Ecosystem Services - Water Purification

Purpose

To use the example of natural water purification to show students that healthy ecosystems provide services to people that are essential to life as we know it.

Context

This lesson was developed by Dr. Penny Firth, a scientist, as part of a set of interdisciplinary Science NetLinks lessons aimed at improved understanding of environmental phenomena and events. Some of the lessons integrate topics that cross biological, ecological, and physical concepts. Others involve elements of economics, history, anthropology, and art. Each lesson is framed by plain-language background information for the teacher, and includes a selection of instructional tips and activities in the boxes.

Ecosystem services are valuable for many reasons, including economic benefits, protection of human health and safety, and support of recreational or aesthetic enjoyment. Students should know that when ecosystems are not healthy, some or all of the services they provide to people may be lost. Replacing these services is often completely beyond current technology, and even when we can replace them, it is usually prohibitively expensive to do so.

Humanity came into being after most ecosystem services had been in operation for hundreds of millions of years. These services are so fundamental to life that they are easy to take for granted, and so large in scale that it is hard to imagine that human activities could irreparably disrupt them. Historically, however, the vital role of natural ecosystem services has not been given much attention. Because they are "free" these services are sometimes thought of as "without value." Nothing could be farther from the truth. Ecosystem services are essential to life as we know it.

In this interdisciplinary lesson, students explore the concept of ecosystem services by investigating natural water purification in their home watershed.

A few key points before getting started:

- Most water pollution is invisible. Trash in our waterways may look unsightly, but the really serious problems come from poisons, very fine sediments, and excess nutrients.
- Water runs downhill. If humans put it on the land, or in the air, it will likely end up in the water eventually.
- The worst problems with pollution in this country come not from industrial discharge pipes, but from "non-point sources" such as agricultural and urban runoff, and contaminated precipitation.

This lesson is about how ecosystems purify water and what kinds of things humans do that alter these processes. It also discusses the value of the natural water purification service to humans. The take-home message is that the key to maintaining water purification services is to protect and restore the ecosystems that provide these services.

Contact Dr. Firth at pfirth@nsf.gov. Click here for more interdisciplinary environmental lessons.

Planning Ahead

This lesson might work best introduced in small bites over several days. The "river newspaper" exercise in the Assessment will probably be most effective if it is approached as a project of a week or so, culminating in the actual "publication" on a day of significance to the students (e.g. last day before winter break; Earth Day).

You should familiarize yourself with Communicating Ecosystem Services, made available through the Ecological Society of America and the Union of Concerned Scientists.

In addition, see Resources at Risk: Valuing Ecosystem Services, on the World Resources Institue site, for some very rough estimates of economic values for these services.

There are many resources on water and water purification. Thorough writings on ecosystem services, however, are just beginning to emerge. See Additional Resources for several print resources on this topic.

Motivation

To begin this activity, ask students where their tap water comes from. Have students visit the EPA's Surf Your Watershed website and type in their zip code to find their watershed. Have them click on the Index of Watershed Indicators and then the Impaired Water map to see the general condition of their watershed as well as what streams are healthy or unhealthy. Provide the zip codes of nearby urban, rural, suburban, and agricultural areas so that the students can see the differences in the watersheds.

Once all the students have had a chance to look at their watershed(s) online, have them discuss questions such as:

- What is the condition of streams in urban, suburban, agricultural or rural watersheds?
- What kinds of pollution could you expect in these different kinds of areas?
- Where would you expect the most nutrient pollution? The most pesticides and herbicides?
- What watersheds probably have the most sedimentation, heavy metal pollution, and thermal (heat) pollution?
- Where might you expect to find the most pathogens in the water?

Have students look at the USGS Water Watch site and judge whether or not their region is presently dry, wet, or average.

Ask them:

- What effect might a drought have on natural purification of waters? (Hint: Pollutants already in the water could be concentrated, but runoff from roads, lawns, and agricultural fields would likely be much lower).
- What effect might a flood have? (Hint: It depends on whether or not there are healthy ecosystems surrounding the water body).

