RipCycles:
Nutrient Cycling in Riparian Ecosystems

Streamside, or **riparian**, forests constitute a unique and biologically diverse **ecosystem**. Like all ecosystems, riparian forests undergo **nutrient cycling**. Riparian ecosystems are unique interfaces between aquatic and terrestrial ecological communities. As a result, nutrient cycling in riparian ecosystems involves aquatic and terrestrial aspects and nutrients.

What is nutrient cycling?

Nutrient cycling is "the repeated pathway of particular nutrients or elements from the environment through one or more organisms back to the environment. Nutrient cycles include the carbon cycle, the nitrogen cycle, and the phosphorous cycle."*

What is a nutrient?

A nutrient is a material or molecule required by plants and animals for maintenance, growth, and reproduction. Examples of nutrients required by animals include water, protein (from nitrogen), vitamins, minerals (such as phosphates), and carbohydrates (from carbon). Examples of nutrients required by plants include carbon (in the form of carbon dioxide, CO_2), water, nitrogen (in the form of nitrates, NO_3^- and ammonia or ammonium ions), and phosphorous (in the form of phosphates, PO_4^{3-}).

Why are nutrient cycles important?

Ecosystems rely on three main processes to function sustainably: 1) nutrient cycling, 2) use of sunlight as the basic source of energy, and 3) population regulation to avoid exhaustion of resources. Because the amount of available nutrients in an ecosystem is fixed, nutrients must be constantly recycled between **biotic** (living) and **abiotic** (non-living) components to meet the requirements of living things in an ecosystem. Biotic components of ecosystems include aquatic and terrestrial producers, consumers, and decomposers. Abiotic components of ecosystems include rocks, soil, the atmosphere, and water. Cycling of the fixed quantity of nutrients ensures that enough nutrients are available to sustain ecosystem function while also avoiding problems associated with nutrient waste and accumulation. Just enough nutrients are available in ecosystems that function efficiently—no more, no less.

Three of the key elements in ecosystems are carbon, nitrogen and phosphorous. Thus, we will focus our study of nutrient cycling in riparian ecosystems on the carbon cycle, the nitrogen cycle, and the phosphorous cycle. Keep in mind that when studying cycles, one could start the cycle anywhere and follow the path of the nutrient through it. That is, a "cycle" is a series of events that occur over and over again. Cycles are continuous, with no beginning or end.

The Carbon Cycle

Carbon in an essential nutrient in ecosystems because it is a structural component of all organic molecules (e.g., carbohydrates, fats, proteins, and nucleic acids [RNA and DNA]). Carbon is also extremely important in living systems because the bonds between carbon atoms and bonds between carbon atoms and other atoms store the chemical energy required for life. We will commence our study of the carbon cycle with the carbon that is in the form of carbon dioxide (CO_2). Carbon dioxide in the air is used by terrestrial producers and dissolved carbon dioxide in water is used by aquatic producers. **Producers** are organisms that use sunlight to make organic molecules (i.e., food and tissues) out of inorganic molecules (e.g., water, minerals, and nutrients, including carbon). Via **photosynthesis** and **metabolism**, riparian producers (plants and trees on land; algae, **phytoplankton**, vegetation, and some bacteria in the water) convert the carbon atoms in CO_2 into plant tissue and energy in the form of sugar molecules (glucose, $C_6H_{12}O_6$).

The carbon in terrestrial producers consumed by terrestrial herbivores and the carbon in phytoplankton consumed by aquatic herbivores then become part of the terrestrial and aquatic food chains. That is, the carbon atoms are successively consumed and become part of the organisms by which they are consumed. For example, rabbits, examples of terrestrial herbivores, feed on vegetation such as wild flowers and assimilate the carbon in that vegetation into food and tissue. Owls prey upon rabbits and assimilate "rabbit carbon" into "owl food and tissue."

