**Bringing Wetlands to Market Part 4 Exercise 2**
**Nitrogen and coastal wetlands**

**Focus Questions**
How does excess nitrogen from activities in a watershed affect the structure of a coastal marsh and its ability to store carbon?

**Performance Task**
Students will be able to describe how excess nitrogen reduces the ability of a coastal marsh to store carbon.
Students will communicate about the connections between activities in a watershed and impacts on coastal areas.

**Overview**
In this exercise, students will read and discuss recent research on the impact of excess nitrogen on the ability of a salt marsh to store carbon. This is a major focus of BWTM.

**Time Required**
One 45-minute class session.

**Teacher Background**
Review the students readings on the nitrogen cycle and "Why are our coastal marshes falling apart?"

**Procedure**

1. Introduce or review the nitrogen cycle with students using this online interactive exercise

2. To study the impact of nitrogen loading on wetlands in coastal areas have students read "Background on the nitrogen cycle." and have them write or discuss the answers to the guiding questions.

**Questions for reading on nitrogen cycle**

a. Why is nitrogen not biologically available to plants, even though it is abundant in the atmosphere?
Plants cannot use nitrogen in its atmospheric form as N2

b. How does nitrogen become biologically available in natural systems?
Nitrogen-fixing bacteria, algae, and lightning make nitrogen biologically available

c. How do humans provide nitrogen for agricultural crops?
Humans manufacture fertilizer which contains nitrogen

d. Why is too much nitrogen a problem in coastal waters?
Too much nitrogen stimulates the growth of algae, which then decompose in a process that depletes oxygen in the water. Abundant algae at the surface also blocks sunlight from marine or aquatic grasses.

3. Have students read "Why Are Our Salt Marshes Falling Apart?" which reports on how an oversupply of nitrogen affects the functioning of coastal wetlands. Provide the following guiding questions for students. Have them write answers or discuss as a group.

   **Questions for article on nitrogen and salt marshes**

   a. What did Dr. Deegan and her colleagues find out about nitrogen supply in salt marshes?
      An oversupply of nitrogen was associated with loss of soil structure in the marsh

   b. What were some of the effects the researchers observed when there was an oversupply of nitrogen to the marsh?
      High levels of nitrogen were associated with more above-ground growth and less growth of roots and below-ground structures

   c. How might nitrogen affect the ability of coastal wetlands to absorb carbon from the atmosphere?
      An oversupply of nitrogen may reduce the ability of a wetland to take up and sequester carbon.

4. Review with students the definition of a watershed: an area of land where all the surface water and ground water drains into the same place, such as a river, stream, lake or estuary. You may wish to refer to the Estuaries 101 activities on watersheds for more detail.

