TIPS, TRICKS & TECHNIQUES

# Using Authentic Environmental Data to Enhance Biology Understanding

WILLIAM KROEN


## Abstract

*Scientists often integrate measurements and data from various sources to ask questions and perform investigations. The exercises described here allow students to think critically and understand concepts that affect biological organisms as they make hypotheses about a selected stream or river, then graph, analyze, and interpret physical and chemical water-quality data (and possibly weather data) from local sources. Details on how to access, download, and manage data sets are provided.*


**Key Words:** *Data management; environment; graphing; hypothesis testing; limnology; weather.*

Benefits of including quantitative analysis in biology courses have been previously stated in this journal (Goldstein & Flynn, 2011). Students can increase their quantitative skills through activities such as building a local database of births and deaths (Gerber & Reineke, 2005), adding data to a long-term collection on salamanders (Grumbine, 2010), studying plant phenology and bud break (Bombaugh et al., 2003), or accessing bird migration data (Sturner & Lucci, 2015). Here, I describe exercises that use data on local waterways to engage upper-level students in the scientific process through data manipulation and interpretation, graph construction, and scientific writing. Assignments are tailored to begin with a question, form a scientific hypothesis, obtain data to test this hypothesis, then complete the scientific process by interpreting and writing about those data. Shorter assignments are given in first-year courses to reinforce specific ideas as students graph and describe smaller data sets.

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## ○ Primary Data Sets

I use data from the National Estuarine Research Reserve System (NERRS) because the St. Jones River, one portion of the Delaware NERR, is located several blocks from our campus. Three monitoring stations that span a range of salinity and tidal conditions along the river are maintained by local scientists. Instruments automatically record selected physical and chemical measurements at each site every 15 minutes during the year, while samples for nutrients and chlorophyll are taken by hand approximately monthly. Data are available from the NERRS Central Data Management Office (http://cdmo.baruch.sc.edu/get/export.cfm). Many NERRS locations have data from multiple years and multiple sampling sites; several St. Jones River sites have data from 1995.

I find it easiest to request the data myself to prevent problems. The process is relatively simple:

(1) Choose the reserve of interest from the map (in our case, Delaware).

(2) Choose the monitoring site of interest (for example, Division Street) from the table, being careful to select the correct data (water quality or nutrients), then click “Proceed with this station.”

(3) Choose the desired date range; I usually request an entire calendar year for ease of file management. After submitting your request, the data center will e-mail you (usually within minutes) a link to access the requested data in a zipped Excel.csv file. Metadata and other documents are also included.

(4) Download and save each original file! They are quite large – an entire year of water-quality data is 35,100 lines long and

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26 columns wide. I review and then delete columns containing quality-control notations before saving "cleaned-up" versions of the data sets.

## ○ Supplemental Data Sets

Weather data are often useful in answering questions about specific events that affect local waters and organisms. Meteorological data are available for some NERRS locations (obtainable as described above) that can be useful in explaining storm-related events. The Delaware Environmental Observing System (http://www.deos.udel.edu/) makes available daily summaries and hourly observations from automated weather stations throughout the state. A weather observation service probably exists in your state, so check with your state climatologist; excellent examples include Pennsylvania (http://climate.psu.edu/data/) and North Carolina (http://www.nc-climate.ncsu.edu/cronos/index.php). Both the Weather Channel (http://www.weather.com) and the GLOBE Program (http://www.globe.gov) can provide historical and comparative data across the country. With luck, the data are displayed in an Excel spreadsheet that you can simply save and clarify. Alternatively, you might get tabular data (as is the case with DEOS) that must be copied and pasted into a blank spreadsheet before use.

## ○ Student Projects

Students in my upper-level limnology course develop and ask the questions that they then answer using these historical data. I spend about an hour of class time introducing the semester-long assignment and available data sets by showing students the NERRS website, then have the class brainstorm a list of potential questions. All subsequent work is conducted by students outside of class. Each student has a week or two to develop a one-page proposal containing the topic and hypothesis (or set of hypotheses) of interest, as well as to select the data needed to examine it (Table 1). I discuss the proposal with each student, often helping them narrow down a vague question into an explanatory hypothesis that can be tested. I never provide a hypothesis, but only ask questions to guide students to refine their own ideas. No two projects in any semester can be the same. I occasionally must suggest a topic for a student, who then develops a question and hypothesis with my help.

Within a few days of approving a proposal, I provide students with the "clean" NERRS data files they request. Most students are able to obtain needed weather data after an initial tutorial. Since students do not need water data from every 15 minutes of the year, they must extract values for specific days and times from the larger files. I typically hold several 1-hour sessions in the computer lab over the next several weeks to teach data sorting in Excel as a way to retain needed data and delete extraneous lines. Each student must work independently, since each requires a different set of values. Some students struggle with these sorting steps, so I carefully check each student's progress and may need to have them make multiple attempts. One student required a complete redo with a "new" file containing the original data.