Terrestrial herbivores are analogous to aquatic grazers. Both terrestrial herbivores and aquatic grazers consume producers. On land, producers such as green plants convert carbon dioxide and sun energy into plant tissue and sugar. In the water, producers such as cyanobacteria (blue-green algae) and phytoplankton transform carbon dioxide and sun energy into bacteria tissue and sugar. Just as terrestrial herbivores consume terrestrial producers and convert carbon from those producers into herbivore tissue and energy, so do aquatic grazers, such as caddisfly larvae, water penny beetle larvae, and some mayfly nymphs, consume aquatic producers and convert carbon from those producers into grazer tissue and energy. Like owls prey upon rabbits in terrestrial ecosystems, aquatic predators such as crayfish, hellgrammites, damselfly and dragonfly nymphs, and fish prey upon aquatic grazers and assimilate "grazer carbon" into "predator food and tissue."

Carbon stored in vegetative matter (leaves, needles, organic matter) that falls from riparian canopies to the forest floor or into waterways follows slightly different carbon cycle pathways. For example, a fallen leaf on the forest floor is consumed by detritivores such as ants, which convert "leaf carbon" into "ant food and tissue." Decomposers such as fungi and bacteria complete the breakdown of the leaf and return the carbon to the atmosphere. A leaf that falls into a waterway is first colonized by bacteria to form **coarse particulate organic matter (CPOM)**. **Shredders** (e.g., cranefly larvae, case-building caddisfly larvae, scuds, aquatic sowbugs) consume CPOM and gradually break it down into **fine particulate organic matter (FPOM).** Filtering collectors (e.g., blackfly larvae, mussels, worms, and net-spinning caddisfly larvae) consume FPOM.

Each time the carbon atoms are consumed, some are broken down during respiration and decomposition. Both respiration and decomposition release carbon back into the atmosphere or water in the form of carbon dioxide. Whether carbon atoms are consumed by herbivores, grazers, detritivores, decomposers, shredders, or collectors, carbon from the consumed organism is assimilated into food and tissue by the consumer. When carbon is assimilated into shell or bone tissue by shellfish, such as freshwater mussels, or vertebrate consumers, such as fish and squirrels, the carbon is first fixed into calcium carbonate ($CaCO_3$). Carbon is locked up in shells and bones in the form of calcium carbonate for long periods of time. However, calcium carbonate is soluble in water, thus waterways and weathering eventually dissolve shells, skeletons, and other deposits of calcium carbonate, releasing carbon back into the atmosphere and waterways. Carbon locked up in biomass is also liberated naturally into the atmosphere, in the form of carbon dioxide, by fires or **combustion**.

Another pathway in the carbon cycle is a process called **sedimentation**. Sedimentation occurs when aquatic biomass settles to the bottom of waterways. Gathering collectors (some mayfly nymphs, caddisfly larvae, and midge larvae) consume some of this biomass. Like other organisms, gathering collectors store carbon in their tissues and release carbon into the water during respiration. Aquatic predators consume many gathering collectors and the carbon atoms continue to move up the food chain. The sedimented aquatic biomass that is not consumed by gathering collectors is converted into coal, oil and natural gas over millions of years. Carbon remains locked up in these forms until it is disturbed by human activity, such as the burning of coal for electricity or the burning of gasoline to power cars. By burning fossil fuels, humans disrupt the carbon cycle and put excess carbon dioxide into the atmosphere. This disruption leads to global climate change.

All nutrient cycle pathways, including the carbon cycle, involve biotic and abiotic components as well as sources and sinks. Waterways and vegetation, including riparian vegetation such as cattails and willows, are referred to as carbon **sinks** because they remove large quantities of carbon from the atmosphere via photosynthesis and deposition of calcium carbonate. Large quantities of carbon are also stored in terrestrial soils like those found in riparian forests. Respiration, decomposition and combustion release carbon into the atmosphere, so they are referred to as carbon **sources**.

The Nitrogen Cycle

Nitrogen is important to living systems because it is used by living organisms to synthesize amino acids, proteins, DNA and RNA. The main source of nitrogen in ecosystems is the air, which consists of about 78% nitrogen gas. Despite the abundance of nitrogen gas in the atmosphere, nitrogen in this form is unusable by producers. Only nitrogen in the form of nitrate ions (NO_3^-), ammonium ions (NH_4^+), or ammonia (NH_3) is useful to producers. Although some bacteria and lightning convert nitrogen gas into nitrates, ammonia or ammonium ions, this usable nitrogen is often available only in small quantities. Therefore, nitrogen is frequently the factor that limits the rate of plant growth in ecosystems.

