 3 to show the type of features (from the computer map) that your transect line crosses. Then turn to the Plant List for a description of the plants.

Answer the following questions using the figures.

1. What three types of features (see the symbols) are now shown to lie within the estuary itself?

2. Which area of the estuary has plants rooted in fairly dry soil?

3. What do these plants provide for the animals that live nearby?

4. What areas have plants with roots submerged (underwater) but leaves emergent (sticking out of the water)?
   Which areas have plants totally submerged?

Names _____________________________ Period __________

Each of the areas crossed by the transect line is able to support a group of animals. Suppose the area is watched for one week. Figure 4 is a list of the larger animals that might be seen and their activities. Remember, these plant communities and their animal visitors are only being SAMPLED. There are many more organisms in the estuary than we have mentioned here.

5. In which part of the estuary would you find the largest number of animals?

6. What are the two main activities carried on by animals in this area?

7. Look at your answers to questions 5 and 6. Why would an area with many aquatic (water) plants be visited by such a large number of different animals? (Hint: See the list of animal activities in Figure 4.)

8. Perhaps you have listed "eating" in some of your answers above. Which of the animals in Figure 4 might be using the marsh plants as food?

9. What is the bottom of the estuary marsh probably like: muddy or rocky? Why do you think so?

The plants in the estuary tend to slow down the stream's flow. When water slows down, it cannot carry as much sediment. Much of the stream's load of sediment is, therefore, deposited in the shallow areas where plants are rooted in the water. Pollutants suspended in the water may also be trapped in the estuary this way.

10. Much of the Old Woman Creek area marked "marsh" on the computer map does not appear that way in Figure 1. An estuary isn't always marshy and a marsh isn't always an estuary. Look back at the introduction and find the "larger meaning" of the term estuary. What is the larger meaning of the term estuary?

11. Based on this definition, why doesn't the Figure 1 photograph show much marshy area?

Names ______________________________ Period __________

Figure 3. Transect and Profile Across Old Woman Creek estuary.

