TIEE

ISSUES : DATA SET

Long-term Response of an Arctic River Community to Phosphorus Fertilization

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THE ECOLOGICAL QUESTION:
How does phosphorus fertilization affect long-term community structure in an arctic stream?

ECOLOGICAL CONTENT:
nutrient enrichment, limiting factor, bottom-up effects, cascade effects, herbivory, food webs, community structure, river community structure

WHAT STUDENTS DO:
Students make Microsoft Excel bar graphs to assess effects of phosphorus addition on epilithic algae, epibenthic moss, mayflies, and arctic grayling fish in the Kuparuk River, in the foothills of the North Slope of Alaska. Data were taken over 15 years at the ARC LTER site at the Toolik field station. With these data, students: 1) hypothesize the influence of nutrient limitation in the community, 2) predict community response to nutrient fertilization, 3) test predictions by analyzing the long term data set, and 4) assess validity of hypotheses. In the process students appreciate the value of long-term ecological data sets.

SKILLS:
Using a computer spreadsheet to make simple graphs, working in groups, oral presentation of analysis, writing a research paper, hypothesizing, analyzing, interpreting, and drawing conclusions.

ASSESSABLE OUTCOMES:
Graphs from spreadsheet data, written or oral analyses, interpretations, conclusions, and hypotheses.

SOURCE:
Slavik, K., Peterson, B. J., Deegan, L. A., Bowden, W. B., Hershey, A. E., Hobbie, J. E. 2004. Long-term responses of the Kuparuk River ecosystem to phosphorus fertilization. *Ecology*: Vol. 85, No. 4, pp. 939–954.

OVERVIEW

This section is written for faculty who can modify the Overview as appropriate for their students. "Student Instructions" also include introductory material.

The research

This Data Set is from the University of Alaska's Toolik Field Station, the location of the Arctic Long-Term Ecological Research site (ARC LTER; http://ecosystems.mbl.edu/arc/) in the foothills of the North Slope of Alaska (north of the Arctic Circle, latitude about 68°N). This area has continuous permafrost, and snow covers the ground for 7-9 months. There are 24 hours of sunlight during short cool summers and periods of complete darkness during long cold winters. There are no trees and many pristine lakes and streams. Vegetation is tundra with tussock tundra in the lower, wetter places (mainly grasses and sedges plus some dwarf birch and willows) and heath tundra on the drier ridge tops.

The focus of the research is the Kuparuk River, a fairly small (about 20 meters across in the study area), clear, and meandering river that is easily accessible by the only highway in the region. Many scientists who work at the Toolik Field Station are ecosystems ecologists from The Ecosystems Center at the Marine Biological Laboratory, Woods Hole, MA. One of these researchers, Bruce Peterson, found that the Kuparuk River was strongly nutrient-limited (Peterson et al. 1985) which lead to the long-term stream fertilization work presented here. This research entailed dripping phosphorus (P) as phosphoric acid into the river during June, July, and August starting in 1992 to increase P concentrations by approximately 0.3 micro-mole per liter. The effects of the P addition were then traced up the stream food web. As is evident in this Data Set, the effect is profound; it is especially interesting that few of these changes could have been predicted ahead of time.

In regard to the study of ecology, the context for this work is the "top-down" versus "bottom-up" debates of the 1980's and 1990's. In typical "bottom-up" aquatic ecosystems studies, scientists added a limiting nutrient (usually N or P) to habitats such as whole lakes (Schindler 1977) and measured cascading effects on the whole system. In contrast, "top-down" ecologists emphasized notable effects when top carnivores, dominant herbivores, and other animals were removed or added to ecosystems (Brooks and Dodson 1965; Paine 1966).

According to their website, a critical focus of the ARC LTER "...is on the interactions between terrestrial and aquatic ecosystems driven by the need to understand these interactions in order to explain variability among individual lakes and streams of the North Slope, and by the need to "scale up" our knowledge to whole landscapes and watersheds. In addition to being strongly nutrient-limited and dependent on nutrient inputs from land to water, the lakes and streams studied thus far are generally heterotrophic, i.e., they are also more dependent on carbon (C) inputs from land than on photosynthetic C fixation *in situ* (Peterson et al. 1985)."

