Introduction to Wetland Ecology Lab

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Overview

Abstract: Wetlands are diverse, productive ecosystems occurring at the interface between aquatic and terrestrial environments. In this laboratory exercise, students will learn about wetlands by sampling ecosystem-level characteristics in a wetland adjacent to our campus several times during the semester. Groups of students will use state-of-the-art water sampling equipment to sample at least four sites (inflow, center, shore, and outflow) at least three times during the semester. Based on the data collected and shared, students will write a report on our wetland based on national standards and comparisons to other, similar systems.

Keywords: wetland, marsh, ecosystem service, water purification, pollution, dissolved oxygen, biological oxygen demand, nutrient load, temperature profile,

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Time Required:

Site and Material Requirements: The site is a small wetland on the TSU campus between the TSU farm, Ed Temple Blvd, and Dr. Walter S. Davis Blvd.

Course Size, Institution Type, Transferability:

Acknowledgements:

Instructor's Introduction

Background: This exercise involves learning about wetlands in general, collecting water quality data from a specific wetland (plus additional data collected in previous years), summarizing the data in tables and graphs, and answering questions about water quality in the marsh. Data analysis is limited to summarizing it in this exercise but, if the student has sufficient statistical skill, analysis can extend to statistical comparisons. The extensive material on wetlands is intended as background that will aid the student in formulating questions that can be addressed using the data collected.

Learning Objectives:

1. The students should be able to formulate appropriate questions about the marsh using concepts and terminology presented in the background material.
2. The student should be able to summarize the data in tabular and/or graphic form.
3. The student should be able to use a multi-parameter probe to measure water quality parameters.
4. The student should be able to utilize the data as evidence upon which answers to the formulated questions are based.

Equipment/Materials:

Logisics:

Student Products:

Description

Introduction: Wetlands are marshes and swamps and lots of things in between. They are everywhere fresh water is found and where land and ocean meet. They can range in size from less than and acre to thousands of square miles (the Pantanal in Brazil is over 50,000 square miles in area, the Sudd in South Sudan is over 20,000 square miles, and the Everglades of Florida are over 2,000 square miles). Some wetlands are remote and uninhabited but man has inhabited other wetlands for thousands of years. People have often seen them as wasteland that would be more valuable if the water were drained away and the land put to use to grow crops or build houses. In this module, you will be introduced to a different view of wetlands that seeks to understand their nature, their value to people as wetlands, and the impact that human activity is having on them.

The US Environmental Protection Agency (EPA) has an official definition of a wetland: "Wetlands are areas where water covers the soil, or is present either at or near the surface of the soil all year or for varying periods of time during the year, including during the growing season." (What Is A Wetland?, 2015). This definition covers habitats from tidal saltwater marshes along the coast to freshwater areas only wet after rains. Thus, it is hard to make general statements about all wetlands.

The difficulty in defining wetlands has lead to multiple systems for delineating types of wetlands. An important difference among systems for classifying wetlands is whether they adopt a broad or narrow definition of wetlands. The Ramsar Classification System for Wetlands was developed for use in the Convention on Wetlands of International Importance signed in 1975 (called the Ramsar Convention for the Iranian city in which it was drafted). The Ramsar Convention sets international environmental standards for wetlands. Its system is an example of an inclusive approach. Under the Ramsar scheme, all inundated areas are wetlands including the rocky intertidal, coral reefs, and all rivers, streams and lakes. The Ramsar definition also includes all man-made wetlands like ponds for fish farming or manure lagoons created to hold waste from animal feed lots. The EPA's classification scheme takes the narrow approach and does not cover coral reefs nor lakes nor manure lagoons. The differences in the systems are neither trivial nor simply a matter of different perspectives. It arises from the fact that natural phenomena are not always amenable to division into separate categories and the intents of those who designed the classifications. The Ramsar Convention's scheme recognizes the interconnection between river and swamp and so includes both while the EPA's approach simply separates a swamp from the river that drains it to allow separate consideration of each under the law. We will adopt the EPA's approach and try to narrow what we mean by wetland. But the EPA's scheme is not even used universally by the entire United States federal government. In practice, the classification scheme is chosen that best meets the organization's goals. The US Fish and Wildlife Service and the US Geological Service use a scheme devised by Cowardin and his co-workers (Cowardin et al., 1979).

We will group wetlands into four general categories: Swamps, Marshes, Bogs and Fens. Water entering the wetland may come from precipitation, inflow from streams, rivers or lakes, or from groundwater. All wetlands have water-saturated soils at least part of the time. The water fills the air spaces in the soils and decay of the dead organic matter resulting from plant growth quickly uses up the available oxygen, turning the soils anaerobic. If the wetland is wet only part of the year, the soils may only be seasonally anaerobic.

Swamps: Permanent wetlands in which the dominant emergent vegetation is composed of trees and shrubs (i. e. woody plants) are called swamps. **Emergent vegetation** simply refers to plants that have their roots in the soil below the water and that have shoots that emerge from the water's surface. Forested and shrub swamps often lie in close proximity. Florida has extensive shrub swamps dominated by a single species of plant: red mangrove (*Rhizophora mangle*). Swamps provide many ecosystem services. They can act as flood barriers and are areas of high biological diversity and production.

Figure 1. A swamp in the southern US.

Marshes: The EPA separates marshes into tidal and non-tidal categories. Most non-tidal wetlands are fresh water and occur in poorly drained depressions along the margins of rivers, streams, and lakes. In one case, the Everglades of southern Florida, one can view the system as either a very large marsh or a very shallow, wide river. Water depth can vary greatly but is usually shallow (½ to 2 feet) and some marshes may seasonally dry out. Parts of the Everglades have dried out through human intervention as water has been drained from the edges of the system to lower the level of the ground water and make it possible to develop the drained areas. As we shall see, what has happened to parts of the Everglades has happened to many wetlands in the United States and worldwide.

Figure 2. A large marsh in Lithuania

Freshwater marshes have highly organic soils with constant input of mineral nutrients from the inflowing water. The water is usually near neutrality and this encourages high primary productivity by both plants and algae. Local conditions can cause some marshes to have alkaline water but even this situation can support significant primary productivity, often from cyanobacteria.

