TIEE
Teaching Issues and Experiments in Ecology - Volume 3, April 2005

ISSUES : DATA SET

Changes in Lake Ice: Ecosystem Response to Global Change

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THE ECOLOGICAL QUESTION:
Is there evidence for global warming in long term data on changes in dates of ice cover in three Wisconsin Lakes?

ECOLOGICAL CONTENT:
Effects of climate change on ecological systems.

WHAT STUDENTS DO:
Students plot more than 100 years of data on dates of "ice on" and "ice off" and duration of ice cover for three Wisconsin Lakes. They examine patterns of variation at different time scales to see the importance of long-term data.

SKILLS:
Interpreting data, making inferences from trends or patterns in data, making spatial and temporal comparisons of ecological systems.

ASSESSABLE OUTCOMES:
Interpretation of data, analyzing trends and patterns in spatial and temporal data, and constructing explanations about the links between abiotic and biotic factors on ecological systems from large-scale data.

SOURCE:
North Temperate Lakes LTER archive
(http://lterquery.limnology.wisc.edu/abstract_new.jsp?id=PHYS)

OVERVIEW

Note: the overview is written for faculty but can be used as the basis for an introduction to the data set for students.

Ice Ridge over Lake Mendota during the winter of 1987-1988

This activity uses ice cover records from three lakes in Madison, Wisconsin. Students work in groups to make predictions based on prior knowledge and assumptions, manipulate and summarize data, interpret the data by suggesting trends, and construct arguments from the data related to evidence of global change. In the main exercise, students work in small groups and attempt to see patterns in 20 years of data; all groups then combine data and only then can the long-term trend be seen.

History

Climatic observations have been made regularly around the world. Many of the records of these observations date back to several centuries. Recent publications have used data from lakes and rivers in the northern hemisphere dating back to the mid 1800's ("Shorter lake and river ice seasons confirm global warming." September 7, 2000. CNN.com http://www.cnn.com/2000/NATURE/09/07/global.warming/index.html). The data used in this exercise are the dates of fall "ice-on" (the initial formation of ice cover), spring "ice-off" (the break-up of winter ice cover), and duration of ice cover on Wisconsin's lakes Mendota, Monona, and Wingra, which are part of the North Temperate Lakes Long-Term Ecological Research site (Assel and Robertson 1995).

Magnuson et al. (2000) looked at river ice cover data from 39 locations in the northern hemisphere including sites in Russia, Finland, Japan, and the U.S. The authors conclude that over the 150-year period from 1846-1995, average rate of change in freeze dates was 5.8 days per 100 days later and that change in breakup averaged 6.5 days per 100 years earlier. These changes translate into increasing air temperature of about 1.2 degrees Celsius per 100 years.

The longest time series is from Lake Constance in central Europe, which has data from the 9th through the 20th centuries (Magnuson et al. 2000). "Total ice cover" is the date on which a Madonna statue could be carried between a church in Germany to another in Switzerland on opposite sides of the lake. These data indicate a warming trend which began during the early 19th century with an increase in rate of change after about 1850.

Long-Term Ecological Research

In the 1970's, ecologists realized that many ecological questions could not be answered by individual or small groups of scientists conducting short-term research. Therefore, in 1980 the National Science Foundation established the Long-Term Ecological Research (LTER) network to support research on long-term ecological phenomena in the U.S. As of 2004, the LTER Network includes 26 sites representing different biomes across the U.S. and Antarctica (http://www.lternet.edu/).

The vision of the North Temperate Lakes LTER is "...to gain a predictive understanding of the ecology of lakes at longer and broader scales than has been traditional in limnology. Thus, we analyze and interpret data we collect over long periods on suites of lakes" (http://lter.limnology.wisc.edu).

References

- Assel, R. A., and D. M. Robertson. 1995. Changes in winter air temperatures near Lake Michigan, 1851-1993, as determined from regional lake-ice records. *Limnology and Oceanography*. 40(1): 165-176.
- Magnuson, J. J., et al. 2000. Historical trends in lake and river ice cover in the northern hemisphere. *Science*. 289: 1743-1746.

