**A Tough Choice in Watershed Management**

Adapted from Nuding and Hampton (2012)

**Learning Objectives: 7 pts total**

1. Be able to analyze large data sets, interpret the data and make comparisons among watersheds.

2. Understand the connections between land use and water quality, the effects of nutrient pollution, how bioindicators are useful to ecologists.

**Evidence of achieving these objectives**:

1. Be able to produce box plots and data table that summarize watershed data from two regions
2. Provide a plausible explanation for each of the four choices and explain your Team’s specific choice

**Overview:**

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).

Two nutrients, nitrogen (N) and phosphorus (P), are among the most common pollutants in streams, lakes and coastal waters, resulting in degraded water quality (EPA 2007). N and P generally come from fertilizer applied to farm lands, from lawns, as well as sewage, and they are carried by ground water, rain water, or irrigation water from land into streams (Vitousek et al. 1997; Smith 2003; Dodds 2006; EPA 2007). These nutrients may also 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).

**Here’s the setting**: As a recent ISU grad, you are now working on a Team within the US Government. This agency is aware that pollution will have long-lasting and far-reaching effects on local streams and their tributaries. They have tasked your Team with solving the following issue.

**Significant Problem:**

Natural resource managers plan to invest in promoting nutrient reduction (NR) strategies, particularly in two different regions of the US, EPA Region 7 and 10 (please see Supplements 1, 2, & 3). However, there is funding available to invest in only **one** of the two regions. Your agency has asked your Team to determine in which of the two regions to invest and to provide the analysis and rationale for your decision. Please provide an explanation as to why each choice below might be a good one, or why not. All Teams will report out their top choice simultaneously. Be prepared to explain why your Team made that particular choice.

**Specific Choices**: Invest in nutrient reduction (NR) strategies in:

1. Region 7 because it has the highest nutrients and thus the higher need for NR
2. Region 10 because it has the higher index of sensitive benthic macroinvertebrates and thus a greater need to protect sensitive organisms
3. Region 7 because Region 10 has too many remote areas, so NR would be difficult to implement there
4. Region 10 because NR strategies are not compatible in an agricultural area such as Region 7.

**Background**

 As we learned in Module 1, a variety of factors can 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 activity we will focus on “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. Inorganic forms are nitrate (NO3-), nitrite (NO2-), ammonia (NH3), and ammonium (NH4+). Organic forms include proteins, peptides, nucleic acids, urea and synthetic organic materials (Pepper et al. 2006). Total phosphorus, similarly, includes all phosphorus-containing compounds in the water, which includes orthophosphate (PO4) and organically bound phosphate.

 When these nutrients become very high, *algae* (photosynthetic organisms) can grow extremely quickly and the waters can become cloudy, reducing the light availability in the stream. 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 (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 (e.g., 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 Set Description**

 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 “wadeable” 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).

 A statistically sound sampling design was necessary for the EPA to be able to detect major trends in stream quality across the nation. Ideally the EPA would take samples from every waterway in the US, but that is totally infeasible; it would be a huge, expensive, and very time-consuming endeavor. Therefore, the EPA devised a sampling regime of wadeable streams. Wadeable streams provide a strong link between land use and water quality, and they contribute to larger rivers systems, so they are a good indicator of the health of waters throughout the entire US (EPA 2007). Even though wadeable 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. The type of sampling design selected for any ecological study or experiment is key to making more general assertions about the status of waterways throughout the nation. 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 1 in 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>).

 **Exploring Data Sets**

**Part 1: Land Cover**

Many agencies and other organizations that have a lot of ecological data, like the U.S. Geological Survey, provide those data online with some tools to explore the data. Look at the map of NLCD land cover ([Supplement 1](http://tiee.esa.org/vol/v8/issues/data_sets/nuding/resources/supplement1.pdf)) to answer the following questions. You may find it helpful to print out a color copy of [Supplement 1](http://tiee.esa.org/vol/v8/issues/data_sets/nuding/resources/supplement1.pdf), or view it on your screen at a larger size (e.g., 200%) to see more detail.

Questions:

1. What are the dominant types of land cover Regions 7 and 10? Based on your knowledge of sources of nutrients, which EPA Region(s) do you predict will have the highest and lowest nutrient values?

**Region 7: Row crops, pasture hay, grasslands/herbaceous – We predict that it will have the highest stream nutrients.**

**Region 10: Evergreen Forest, Shrub cover – We predict that it will have the lowest stream nutrients.**

 **0.5 pt**

1. Now look at the table of mean (average) values of total nitrogen (NTL) and total phosphorus (PTL) in each EPA region, located in [Supplement 3](http://tiee.esa.org/vol/v8/issues/data_sets/nuding/resources/supplement3.pdf). Which region has the lowest and highest mean nutrients, and how does this compare with your prediction? Are the mean values useful for characterizing streams in a region? Why or why not? Offer some suggestions about what additional information would be useful to more fully characterize nutrient levels within an EPA region.