Development

Water purification occurs in nature in several different ways
Begin with a brainstorming session on how natural purification of water really works. Bring in a clear glass

of muddy water (put it somewhere to settle), a sponge, and a coffee filter. Ask students what natural ecosystems could perform the functions of these items. (Hint: ponds, wetlands, and forests). It might be a little more challenging to mimic the functions of the living organisms that contribute so much to water purification. There are some websites below that will show students what these microbes look like. It's what they "do for a living" that makes them so important to this ecosystem service.

Water purification occurs when ecosystems slow the water down
Forests, woodlands, wetlands, and natural grasslands act as sponges to slow the movement of water from where it falls as precipitation to where it enters streams, lakes, and estuaries. This is important to natural purification because many of the processes by which the water is cleaned are biological processes—often performed by microbes like bacteria and fungi. The layer of bacteria, fungi, and algae that covers underwater surfaces has a technical name: "slime." Only kidding. Actually it is known as "periphyton" (which means "slime growing on underwater objects").

To show students what some of these organisms look like in real life at their own minuscule scale, go to the **Cyanobacterial Image Gallery**. Click on Eubacteria ("true bacteria") and then on Cyanobacteria ("blue-green bacteria") for photos and a video called The Great Escape that shows a cyanobacterium defending itself from a predator.

You can find good photos of the green algae on the Tree of Life website at the **Popular Groups on the Tree of Life** page. Click on Green Plants, then on Zygnematales (pronounced "ZIGE nee mah TALE ees").

Biological processes take time, so the longer water takes to make its way across the landscape, the greater the chance that biological processes will clean the water. When humans replace natural vegetation with impervious surfaces such as paved roads and parking lots, water runs off the landscape very quickly and usually is not naturally purified much at all before it reaches the stream or lake. Unfortunately, these same impervious surfaces are usually a source of additional pollutants that come from cars, things people drop, things animals drop (!), and other wastes.

Once runoff water reaches a stream, natural woody debris dams become very important. Debris dams form when streamside trees die and fall into the water. Leaves and sticks catch on the wood, and the water is forced to slow down a bit as it moves through and over the dam. When the water is slowed by a debris dam, the periphyton organisms described above have more time to act, and thus a better chance of doing their job.

For a long time, people thought that debris dams were messy, and contributed to floods during high water. They were removed from many miles of streams and rivers by dredging. We now understand that they are very important to the retention, or slowing, of water and materials carried by the water. They are the sites of a lot of in-stream water purification. Along the shores of lakes, trees also fall into the water, and can be similarly important to water purification by providing surfaces for the microbes that do it. Incidentally, trees that fall into lakes are called "structure" by fishermen, and are usually great places to catch fish because of the habitat they provide.

Wood is good! See **Wood in Streams**, part of a report on The State of Maryland's Freshwater Streams. This section discusses the importance of wood in streams and includes a picture of a Maryland stream that is in good shape for wood, and the services that it provides.

For contrast, you can take your students to the **Los Angeles River Tour**. Not very far from the headwaters, students will find that the river is actually a big concrete channel. There is nothing in this river to slow the water down, and any ecosystem services that it might have provided in its natural state have been lost.

You might also check out the **USGS Water Science for Schools** site, where students can learn more about impervious surfaces in urban and suburban areas. Ask students where the impervious areas are in their watersheds. Are there several large ones? Many small ones? (Hint: Don't forget roofs!).

You can perform a simple experiment with your students that shows the difference in runoff speed between an impervious (paved) and a pervious (vegetated) area. Select the sites matched as closely as possible for slope, and measure off the same distance for each (a couple of meters will work well). Pour a measured amount of water—3-5 gallons—at the top of the slope and time how long it takes to get to the bottom. Use enough water so that you can easily see it moving along the vegetated slope. In some places, the water may all be absorbed by the soil with vegetation on it before it gets to the bottom of the slope!

Water purification occurs when ecosystems remove pollution from the water
Wetlands and streamside (riparian) forests are particularly important for removing fine sediments from runoff. As sediment-laden water moves across and through these ecosystems, 80-90% of the fine particles settle to the bottom or are filtered out. Other pollutants such as organics, metals, and radionuclides (radioactive elements) are often adsorbed by (stuck onto) silt particles. Settling of the silt removes these pollutants from the water. Thus sediment deposition provides multiple benefits to downstream water quality.