Marshes provide multiple ecosystem services. They can act as reservoirs of water that is released during sporadic or seasonal droughts. On the other hand, they can act as storage areas for flood water, lessening the floods effects on surrounding terrestrial habitats. Water flow slows in the marsh and sediments, including the pollutants that may be adsorbed on them, may settle out and be trapped in the marsh. Algae and plants growing in the marsh may also use up excess nutrients in the water that flows into the marsh, reducing the nutrient concentration in outflowing water. Marshes have high biodiversity and are often important nurseries for animals and birds.

Some non-tidal marshes are distinct enough that they are given specific names in the EPA scheme. Wet meadows are marshes that form in shallow depressions and are so shallow that they look like grasslands, at least along the edges. Prairie pothole marshes form in depressions caused by glaciation. They may have water year-round or only seasonally and are most common in the upper Midwest. Vernal pools are wetlands in depressions that only fill during spring rains and are often dry at other times of the year. Playa lakes are temporary lakes that fill only seasonally or during intermittent rainfalls and are found in dry areas in the western United States. They may be very important resources for migrating birds.

Figure 3. Prairie Potholes

Bogs: These are wetlands that form in shallow depressions that have no input from either groundwater or streams. They have highly acidic water due to the decomposition of a specially adapted genus of moss, *Sphagnum*. The decomposition produces organic acids that lower the pH of the water. The increased acidity, in turn, slows down the process of decomposition (an example of negative feedback). Bogs also tend to occur in colder regions. The combination of temperature, acidity and anoxia in bog sediments can bring decomposition to a halt even as surface productivity increases the amount of organic sediments as the *Sphagnum* dies and sinks to the bottom. At the bottom of the sediment profile, the undecomposed plant remains are compressed by the weight of sediments above them into **peat**. Peat is still burned for cooking and heating in some places.

Not all bogs form at higher latitudes. Pocosins are found southeast of the U. S. They are depressions with water-saturated, acidic, nutrient-poor soils as are all bogs but they are not dominated by *Sphagnum* but by evergreen trees like pines and bay trees. Peat is still formed and, because pocosins are more likely to dry out than northern bogs, the peat often contains charcoal from wild fires that periodically burn the pocosin. Large pocosins on the Atlantic coastal plain are important refuge habitats for large animals like the black bear.

Bogs may produce so much vegetation that they fill in, a process called terrestrialization. The growth of the vegetation often raises the surface of the bog above the surrounding land. During this process, the surface of the bog may look solid but may shift as you walk over it due to the water sill underfoot. This sort of a bog is called a quaking bog and is only a temporary condition on the way to full terrestrialization.

Figure 4. A bog in southern Canada

Fens: Fens are also peat-forming wetlands but, unlike bogs, they have a water source other than precipitation. Their soils are, like bogs, acidic, plant nutrient-poor, and tend to be anoxic but, because the water input can bring in oxygen and nutrients and carry away acids, they are less acidic with more nutrients than bogs. They are more common at northern latitudes than southern, again like bogs. They often form in depressions that receive ground water drainage from adjacent land at higher elevation.

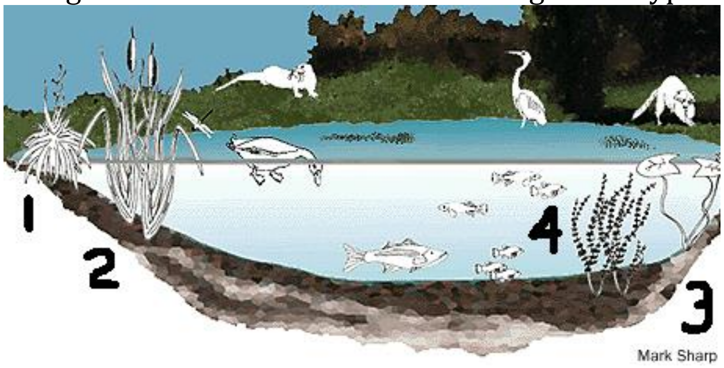
Fens can be dominated by herbaceous plants including grasses, sedges, and rushes or, less commonly, by trees. The growing conditions are less harsh than those found in bogs and this allows a greater diversity of plants than are found in bogs.

Figure 5. A Fen in Michigan,

Wetland Vegetation

Wetlands have a very diverse set of plants, ranging from large trees to the smallest flowering plants, commonly called duckweed (several species in the genera *Wolffia*, *Lemna* and *Spirodela*), consisting of only one or two tiny leaves and minute flowers. Duckweed plants can be seen floating in great numbers on nutrient-rich ponds throughout Tennessee. This diversity has lead to various schemes that place the plants into broad categories, much like the diversity among wetlands necessitated a scheme to organize and define them.

Wetland vegetation is often divided into four general types (Figure 5) :



1. **Shoreline Plants**: Plants that tolerate wet soil but grow above the waterline on the margins of the wetland. Almost all types of plant can be found here: trees, shrubs, forbs and grasses. *Equisetum*, a member of an ancient lineage of non-flowering vascular plants, may be found lining Tennessee wetland shores.
2. **Emergent Plants**: Plants with roots in the saturated soils below the waterline but with stems that carry their leaves and flowers above the waterline are emergent. The trees in swamps are the largest examples of emergent plants but many wetland shrubs, forbs, and grasses belong in this group. Cattails (*Typha* spp.) are common emergent plants found throughout the Northern Hemisphere. Their edible rhizomes may have been a food source as long as 30,000 years ago. If you don't know what a cattail is, perhaps another of the many common names used in the US will help jog your memory. Some call them corndog plants. Another prominent emergent plant (also a shoreline plant) in Tennessee is the common reed (*Phragmites australis*), a large grass-like plant that can dominate large areas where found. It is found world-wide and there are several sub-species native to the US. However, the European subspecies has been introduced to the US and has become invasive across the Eastern US and Midwest. It is not know which subspecies we have in the TSU marsh. The invasive European type crowds out the native subspecies and forms dense stands that also deprive other native species of their normal habitat.

Figure 6. (Left) *Typha latifolia*, cattails; (Right) P*hragmites australis*, common reed

3. **Floating Plants**: These are plants with leaves that float on the surface. They may have no roots at all (duckweed) or have stems and roots in the saturated soils but leaves

that float (water lilies and lotus).