**Region 7: NTL: 6143 ug/L PTL: 183 ug/L**

**Region 10: NTL: 178 ug/L PTL: 21 ug/L**

* 1. **pt**

**Part 2: Nutrients**

 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 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. To find Q1, you take the median of the data points that lie between your lowest value and Q2. To find Q3, you take the median of the data points that lie between your highest value and Q2. The upper extreme is the largest value that is less than Q3+ 1.5\*(Q3-Q1). The lower extreme is the smallest value that is greater than Q1- 1.5\*(Q3-Q1). “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).

 Open the WSA data table ‘WSA\_data\_for\_students.txt’ on Canvas. Find the median, quartile, extreme and outlier values of total nitrogen for Regions 7 and 10 separately, and fill in the results in Table 1. The median and quartiles can be found using the following Excel functions, or your instructor may suggest using alternative methods.

 The parentheses should contain the column or row of data you wish to analyze. Here we use cells E1:E70, just as an example.

 To calculate the median, type (without the quotation marks) “=MEDIAN(E1:E70)”

 To calculate the Q1, type “=QUARTILE(E1:E70,1)”

 To calculate Q3, type “=QUARTILE(E1:E70,3)”

The remainder of the boxplot data points can be obtained from the equations provided, and from inspection of the data.



Figure 1. An example of a box plot table for total nitrogen (NTL).

 Using these data, sketch box plots for each region on the same chart, in the **Excel spreadsheet**. What percent of the dataset lies within the box? Describe the distribution of the data outside the box, e.g. are the points relatively close or spread widely, where are outliers, etc. Given what you have learned so far, would you expect an “outlier below Q1” to have more or less algae than other streams?

**Table 1. Levels of total nitrogen (NTL) for EPA Regions 7 and 10**

 **(Values from Faculty spreadsheet ) 2 pts**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | Median (µg/L) | Q1 (µg/L) | Q3 (µg/L) | Upper Extreme(µg/L) | Lower Extreme(µg/L) | # outliers above Q3 (upper extreme)  | # outliers below Q1 (lower extreme) |
| EPA Region 7 | 3450 | 759 | 9225 | 21538 | 154 | 2 | 0 |
| EPA Region 10 | 99 | 55 | 177.5 | 354 | 11 | 17 | 0 |

In a separate nutrient study by the EPA (EPA 2001), the lower quartile (Q1) value from water samples was recommended as the level below which nutrients in streams should be maintained in each *ecoregion* - note this is not the same as an *EPA Region*, as you can see in the map provided in [Supplement 4](http://tiee.esa.org/vol/v8/issues/data_sets/nuding/resources/supplement4.pdf). Below are the **recommended total nitrogen values** for the ecoregions within EPA Regions 7 and 10. The full data set and a map of the ecoregions are available in [Supplement 4](http://tiee.esa.org/vol/v8/issues/data_sets/nuding/resources/supplement4.pdf).

EPA REGION 7:

Ecoregion IV (Great Plains Grass and Shrublands) – 560 ug/L

Ecoregion V (South Central Cultivated Great Plains) – 880 ug/L

Ecoregion VI (Corn Belt and Northern Great Plains) – 2180 ug/L

EPA REGION 10:

Ecoregion II (Western Forested Mountain) – 120 ug/L

Ecoregion III (Xeric West) – 380 ug/L

Compare the information you generated in Table 1 with the EPA recommended nutrient criteria.

**Questions:**

1. How do the values you calculated for Region 7 and Region 10 compare to EPA’s recommendations for various ecosystem types, or ecoregions, within these two regions?

**Region 7: The calculated median NTL of 3450 is far above the recommended TN values of 560-2180 ug/L. The upper extreme value is nearly 10 times the recommended TN value.**

**Region 10: The calculated median NTL of 99 is well below the recommended TN values of 120-380 ug/L and even the extreme value of 354 is below the recommended TN value.**

 **0.5 pt**

1. Based on the data and maps provided, can you assert whether the waters in EPA Regions 7 and 10 are “clean” or “polluted”? Explain your answer using data from parts I and II. If you feel more information is needed to make an assertion, state what information you would need to have. Note: there is not one “right” answer here, so what is important is how well you explain your answer.