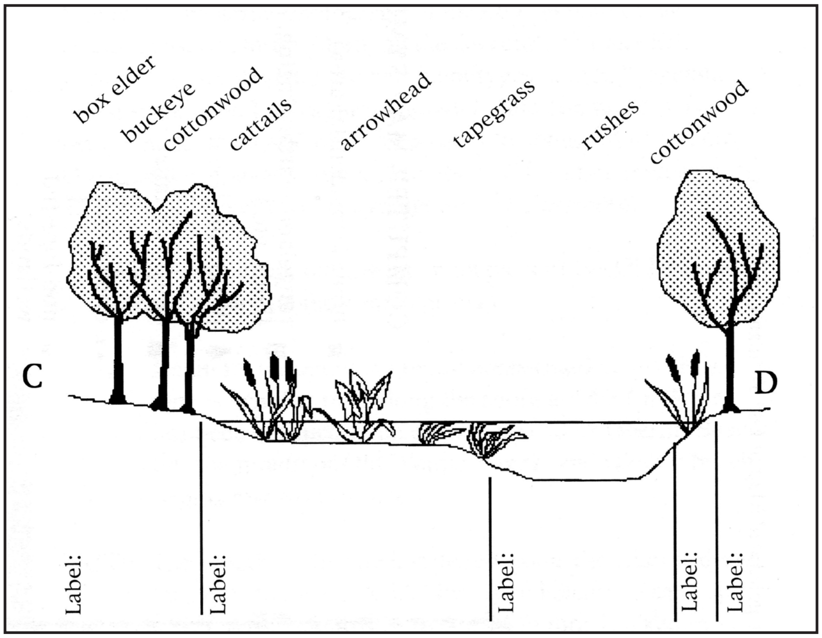


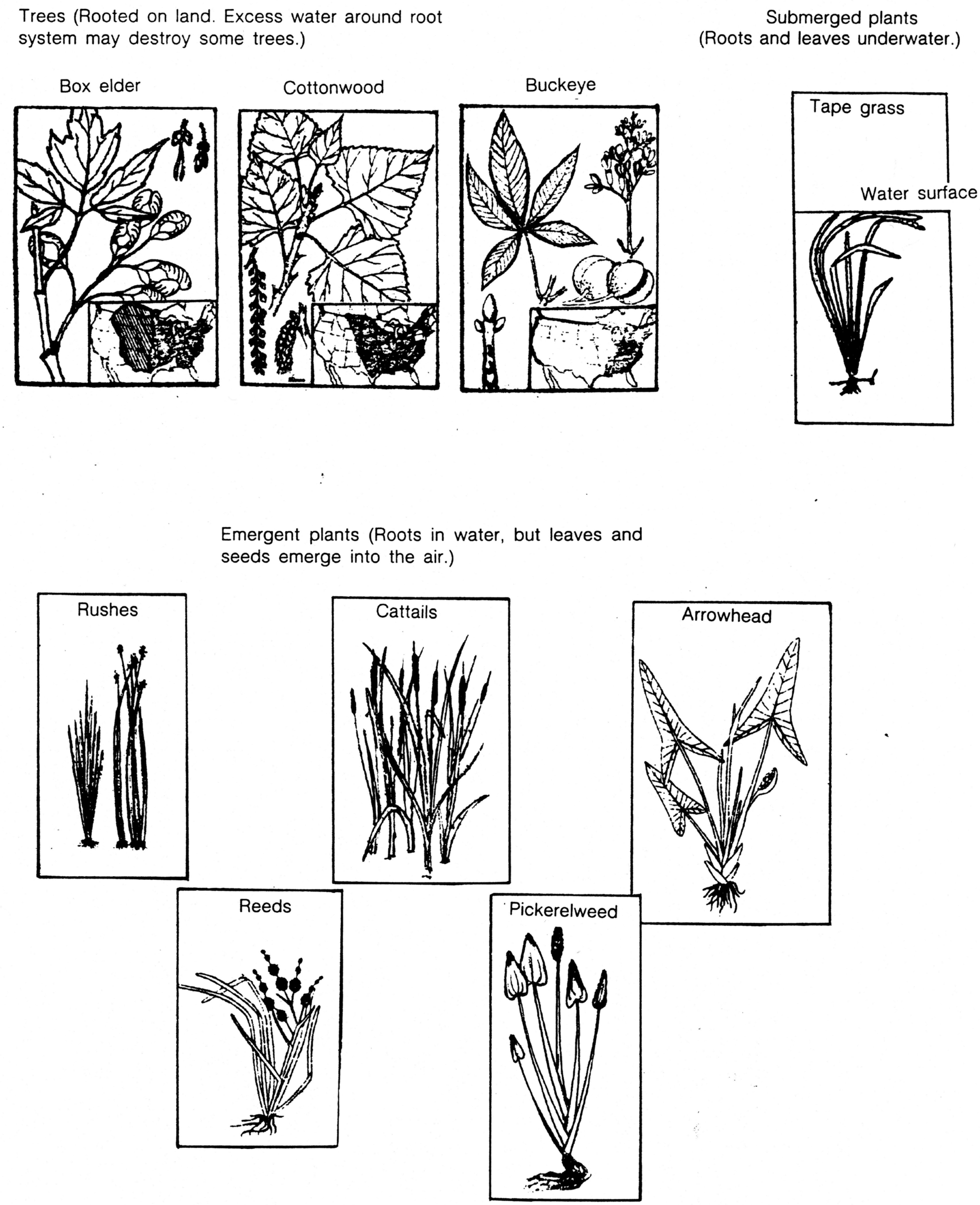
Figure 4. Animals' Use of the Transect Area of Old Woman Creek Estuary.

Animals observed in a typical Great Lakes estuary during one week

ANIMAL	HOW MANY	AREA	HUNTING	EATING	REPRODUCING	HIDING	OTHER
			ACTIVITY				
Raccoon	1	forest edge		X			washing food
White-tail deer	2	forest		X		X	drinking
Fox	1	forest	X	X			
Songbirds	21	forest edge		X	X		nesting
Blacksnake	1	forest	X			X	
American egret	8	forest			X		nesting
American egret	15	marsh	X	X			
Green heron	2	marsh	X	X			
Kingfisher	4	marsh	X	X	X		
Watersnake	1	marsh	X	X			swimming
Seagull	4	marsh		X	X		
Carp	8	marsh		X	X		
Yellow perch	60	marsh		X	X		
Yellow perch	12	open water		X			swimming
Freshwater drum	9	marsh		X			
Gizzard shad	150	marsh			X		swimming
Gizzard shad	30	open water		X			
Clam	17	marsh mud		X	X		
Emerald Shiner	42	open water		X			
Walleye	84	marsh		X	X		

Names ______________________________ Period __________

Figure 5. Macroscopic Plants of the Estuary (Old Woman Creek)



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Originally modified from OEAGLES EP-016A, "The Estuary: A Special Place." By Rosanne W. Fortner and Ron Mischler

Teacher Activity B: How do estuaries impact nutrients entering a lake?