The nutrient addition research at Toolik is applicable to many aquatic ecosystems worldwide. As a result of extensive anthropogenic changes in watersheds, nutrients from agriculture, sewage, and other source nutrients are being loaded into rivers, wetlands, and estuaries at alarming rates with great effects (see Ecological Society of America's *Issues in Ecology* Nos. 1,3, and 7; http://www.esa.org/science/Issues/).

The ARC LTER

The information below is quoted directly from http://ecosystems.mbl.edu/arc/arc_gen.html.

The goal of the Arctic LTER project is to predict the future ecological characteristics of the site based upon our knowledge of the controls of ecosystem structure and function as exerted by physical and geologic factors, climatic factors, biotic factors, and the changes in fluxes of water and materials from land to water.

To achieve this goal the Arctic LTER uses several approaches:

- Long-term monitoring and surveys of natural variation of ecosystem characteristics in space and time. Includes: climate, plant communities and productivity, thaw depth, stream flow, chemistry of streams and lakes, temperatures of streams and lakes, lake chlorophyll, lake productivity, zooplankton abundance.

- Experimental manipulation of ecosystems for years and decades. Includes: tundra warming, shading, and fertilizing, grazer exclusions, fertilization of lakes and streams, addition and subtraction of predators.

- Synthesis of results and predictive modeling at ecosystem and watershed scales. Includes: stream N cycling, lake physics, bioenergetics of fish populations, water movement and transfer of DOC and nutrients from land to water, soil respiration, cycling and storage of C in tundra under different scenarios of future climates.

References

- Brooks, J.L. and S.I. Dodson. 1965. Predation, body size and composition of plankton. *Science* 150: 28-35.

- Paine, R.T. 1966. Food web complexity and species diversity. *The American Naturalist* 100: 65-75.

- Peterson, B.J et al. 1985. Transformation of a tundra river from heterotrophy to autotrophy by addition of phosphorus. *Science* 229: 1383-1386.

- Schindler, D.W. 1977. Evolution of phosphorous limitation in lakes. *Science* 195: 260-267.

Resources

Arctic Grayling

- http://www.adfg.state.ak.us/pubs/notebook/fish/grayling.php
  Alaska Department of Fish and Game - Arctic Grayling information

Baetis

- http://lakes.chebucto.org/ZOOBENTH/BENTHOS/iii.html#life
  Information about life history, distribution and habitat, feeding and tolerances.

- http://www.flyfishusa.com/flies/baetis.htm
  A commercial fly-fishing site with mayfly information; students might be interested to see commercial importance of mayflies.

ARC LTER

- Main ARC LTER website:
  http://ecosystems.mbl.edu/arc/

- http://ecosystems.mbl.edu/arc/data_doc/streams/protocol2.html#Bryophytes Kuparuk River protocols (flow, nutrients, algae, mosses, etc)

- http://lternet.edu/vignettes/arc.html Brief article on LTER site: "20-year long Nitrogen Addition Experiment Causes Functional Changes to Arctic Ecosystems"

General

- http://lakes.chebucto.org/glossary.html
  Limnological terms, definition, acronyms, and concepts. Soil and Water Conservation Society of Metro Halifax, Nova Scotia, Canada

Excel Tutorials

- http://www.usd.edu/trio/tut/excel/
  Basic information: how to use functions, filling down, formatting, inserting, graphs and graphing. University of South Dakota, TRIO.

- http://www.fgcu.edu/support/office2000/excel/
  Florida Gulf Coast University - Excel 2000 basic tutorial, includes visuals

- http://www.baycongroup.com/el0.htm
  Introductory information; BayCon Group - a commercial site

STUDENT INSTRUCTIONS

The Kuparuk River Experiment

The Data Set you will be working with is from a 15-year study (1983-1998) in a small arctic river. The site is the Arctic Long-Term Ecological Research (ARC LTER) site (http://ecosystems.mbl.edu/arc/overview.html) in the beautiful foothills of the North Slope of Alaska (north of the Arctic Circle, latitude about 68°N). This area has continuous permafrost, and snow covers the ground for 7-9 months. There is 24 hours of sunlight during short cool summers and periods of complete darkness during long cold winters. There are no trees and many pristine lakes and streams. Vegetation is tundra with tussock tundra in the lower, wetter places (mainly grasses and sedges plus some dwarf birch and willows) and heath tundra on the drier ridge tops.