Ranchers and watershed managers in the West are employing some of nature's own engineers for water quality improvement. Beaver-created impoundments (the "lakes" that form upstream of their dams) can be extremely useful in agricultural watersheds. They have been known to retain up to 1,000 times more nitrogen than streams without beaver dams. This has really opened the eyes of some water quality managers to ecosystem services.

There are many other stream animals that help filter the water. Many of the caddisflies construct nets that filter particles out of moving water. They clean their nets periodically, and eat some of the munchies that get stuck there. Black flies are also filter feeders, but their filtering devices are actually modified antennae that look kind of like giant Mickey Mouse ears sticking up from their heads.

If you have a relatively clean stream nearby, you can find filtering animals on a field trip. Just look very closely on or under rocks in a swift water area of the stream. The New York State Department of Environmental Conservation site has a nice photo identification guide, **Key to Aquatic Macroinvertebrates**. If you cannot take a real field trip, you can take students to websites showing aquatic animals that help remove suspended materials from the water.

Beavers will be familiar to youngsters, but if anyone wants to see and read more about nature's engineers, **Nature's Hydrologists**, the second chapter of Alice Outwater's book, *Water: A Natural History*, offers a lyrical glimpse at the rodents.

The site of the **North American Benthological Society** includes photos of black flies as well as the aquatic insects that build filtering nets on rocks. There are pictures of these nets as well as time lapse photos of a net being clogged (intentionally, by the diabolical scientists who study the insects), and how the insect modifies its net to foil the scientists and continue collecting its lunch. Benthological is an under-appreciated word that means "bottom living."

Not all of the water purification services are provided by aquatic ecosystems, a lot happens on the land too. Precipitation moves into soil and is gradually released to plants, as well as to underground water (aquifers) and surface streams. Without soil and plants, as mentioned above, water runs off the land in flash floods. Plants shield the soil from the force of raindrops, which would otherwise quickly turn the soil into mud and wash much of it away. The amount of water that soaks into soil is determined by the soil organic matter content. Human disturbance, such as cultivation, reduces soil organic matter, makes soils more prone to erosion, and reduces their water-holding capacity. These changes, in turn, alter stream flow: increasing the frequency, severity, and unpredictability of floods. Floods tend to erode stream channels, lower water quality, and degrade aquatic habitat.

Ask students to illustrate, with pictures drawn or cut from magazines, the ways that soil and plants contribute to the ecosystem service of water purification.

There is still much that we do not understand about how aquatic and terrestrial ecosystems perform the service of water purification. Factors such as location, size, type of soil and vegetation, water flow (patterns and extremes), and the landscape in which the ecosystem exists are all important. But predicting how much and what type of materials and pollutants can be "processed" within a natural ecosystem—without permanently harming the ecosystem—is very difficult.

Healthy microbial assemblages in soil and on surfaces in water change the form (and possibly the toxicity) of pesticides and they also remove heavy metals, such as mercury, that are harmful to life. Wetlands can remove 20-60% of heavy metals in the waters moving through them, and microbes in ecosystems can also change herbicides so that they are no longer toxic.

You can't talk very long about natural water purification without mentioning the hydrologic (water) cycle. Get your students to talk about the cycle, and explore **The Water Cycle**, on the USGS website. Did the artist show wetlands and riparian forests in this graphic? What are the potential pollution sources in the picture? What ecosystems might work to purify the water? Should they be larger in relation to the pollution sources? The role of plants, roots, and microbes in water purification can be difficult for children to picture in their minds, as well as challenging to simulate in the classroom. Try the EPA Safewater website, which describes a simple and inexpensive experiment (**Role of Plants in Water Filtration**) that you and your students can do to demonstrate how contaminants can be removed from water. Now and then the news will cover natural water purification—usually by mentioning the role of wetlands. **The Environmental News Network** site sometimes carries targeted articles that might be of interest to your class.

The U.S. federal government spends more than $2 billion annually for clean water initiatives. This number might be hard for school children to conceive of. Just to give them an idea of how big a number 2 billion is, if you neatly piled up 2 billion pennies, they would occupy the same amount of space as 10 school buses. How much more might be spent if natural water purification was no longer working properly?