BACKGROUND

How do phosphorus and nitrogen get into the Great Lakes? One way is from water runoff. Rainwater falling on farm fields, parking lots, roads and backyards flows into creeks, streams and rivers. The rainwater carries soil, fertilizers and pollution that have washed from the land. You have probably seen how much more water creeks carry just after a storm and how muddy the water looks. Eventually, all this water runs into the lakes, bringing nutrients and other chemicals with it.

Objectives: Students analyze a map and data to learn how estuaries affect nutrient levels as water enters a lake. They make predictions about how the effects of climate change might affect an estuary's ability to improve water quality. After completing this investigation, students will be able to:

- List sources of nutrient inputs to Lake Erie.
- Explain how estuaries can improve water quality.
- Discuss how varying lake levels might affect an estuary's ability to function properly.

Materials:

Nitrate and phosphate data chart [included]	1 per student/group
Map of Old Woman Creek [included]	1 set per student/group
Graph paper [included]	1 set per student/group
Colored pencils (3 colors)	1 per student/group
2 glass jars, soil, water	1/class demonstration

Time required: 1-2 class periods

ALLIGNMENT

National Framework for K-12 Science Education:
SEP4: Analyzing and Interpreting data
CC3: Scale, proportion and quantity
CC5: Energy and matter: Flows, cycles and conservation
Core Idea LS2: Ecosystems: Interactions, Energy and Dynamics

Great Lakes Literacy Principles:
#1d: The Great Lakes, bodies of fresh water with many features, are connected to each other and to the world ocean.
#5f,h: The Great Lakes support a broad diversity of life and ecosystems.
#6d,e: The Great Lakes and humans in its watershed are inextricably interconnected.

Climate Literacy Principles:
#3c: Life on Earth depends on, is shaped by, and affects climate.
#7e: Climate change will have consequences for the Earth system and human lives.

ENGAGE

Students watch a demonstration to visualize how an estuary serves as a filter. Let students know that what they are seeing in the demonstration will help understand what is going on later in the activity. Teachers may want to refer back to the two jars as the lesson progresses.

1. Fill two jars half full of water. Put a handful of soil into each jar.
2. Allow Jar A to be still so the soil settles to the bottom of the jar.
3. Shake Jar B so the water and soil are moving quickly and get mixed together.
4. Pose these questions to students:
    a. Which jar represents water in a creek soon after a storm? [Jar B]
    b. Which jar represents water in a creek when there hasn't been a storm? [Jar A]
    c. Why does creek water look muddy or cloudy after a storm? What has happened? [Following a storm, creek water is muddy from carrying soil and nutrients, and it is moving very quickly.]
    d. How long might it take for creek water to return to a clearer state? [This will vary, but is heavily dependent on the frequency and size of storm events.]
    e. What kinds of things in an ecosystem influence how fast a creek returns to a clearer state? [These will vary, but will include the frequency and size of storm events, the amount of sediment and runoff from solid surfaces, and types and quantities of vegetation in and around a creek.]

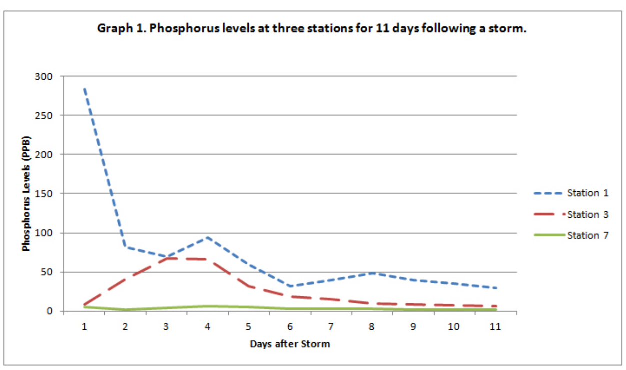
EXPLORE

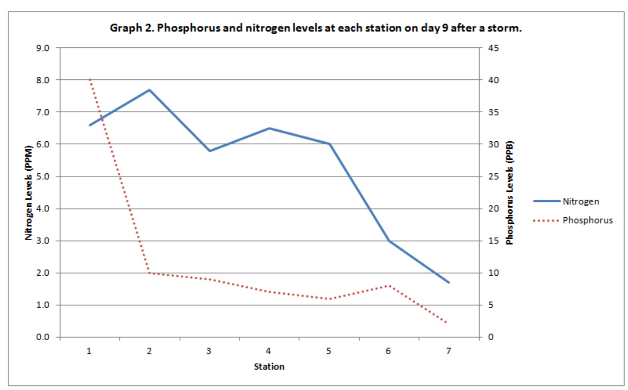
After analyzing a map and graphing data, students draw conclusions about nutrient levels at various points in an estuary.