For background on limnology and lake ecology see:

- Dodson, S. I. 2005. *Introduction to Limnology*. McGraw-Hill.
- Horne, A.J., and C.R. Goldman. 1994. *Limnology*. McGraw-Hill.
- Kalff, J. 2001. *Limnology*. Prentice-Hall.
- Water on the Web. Understanding: Lake Ecology Primer http://wow.nrri.umn.edu/wow/under/primer/index.html

Resources

- LTER homepage (http://www.lternet.edu)

Global Warming Science

- Ecological Society of America Global Climate Change – Summary includes concerns for effects on ecosystems http://www.esa.org/education/edupdfs/globalclimatechange.pdf
- US-EPA Global Warming Site (http://yosemite.epa.gov/oar/globalwarming.nsf/content/index.html)
- NOAA Global Warming - Frequently Asked Questions (http://lwf.ncdc.noaa.gov/oa/climate/globalwarming.html)
- Sierra Club's Global Warming and Energy (http://www.sierraclub.org/globalwarming)
- National Academy of Sciences - A Closer Look at Global Warming, includes sections on evidence and uncertainty (http://www4.nas.edu/onpi/webextra.nsf/web/climate?OpenDocument)

- Union of Concerned Scientists - Special features, the science, impacts, solutions (http://www.ucsusa.org/global_environment/global_warming/index.cfm)
- U.S. Global Change Research Information Office (http://www.gcrio.org/index.htm)
- Woods Hole Research Center - Warming of the Earth, includes "what skeptics don't tell you"? (http://whrc.org/resources/online_publications/warming_earth/index.htm)
- NOVA and Frontline - What's Up with the Weather? Examines the truth about global warming (http://www.pbs.org/wgbh/warming)
- National Consumer Coalition's Cooler Heads Coalition, a consumer activist group - Globalwarming.org (http://www.globalwarming.org/)
- Global Map - Early warning signs, shows clickable "fingerprints" and "harbingers." Designed by World Resources Institute and the Union of Concerned Scientists. (http://www.climatehotmap.org/)

Skeptics

- Skepticism.net - Essays from skeptics (http://www.skepticism.net/faq/environment/global_warming/)
- Competitive Enterprise Institute. Environment - global warming. (http://www.cei.org/sections/section17.cfm)
- George C. Marshall Institute - More from the other side (http://www.marshall.org/subcategory.php?id=9)
- Essays by MIT Professor Richard Lindzen on why GTC Models might be poor predictors of the effects of increased atmospheric "greenhouse gas" levels.
  - Lindzen, R.S. and K. Emanuel. 2002. The greenhouse effect. *In Encyclopedia of Global Change, Environmental Change and Human Society, Volume 1*, Andrew S. Goudie, editor in chief, pp 562-566, Oxford University Press, New York, 710 pp. (http://eaps.mit.edu/faculty/lindzen/198_greenhouse.pdf) (782 KB)
  - Linzden, R. S. 1997. Can increasing carbon dioxide cause climate change? *Proc. Natl. Acad. Sci.* 94: 8335–8342, Colloquium Paper (http://eaps.mit.edu/faculty/lindzen/181_PNAS97.pdf) (627 KB)

Global Warming: Physical Limnological Effects

- "Mixing dynamics in Crater Lake, Oregon"; nice introduction to this type of research, includes photographs (http://www.humboldt.edu/~gbc3/CL/#B)

- "Impact of climate on the physics, hydrology, and biogeochemistry of Crater Lake, Oregon; USGS site, good overview, includes photographs (http://www.nrel.colostate.edu/brd_global_change/proj_09_crater_lake.html)
- Great Lake daily water level plots; NOAA (http://www.glerl.noaa.gov/data/now/wlevels/)
- Explains response of large and small lakes in Canada to climate change; Environment Canada (http://www.nwri.ca/threats2full/ch12-2-e.html)
- Mortsch, L. and F. Quinn. 1996. Climate Change Scenarios for Great Lakes Basin Ecosystem Studies. *Limnology and Oceanography* 41: 903-911 (http://www.ucowr.siu.edu/updates/pdf/V112_A3.pdf)

Other Climate Change Data

- National Phenology Network - plant phenological data to support climate change research, includes lilac first leaf data: (http://www.uwm.edu/Dept/Geography/npn/index.html)
- Grape ripening as past climate indicator, grape harvest dates and temperature: (http://www.ncdc.noaa.gov/paleo/pubs/chuine2004/chuine2004.html)