**Based on NTL data, the waters in Region 7 are highly polluted, and the waters in Region 10 are ‘clean.’**

 **0.5 pt**

**Part 3: Macroinvertebrates**

 Streams often contain a large number and a wide variety of benthic macroinvertebrates. These are the bottom-dwelling small aquatic invertebrates and aquatic larval stages of insects that you can see with the naked eye. Stream ecologists often look for the pollution-sensitive insects, because they serve as bioindicators of stream health. The following taxonomic orders of pollutant-intolerant insects are collectively referred to as “EPT” because they are such a useful grouping of insects that react strongly to pollution: Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies). These insects begin their lives in the water, and later emerge as adults to live on the land.

 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 (e.g., EPT).

 The EPA developed a method of characterization that worked best for the Wadeable Stream Assessment and called it “MMI” for “Multi Metric Index” (EPA 2007). It includes the following six categories:

1. Taxonomic richness – the number of distinct taxa (e.g., species)
2. Taxonomic composition – a measure of the abundance of the ecologically important taxa in the sample
3. Taxonomic diversity – the distribution of the numbers of organisms in different taxa
4. Feeding groups – the distribution of macroinvertebrates that have different feeding habits (e.g. leaf shredders vs. algal feeders)
5. Habits –the distribution of macroinvertebrates that burrow, cling, crawl and/or swim
6. Pollution tolerance – a measure of how many taxa present are pollution tolerant and intolerant

More information about these groups 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.

Using the WSA data, create a scatter plot of MMI vs. NTL in Excel, one plot of MMI vs. Log NTL for Region 7 and one for Region 10. Note that because the nitrogen data have such a wide range of values (over three orders of magnitude) and many data points are clustered at one end, we will use the logarithm (log) of the nitrogen data. Make sure your axes on both graphs have identical value ranges to allow for easier comparison. When you do a linear regression of MMI with NTL, the R2 can tell you how well the trend line fits the data (how strong is the relationship between the x and y variables). Display the R2 on each chart.

Describe the differences in the slopes of the lines, and the distribution of points between the two plots. Do these graphs demonstrate what you expected to see? Why or why not?

**The general trend was that the “MMI” (Multi Metric Index), an index of the health of the stream for macroinvertebrates, declined as stream nitrogen increased. This makes sense, based on what we have learned about the stimulation of productivity by excess nitrogen, and the subsequent reduction in dissolved oxygen, leading to hypoxia in lower-order streams spreading downstream as excess nitrogen flows into higher-order streams and the Gulf of Mexico.**

 **1 pt**

Visit the EPA website for worksheet and analytical examples of causal analysis

<https://www.epa.gov/caddis-vol1/about-causal-assessment>

<https://www.epa.gov/caddis-vol3/caddis-volume-3-examples-and-applications-worksheets-little-scioto-river-oh>

**Part 4:** Discuss with teammates the 4 choices and for each choice, provide an explanation for why it is or is not a good choice: **2 pts**

**Specific Choices**: Invest in nutrient reduction (NR) strategies in: **Possible response include:**

1. Region 7 because it has the highest nutrients and thus the higher need for NR

**Streams in Region 7 flow into the Gulf of Mexico, where the excess N and P cause hypoxia, the Dead Zone, that kills aquatic organisms and impacts the fishing industry. Cleaning up streams in Region 7 will thus have both local and regional effects, from local groundwater protection to regaining aquatic provisions and livelihoods previously lost to hypoxia in the Gulf of Mexico.**

1. Region 10 because it has the higher index of sensitive benthic macroinvertebrates and thus a greater need to protect sensitive organisms

**Even though these streams are ranked as ‘clean’, they are subject to growing pressure from agriculture and recreation. These streams provide habitat for a higher diversity of macro-invertebrates, many of which are very sensitive to small changes in water quality. Thus, these streams are very vulnerable to changes in quality. Investment in protecting them from increased pollution now would avert loss of biodiversity before it’s too late.**

1. Region 7 because Region 10 has too many remote areas, so NR would be difficult to implement there

**With so many lower-order streams in remote areas in Region 10, it would be difficult to devise a plan to reduce nutrients inputs and to enforce new rules. Plus, agriculture is becoming an important component of the economy in these regions, and it would not be fair to that region to curtail their new development. Also, important products would not be available from Region 10 if new rules were implemented.**

1. Region 10 because NR strategies are not compatible in an agricultural area such as Region 7.

**In Region 7, nutrient reduction strategies involve practices that take place at the level of the individual farm. The government does not have the power to force farmers to implement the strategies, e.g., reduce N and P application, use cover crops, install riparian forest buffers, etc. This is especially true if the NR strategies reduce yield or income for farmers. Thus, the funding would be better spent in Region 10 that does not depend so much on agriculture for its economy.**

**Adapted from**:

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**Literature Cited**

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Wallace, J. and J. Webster. 1996. The role of macroinvertebrates in stream ecosystem function. Annual Review of Entomology 41:115-139.

**ADDITIONAL RESOURCES**

Benthic Macroinvertebrate Indices:

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