Water purification by nature is worth a lot. But how much is it worth? Begin with a brainstorming session on the kinds of services provided by ecosystems, and how natural water purification fits into these categories. Three that you might consider are: • production inputs—that is, how the ecosystem contributes to the production of certain goods

and services (e.g. clean drinking water);

- the sustenance of plant and animal life—that is, how the ecosystem contributes to the organisms that are used directly by humans (e.g. fish, forests), as well as those in the supporting food web (e.g. insects, fungi);
- non-use values—that is, how the ecosystem might be valued in ways that do not contribute directly or indirectly to the economy. One that has been considered is "existence value" or the value of just knowing that the ecosystem is there, even if you don't intend to use it for anything

One way of estimating the value of an ecosystem service is to figure out what the replacement cost would be if the service was lost. In New York City, the replacement cost for the water purification services once provided "free" by its now-contaminated watershed was estimated at $6 to $8 billion to build a filtration plant (plus $300 million per year to operate it). Officials discovered that restoring the health of the watershed—and hence its water purification service—would cost only $1 billion. This was an easy decision for New York State. The restoration includes costs to purchase and halt development on land in the watershed, to compensate landowners for restrictions on development, and to improve septic systems.

Another way of estimating the value of natural water purification is to look at how humans try to mimic this ecosystem service in order to save money. Constructed wetlands are a good example. Wetlands are sometimes constructed as an alternative to wastewater treatment facilities. Water purification technology is costly, and in the case of drinking water, the more polluted the water, the more money is needed for disinfectants, such as chlorination, and the higher the energy, equipment, and labor costs. Constructed wetlands mimic the filtration and pollution-conversion functions of natural wetlands and are sometimes cost efficient for small communities that cannot afford wastewater treatment plants. Constructed wetlands are also used to treat agricultural runoff, suburban runoff, and other non-point sources of pollution.

Valuation of ecosystem services need not be limited to monetary notions. The value of the services can include aesthetic, biological, recreational, and health benefits. It is often difficult to give a monetary value to the services provided by natural ecosystems. There are many hidden benefits or tradeoffs that make it hard to evaluate and easy to underestimate the true value of any particular service. How much is your health worth? Sure, you can exercise and eat right, but what if the water you drink could make you sick?

The key to maintaining water purification services—and the value that they contribute to human life—is to protect and restore the ecosystems that provide these services. It makes economic sense for the present generation, and it makes sense to keep ecosystem services viable for generations yet to come.

Assessment

Ask your students to develop a "river newspaper." See the following suggestions:

- Reporters (who could pretend that they are drops of water) could interview the trees and soil in the surrounding ecosystems for news stories on how they helped keep the river clean.
- Include a letter-to-the-editor from a wetland. For example, the letter could complain about invasive exotic species.
- Have a feature article written by a net-building caddisfly. For example, "Look what I got from my net last week."
- Include advertisements designed for woody debris dams from the local beaver colony.

- Have students come up with a song or rap about ecosystem services, and have "reporters" cover it on the Entertainment page.
- Have students write classified ads, and maybe even some personal ads.
- Include a lot of artwork (fallen trees in streams are beautiful too).

Then… for real effect… invite a reporter from the local newspaper to visit the class and check out your river newspaper. Be sure to come up with a good name for it!

Extensions

For other systems lessons, see these Science NetLinks lessons:

- The Bicycle as a System
- The Cell as a System
- Building a Water Clock

For other Science NetLinks lessons addressing the Interdependence of Life benchmarks, see:

- Birds of Prey
- Food Webs in the Bay
- Hatching Brine Shrimp
- Brine Shrimp Survival

Water, Water, Everywhere, on the EconEdLink website, is related to this lesson. Although it does not discuss ecosystem services per se, it does refer to water as a "gift of nature" and lists some ways in which water is used as an economic resource. The central messages in this lesson and the Water, Water, Everywhere lesson are applicable to all grade levels.

Depending on the age of your students, you may wish to download the Wetlands Coloring Book available on the U.S. Fish & Wildlife Service website.