Figure 7. Two species of duckweed

4. **Submerged Plants**: Submerged plants like the many pondweeds have roots, stems and leaves that do not break the water's surface. Some submerged plants have flowering stems that do grow above the surface. Several species of water milfoil (*Myriophyllum,* a plant with both submerged and emergent leaves) have become invasive species throughout North America. They can form dense mats near the water surface and profoundly alter the ecology of a wetland. Efforts to control their spread have not been effective and, in some areas, attempts to control their populations have centered on harvesting them (sometimes by hand). *Sphagnum* spp. is a moss that is often a major constituent of peat formed in bogs. Submerged plants are favorites for freshwater aquaria and species imported for aquaria have escaped into nature.


Figure 8. *Myriophyllum*, water milfoil

Wetland Animals

This section will be brief as there are so many animals that visit or live in wetlands it is impossible to discuss or even to mention them all. We will focus on freshwater wetlands here but if we were to include saltwater wetlands, the list would expand greatly to most likely include species from every known animal phylum.

Even restricting our discussion to freshwater wetlands, the list is extensive. Spiders and insects abound in wetlands but they are not the only arthropods found there. Crustaceans from crabs and crayfish to copepods and *Daphnia* are also abundant. Wetland molluscs are represented by clams and snails for the most part. Annelids (earthworms and relatives) and several small animal phyla all have representatives living in wetlands. Although cnidaria (jellyfish, corals and relatives) are exceedingly rare in freshwater wetlands (and in freshwater in general), there are some 30 species of freshwater sponges found in North American wetlands.

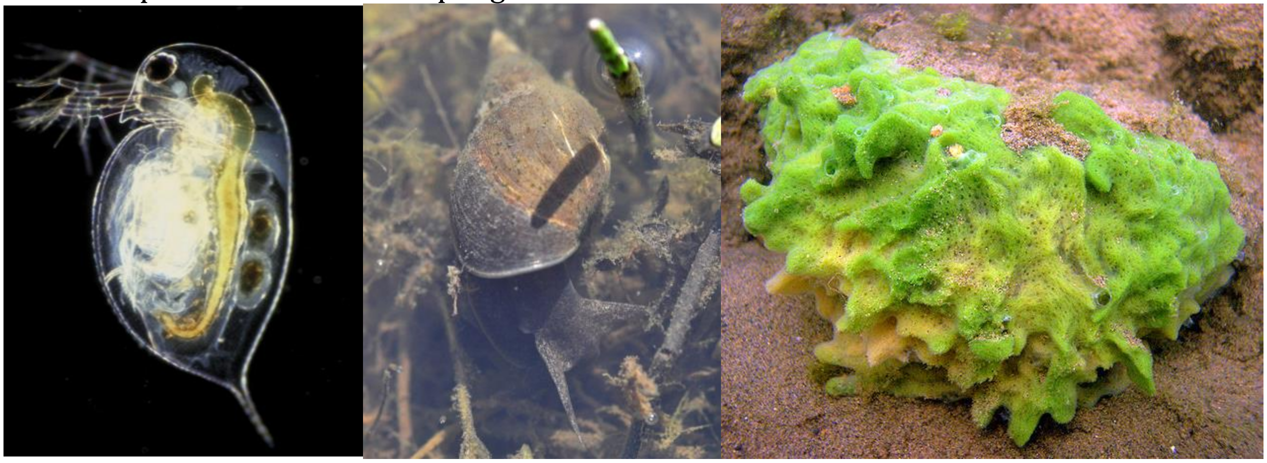


Figure 9. (Left) *Daphnea pulex*, a water flea [a small crustacean]; (Middle) *Lymnea staginalis*, a dextral snail; (Right) *Spongilla lacrustis*, a freshwater sponge

Vertebrates associated with wetlands include fish, mammals, birds, amphibians, and reptiles. Some have a closer association with wetlands than others. Aquatic waterfowl are a prominent component of wetland fauna and can often be seen feeding and nesting in the TSU wetland. Many wetlands have abundant turtles and snakes, including the TSU wetland. Many frogs and some salamanders either live in wetlands as larvae or as both larvae and adults. Beaver, muskrat, otter, and many small rodents are some of the mammals common in wetlands. There are even a swamp rabbit (*Sylvilagus aquaticus*) and a marsh rabbit (*Sylvilagus palustris*) found in the southern US (we are just a bit to far north for the swamper and too far west for the marsher). Both like to swim which is not usual for rabbits. Of course, many mammals (from deer to bear to bats) visit wetlands to feed on the vegetation or on other animals found there.

Figure 10. (Left) *Pseudemys nelsoni*, Red Bellied Turtle; (Middle Left) *Ardea purpurea*, Purple Heron; (Middle Right) Treefrog in a Pitcher Plant; (Right) *Sylvilagus palustris*, Marsh Rabbit

Benefits derived from wetlands

The idea that wetlands are beneficial is actually something new. Many authors have made reference to a call by the American Medical Association for a national program to completely eliminate wetlands. Of course, that call to action was made over a century ago when wetlands were viewed, at best, as wastelands without value or, at worst, as sources of disease (hence the AMA's desire to eliminate them). Attitudes have changed and today, wetlands are seen as valuable resources to be preserved. Ecologists, environmental scientists, hydrologists and sanitation engineers have cataloged many important benefits provided to human society by wetlands.

The diversity in size, structure, origin, fauna and flora among wetlands means that the benefits of wetlands in general do not all apply to each and every wetland area. However, even small wetlands often provide significant benefits to those living near them. The TSU wetland is an example of a small wetland that has significant benefits for the urban neighborhoods surrounding it and to those who make use of the Cumberland River downstream of the point at which the TSU wetland discharges its water into the river.

Wetlands are productive ecosystems: Primary production is the foundation for all living systems, both natural and human. New organic matter in wetland ecosystems mostly comes from algal and plant production within the system (**autochthonous** production) rather than input from external sources. Productivity ranges from highly productive marshes to lower productivity bogs. Highly productive wetlands are among the most productive ecosystems on Earth and can equal the productivity of coral reefs or rainforests. Productivity will depend on both the general nature of the system (described above) and on local conditions like temperature, geology, soil and water chemistry, and biodiversity. The abundance of food found in productive wetlands makes them valuable as resources for juveniles of many species of animals. In general, the job of juveniles is to become successful adults and abundant food means juveniles are more likely to become large and healthy adults. For this reason, wetland productivity may play a vital role in the life of animals in adjacent forest and grassland systems and loss of wetlands may lead to animal population declines in those systems. In the case of migrant species like waterfowl that rear their offspring in wetlands, local wetland productivity may have impacts thousands of miles away.