Lake Mendota, Monona, and Wingra

- The ice records online; Wisconsin Lake Climatology Lab (http://www.uwex.edu/sco/icesum.html)
- Maps of the lakes (http://www.cows.org/about/maps/map-1-print.pdf)
- Landsat images of the 3 lakes (http://www.lakesat.org/galleryindex.php)
- Madison Area Lakes (http://lter.limnology.wisc.edu/lter_lake.html)
- Lake Monona characteristics, including hydrographic map and water column profiles (http://limnology.wisc.edu/lake_information/other_yahara_lakes/monona.html)
- Characteristics of Lake Mendota - volume, maximum depth, etc. (http://limnology.wisc.edu/lake_information/mendota/mendota.html)
- Webcam (http://www.soils.wisc.edu/asig/webcam.html)
- "For the record: Ice On and Ice Off"; very readable description of this research on Lake Mendota (http://www.uwsp.edu/cnr/uwexlakes/laketides/vol29-4/Text-only.htm#2)

Excel tutorials

- http://www.usd.edu/trio/tut/excel/index.html

- http://einstein.cs.uri.edu/tutorials/csc101/pc/excel97/excel.html
- http://www.fgcu.edu/support/office2000/excel/
- http://www.baycongroup.com/el0.htm

STUDENT INSTRUCTIONS

Lake Mendota photgraphed from University Bay
by Dale Robertson on December 12, 1985.

Introduction

It is clear that global warming is taking place. Global temperatures have increased by about 1 degree Fahrenheit during the last century, most likely the result of “greenhouse gases” such as carbon dioxide from burning of gasoline, oil, and coal. (How do these gases cause an increase in earth’s temperature?) One degree may not seem like a lot, but realize that this is an average change; in some places the increase is greater. For instance, in many locations in North America the hottest days on record happened in the late 1990s.

There are many environmental consequences of warmer temperatures, some unexpected. In Alaska, for instance, warmer weather allows the spruce bark beetle to complete its normally two-year life cycle in just one year; the result is millions of acres of spruce forest killed by the beetle. As another example, mosquitoes carrying diseases have spread to areas where they have never before been recorded.

One challenge to our understanding of environmental effects due to global warming is lack of data collected over long periods of time. The data from lakes in Wisconsin that you will work with is very unusual because it spans 150 years.

Plotting the lake ice records for Lake Mendota

The data you will work with are 1) the duration of ice cover, 2) dates of spring "ice-off" (the break-up of winter ice cover) and 3) dates of "ice-on" for Wisconsin's Lake Mendota, which is part of the North Temperate Lakes Long-Term Ecological Research site. Each of these measures may provide different types of evidence related to global change.

In groups of 3-5 students, discuss the three measures from the data sets and brainstorm what evidence each of these may provide related to global change. For example, ice-off data are especially useful for assessing long-term trends since they integrate air temperature over many days. Therefore this single data point actually expresses the cumulative effects of local weather conditions over the winter season.

1. Examine the spreadsheet given to you. This spreadsheet includes the original ice data collected at lakes Mendota over a 150-year period.

2. Look at the headings at the top of the columns to make sure you understand each one.

3. Take a look at the first row of data, for the winter of 1855-56. In this winter, the ice froze on December 18 and melted on April 14. So the "Ice Duration" was from Dec. 18 to April 14, a total of 118 days.

4. Notice that, in addition to being expressed as dates, "Ice On" and "Ice Off" are also expressed as numerals, the number of days since January 1. For example, look in the sixth column. The "Ice Off (Day of Year)" for 1855 is 105 (January 1, 1856 to April 14, 1856). Finally, notice that the "Ice On" date for some years (e.g., 1931) is greater than 365. That's because the ice on the lake did not form until after the end of the year (e.g., January 31).

5. Your teacher will either tell you, or you will decide as a class, which data you will graph (ice-on, ice-off, or ice duration). Which do you think will give you the most useful information or the clearest evidence of a trend? What is your hypothesis for this data set – what do you expect to find? Make a sketch of the pattern you predict to see.

6. For each graph you create, use the x-axis to indicate years.

7. Before making your graphs, the entire class needs to agree on a labeling system and scale for the graphs. At the end of this activity, you will be merging your graphs with other groups' graphs. It is essential that you label the values on the axes in exactly the same way and have the same scale on all the graphs.