Teacher's Notes:

- If modifying the activity for lower-level students, consider putting labels and scales on the graph axes before giving the activity to students.
- The best way to construct graph 2 is to label and make a scale for phosphorus on the left Y-axis, and then label and make a scale for nitrogen on the right Y-axis. List the station numbers along the X-axis.

Sample Graphs:





EXPLAIN

Students answer questions comparing and contrasting nitrogen and phosphorus levels at different points in an estuary and at different times. They also make predictions about the effects of severe weather events on nutrient levels and the functioning of an estuary.

Answers to Student Worksheet

Analyzing Maps

1. The creek flows north into Old Woman Creek Estuary and then empties into Lake Erie.
2. US Highway 6, Ohio routes 2 and 61, and other roads run through the watershed. There are also several farms. Runoff water from roads and farms will carry pollutants.
3. There are seven water test stations in or near the estuary. Station 1 is closest to where the creek enters the estuary. Station 7 is near the entrance of the creek into Lake Erie.

Analyzing Data

1. Phosphorus levels were highest one day after the storm and lowest 11 days after the storm's onset. At day 1, a lot of runoff water was entering the estuary. This water contained high concentrations of phosphorus. By day 11, there was much less runoff from the storm. Thus, fewer nutrients were being carried into the estuary.
2. Peak phosphorus concentrations occurred on day 3 at Station 3 and on day 4 at Station 6. Stations 3 and 6 are located further downstream in the creek. Water from the creek reaches Station 1 first, then Station 3, then Station 6. Nutrients such as phosphorus being carried by the water reach these stations in the same order.
3. Peak nitrogen concentrations occur at Station 1 on day 4, at Station 3 on day 6, and at Station 7 on day 8. Nitrogen concentrations are following the same general pattern as phosphorus concentrations. The peak concentration of nitrogen occurs at upstream stations before occurring downstream.
4. By day 9, the peaks in phosphorus and nitrogen concentrations have occurred at each of the stations.
5. Phosphorus concentrations on day 9 are highest at Station 1 and lowest at Station 7. This suggests that nutrients are removed as the water passes through the estuary before entering Lake Erie.
6. Nitrogen concentrations are the highest at Station 2 and the lowest at Station 7. Forms of nitrate and phosphate can be dissolved in the water, suspended as particles, or attached to sediments.
7. Following a storm, creek water is muddy from carrying soil and nutrients and it is moving very quickly. As water flows through the estuary, its movement is slowed. Much of the sediment, soil and nutrients in the water settle out as the water slows down. Thus, the water reaching downstream stations is clearer and has lower concentrations of nutrients than the water flowing through the upstream stations.
8. Plants in the estuary need phosphorus and nitrogen as nutrients to grow. Thus, plants in the estuary take up and use phosphorus and nitrogen from the creek water as it passes through the estuary. The plants filter out nutrients that they need from the creek water. This is another reason why fewer nutrients reach the downstream stations.
9. Because of the estuary's filtering action, water entering the lake will contain fewer nutrients than it otherwise would. Many of Lake Erie's water problems result from too many nutrients entering the lake. Estuaries may improve water quality in the lake by reducing the nutrients in it.

EXTEND

"Nutrients in an Estuary" is part of NOAA's *Estuaries 101* curriculum. In this activity, students build a model of an estuary, analyze nitrogen and dissolved oxygen data at various points in an estuary, and use Google Earth to analyze land use in a watershed to determine possible sources of pollutants and sediment entering an estuary. It can be accessed at ***http://estuaries.noaa.gov/Doc/PDF/LS2_NutrientsEstuary.pdf***.