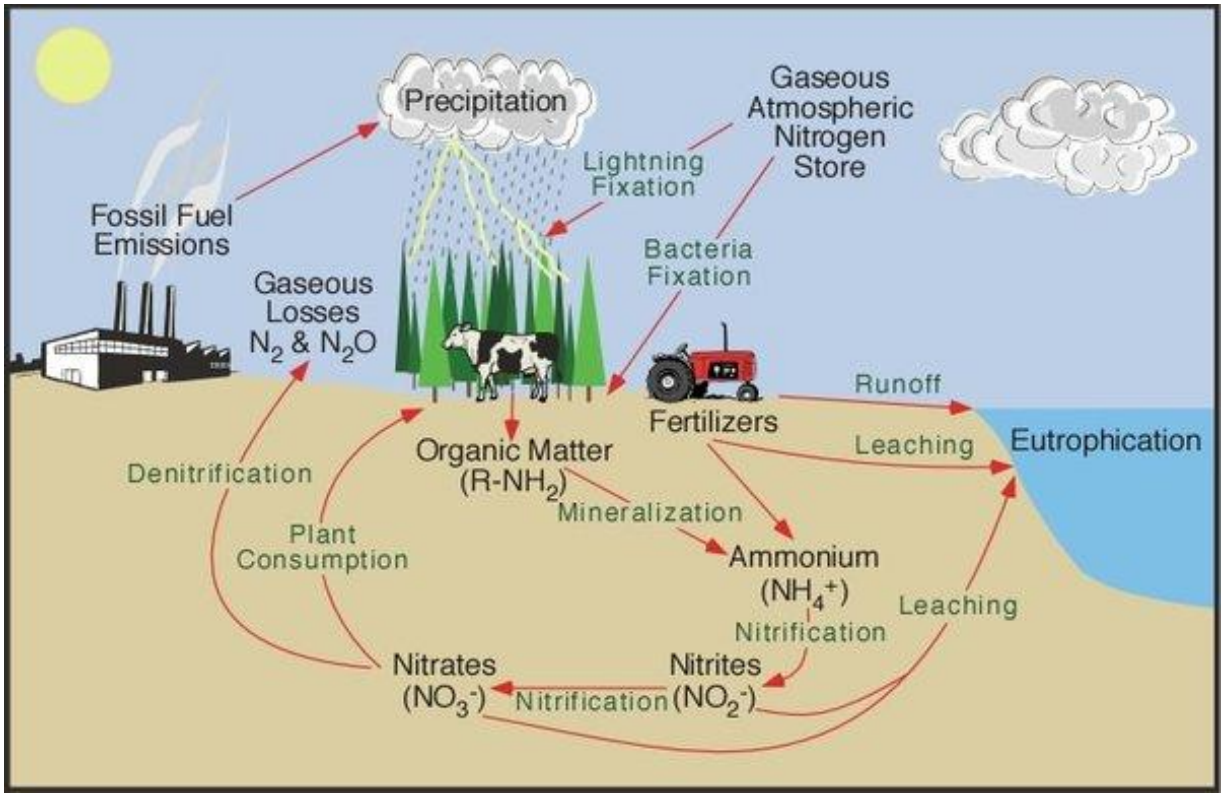
   Discuss with the class the connections between activities throughout a watershed, including inland areas, and impacts on coastal areas. Challenge students to find an engaging way to communicate to peers that the actions and land use throughout a watershed can have harmful effects on coastal areas, even if they are distant. Students could create a poster, video, or logo, or could write a Public Service Announcement for radio or a community note that could be broadcast on a local cable station. This activity would make a wonderful component of a class stewardship project or "Adopt a wetland" project.

**Additional resource**

For a more in-depth activity on the impact of nitrogen in coastal systems, refer to the Estuaries 101 lesson and activity about nitrogen loading and eutrophication

**Student Reading**
**Background on the nitrogen cycle**
Adapted from Pidwirny et al 2007. In Encyclopedia of Earth.
http://www.eoearth.org/article/Nitrogen_cycle

The nitrogen cycle (see diagram below) represents one of the most important nutrient cycles found in ecosystems. Nitrogen is a required nutrient for all living organisms to produce complex organic molecules like amino acids, the building blocks of proteins, and nucleic acids, including DNA and RNA. The ultimate store of nitrogen is in the atmosphere, where it exists as nitrogen gas ($N_2$). This store is about one million times larger than the total nitrogen contained in living organisms. Other major stores of nitrogen include organic matter in soil and the oceans. Despite its abundance in the atmosphere, nitrogen is often the most limiting nutrient for plant growth. This problem occurs because $N_2$ gas is not biochemically usable by plants. Plants can only take up nitrogen in the form of ammonium ion ($NH_4^+$), nitrate ion ($NO_3^-$), or, less commonly, as amino acids. Animals receive the nitrogen they need for metabolism, growth, and reproduction by the consumption of living or dead organic matter containing molecules composed partially of nitrogen.




Nitrogen cycle. (Source: PhysicalGeography.net)

In most ecosystems nitrogen is primarily stored in living and dead organic matter. This organic nitrogen is converted into inorganic forms when it re-enters the biogeochemical cycle via