The focus of the research is the Kuparuk River, a fairly small (about 20 meters across in the study area), clear, and meandering river easily accessible by the only highway in the region. Many scientists who work at the ARC LTER are interested in questions related to nutrient limitation. Ecologists study "limiting nutrients" such as nitrogen (N) or phosphorus (P) by adding these nutrients to a system and watching what happens. When people grow vegetables, they add these same limiting nutrients when they use fertilizers.

Ecologists are interested in nutrient effects on ecosystems because human activity (agriculture, sewage, car emissions) is resulting in massive additions of nutrients to aquatic and terrestrial ecosystems worldwide. The scientists working on the Kuparuk River look at these effects in a pristine location in northern Alaska to assess human influences in a place with little obvious contamination so far.

This research entailed dripping P into the river during summer months in order to increase P concentrations to a set concentration above the very low background levels. The effects of the P addition were then traced up the stream food web. As is evident in this Data Set, the effect is profound; it is especially interesting that these changes could not have been predicted ahead of time.

The vegetation in this river includes algae and moss growing on rocks on the river bottom. To assess algal abundance, the scientists measured the amount of the green pigment chlorophyll on randomly collected rocks. These algae are called "epilithic" because they grow on top of rocks (*epi*="on", *lithic*="rocks"). Moss abundance was estimated as percent cover in randomly selected 0.25 square meter areas. One hundred percent cover means the square area is completely covered with moss, 50% means half covered, and so on.

Most animals living on the river bottom in the Kuparuk are insect larvae (the aquatic stages of flying insects such as mosquitoes and black flies which are abundant in Alaska). The ecologists focused on *Baetis* species (mayflies) because they are the main grazing animals that eat the epilithic algae.

Higher up the food web in this river are Arctic grayling, the only fish in the specific study site. These are beautiful fish that look something like trout. On average they are about 30-40 cm long (6" = about 15 cm) and dark with iridescent spots on the sail-like dorsal fin. They eat drifting aquatic insects such as mayflies and caddis flies. Their maximum age is 11-12 years. Arctic grayling are caught by Inuit, Native Americans, and many sports fishermen.

Arctic Grayling
Copyright: Jonathan Benstead, The Ecosystems Center at MBL

The Data Set

You will be working with data in the Excel file provided to you. These are the actual data collected by the ARC LTER scientists. First look at all the headings at the tops of the columns to make sure you understand the data overall.

Epilithic Chlorophyll A: To make a graph of the chlorophyll concentrations (a measure of algal biomass) from 1983-1998, first select the Graph Wizard Icon on your toolbar. This will open a new window for creating your graph. To make a simple bar graph of chlorophyll over time choose the "Column" chart type and then "Clustered Column" from among the chart sub-types; then click the "Next" button. Excel will ask you for the Data Range. Highlight only the numbers in the column labeled "Reference chl a." These are the chlorophyll values in the non-fertilized part of the river just upstream of the drip location. Next click on the tab titled "Series" at the top of the new window. Excel will now ask you for the values for the x-axis. Click on the box next to "Category (x) axis labels" and then highlight the numbers 83-98 in the column titled "Year." In the box next to "Name" in this same window, type "Reference." Then click "Next."

You can now see the graph you just made of chlorophyll concentration over time in the reference location. Fill in the boxes titled "chart title" and so on. Keep these labels very simple,.e.g., "Chlorophyll *a*", "Year," etc.

Now add the Standard Error bars to the data on your graph. These are a statistical measure of the variation between samples. On your graph, simply right-click on one of the bars. On the menu that appears you will see a range of options. Select "Format Data Series." Then select "Y Error Bars" from the tabs at the top of the new window. The Display choices at the top of the window indicate whether you want both plus and minus error bars, plus only, etc. For now, select "both" — you can change it later if you wish. Since each standard error (S.E.) is different for each chlorophyll value, select "Custom." First click the "+" box and then highlight the column labeled "S.E." next to the chlorophyll *a* reference values. Click on the "-" box and then highlight the same column. Select "OK" and the standard error numbers will be added to the graph.

The next step is to add the chlorophyll values for the fertilized section of the river. To do this, first left-click anywhere in the chart area. This will make the "Chart" option appear on the Excel toolbar. Click "Chart" on the toolbar, and from the drop-down menu select "Add Data…" Excel will ask for the range of the data you want to add; highlight the numbers in the "Fertilized Chl a" column. Now you can compare the pigment concentrations in the fertilized and non-fertilized parts of the river. Add the S.E. values for the Fertilized numbers as described above. To add a name to this data series, first right-click on any one of the bars. Select "Source Data" from the menu that appears. In the box titled "Series," select "Series 2." Then type "Fertilized" in the box next to "Name." You should now have a legend which indicates which bars correspond with each group of data.