EVALUATE

Sample evaluation questions

1. How do estuaries act as "sinks" and "sponges" to improve the quality of water going through them and reaching a lake? [Plants in the estuary take up and use the nutrients they need from the water passing through the estuary, thus acting as sponges. As water flows through the estuary, its movement is slowed. Much of the soil and nutrients in the water settle out as it slows down. Thus, the wetlands act as nutrient sinks. Estuaries may improve the water quality in the lake by reducing the amount of nutrients entering the lake.]
2. What happens when nutrients are readily available in, or are added to, a lake? [The nutrients act as a fertilizer, allowing plants to grow. Adding nutrients increases plant growth, especially the growth of algae. The algae may be green or blue-green depending on what nutrients are available.]
3. What are some of the human-produced sources of nutrients entering a lake? [Nutrients enter the lake from runoff from farms, parking lots, roads and yards. This runoff contains soil, fertilizers and pollution it has carried from the land.]
4. Think back to the demonstration with the two jars. Which jar could represent station 1? Which jar could represent station 7? How do the jars show how an estuary can act as a filter? [Station 1: Jar B; Station 7: Jar B; The jars represent water clarity and nutrient concentrations as water moves in an estuary. As the water flows through the estuary, its movement is slowed. Much of the sediment, soil and nutrients in the water settles out as the water slows down. Thus, the water reaching downstream stations (leaving the estuary) is clearer and has lower concentrations of nutrients than the water flowing through the upstream stations.]

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Name ____________________________ Period __________

Student Activity B: How do estuaries impact nutrients entering a lake?

BACKGROUND

How do phosphorus and nitrogen get into the Great Lakes? One way is from water runoff. Rainwater falling on farm fields, parking lots, roads and backyards flows into creeks, streams and rivers. The rainwater carries soil, fertilizers and pollution that have washed from the land. You have probably seen how much more water creeks carry just after a storm and how muddy the water looks. Eventually, all this water runs into the lakes, bringing nutrients and other chemicals with it. The water in Old Woman Creek runs through the estuary and into Lake Erie.

In this activity, you will analyze maps and data to learn how estuaries affect nutrient levels as water enters a lake. You will also make predictions about how the effects of climate change might affect an estuary's ability to improve water quality.

Use the maps and data table provided at the end of the activity.

Analyzing Maps

1. Use Google Maps to view Old Woman Creek. Look at the land surrounding the creek. All the land within the dotted line on Figure 1 is the watershed of Old Woman Creek. Water from this land runs off into Old Woman Creek, then through Old Woman Creek Estuary, before reaching Lake Erie. A watershed is all of the land drained by a creek, stream or river. From the satellite image, are there any roads or farms in the Old Woman Creek watershed? How might these affect the water entering the creek?

2. The numbers on the map shows places in the estuary where scientists have tested the creek's water to see how much phosphorus and nitrogen it contains. How many test stations are located in or near the estuary? Which station is nearest to the lake? Which is nearest where the creek enters the estuary?

Name ____________________________ Period __________

Analyzing Data

Construct two graphs.

First, graph the concentrations of phosphorus at Station 1, Station 3 and Station 7 in the estuary for each day after the storm from day 1 to day 11. Make a line graph and remember to add a key to identify your lines.

Second, graph the concentrations of phosphorus and nitrogen at each station in the estuary on day 9. Make a bar graph and remember to add a key to identify your lines. Note: nitrogen and phosphorus are not measured in the same units.

Graph 1. Phosphorus levels at three stations for 11 days following a storm.

Graph 2. Phosphorus and nitrogen levels at each station on day 9 after a storm.

Name ______________________________ Period __________

Questions

1. At Station 1, how many days after the storm were phosphorus levels the highest? When were phosphorus levels the lowest? How can you explain this?

2. What day did peak phosphorus concentrations (highest) occur at Station 1? Station 3? Station 7? What relationship do you see between station locations and the time when phosphorus concentrations peaked at those locations? Suggest an explanation for this trend.

3. On what day do the peak concentrations of nitrogen occur at each station? Does it seem that the peak nitrogen concentrations are following the same kind of pattern the peak phosphorus concentrations showed?

4. By day 9, have the peaks in phosphorus and nitrogen concentrations occurred at all seven stations?

5. For Day 8, at which station are phosphorus concentrations the highest? At which station are they the lowest? What might this suggest about the action of the estuary on water flowing through Old Woman Creek?

6. At which station are nitrogen concentrations the highest? At which are they the lowest?

7. Where do you think estuary water will be the muddiest? Where will it be the clearest? What is one reason why phosphorus and nitrogen levels are lower at Station 7 than at Station 1?

