Human impacts on stream ecology: locally and nationally

Module information

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# Overview

In this module, we’ll explore how land cover change impacts streams from around the nation and locally. This module is adapted from a TIEE module published in 2012 by Amelia Nuding1 and Stephanie Hampton1,2 that can be found [here](https://tiee.esa.org/vol/v8/issues/data_sets/nuding/abstract.html). I have subsequently modified it to fit within a Landscape Ecology curriculum and made some modifications to be more inclusive. This module was tested using an online synchronous class setup, so modifications included making the module accessible for online learning and group work.

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## Connection to other modules

This module can be enhanced by combining it with two other modules available online:

* [The NEON Data module (my version)](https://qubeshub.org/qubesresources/publications/1858/1) - modified to introduce metadata, GIS, and R so that R is familiar to students. The students are also introduced to the National Land Cover Database (NLCD) in the NEON module, which is then revisited in this module. Alternatively, any quick introduction to R will work for this module, since the R markdown script for this module is relatively self-contained and ready for students to run even if they only have a surficial understanding of R.
* [The NELF Explorer: Drivers of Landscape Change module](https://qubeshub.org/qubesresources/publications/1867/1) - a module that introduces land use and land cover change as well as how modeling future land use decisions can be useful. We use the scenarios presented in the New England Landscape Futures (NELF) project in this module to hypothesize what might happen to stream ecology as a result of future land use change in New England. The NELF module introduces the future scenarios of land use and what the results of the modeling of future land use look like in terms of land cover change. Alternatively, the information contained within the NELF module could be provided to the students without them needing to complete the activity if you would like to use the scenarios in this module without having the students complete the full NELF module prior to this one.

# Learning objectives

By the end of the module, students should be able to:

* understand some of the relationships between water quality and land use/land cover
* relate water quality with stream ecology and nutrient pollution and bioindicators
* use R to create simple plots and identify differences in nutrient loading in different EPA regions
* interpret land cover maps and land cover change

## Inclusivity for an online teaching platform

This module was created and tested using an online learning platform (using Zoom for synchronous meetings) and created with a few new inclusive pedagogical practices. This module naturally lends itself to setting the stage for having more difficult conversations about how human needs (like food) impact stream ecology, so introducing inclusive practices with this module is very helpful. Earlier in the semester I talked about the value of multiple perspectives when studying landscape change, and I reminded students of the power of multiple perspectives in future planning of land use change for this module. I then assigned students to groups of ~3 to work through the module using the “breakout room” feature on Zoom (though this could be done in in-person classes as well). Creating smaller groups gave the students a hopefully safer and more comfortable environment to begin to talk about the impacts of land use. I popped into each breakout room a couple of times as they worked to check in on the group work and tried to assess if all group members' opinions and perspectives are being valued and respected in the discussion, but without judging their current discussion for accuracy. Then as a full class at the end of the module, we discussed how certain land uses, like industrial farming, have value to humans as food sources, while also causing a decline in stream health - and how that is spatially distributed across the conterminous US. I ended class by telling them we would revisit this concept in the following class period and talk about how to balance land uses: how can we provide food equitably while also trying to improve stream health. It was helpful that we ended the class focusing on the region where we live (we are in Massachusetts), so if you are outside of New England, it may be helpful to add a step talking about your specific [EPA region](https://www.epa.gov/aboutepa). This can give students a more accessible entry into land use change, since many of them will have observed the mapped land covers in their specific region.

# Data and code

* wade-able streams data from the conterminous United States (WSA\_data\_for\_students.csv)
* New England Landscape Futures scenarios - <https://newenglandlandscapes.org/>
* National Land Cover Database - <https://www.mrlc.gov/viewer/>
* Code: LU-streams.Rmd

# Assessment strategies

I have the students preparing a few slides describing their findings from the exploration of the wade-able stream data, as well as what they thought might happen in each of the NELF scenarios. Since I completed the activity in a single 1.25 hr class period, I did not assign a grade to those presentations and used it as a practice for the students in creating and then talking about their findings and emphasizing the discussion aspect of the presentation, rather than whether or not they were right. This seemed to work well for an upper-level undergraduate/graduate level class.