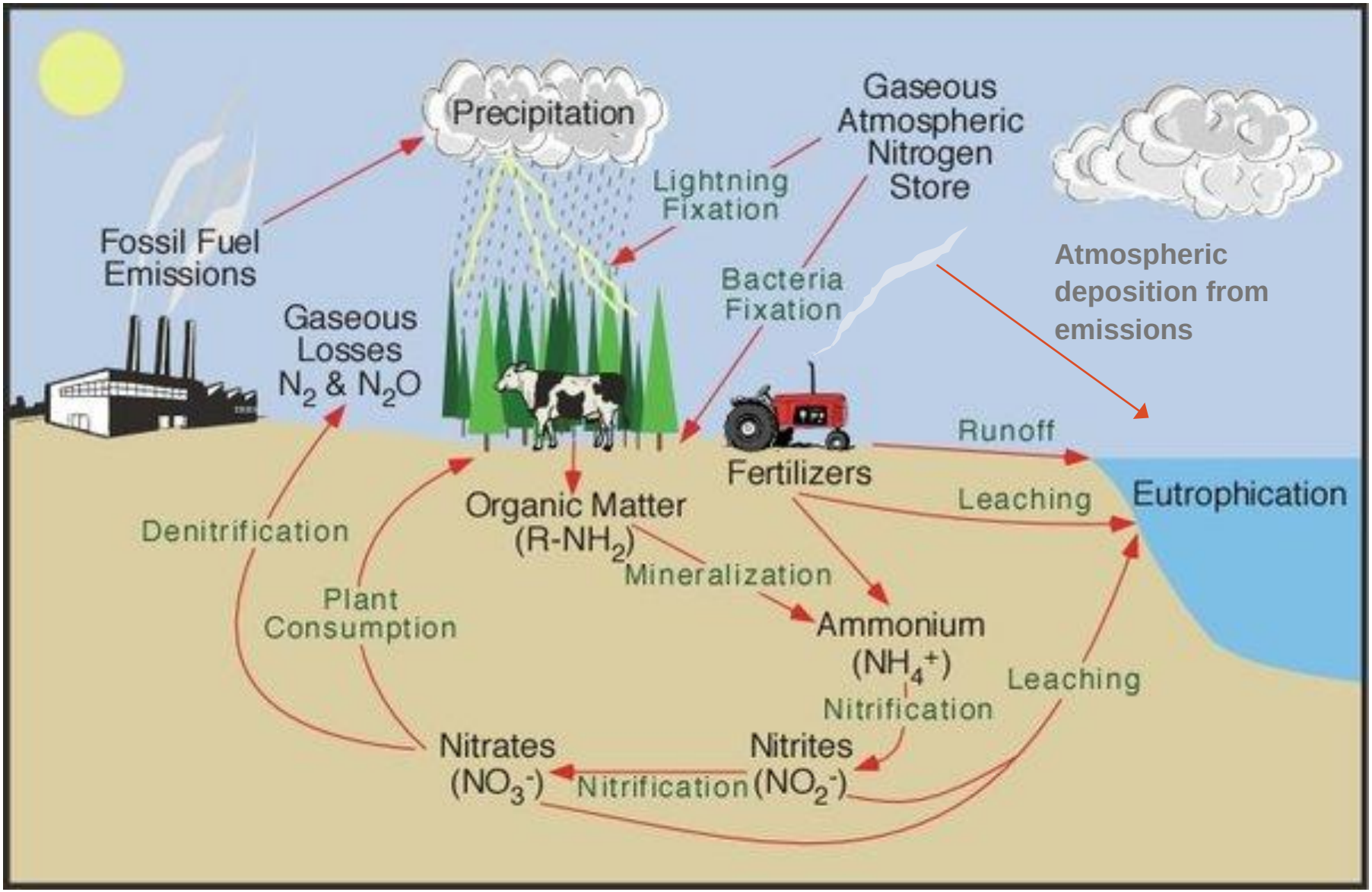
decomposition. Decomposers chemically modify the nitrogen found in organic matter to ammonium ion ($NH_4^+$). This process is known as mineralization and it is carried out by a variety of bacteria and fungi.

Most of the ammonium is chemically altered by a specific type of autotrophic bacteria (bacteria that belong to the genus Nitrosomonas) into nitrite ($NO_2^-$). Further modification by another type of bacteria (belonging to the genus Nitrobacter) converts the nitrite to nitrate ($NO_3$-). Both of these processes involve chemical oxidation and are known collectively as nitrification. However, nitrate is very soluble and it is easily lost from the soil system by leaching. Some of this leached nitrate flows through the hydrologic system until it reaches estuaries, coastal systems, and the ocean. Nitrogen can be returned to the atmosphere by denitrification. Denitrification is common in anaerobic soils and is carried out by heterotrophic bacteria. The process of denitrification involves the metabolic reduction of nitrate ($NO_3^-$) into nitrogen ($N_2$) or nitrous oxide ($N_2O$) gas. Both of these gases then diffuse into the atmosphere, thus removing nitrogen from the soil or water.