Wetlands productivity is also a direct resource for us. Saltwater wetlands are where most of the shellfish we eat are harvested, whether wild or farmed shellfish. Cranberries, blueberries and wild rice are harvested from freshwater wetlands. Lumber is also taken from swamps. The EPA estimates that, in the southeastern US, almost all commercial fish and more than half of recreational fish come from species dependent on coastal marshes. Commercial fishing is a multi-billion dollar industry in these states.

Wetlands are also home to many endemic species, especially low-productivity wetlands. Low-productivity wetlands are stressful environments for most organisms but the algae, plants and animals that live there often have special adaptations that help them overcome the stress. Good examples of this are carnivorous plants like sundews and the famous Venus fly-trap. Plant carnivory supplies the plant with the mineral nutrients from the animal tissues digested and is most adaptive when soils are nutrient poor. Bogs and fens have a higher proportion of endemic species than do surrounding terrestrial systems.

Wetlands provide important ecosystem services: Often, the natural environment is contrasted with the environment we humans have built as though the two were independent of one another. Nothing, in fact, could be further from the truth. The environment we have constructed, whether we live on a farm or in a city, depends on natural systems in order to function as intended. The things supplied by natural systems are grouped together under the general title of “ecosystem services”. For many of these services, wetlands are either the primary or an important provider of the service. In this section, we will take a look at those services.

At the largest scale, microbes and plants in wetlands play important roles in the global cycling of carbon, water, nitrogen, and sulfur. Wetlands are important repositories for carbon and the loss of wetlands results in the stored carbon being released into the atmosphere as CO_2. CO_2 isn’t the only interface between global warming and wetlands. Bacterial mineralization of organic nitrogen in wetlands also contributes to the emission of nitrogen-containing greenhouse gasses, specifically laughing gas (nitrous oxide, N_2O). A molecule of nitrous oxide has almost 300 times the greenhouse impact as a molecule of CO_2. But many of the ecosystem services from wetlands come at the local, not the global, scale. We will look at these local services below.

Flood and Erosion Control: Wetlands act as a buffer between the land and flowing water. This “buffering” allows wetlands to mitigate the harm done by floods and erosion. Wetlands can absorb floodwater and reduce flooding downstream. Wetlands reduce erosion in more than one way. Marshes along streams slow the movement of water and help stabilize riverbanks. Marshes on large lakes can reduce erosion from storm waves. Sediment eroded by precipitation may be trapped in wetlands when the runoff slows upon entering the wetland.

Groundwater Recharge and Discharge. For many years wetlands were believed to act as a reservoir that releases water to adjacent rivers and streams during periods of low flow. Reviews of dozens of studies have challenged this idea. In fact, evapotranspiration from a wetland can actually reduce water level downstream. The water in wetlands is linked to the surrounding groundwater and, where discharge maintains stream levels, the water discharge is now treated as a function of groundwater flow. Groundwater is an important resource. We pump it up to the surface for irrigation and to drink. Some groundwater may be separated from the surface of the land by layers of impermeable rock (the water in such aquifers is often called fossil water as it may have been trapped in the aquifer long ago). Many aquifers are actively recharged by precipitation. Wetlands are often important components of the recharging process. They trap surface water that would otherwise run off into streams and allow the trapped water time to percolate into the aquifer. Removing wetlands may seriously degrade the associated groundwater aquifer as a resource.

Shoreline Protection. Coastal wetlands (grass-dominated salt water marshes and mangrove forests) that occur where violent storms make landfall can be important in preventing erosion of our coasts. The rate of erosion increases as the amount of matter and energy involved in the storm increases. Violent storms (whether hurricanes like Katrina in 2005 or Sandy in 2012) can do more damage in a few days than many years of normal storm damage. The two storms mentioned accounted for over 1400 deaths and 200 billion dollars in damage. Coastal wetlands have proven to mitigate the effect of hurricanes landfall by reducing storm surge (the water brought onto land by the storm), wind speed, and absorbing wave energy. One study estimated that each hectare of coastal wetland reduced hurricane damage by as much as $33,000 and that storm damage in the US was reduced by an average of over 23 billion dollars each year (Costanza et al. 2008). There are two immediate threats to the protection afforded by coastal wetlands: economic development and sea level rise. Economic development converts wetlands into industrial, commercial and residential property, none of which has any value as protection from hurricane damage. The level of the sea is rising due to the warming of the Earth. As the rise takes place, wetlands must either move inland or disappear. Current development plans for the states on the east coast of the US do not recognize the value of storm protection, conserve wetlands, or plan for the effect of sea level rise by identifying where new wetlands are to be encouraged (Titus et al., 2009).

Water Purification. Water that enters a wetland is not pure water. Whether it comes from precipitation, surface runoff, groundwater flow, stream flow, or from an adjacent lake, it will contain naturally occurring materials such as **sediment** (small particles held in suspension but not dissolved), dissolved inorganic ions, and organic molecules. Human activity can greatly expand both the types and level of sediment, dissolved inorganic materials, and organic molecules. Often, the material we add is considered to be pollution, a very broad term. Until we discuss it's meaning, let it be anything in the water that has the potential to harm us or cause disruption of natural systems. The level of pollutants in the water that flows out of a wetland is often less than the level in water flowing into them. This water purification is a very significant ecosystem service.

Sediment Load: In general, water flowing into wetlands slows down. Sediment carried by the incoming flow will tend to settle out. How much settles out depends on several factors: the net change in velocity, residence time, and particle size. Faster water can carry larger sediments and, as water slows, the larger sediment may fall out of the water. **Residence time** is the average time a molecule of water that enters the wetland spends there before leaving, either as outflow or by **evapotranspiration** (a term that covers water lost through evaporation plus that lost by plant transpiration). The longer a particle spends in the wetland, the more likely it is to settle out of suspension. Smaller particles take longer to settle out than larger, so as residence times increase, the proportion of the smallest sediments removed will also increase.

Sediments also can be filtered by vegetation found in the wetland. Vegetation can directly filter sediments and can also increase residence time and reduce velocity. It is not unusual for wetlands to remove 80 to 90 % of sediments in precipitation runoff. Of course, the sediments that remain change the wetland, either by expanding its size or by filling in the depression that holds the water.