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Student directions

For this module, I will split us into random breakout rooms on Zoom and you will work through it together. **At the end of the class period, I will ask you to share with the class 2-3 slides that answer the questions below.**

# Ecological background

Small streams are vital to the United States' major rivers because they deliver water and provide pathways for the movement of fish and other aquatic organisms. Humans rely on both large and small waterways for drinking, irrigation, industrial uses and transportation. Thus, if the water quality of any particular stream is impacted, it affects not only local fish, aquatic organisms and plants, but also non-local organisms, in other parts of the state or country, and ultimately the livelihood of humans. While the term “environmental health” is a scientifically controversial term (Simberloff 1998), we may find it useful to think about stream “health” as describing the conditions that humans find desirable such as water with low levels of pollutants and pathogens, high levels of oxygen, and providing otherwise good habitat for fish and wildlife (Meyer 1997; Gordon et al. 2004). A variety of factors affect which aquatic organisms are present, such as the stream's size and morphology, geographic location, stream flow (volume and speed of water), available light, temperature, and water quality (Vannote et al. 1980; Poff 1997).

In this exercise we will examine two water quality parameters of great importance in streams: levels of nitrogen and phosphorus. These two nutrients are among the most common pollutants in streams, lakes and coastal waters and high levels of these nutrients result in degraded water quality (EPA 2007). Nitrogen and phosphorus generally come from fertilizer applied to farm lands (and from lawns, to a lesser extent), as well as sewage, and they are carried by groundwater, rain water, or irrigation water from the land into streams (Vitousek et al. 1997; Smith 2003; Dodds 2006; EPA 2007). In addition, these nutrients may be deposited on land or water through the air after the combustion of fossil fuels or other industrial operations (Driscoll et al. 2006; Pepper et al. 2006). Specifically, in this activity you will be looking at values of “total nitrogen” and “total phosphorus”, two very commonly measured water quality parameters. Total nitrogen includes all organic and inorganic nitrogen-containing compounds in the water. Total phosphorus, similarly, includes all phosphorus-containing compounds in the water.

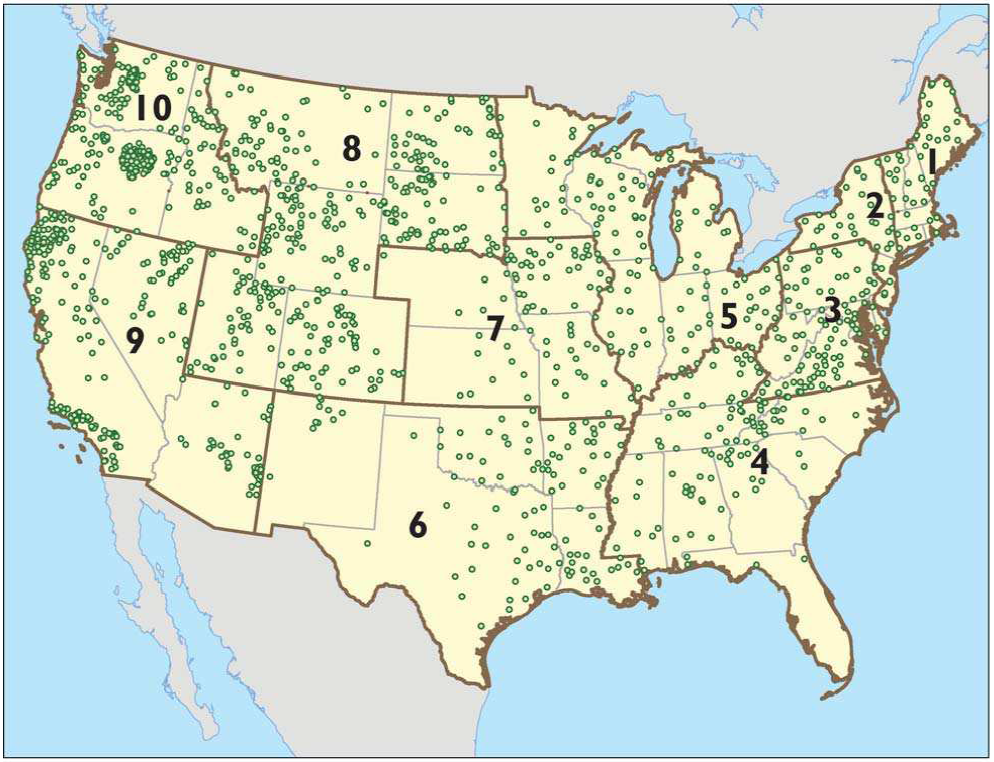
When nitrogen and phosphorus become very high, algae (photosynthetic organisms) can grow extremely quickly and the waters can become cloudy, reducing the light availability in the stream. Importantly, when these algal blooms die, this large amount of dead algae fuels bacterial growth in the water. The bacteria decompose the algae and in doing so they consume much of the oxygen available in the water, called **eutrophication** (Mallin et al. 2006). In many cases the waters become uninhabitable by aquatic organisms because of the lack of dissolved oxygen in the water. An extreme example of this is the “dead zone” in the Gulf of Mexico, which is an area of the ocean about as large as Connecticut, in which few aquatic organisms can survive, primarily due to the input of nutrients from the Mississippi River (USGS 2010).