Students are given several weeks to graph their variables. Upper-level students are generally well versed in graphing using Excel, but one typical stumbling block is setting the range for the time/date

**Table 1. Selected student hypotheses in an upper-level college limnology course and the data sets required to address each.**

| Hypothesis | Required Data Sets |
|---|---|
| Runoff from snowmelt (or rain events) will increase turbidity, salinity, and pH as particles and ions are carried into the water. | One site, (portion of) 1 year water quality |
| Monthly chlorophyll-*a* measures will correlate with nutrients, since nutrients fuel growth of phytoplankton. | One (or all three) sites, 1 (to several) year nutrients |
| Water depth and dissolved oxygen (DO) will decrease before Hurricane Sandy due to outflow of river water, but depth, DO, salinity, and turbidity will all increase afterward as ocean water floods back in. | One site, (portion of) year 2012 water quality; NERRS and DEOS meteorology October 2012 |
| Turbidity changes will be higher in tidal than in nontidal parts of the river due to mixing and intrusion of "dirty" Delaware Bay waters. | All three sites, 1 (or more) year water quality |
| Diel changes in DO concentration will occur due to photosynthesis by aquatic plants, and these changes will be the same magnitude in all months of the year. | One site, 1 year water quality |
| Turbidity and nutrients will increase sequentially after each successive coastal storm in fall 2011, whereas temperature will decrease with each storm; both outcomes are due to more and more runoff entering the river. | One site, (portion of) year 2011 water quality and nutrients; DEOS meteorology September–November 2011 |
| Nutrient concentrations will be higher in 2002–2006 than after 2006, when new regulations reducing runoff were implemented in the county. | One site, 2002–2013 nutrients |

format on the x-axis (since date values are numerical in Excel); I often must help students with this one task. Good line graphs provide a visual format that allows comprehension of quantitative information, including positive and negative trends (Shah & Hoeffner, 2002; Taylor, 2010). Most students can successfully describe patterns in their data and note absolute or temporal differences that occur between samples from different times or locations (e.g., hypothesis 3 or 4 in Table 1). Some hypotheses (e.g., the first and last in Table 1) require calculation of mean values for multiple samples, but few other statistical analyses are possible, because each datum is a single point at a single location. The exceptions are when advanced students with a background in statistics examine relationships between variables by linear regression (e.g., hypothesis 2) and report correlation coefficients.

Each student must then interpret their results, forming a coherent explanation that links evidence to known concepts in aquatic science. I often discuss their interpretations with students, affirming plausible ideas and sometimes pointing them toward new areas of understanding (e.g., noting that this tidal river does not function like a stratified lake). Some projects, particularly storm events, require some tutoring as students gain an understanding of how weather events move water masses and thus affect basic water chemistry and biology.

Some hypotheses are supported (runoff does sometimes increase turbidity through sediment influx, though it can be quite transient) while others are not (chlorophyll concentration does not correlate with nutrient concentration throughout the year, since available nutrients are rapidly recycled into cells). I am less concerned that a hypothesis is supported than that the student understands the ecological concepts involved. However, students are often quite concerned that their hypothesis was not "proven." Negative data are useful in that they often require students to rethink their hypothetical reasoning and correct initial misunderstandings. Also, do not worry about students being perplexed when you can't tell them the "right" answer – even I don't know the outcome of some hypothesis tests until the data are analyzed. This project allows everyone to learn how dynamic natural waters are, even under normal conditions. Students who explore storm events are particularly impressed by how fast changes occur.

Students report their findings and interpretations in a journal-format paper and orally to the class in a 10-minute PowerPoint presentation. Papers are expected to have sufficient background that sets up the hypothesis, a Methods section detailing data sources and manipulations, a Results section with clean graphs and a description of the pattern in each, and a Discussion with plausible explanations for the evidence presented. Guidelines and grading rubrics for the paper and oral presentation are posted on the course website and reviewed in class prior to the assignment due dates. Breaking up the project into sections that incorporate peer review (Kroen, 2004) is very valuable to students and usually results in better projects and increased understanding. Each section (Methods, Results, and Discussion) is due at about 3-week intervals. Since students might procrastinate and might not turn in sections, I assign specific due dates and give grades for their reviews.

## ○ Additional or Alternative Projects

I provide students in entry-level courses for nonmajors with specific sets of data to drive home specific concepts. For example, I task students in a Local Environment course to graph the pattern of water depth at one tidal river site, to determine the time period between high peaks, and to suggest a reason for the observed pattern. Many students need help creating the graphs (mainly the time/date format on the x-axis), but those who successfully complete this assignment easily recognize the semidiurnal pattern of tidal flow common in the mid-Atlantic region. They can then investigate whether tidal status affects biological indicators such as dissolved oxygen concentration or temperature. Other students must initially learn about variables and constructing graphs before they are able to understand the influence of tides.

A nice additional class activity for us involves an afternoon trip to visit the three St. Jones River sites. Students make real-time measurements of physical characteristics (using a YSI-85 probe) and nutrients (using Hach test kits), gaining experience in field sampling and the importance of keeping proper notes. Students are then asked to compare their values with historical ones to determine whether the current data fit the historical pattern.

These listed sources and exercises are a starting point that can easily be adapted for your class – once you can access data, how much you want to explore and learn is up to the creativity of the teacher and class.

## ○ Additional Data Sets

If NERRS data do not work for you, it is likely that state-level water-quality monitoring programs in your area can provide useful data sets for classroom use. The U.S. Environmental Protection Agency has extensive data on waterways across the country, available through STORET (http://www.epa.gov/storet/), though this site requires multiple steps to designate locations and download data. The GLOBE Program (http://www.globe.gov) has water-quality and select biological data from participating schools that might be in your area. Alternatively, abundant data are available for the nation's best-studied estuary, Chesapeake Bay (http://mddnr.chesapeakebay.net/eyesonthebay/index.cfm). Graphs and tables of real-time data are easily created for multiple sites (up and down the estuary or its tributaries) that allow students to make comparisons across environmental gradients and across tidal cycles. Unfortunately, downloads of historical data are not always successful.

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WILLIAM KROEN is a Professor of Biology in the Department of Biology, Chemistry, Physics and the Environment, Wesley College, Dover, DE 19901; e-mail: william.kroen@wesley.edu.