Your teacher will help you with the finer details of making clear and simple graphs, but here is a suggestion about the look of the bars (i.e., colored, patterned, etc.). You will probably want to use colors; that is OK but scientists publishing their data in a research paper do not usually do that since they have to use black and white. To make a visually clear graph, right-click on one of "Fertilized" bars, select the "Format Data Series" option, and then select "Patterns" from the tabs at the top of the new window. Instead of a color, select the little black square; now the fertilized values will be black. Do the same thing for the reference numbers but select white instead of black. You now have an easy to read, straightforward graph.

***Baetis* and Arctic grayling**: Follow the same steps as described above to make graphs of the *Baetis* (mayflies) densities and Arctic grayling weight.

River Temperature and Flow Rate: Again, use the same procedure to make these graphs.

Interpretation and Discussion: After you make your graphs, your teacher will explain the next steps.

NOTES TO FACULTY

Advanced vs. Beginning Students

The Student Instructions are written for students in introductory ecology courses with little spreadsheet experience. More advanced students can likely work with the student Excel file alone after a discussion about questions that can be addressed with the data. The Overview is also appropriate for these students; there is some additional information in the Student Instructions that might be useful as well. The 2004 *Ecology* paper described below would be a good paper for advanced student to read; a PDF of this paper is also included.

Logistics

Background Information:

The time required for this Data Set depends on your students' expertise with Excel, including making bar graphs on Excel and their experience with data presentation and interpretation. The Student Instructions begin with a fair amount of background text before the detailed description of how to make the figures. To save time, ask students to read this background description ahead of time for homework.

The Overview provides good background for students, but the section of the Student Instructions titled *The Kuparuk River Experiment* will probably be enough of an overview with some added introduction by you. For the group work described below, you will need a computer for each three to four students (make sure the students rotate so that one student is not doing all of the work on the Excel file).

Working with the Excel File:

The Student Instructions include step-by-step procedures for making bar graphs with standard error bars. If your students are Excel novices, give them an Excel tutorial ahead of time (e.g., in a prior lab). The Resource section includes online tutorials. Many questions will arise about making graphs; since you cannot be everywhere at once, an older student can be an enormous help in this situation. The Instructions include suggestions for making simple and clear black-and-white figures; it is a good idea for you to explain this briefly.

What To Do

The Student Instructions take the students through creation of five bar graphs: Epilithic Chlorophyll, Moss, Mayflies, Fish, Temperature, and Flow. Below are some specific ideas for follow-up and different approaches:

- Divide students into groups of three or four. Instruct each group to make five same-sized figures and stack them vertically, either on the Excel file or as printed out graphs. If they work efficiently and are familiar with Excel and figure making, they should be able to do this in a 3 hour lab. Ask groups to briefly write their data interpretation, analysis, and conclusions (200-300 words) plus major questions they have. Groups can do this as homework which they will hand in. In the next session, groups can report their findings, interpretations, and questions.

- Have students work in groups as above but ask each student to write their own data description, interpretation, and questions for homework. Have groups report out as above.

- Make the first figure yourself so students can see what you are looking for; then follow either set of ideas above.

- Use the questions below as the basis for a discussion or for a homework question or two.

The flow and temperature data do not necessarily explain the biological data, but are of course potentially useful information. You will probably need to make this point.

Misconceptions

The table below summarizes likely conclusions students will make about this Data Set and associated ecological concepts. The "misconception" column identifies common incorrect ideas your students might have related to each conclusion. It is important to be aware of students' misconceptions because these naïve ideas can interfere with students' learning new concepts (TIEE Glossary: Misconceptions). You can expose student misconceptions in a variety of ways — through essay or short answer written questions, class discussion, or direct questions.