**Aquatic benthic macroinvertebrates** are insects and other small invertebrates (like crustaceans, mollusks and aquatic worms) that live in streams and other aquatic habitats. **Benthic** refers to the lowest level of a water body, which in this case is the stream bed, and this is where these animals reside. **Macro** means that these animals are large enough to be seen with the naked eye, and **invertebrates** means that they have no spine. Many common flying insects have larval stages in streams and lakes, such as mayflies, stoneflies and dragonflies. These stream macroinvertebrates play very important roles in the stream ecosystem. For example, by shredding leaves and other detritus that falls into streams, they convert terrestrial carbon and other nutrients into forms available to other stream organisms (Vannote et al. 1980; Wallace and Webster 1996). Some macroinvertebrates eat algae, and others are predators on small invertebrates. Most macroinvertebrates eventually become an important food resource to fish and birds (Vannote et al. 1980; Wallace and Webster 1996).

Because benthic macroinvertebrates are such important members of the food web and they respond relatively quickly to ecological changes, they can be very useful to humans as indicators of the health of a stream. Accordingly, they are called **bioindicators**. Some macroinvertebrates require high levels of oxygen and low pollutant levels, and so they are useful as indicators of good water quality, while other groups of macroinvertebrates can tolerate low oxygen and high pollutant levels, thereby indicating lower water quality (EPA 2007). They are not highly mobile (especially compared with fish) and so they are susceptible to the water quality conditions around them and whatever pollutants may have accumulated in the sediment of the stream bed.

# Data sets

## Wade-able streams



**Figure 1**. Wade-able streams that were sampled within each of the ten designated EPA regions.

In 2002, the US Environmental Protection Agency (EPA) set out to characterize the health of all the waterways throughout the continental US. The EPA is required by law as set forth in the Clean Water Act to report to Congress on the health of the nation’s waters. This survey of “wade-able” streams – streams shallow enough to sample without a boat – is the EPA’s largest effort to make a scientifically and statistically defensible claim about how healthy, or unhealthy, the nation’s waters are (EPA 2007). Wade-able streams provide a strong link between land use and water quality, and they contribute to larger river systems, so they are a good indicator of the health of waters throughout the entire US (EPA 2007). Even though wade-able streams are relatively small and shallow, they comprise about 90% of the length of all perennial waterways.