Almost all of the nitrogen found in any ecosystem originally came from the atmosphere. Significant amounts enter the soil in rainfall or through the effects of lightning. The majority, however, is biochemically fixed in ecosystems by specialized micro-organisms, all of which are bacteria of various types. Members of the bean family (legumes) and some other kinds of plants form mutualistic symbiotic relationships with certain types of nitrogen-fixing bacteria. In exchange for some nitrogen, the bacteria receive from the plants carbohydrates and special structures (nodules) in the roots where they can exist in a protected environment. Scientists estimate that biological fixation globally adds approximately 140 million metric tons of nitrogen to ecosystems every year.

Humans now fix approximately as much nitrogen industrially as does natural nitrogen fixation, thus dramatically altering the N cycle. The application of nitrogen fertilizers to crops, along with wastewater and septic tank leaching. has caused increased rates of nitrate to flow into groundwater. The additional nitrogen entering the groundwater system eventually flows into streams, rivers, lakes, and estuaries. In these systems, the added nitrogen can be an oversupply and result in hypoxia, or low-oxygen events.

How can this natural fertilizer have negative impacts? It is just too much of a good thing. It over-fertilizes the water, producing such large volumes of algae and other biomass that decomposers consume almost all the oxygen in the water, causing stress for the organisms in the ecosystem. Coastal bays, inlets and estuaries around the world are affected by this process, known as eutrophication.




**Nitrogen cycle** Note that nitrogen from distant sources can be transported to coastal areas in surface water, groundwater, and from the atmosphere. (Source: PhysicalGeography.net)

**Student Reading**
**Why Are Our Salt Marshes Falling Apart?**
October 17, 2012 by Diane Kenney, MBL

WOODS HOLE, Mass.—Salt marshes have been disintegrating and dying over the past two decades along the U.S. Eastern seaboard and other highly developed coastlines, without anyone fully understanding why. This week in the journal *Nature*, MBL Ecosystems Center scientist Linda Deegan and colleagues report that nutrients—such as nitrogen and phosphorus from septic and sewer systems and lawn fertilizers—can cause salt-marsh loss.

**Left:** Healthy salt marsh creeks at Plum Island Estuary, Massachusetts, are lined with lush, smooth cordgrass. The plant's below-ground roots and above-ground leaves build and maintain salt marshes. Credit: David S. Johnson

Salt marshes are a critical interface between the land and sea," Deegan says. "They provide habitat for fish, birds, and shellfish; protect coastal cities from storms; and they take nutrients out of the water coming from upland areas, which protects coastal bays from over-pollution." Losses of healthy salt marsh have accelerated in recent decades, with some losses caused by sea-level rise and development.

"This is the first study to show that nutrient enrichment can be a driver of salt-marsh loss, as well," says David S. Johnson of the MBL, a member of the team since the project began in 2003.

This conclusion, which surprised the scientists, emerged from a long-term, large-scale study of salt marsh landscapes in an undeveloped coastline section of the Plum Island Estuary in Massachusetts. Over nine years, the scientists added nitrogen and phosphorus to the tidal water flushing through the marsh's creeks at levels typical of nutrient enrichment in densely developed areas, such as Cape Cod, Mass., and Long Island, N.Y. (Usually, nutrients originating from septic systems, sewerage, and soil fertilizers on land flow with rainwater down to the coastal ocean.)

A few years after the experiment began, wide cracks began forming in the grassy banks of the tidal creeks, which eventually slumped down and collapsed into the muddy creek. "The long-term effect is conversion of a vegetated marsh into a mudflat, which is a much less productive

ecosystem and does not provide the same benefits to humans or habitat for fish and wildlife," Deegan says.

Until this study, it seemed that salt marshes had unlimited capacity for nutrient removal, with no harmful effects on the marshes themselves. "Now we really understand that there are limits to what salt marshes can do," Deegan says. "And in many places along the Eastern seaboard—such as Jamaica Bay in New York, where marshes have been falling apart for years—we have exceeded those limits."