Metal Ions: Heavy metal ions such as arsenic, lead, chromium, cadmium, and a host of others can pose serious health risks to people and to other organisms. Wetlands can greatly reduce the amount flowing into lakes and rivers. The most important means of removal is sedimentation. Many metal ions will adhere to particles and be lost from the water as the particles settle out. Some of the metal ions will adsorb to material already in the wetland. Clays and dead organic matter are both important absorption surfaces. The water in the wetland may be significantly different that the incoming water with respect to temperature, pH, and the concentration of various ions. The change in chemical environment can cause some metals to precipitate as a chloride, hydroxide, or carbonate. Finally, emergent vegetation can take up metal ions and store them in their tissues. Uptake is linked to the species of plant and the species of ion present.

I**norganic Nutrients**: Liebig's Law states that the rate at which a process proceeds is limited by the necessary component in least supply compared to its optimal supply. Plant and algal growth are often limited by one of two nutrients: phosphate or nitrogen (such as ammonia, nitrate, and nitrite but excluding pure nitrogen, N_2). Both nutrients can be added in excess by human activity and wetlands can help remove the excess.

Nitrogen: Runoff and groundwater can carry significant concentrations of ammonium (NH_4^+, urea breaks down into ammonia), nitrite (NO_2^-, found in preserved meats and in explosives but easily oxidized into nitrate) and nitrate (NO_3^-, often from industry-made fertilizer in runoff and from air pollution in precipitation). All three are plant or algal nutrients and can cause severe disruption of aquatic systems due to the excess production they may cause. Both ammonium and nitrates are toxic to humans at high concentrations. Nitrate is linked to the induction of human cancers.

To understand how wetlands change nitrogen concentrations in water, it is best to review what we know about the nitrogen cycle. Most of the atmosphere is nitrogen, N_2, but it is not a nutrient in that form as it is too unreactive. Both the reduced (NH_4^+) and oxidized (NO_3^-, NO_2) forms are useable as nutrients. There are three processes that convert N_2 to a useable form (a process called **nitrogen fixation**): lightening, nitrogen fixation by a handful of prokaryotic species, and the Haber-Bosch process used to make nitrogen fertilizer. Globally, 20 times more nitrogen is fixed by prokaryotes than by lightening. The global production of industrial fertilizer fixes approximately as much nitrogen as do all of the nitrogen-fixing prokaryotes on the Earth. Opposing the creation of biologically useable nitrogen are three biochemical process that result in the production of N_2: ammonification, nitrification, and denitrification. Prokaryotes and fungi do all three.

Ammonification: The nitrogen in living tissue and in animal waste is converted to ammonium ions through the action of several enzymes found in fungi and microbes responsible for decomposition, including the decomposers found in wetlands.

Nitrification: Ammonia is the energy resource for a group of aerobic chemoautotrophic bacteria and archaea. The ammonium ion is oxidized first to nitrite and then the nitrite is oxidized to nitrate. Each step generates ATP for the microbe (oxidation is often an exothermic process). Interestingly, the two steps are done by two different sets of microbes (*Nitrosomonas* and *Nitrosococcus* are the most well know consumers of ammonium and *Nitrobacter* and *Nitrospira* consume nitrite). A few Archaeal species can consume ammonium as well.

Denitrification: The final step, converting nitrate to elemental nitrogen and water, results from the activity of relatively few bacterial species, all either anaerobes or facultative aerobes. Unlike nitrification, the nitrate consumed in denitrification is not an energy source. Rather, it is used as an electron acceptor in cellular respiration, playing oxygen's role when there is no free oxygen (O_2) present in the microbe's environment. N_2 is major product of denitrification but not the only product of denitrification. N_2O and NO are also produced. We have already mentioned the potential N_2O has as a greenhouse gas. Under anaerobic conditions, sulfur is also used as an electron acceptor in cellular respiration, producing H_2S rather than H_2O. H_2S, hydrogen sulfide, can make a wetland smell like rotten eggs, perhaps one of the reasons people have negative attitudes about wetlands. H_2S is both a neurotransmitter and a very potent neurotoxin. Toxic effects start with irritation of eyes and respiratory surfaces at 20 ppm, eye damage at 50 ppm, and death above about 350 ppm. The EPA limits exposure to 10 ppm. However, these levels are rarely produced in natural situations. If you can smell rotten eggs, don't worry. We can smell H_2S at a concentration of 0.0005 ppm, considerably below the level of toxic effects.

Wetlands slow and hold water that would otherwise flow into groundwater or surface water. During the residence of the water in the wetland, microbial ammonification, nitrification, and denitrification all take place, removing biologically active nitrogen from the water. The process can be very effective, possibly removing 80 to 90% of biologically active nitrogen from incoming water. Although plants absorb some of the biologically active nitrogen, this is not counted as removal from the system. When the plant tissue dies, the nitrogen is released back into the water.

Phosphorous: Phosphorous on the Earth's surface occurs as the phosphate ion (PO_4^{3-}). It is found adsorbed onto sediments and dissolved in water. Normally, the majority is with the sediment fraction but human activity can greatly increase the fraction that is dissolved. Many detergents once contained soaps that, when decomposed, released phosphate. This is less of a problem today as sulfate and other anions are now used in place of the phosphate. Still, phosphate is a component of many manufactured organic compounds and these release phosphate when degraded.

The primary mechanism of phosphate removal in wetlands is sedimentation. Because wetlands differ in their ability to trap sediments, they also differ in their ability to remove phosphate by this mechanism. Plant, bacterial, and algal growth requires phosphate. Uptake of dissolved phosphate by the living portion of the wetland can remove much of this fraction of the total phosphate coming into the wetland. However, neither adsorbtion nor uptake are necessarily permanent storage. Death of the plant, bacterium or alga releases phosphate and can lead to seasonal discharges of phosphate from wetlands. Changes in water chemistry like anoxia during drought periods can release adsorbed phosphate. How much adsorbed phosphate is released depends on the elemental composition of the soil and the fraction of soil that is dead organic matter.