8. What should be the lowest value on the y-axis? What should be the highest value? What are the units? You will need to make a scale that can incorporate the highest and lowest values for the entire 150-year data set.

9. Each group will work with 20 years of data; your teacher will tell you which 20 years your group will graph. Graph your 20 years of data. For each graph, answer the following questions:

    - Is there much variability from year to year, or only a little?
    - Do you see a trend? As time elapses, does the value tend to increase, decrease, fluctuate, or stay the same?

10. Pair up with one other group and compare your results. Did you reach the same or different conclusions based on your data set?

11. Now, combine the graphs from the entire class. Tape them together so they form a continuous graph. Answer the following question as well as questions you come up with on your own. Do you see a trend with the longer-term data set?

12. If you graphed ice duration, answer the following questions. (You may want to adapt these questions for ice formation and ice-off data, using the numeric value for date.)

    - What is the average ice duration in your 20-year data set?
    - How does this compare to the average ice duration over 150 years?
    - What is the longest period of ice duration in your 20-year data set?

- What is the shortest period of ice duration in your 20-year data set?
- What are the longest and shortest periods of ice duration in the entire data set?
- In what years do they occur?

13. On your graph, draw a line to indicate average ice duration. Within your short-term data set, how many years have longer-than-average ice duration? How many years have shorter-than-average ice duration? Compare these values among all of the groups. Do you see a trend in years with longer or shorter than average ice duration over time?

14. To conclude the activity, think about the implications of your data analysis. You should answer the following questions as well as any questions the class generates.

Questions for Discussion of Implications

- To what extent do data on ice cover provide evidence for global change?
- To what extent do data on ice cover not provide evidence for global change?
- In regard to these two questions, which evidence for global change or lack of evidence for global change is stronger? Why?
- What other kinds of data do you feel you need to make your arguments stronger? Provide specific examples.
- How might the observed trends in ice cover influence the ecology of lakes? What changes might you predict in biological diversity, productivity, water quality, etc? Why?

NOTES TO FACULTY

Proposed Main Activity: Lake Mendota (see Faculty & Student Excel file)

In the suggested group investigation (see "Student Instructions"), students work in teams to plot data over 20-year intervals. Decide how groups will be assigned their data sets. Each group first looks at their own time frame to decide on possible patterns and hypotheses to explain the data. In the final step, groups line up all their figures to see long-term trends. Hopefully students will also gain an appreciation for the value of long-term data sets.

There are several additional steps in these instructions that you can include or not, depending on time. Before working with the data, students are asked to discuss the usefulness of ice-off, ice-on, and duration data in studies of global change. Also, after working with their data, students are asked to pair with another group to compare findings before looking at the whole data set.

On the Excel file for faculty, the ice duration data are plotted for 20-year intervals so that you can easily see the type of figures students will make. In addition, there are separate figures for the full 150-year period for ice duration, ice-off date, and ice-on date. Students can work with any of these three measurements or several of them, depending on how much time you want to devote to this.

Students can work with the “ice-off,” “ice-on,” or “ice duration” data. If you have time, the class could decide as a whole which type of data to examine. A note about the duration calculations: in a few isolated cases the total number of days of ice cover is not simply a subtraction of the ice on day from the ice off date. Rather, the number of days of ice cover is the total number of continuous days of ice cover. For example in 2001, even though the lake first froze on 1/2/02 (day 2) and last thawed on 3/15/02 (day 74), it was only continuously covered with ice for 21 days that season. In that particular year, it thawed after the initial freeze and then refroze a few weeks later.

If your students have minimal experience with data sets like this, it would be a good idea for them to first plot the data by hand. There are several advantages in doing so. First, you don't need computers and students don't need to know how to use Excel. Second, for a simple data set like this (20 years) students will pay more attention to the pattern because they are actually drawing the trend by hand and take more time making the figure. If you decide to go directly to use of Excel, be sure that they look carefully at the year-to-year variation.

If your students are not familiar with Excel, you can also use this exercise to teach them how to use this spreadsheet. There are several good Excel tutorials on line for your students (see the Resources section in the Overview). This would have to be done in an additional session before the lake data exercise.