8. The estuary has many plants growing in it. How might the plants affect the nutrients reaching each station?

9. How might an estuary's action as a sink and sponge for nutrients affect the lake into which the creek empties?

Name ______________________________ Period __________

Figure 1. The Old Woman Creek Watershed with Water Test Stations

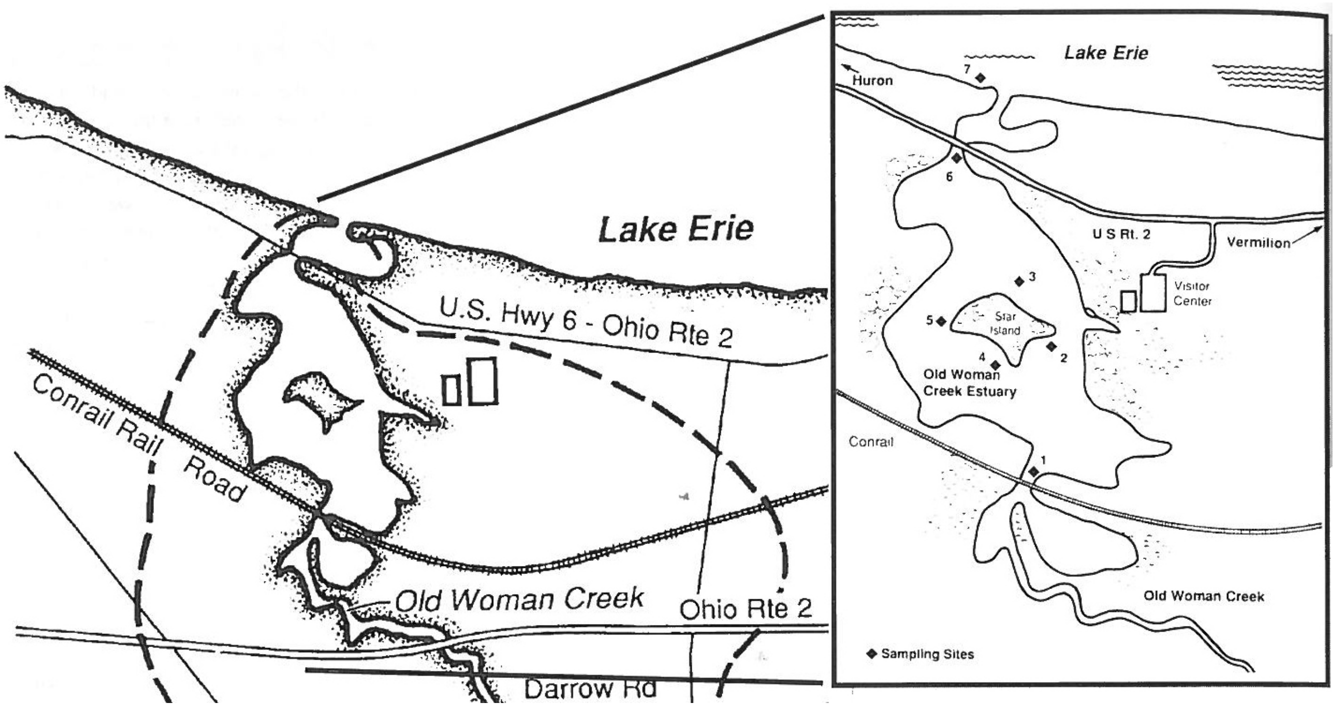

Figure 2. Changes in nitrate (nitrogen) and phosphate (phosphorus) concentration in water at sites along Old Woman Creek following a storm.

Station	**NITROGEN LEVELS (PPM) DAYS AFTER STORM**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	283	82	70	94	60	32	40	49	40	35	30
2	104	97	79	79	50	35	21	12	10	7	3
3	9	41	67	66	32	19	15	10	9	8	7
4	9	7	35	28	29	11	11	10	7	5	3
5	8	11	10	22	20	16	12	10	6	3	2
6	9	5	10	26	19	11	10	10	8	6	5
7	5	2	4	6	5	3	3	3	2	2	2

Station	**PHOSPHORUS LEVELS (PPB) DAYS AFTER STORM**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	6.5	6.9	9.7	12.4	10.5	9.5	7.8	6.5	6.6	6.5	6.6
2	1.5	3.3	6.1	8.7	9.0	10.1	9.0	8.0	7.7	6.5	5.9
3	0.4	1.9	2.8	7.6	5.4	9.9	8.0	6.8	5.8	4.1	2.3
4	0.2	0.3	2.4	3.3	5.1	8.8	8.7	8.4	6.5	4.8	2.2
5	0.2	0.8	0.6	2.6	4.9	9.7	7.8	6.9	6.0	4.1	2.3
6	0.5	0.5	2.0	3.4	3.4	3.4	3.3	3.3	3.0	2.7	1.7
7	0.9	1.0	1.1	1.4	1.6	1.7	2.0	2.1	1.7	1.5	1.2

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