Biological Oxygen Demand: Organic matter (often human or livestock sewage) in water acts as food for decomposers. Most decomposers break down these compounds aerobically and this process can strip oxygen from the water column, leaving little or no oxygen for other aquatic organisms. Some fish kills result from asphyxiation due to low oxygen concentration. Aquatic scientists use the idea of oxygen demand to measure the potential for organic material to reduce oxygen concentrations. Oxygen demand is the amount of oxygen needed to oxidize all organic matter in a standard volume of water and can be split into the portion due to the activity of decomposers (biological oxygen demand, **BOD**) and the oxidation of residual organic compounds through chemical oxidation. Water with a high BOD is subject to becoming anoxic. Anoxia can result in fish kills and loss of productivity. Wetlands can help mitigate the effect of high BOD. Water entering wetlands with a high biological oxygen demand may leave with a lowered BOD due to the removal of organic compounds by sedimentation and decomposition.

Toxic Organic Molecules: Industry produces a very diverse set of organic molecules not normally found in living systems (**xenobiotics**). These include hydrophobic solvents, hydrocarbons, pharmaceuticals, plastic polymers and their monomers, and pesticides. Many, if not most, of those are toxic to humans or other organisms. Wetlands often reduce the concentration of toxic organic chemicals through three mechanisms: phytochemical oxidation, biodegradation, and plant uptake. Each of these processes becomes more effective at removing the toxin as residence time for the water in the wetland increases. **Photochemical oxidation** happens when sunlight (including UV) breaks bonds in the organic molecule and is important in degrading hydrocarbons and ring structures. **Biodegradation** is carried out by decomposers: bacteria and fungi that specialize in metabolizing non-living organic material. The diversity of xenobiotic compounds that are degraded by microbes is very large and includes all common sorts of pollution. Plant uptake of organic molecules often sequesters the molecule in the plant's tissue but plant metabolism may also degrade the toxin (this is a process known as **phytotransformation**).

Pathogens: Water entering wetlands may carry heavy loads of pathogenic organisms including viruses and bacteria like *Salmonella*. The sedimentation, filtration, and degradation processes in wetlands that trap and transform particles in general also trap and kill many pathogens. Once again, residence time is positively correlated with the proportion of pathogens removed. Even if the pathogen does not settle out of the water, most pathogens have a limited life expectancy outside their host and the longer the pathogens remain in the wetland, the fewer pathogens will leave the wetland. Sewage treatment plants often use artificially constructed wetlands to perform this function if no natural wetland is available.

Direct Economic Benefits. So far, the benefits discussed have been ecosystem services provided by wetlands to nearby human societies. Because they are provided by natural activity, services are usually not given a dollar value and, for this reason, do not appear in personal, business, or governmental budgets. If a wetland's ability to purify water and recharge an aquifer means that a municipality pumps abundant water for home, commercial, industrial, and agricultural use, that benefit appears nowhere as money saved. In this section, we will look at benefits that are measured directly in dollars.

Recreation: Wetlands offer significant benefits as recreational destinations. People like to canoe, hunt (waterfowl and mammals), hike, bird watch, and fish in wetlands. Significant tourist industries have grown around all of these activities where the wetlands are sufficiently large and protected to support the recreation industry.

Fisheries Habitat: Coastal wetlands are important habitat for many commercially fished species. It is often the juvenile life stages that spend significant time in wetlands. They are also home to important shellfish (both farmed and wild-caught) industries. This benefit is less often provided by freshwater wetlands. The principal commercially fished anadromous fish (fish that spawn in fresh water but live as adults in salt water) like salmon and shad prefer clear, fast running streams in which to spawn and as juvenile habitat rather than wetlands.

Harvest of Wetland Resources: Cranberries, blueberries, and bayberry wax are all harvested from freshwater wetlands in North America. In the case of cranberries, wetlands have been created to increase their harvest but natural wetlands are also harvested. Wild blueberries (also called low-bush blueberries), a valuable crop, come mostly from wetlands. There is also significant timber harvest from wetlands. Two hundred years ago, there was an additional "harvest" from some wetlands: bog iron. Some bogs accumulate iron oxide through biological and chemical precipitation. During the U. S. colonial period, bog iron was the first iron produced in North America.

Threats to Wetlands:

Human activity both destroys and creates wetlands, although the balance has been heavily in favor of destruction historically. Wetlands are created as part of sewage treatment systems, as substitutes for wetlands destroyed by construction (mitigation wetlands), or as buffers against storm and flood damage. However, many more hectares of wetlands have been destroyed than created both worldwide and in the US. Although destruction is the most severe threat to wetlands, there are many "sub-lethal" human impacts as well. Human activity may alter wetland structure and function in ways that reduce their ability to deliver ecosystem services without completely destroying the wetland.

The consensus is that most wetlands worldwide have been lost and that the rate of loss is accelerating. Local fractions lost and rate of loss varies considerably in different parts of the world. Davidson (2014) summarized the findings of 189 publications that dealt with loss of wetlands. The long-term proportion lost is not easy to measure because the total area of wetland lost depends on when you begin counting. The current total wetland area has been reasonably well determined (it will differ for different definitions a wetland) but as you go farther back in time the total wetland area used to begin the comparison gets larger and the % loss will grow as well. Humans have been draining wetlands for a long time. Davidson sums up the results by saying that "long-term loss" is between 54% to 57% but that, since 1700 AD, as much as 87% may have been lost. Other conclusions are not so difficult to reach. The yearly rate of loss is over 3 times greater since 1900 AD than before. Percentage losses have been larger and rate of loss greater for freshwater wetlands than for coastal, saline wetlands. Over the last 60 years, a gap has opened between loss rates in Europe and North America versus Asia and probably for Africa and Oceania as well. Davidson's conclusions are echoed by the Ramsar Convention Secretariat (2015), who estimate that the proportion of wetlands lost since 1900 AD at between 64% and 71%

Harmful impacts on wetlands come from a variety of human activities. Harmful activities can operate at local, landscape and global scales. Local-scale impacts are harmful activities that occur due to human-caused activity within the wetland itself. If cattle disturb wetland vegetation by eating and trampling it, this happens at the local scale. If the source of the disturbance is an activity that occurs in the neighborhood of the wetland, the physical scale is now the local landscape, not just the wetland. Nutrient runoff from nearby agricultural fields or residential lawns higher up in the wetland's watershed that drains into a wetland is a landscape scale disturbance. Finally, wetlands are being degraded by collective, worldwide human activity and these impacts are at the global scale. Global warming caused by greenhouse gasses that alters a wetland habitat is a global-scale disturbance. We will consider threats from all scales of impact.