Additional Activity:

Making Predictions Through Comparison of Three Lakes (see Extra Data Set Excel file)

The excel file “Extra Data Set” contains data for three lakes in Madison: Mendota (labeled ME), Monona (MO), and Wingra (WI). The Lake Mendota and Lake Monona data are from 1853-2002 and the Lake Wingra data from 1877-2002. Note: the Lake Wingra data set is incomplete with several years of missing data. This data set provides opportunities for students to try to make sense of incomplete data. You may modify the activity by focusing on temporal changes alone for one or more of the lakes.

In groups of 3-5 students, students should make predictions of ice cover for these three different LTER study lakes in Madison, Wisconsin. Students should discuss and identify how differences in the physical characteristics of the three lakes might result in differences in trends of changes in ice cover. Groups should use the following lake information in their discussions.

Table 1. Physical Characteristics of Madison-area study lakes.

Lake	Surface Area (ha)	Mean Depth (m)	Max Depth (m)
Mendota	3937.7	12.8	25.3
Monona	1324.0	8.2	22.5
Wingra	139.6	2.7	6.7

Predicting Beyond 2001

The lake ice data excel spreadsheets include data through the winter of 2001. Faculty should note that these spreadsheets were developed from a data catalog that adds new data each year. These may be found at http://lterquery.limnology.wisc.edu/abstract_new.jsp?id=PHYS which holds the data catalog for physical limnology of North Temperate Lakes Primary Study Lakes. The physical limnology data catalog includes the dataset North Temperate Lakes LTER: Ice Duration Madison Area Lakes. To access this dataset you will need to set up a username and password before querying the dataset and identify how you plan to use the data (e.g., education materials). Identify the fields that you wish to retrieve, lake id or name of the lake, the winter season, ice duration, ice on, or ice off and specify the output (Excel spreadsheet, screen, or comma-delimited file).

Because these datasets include new data each year, faculty may wish to consider an extension of the main activity, and may choose to ask students to predict ice cover (e.g., duration of ice cover and / or date of freezing and thawing) from 2001 to the current year. Students should explain why they made their particular prediction and identify factors they considered when making their prediction. They can then compare their prediction with actual observations. This extension of the main activity is an effective way for students to develop and evaluate a simple predictive model from their analyses and interpretation of the pattern that emerges from the long-term dataset. This could be used as an interesting assessment that can help determine if and how students apply their analyses and interpretation.

Questions for Discussion

1. What are the key differences in the physical characteristics of the three lakes?
2. How do you think each of these might influence ice cover? Why?
3. Which of the three physical characteristics do you think would likely have the most impact on ice cover? Why?
4. What other physical attributes of lakes might impact ice cover?

Teaching Evaluation

Assessment

1. Ask students to do a minute paper (a short one-two paragraph explanation or interpretation) on the trend or patterns that they see in the 20-year data range that they have plotted.
2. Ask students to do a minute paper on the limitations of interpreting short-term versus longer-term trends in data.
3. Ask the students to design an experiment to test a hypothesis that emerged from their analysis of the ice data.
4. Ask students to predict the trend in ice cover for a very different lake (describe the physical characteristics) and to discuss the reasoning for their predictions.

Additional Assessment Notes:

Margaret Waterman and Ethel Stanley (http://serc.carleton.edu/introgeo/icbl/assess.html) suggest that the following be considered when assessing students engaged in problem-based learning activities such as this one:

- Extent of participation and contribution to work in groups
- Development of new questions that emerge from analyses of the data
- Organization or reorganization of the data for analysis
- Development of multiple strategies for analysis and interpretation
- Connections to other relevant work
- Application to a second scenario involving analysis and interpretation of large-scale data
- Construction of additional investigations to test predictions or assumptions
- Location of additional relevant resources
- Quality of graphs, tables, posters, or reports (written or oral)
- Extent to which the students' interpretation use relevant data to make conclusions
- Apply problem-solving to a real-world and complex problem
- Evaluate the robustness of data and evidence

Cathryn Manduca and David Mogk (Carleton College), Using Data in Undergraduate Science Classrooms, (http://serc.carleton.edu/research_education/usingdata/report.html) provides an excellent background on using data and assessment ideas. See also http://serc.carleton.edu/research_education/usingdata/ for additional information and resources.