A total of 1,392 sites were sampled in the 48 states and grouped into 10 regions (Figure 1). The sampling was designed to ensure that the site selection was representative and random. More information about the sampling design can be found in Chapter 1in the section of the WSA Report entitled “How Were Sampling Sites Chosen?” (pgs. 15 – 17, <http://www.epa.gov/owow/streamsurvey/pdf/WSA_Assessment_May2007.pdf>). In this module, we will be looking at concentrations of total nitrogen (µg/L), total phosphorus (µg/L), and macroinvertebrates; where higher levels of total nitrogen and phosphorus indicate an unhealthy stream; but macroinvertebrates are a bit different.

Macroinvertebrates can be sampled by shuffling a net along the bottom of the stream bed and counting the number and types of insects brought up in the net. Ecologists have developed sophisticated methods of characterizing these benthic macroinvertebrate communities – rather than just counting the number of insects, we consider things like the diversity of the species present, and how many of those species are known to be pollution intolerant.

The EPA developed a method of characterization that worked best for the Wade-able Stream Assessment and called it “MMI” for “Multi Metric Index” (EPA 2007). It includes measures of macroinvertebrate taxonomic richness, composition, and diversity, as well as feeding groups, habits, and pollution tolerance and assigns a MMI score to each stream. More information about these groups and measures can be found in the WSA report (Ch 2, pgs. 27 – 29). In all cases, a higher value indicates a greater diversity of organisms and is considered to be indicative of a healthier stream. A high MMI score (max = 100) tends to indicate a healthy stream, and low score (min = 0) tends to indicate an impaired stream.

## Land cover



**Figure 2.** 2016 National Land Cover Database for the lower 48 states.

The National Land Cover Database is a 30 m resolution land cover map of the United States (here of the lower 48, Figure 2). Each land cover type contributes more or less toward nutrient runoff into streams. You can view the NLCD in more detail online [here](https://www.mrlc.gov/viewer/).

# In groups: How do the different regions compare?

**First together:** check out the land cover map from the lower 48 and hypothesize which EPA region will have the worst water quality. What about the best? Let’s test these hypotheses!

Fortunately, the EPA has already aggregated much of the data for us for this analysis, so we have nutrient loads in each of the regions. We will use an R markdown script I have already prepared to try to find out more about these regions and their nutrients. Please switch over to the .Rmd now, and once you have completed the script, come back here for more directions!

…

Great! Looks like you finished the script.

**Second:** using [the NLCD map](https://www.mrlc.gov/viewer/), the results from the streams analysis by region (the script), and [the NELF explorer](https://newenglandlandscapes.org/?map=1&lat=44.0000&lon=-70.0000&zoom=7&leftScenario=rt&rightScenario=cc&leftYear=2010&rightYear=2060) – talk with your group to answer the question:

**What do you hypothesize might happen to water quality in EPA Region 1 (New England) in each of the New England Landscape Futures (NELF) scenarios? Why?**

**Finally:** Create 2-3 slides that help you explain to the class (and decide who will share the slides and who will talk for each slide):

* your original hypotheses about the wade-able streams and the results from the R exploration of the data; and
* your hypotheses (and why) about what will happen to water quality in EPA Region 1 in each of the NELF explorer scenarios. (Note, this is a chance to get groups used to sharing a slide as well as a nice way to share your thoughts)

# Other helpful material

## Boxplot refresher

A common first step in analyzing the distribution of data points is through the use of box plots. Box plots show you where the median of your data is – the point at which half (50%) of the data points are below that value, and half of them are above. The median is shown as the thick black line in the “middle” of the box (it doesn’t have to be centered though!). The lower quartile, Q1, is the point below which 25% of the data is contained. The second quartile (Q2) is the same as your median. The upper quartile, Q3, is the point below which 75% of the data is contained. The upper “extreme” is the largest value that is less than Q3+ 1.5\*(Q3-Q1), where Q3-Q1 is called the “inter-quartile range”. The lower “extreme” is the smallest value that is greater than Q1- 1.5\*(Q3-Q1). Potential “outliers” are points far outside the range of the majority of the data - specifically, if their value is larger than the upper extreme, Q3+ 1.5\*(Q3-Q1), or less than the lower extreme, Q1- 1.5\*(Q3-Q1).



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