Development: Wetlands are favorite targets for "development". They are often less expensive to purchase on the open market because their value accrues to the local population, not only to the land's legal owners. Although actual construction costs may be greater, often this is more than offset by the low purchase price. Only when both value and ownership are shared by those receiving benefit from the wetlands will the market price the wetland fairly. Many argue that this makes it important for the appropriate level of government to own wetlands so that ownership, as well as value, is shared.

Urbanization (including residential development}, commercial development (including docks and marinas), industrial development, agricultural or silvicultural (timber growing and harvest) development, and mining are all capable of destroying wetlands at the local scale. If the development destroys only a portion of the wetland, the developed area often becomes a source of polluted water that drains into the wetland, degrading the wetland the development left intact.

Development often starts by building canals to drain the water from the wetland and lower the water table below the soil surface or by filling in the wetland to bring the surface of the soil above the level of the water table. Draining can lower the water table in areas not actually developed. The material used to fill in a wetland can be carried as sediment into the undeveloped portion of the wetland.

Road building often accompanies development. Wetlands are level land and may be chosen as inexpensive routes for new road construction. It is much less expensive to fill in a wetland than to tunnel or blast roadway through the adjacent hills. Roads that run along streams and rivers are often built on filled-in wetlands.

Mining: Mining produces more waste than valuable ore and the waste is often deposited where it is least expensive to do so. The generally low per acre price of wetlands has attracted miners who use them as an inexpensive places for dumping their waste. Mine tailings not only destroy the wetlands where they are deposited but they can damage adjacent wetlands. Rain that falls on the tailings can leach toxic metals from the newly exposed rock and run off of the tailings into adjacent wetlands that have not been covered by mine waste. Some wetlands have been lost as an indirect effect of mining. Groundwater can flood mines and, in order to mine, water tables may lowered through drainage to clear water from the mine. Adjacent wetlands may be deprived of water and suffer complete destruction.

In addition to wetlands being covered over with mine waste, some materials are mined directly from wetlands. Peat, sand and river gravel, sphagnum moss (used as mulch), gold, some gemstones, and tin are all mined in wetlands. The mining operation always disrupts the mine area but, like tailings dumped into wetlands from mines not in wetlands, tailings can be a source of toxic materials long after mining operations have ceased.

Physical and Biotic Alteration: Wetlands can be permanently altered by human activity, often reducing the ability of the wetland to provide ecosystem-level services to local populations. Development may mean dredging channels through portions of the wetland. If rivers are channelized and dredged, water may flow faster and this may destabilize wetland riverbanks. Not all physical alteration is so severe. Drainage may be only partial. Animal grazing can alter the vegetative structure as grazing strips out selected species. Agricultural practice, such as plowing or the creation of paddies, may alter soil structure and destabilize stream and river banks. Grazing animals often spend disproportionate time in wetlands as they contain food and water in the same place. In each case, the wetland's ability to provide the services discussed above will be reduced.

Pumping groundwater to the surface for irrigation or human consumption often lowers the local water table (the surface of the groundwater). Although the pumps may be some distance from the wetland, the drop in the water table is the equivalent of draining a marsh or swamp using a canal. It can destroy part of or the entire wetland.

Non-native species introduced by human agency may become invasive in the wetland environment. The introduction of some invasive species may be linked to grazing. The removal of native plants and soil disruption can be key prerequisites to the invasion. Invasive plants may not be quality food for wetland animals and invasive animals may replace animals that have significant economic value.

Water Pollution: Water entering a wetland, whether from precipitation, surface flow, or groundwater flow, may bring a significant load of pollutants. Precipitation may be very acid due to acid rain and this can change the pH of the soil and water in wetlands normally at a neutral or basic pH. Both surface and ground water draining from agricultural land often carries much of the fertilizer, herbicide, and insecticide farmers have sprayed on their fields. Industrial and urban areas may add toxic metals and organic molecules as well as fertilizer and pesticides to the water flowing into wetlands. There are at least five general types of water pollution that affect wetlands:

1. Sand and Silt that may act to fill in wetlands or cover over bottom-dwelling vegetation and animals.
2. Suspended Particles that may increase turbidity, lower photosynthesis and the wetland's productivity.
3. Salt from roads that may both cause direct harm to salt-intolerant species in the wetland and indirect harm through altering the environment to favor salt-tolerant species.
4. Nutrients from agriculture and residential fertilizers that may result in bacterial or algal blooms that either produce toxins or lower oxygen levels by increasing total respiration in the wetland.
5. Agricultural, Mining and Industrial chemicals like pesticides, acids, pharmaceuticals, solvents, hydrocarbons, and hormone-mimics that directly harm wetland species.

In wetlands where hunting waterfowl is common, an additional source of water pollution falls from the sky, but not as precipitation. Lead pellets that missed their intended target fall to Earth and these can be a significant pollution problem. The pellets can leach lead into the wetland's water or fish and waterfowl may eat the pellets (Anderson et al,, 2000). The resulting lead poisoning can kill birds and, if the poisoned bird is eaten, can raise the level of lead in people who eat the bird (Mateo et al., 2013). The US has banned lead shot since 1991 and the rest of the world is also implementing bans but they are not universal. Once the ban is effective, the lead shot is normally buried by sediment quickly and the birds do not eat it, although the pellet remains a source of leached lead.

Materials and Methods:

For this laboratory, you will measure several physical and chemical characteristics of the water entering, within, and leaving the TSU marsh. The parameters are: temperature, turbidity, conductance, pH, and the concentrations of dissolved oxygen, ammonia, chloride, and nitrate.

1. **Turbidity** is the obverse of clarity and refers to the ability of light to penetrate the water. It is caused by opaque particles suspended in the water (for example, soil particles or algae) and determines the depth of the photic zone in a body of water. It is measured as the proportion of incident light that passes through a defined depth of water. It can be measured in several ways. One can lower a special metal disk, called a Secchi disk, into the

water on a rope and record the depth at which it can no longer be seen. The euphotic zone, where there is sufficient PAR (photosynthetically active radiation) to support photosynthesis, can then be calculated from the Secchi depth (Luhtala and Tolvanen, 2013). However, there is great error in Secchi readings and other methods have been developed. We will use a special probe that measures turbidity by directing a beam of light into a chamber and detecting photons that are scattered perpendicular to the path of the beam. The unit of measurement varies from depth in meters to % transmission, to optical density.