Conclusion	Concept	Possible Misconception
P stimulates algal growth; P limits algal growth at first.	limiting factor, bottom-up effect, nutrient enrichment	Primary producers won't respond to nutrients because it is too cold.
Cascade effect of nutrient addition on mayflies and grayling.	cascade effect, community structure	This reinforces the misconception of the simple linear "food chain."
Nutrient addition results in appearance of new moss.	community structure	The simple addition of P can't change community structure this much.
Moss shades algae.	competition	Shading only occurs in forests with trees.
After initial increase, algal production decreases due to grazing by mayflies.	community structure	Primary production is limited by nutrients or grazers but not by an interaction of the two.
Large interannual variation in all parameters.	temporal variation	Such variation indicates something "wrong" with the system.

Data Interpretation and useful information

A 2004 paper by Slavik et al. published in *Ecology* titled "Long-term responses of the Kuparuk River ecosystem to phosphorus fertilization" (Vol. 85, No. 4, pp. 939–954) includes some of these data plus much more. Several points in this paper provide helpful additional information:

- In addition to nutrient addition from precipitation and local anthropogenic activity, global warming may result in permafrost thaw and increased on organic matter turnover and nutrient availability in the tundra. This is a nice example of unexpected effects of global warming.

- Epilithic algae were scrubbed off of randomly selected rocks with a steel brush. Insects were also removed from rocks and counted. Fish growth was measured on individually tagged fish.

- Statistical tests were paired t-tests and linear regressions.

- River temperature and flow varied with radiation input and precipitation and inter-annual differences in weather.

- The bryophyte *Hygrohypnum* spp., the primary moss species, was not seen the river before 1990. In later years it formed a continuous carpet of filamentous moss on parts of the river bottom in the fertilized reach. This is clearly had a large impact. *Hygrohypnum* replaced epilithic algae as the dominant primary producer; about 80% of NPP was driven by moss and 20% by algae (which can grow on the moss). Production of epiphytic algae growing on the moss was high. The animal benthic community composition was also altered; Chironomids (midges) changed most — from low numbers to about 40,000/m^2 in '95-'98.

- The obvious decrease in epilithic algae in the fertilized reach after 1989 is due to shading and abrasian by the moss and increased grazing pressure.

- Although the increase in moss cover impacted insects and microalgae, there is no measurable effect of moss cover increase on young or adult fish. Although *Baetis* abundance varied, *Brachycentrus* densities remained high in the fertilized reach and the large mayfly *Ephemerella* steadily increased in the fertilized reach (both were about 10% of *Baetis* biomass however). Fish may be impacted in the future as further moss growth inhibits insect drift.

- Like other stream fertilization studies, epilithic algae production in the Kuparuk River appears to have been first limited by nutrients and later by invertebrate grazing. In contrast to other studies, this changed after 8-10 years when mosses became the dominant cover in fertilized riffles.

- Slavik et al. conclude by saying "In the Kuparuk River, the impact of fertilization was more complex than a positive increase in production from one trophic level to the next. We showed how the ecosystem structure changed over time in response to nutrient enrichment. This observation emphasizes the need for long-term, whole-stream studies if we expect to predict stream response to chronic perturbation."

* REFERENCE AVAILABLE AS PDF (407 KB)
     Slavik, K., Peterson, B. J., Deegan, L. A., Bowden, W. B., Hershey, A. E., Hobbie, J. E. 2004. Long-term responses of the Kuparuk River ecosystem to phosphorus fertilization. *Ecology*: Vol. 85, No. 4, pp. 939–954.

Questions for Discussion

1. Explain the concept of "limiting nutrients." Why are ecologists interested in this concept?

2. Why are N and P the major limiting nutrients in a wide range of habitats (not just rivers)?

3. How is this research relevant to less pristine places? What are major sources of nutrient contamination elsewhere in the US?

4. The chlorophyll *a* concentrations decrease noticeably from 1992 on and the *Baetis* densities are lower starting in 1989. What is the most likely explanation for these changes? Why do you think that the scientists started measuring moss cover starting in 1992 and not before that?

5. Based on these data, describe what the bottom of the river in the fertilized section would look like before 1989 and after 1992? In other words, if you were snorkeling down the river what would you see on the bottom before 1989 and after 1992?

6. Even though grayling eat mayflies (*Baetis*), years with low mayfly density don't consistently match years with low fish biomass. What are several reasons why this might be so?

7. There is considerable year-to-year variation in the fish biomass. Does this indicate an environmental problem of some sort? Why might this be so? What information would help you understand this variation better? Why does this degree of variation between years make ecological research often so difficult?

8. What is the value of a long-term data set like this one? What conclusions would have been different with only a few years of data?