**Left:** After eight years of nutrient enrichment, the edge of this salt marsh at Plum Island Estuary has fragmented and turf has slumped into the channel. Credit: Christopher Neill

The disintegration of the nutrient-enriched marsh in this study happened in several stages, the scientists report. In the first few years, the nutrients caused the marsh grass (primarily cordgrass *Spartina spp*.) along the creek edges to get greener and grow taller, "just like when you add fertilizer to your garden," Deegan says. This taller grass also, however, produced fewer roots and rhizomes, which normally help stabilize the edge of the marsh creek. The added nutrients also boosted microbial decomposition of leaves, stems, and other biomass in the marsh peat, which further destabilized the creek banks. Eventually, the poorly rooted grass grew too tall and fell over, where the twice-daily tides tugged and pulled it. The weakened creek bank then cracked and fell into the creek.

By year six of the experiment, the scientists started seeing impacts at higher marsh elevations, above the lower creek banks. Three times more cracks, and bigger cracks, emerged at the top of the banks parallel to the creeks, than in a control marsh where no nutrients were added. Eventually, parts of the higher marsh also broke off and slid down toward the creek (which the scientists call the 'toupee effect,' because it leaves behind patches of bare, unvegetated mud). All told, at least 2.5 times more chunks of marsh fell into the creeks in the nutrient-enriched marsh than in the control system.

"We honestly did not anticipate the changes we measured," says Deegan. "Based on prior small-scale experiments, we predicted nutrient enrichment would cause the marsh grass to grow better

and remain stable. But when we allowed different parts of the ecosystem to interact with the nitrogen enrichment over time, the small process changes we saw in the first few years resulted in the creek banks later falling apart. This could not have been extrapolated from the smaller-scale, shorter term studies."

**Above:** Linda Deegan, senior scientist in the MBL's Ecosystems Center, shows an assistant how to sample water to test for nutrients from a salt marsh creek at Plum Island Estuary, MA. Credit: Christopher Neill

Nutrient enrichment of coastal areas is known to cause harmful algae blooms, which create low-oxygen conditions that kill off marine life. "Now we understand that nutrient enrichment also causes a very important loss of salt marsh habitat for fish and shellfish," Deegan says. "This is one more reason why we need better treatment of household waste in our towns and cities." Individuals can help by not using fertilizers on their lawns and gardens. "If you have a green lawn because you are fertilizing it, you are contributing to loss of salt marshes and ultimately of fish," Deegan says.
This study could not have been accomplished without the cooperation and fore-sightedness of officials from the towns of Ipswich, Mass., and Rowley, Mass., and the Essex County Greenbelt Association, the scientists say.

"They recognized the importance of the work," Johnson says. "They understood that our work would not affect the much larger Plum Island Estuary, since the area manipulated was small relative to the large area of the sound and the marsh is able to process a lot of the nutrients before they get anywhere near the sound. They realized that whatever we discovered would help their towns, and society in general, make better decisions about treating the excessive nutrient enrichment of our coast."

This study is part of the Plum Island Ecosystem Long-Term Ecological Research (PIE-LTER) program, supported by the National Science Foundation (NSF). The PIE-LTER conducts basic science and provides information to coastal managers to help them make more informed decisions.
"This is a landmark study addressing the drivers of change in productive salt marsh ecosystems, and a stellar example of the value of supporting LTER sites," says David Garrison, program director in NSF's Division of Ocean Sciences, which supports the LTER program along with NSF's Division of Environmental Biology.

In the next phase of research, the scientists will study the recovery of the nutrient-enriched marsh. "After we stop adding the nitrogen, how long does it take the system to rebound to its natural state?" Deegan asks. This information will be important in reclaiming the health of salt marshes that are currently suffering from nutrient enrichment.

In addition to Deegan, Johnson, and Bruce J. Peterson of the MBL, co-authors of this study in *Nature* include: R. Scott Warren of Connecticut College; John W. Fleeger of Louisiana State University; Sergio Fagherazzi of Boston University; and Wilfred M. Wollheim of The University of New Hampshire.

**Citation:**

Deegan LA, Johnson DS, Warren RS, Peterson BJ, Fleeger JW, Fagherazzi S, and Wollheim WM ( 2012) Coastal Eutrophication as a Driver of Salt Marsh Loss. *Nature* 490: 388-392.

**Nature News & Views article:**

Pennings, SC (2012) Ecology: The big picture of marsh loss. *Nature* 490: 352-353.

Video Interview with Linda Deegan at Plum Island Estuary: http://youtu.be/eP3hRkX03Q8