2. **Dissolved Oxygen**: Organisms consume oxygen through oxidative respiration and oxidation of various reduced compounds and produced it through photosynthesis. In addition, oxygen is highly reactive and participates in chemical reactions not mediated by living organisms. Because it is so important to living chemistry, the level of oxygen dissolved in natural waters is an important determinant of water quality. Our probe measures oxygen by detecting photons given off by free oxygen molecules in the water through luminescence (the light given off by a body not due to conversion of heat energy into photons – a red hot iron bar is not luminescing but incandescing) when the oxygen molecules contact a phosphor. The unit of measurement is usually mg/l.
3. **Temperature** is measured using a thermistor, a strip of metal that resists the flow of electrons. In a thermistor, increasing temperature causes an increase in resistance that is detected. The temperature is calculated from the measured resistance. The unit of measurement is the centigrade degree.
4. **Ammonium** is an important plant and algal nutrient (as ammonium, NH_4^+) but also occurs in water as a neutral molecule (NH_3). The ion is relatively non-toxic but the non-ionic form is a toxin. The balance between the two forms is affected by the pH and temperature of the water. As pH goes up, so does the proportion of NH_3. Ammonium can form in water from the anaerobic decomposition of organic materials (such as animal waste). The concentration of ammonium and other ions can be measured using the potentiometric measurement principle and ion-selective membranes (Winkler et al., 2004). The measurement probe has a reference electrode and a second electrode using a selective membrane. The membrane will bind to the ion of interest (that's the selective part) to create a gradient between the inner surface of the membrane facing a reference electrolyte solution and the outer surface facing the water being sampled. As the ion's concentration in the sampled water changes, so does the concentration gradient across the membrane. An ion gradient, since ions carry a charge, is also a gradient in electrical potential. This difference in potential between the outside and inside of the membrane can be measured with a voltmeter and this reading can be compared to the reference electrode to detect changes. The voltage change can be converted to ion concentration using the Nernst equation. The unit of measurement is usually mg/l.
5. **Hydrogen ion concentration** (**pH**) is measured in a manner basically the same as ammonium or any other ion (see above) by detecting a voltage difference between the inside of a glass bulb (the reference solution is in the bulb) and the outside of a bulb, which is exposed to the water being sampled. In this case, the selective membrane is actually made of glass. The inner and outer glass surfaces bind to hydrogen ions and any difference between the hydrogen ions bound to the inside versus the outside generates an electrical potential across the glass (similar to the electrical potential across a cell membrane). The solution on the inside is a standard and won't change so the it is changes in the water sample's pH that will alter the ion gradient and, therefore, the electrical potential. This change can be measured, compared to the potential across a reference electrode, and

converted into pH. The unit of measurement is –log[H$^+$], negative log of the hydrogen ion concentration, or pH unit.

6. **Nitrate** is a second form of nitrogen found in water. It is also a plant nutrient but human activity often adds large amounts to surface and ground water. It is measured in a manner very similar to ammonium (see above) but the ion-selective membrane binds nitrate, not ammonium. The unit of measurement is usually mg/l.
7. **Chloride** is an important ion in plants and animals but can be harmful if the concentration reaches toxic levels. It is measured in a manner very similar to ammonium (see above) but the ion-selective membrane binds chloride, not ammonium.
8. Conductivity is the capacity of a solution to carry a current. It is the inverse of resistance. **Conductivity** depends on the total ion concentration of a solution. It is a way of measuring the "saltiness" of water. When salt concentrations build up in water, the water becomes toxic to many plants and animals, including crops and livestock. Salt concentrations can become so high in natural waters that the salts precipitate out of solution as salt crystals. Conductivity is measured by electrodes in the probe and the voltage is converted to conductance using Ohm's Law. The unit of measurement is the siemens, which is often called a mho. "Mho" is the inverse of "ohm", the unit of electrical resistance.

All of these parameters can be measured using a single instrument with multiple probes attached for specific parameters. In some cases, it is possible to place the instrument permanently and monitor the water continuously over long periods of time. The instrument doing the sampling communicates with a computer where the data is permanently stored and analyzed.

What you will do:
Materials needed:

1. Appropriate clothing for sampling in a marsh.
2. YSI Pro Plus meter with multi-parameter sondes (sonde just means an instrument for measuring a physical parameter) fitted out with multiple probes, each probe to measure a different parameter.
3. Notebook to record data.
4. Data previously collected.

With your instructor, choose at least 4 sites for monitoring. One should be close to the inflow from the creek draining parts of North Nashville. One should be as close as possible to the outfall of the marsh into the Cumberland River. The third and fourth should be about halfway between the inflow and outflow sampling points. One should be from the edge of the water and the last from as close to mid-way across the water as possible. You will need to designate someone from your lab group to accompany the instructor in the row boat to get to the sampling site in deeper water.

Your instructors will demonstrate the use of the YSI Pro and choose the parameters to be measured. They will also show you where the instruments collecting data continuously are placed.

Once the data has been collected and you have access to the data previously collected, you task will be to analyze the data. You should present summaries of the data, including what you collected, in tabular or graphic form. The tables or graphs should be constructed with the intent to present supporting evidence for your answers to questions about the wetland. So, develop the questions first, based on what you have learned about wetlands and the nature of the data collected, then summarize and present the data so that it becomes evidence for your answer to the question. Some examples are given below but they are intended to get you started and are not a complete set of questions one might investigate using the available data. As the data available will change, there may be questions below to which the data can't be applied. But these sorts of questions might be asked of many of the parameters.

Questions:

How salty is the water in the TSU marsh compared to pure water and to ocean water?

Does the saltiness change from inflow to outflow?

Does the saltiness of the marsh change with the seasons?

How do heavy rainstorms in Nashville change the saltiness of the wetland?

Is the wetland a barrier to the release of salty water into the Cumberland River?

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Comments from users

Equipment, methods, analysis, safety:

Introducing the exercise to the student:

Assignments/Extension Questions:
Learning Objectives Assessment

Transferability to other institutions, field sites, habitats:

Appendix