Useless nitrogen gas is transformed into useful ammonium ions by bacteria in the process of **nitrogen fixation.** In terrestrial ecosystems, the bacterium *Rhizobium* is the most important agent of nitrogen fixation. *Rhizobium* can be free living in the soil but most live in the nodules of **leguminous** plants and trees such as peas, beans, clover and alfalfa, *Acacia* trees and black locusts. Alders are non-leguminous trees but they do have root nodules in which *Rhizobium* live. These bacteria provide usable nitrogen to these producers in return for food and a place to live. Another important terrestrial nitrogen-fixing bacteria is *Frankia*. *Frankia* live in the roots of trees and woody shrubs. Therefore, *Frankia* is the most likely agent of nitrogen fixation in riparian forests. Cyanobacteria, or blue-green algae, are the most important nitrogen fixers in aquatic ecosystems but are also important in damp areas of forests where they live in symbiosis with lichens.

In both terrestrial and aquatic ecosystems, the process of nitrogen fixation produces ammonium ions that are usable by producers. However, many of these ammonium ions do not remain in that form. Via the process of **nitrification**, ammonium ions are converted to plant-toxic nitrite ions and eventually to non-toxic nitrate ions, which are taken up by producers. During **assimilation**, plant roots absorb ammonium and/or nitrate ions and use them to synthesize amino acids, proteins, RNA and DNA. A small amount of atmospheric nitrogen gas is converted to ammonium ions by lightning in a process called **atmospheric nitrogen fixation**. These ammonium ions are then available to be assimilated by vegetation that cannot fix its own nitrogen.

As in the carbon cycle, nitrogen in vegetation is consumed and enters the food chain. Like carbon, nitrogen is returned to the environment via respiration. Specifically, excretion puts nitrogen back into the soil. Nitrogen escapes into the atmosphere when anaerobic bacteria transform dissolved nitrogen into nitrogen gas in the process of **denitrification**. Decomposers transform dead, nitrogen-rich organic matter into ammonia and ammonium ions via **ammonification**. All of these processes keep nitrogen from building up in soil and water.

Although natural nitrogen cycling prevents build-up and shortages of nitrogen, human disruption of this cycle leads to excess nitrogen in our soils and water. Nitrogen is added to agricultural fields as fertilizer. Much of this nitrogen is eventually washed into waterways in runoff. The result of excess nitrogen in waterways is an algal bloom or explosive algal growth. When the algae dies, the decomposers that break it down deplete the waterway of oxygen, adversely affecting aquatic life.

The Phosphorous Cycle

Phosphorous is a crucial mineral nutrient because compounds containing phosphorous are instrumental in energy transfer processes, which affect productivity. Phosphorous is also part of DNA, nucleic acids, and fats, as well as animal teeth, shells, and bones. Phosphorous is found in rock and soil minerals in the form of phosphate ions (PO_4^{3-}). Inorganic phosphate ions are released as these rocks and soils are weathered and broken down. Phosphate is water-soluble but is not found in the air, unlike carbon and nitrogen. Phosphates are often the limiting factor for aquatic and terrestrial producers (e.g., plants and algae) because of the slow weathering process of rocks. Phosphorous is also a limiting factor in ecosystems because phosphorous is not available in gaseous form and is only slightly water-soluble.

Producers absorb inorganic phosphate from soil and water and fix it into organic phosphate. Organic phosphate enters the food chain when producers are consumed. Like the other nutrients, phosphorous is liberated during respiration and returned to the environment during excretion and decomposition, making it available to be reabsorbed by other producers. Phosphate does not have a gaseous state so it can only be recycled where it is excreted, making for efficient recycling. All other mineral nutrients are cycled in a similar fashion.

Because phosphorous is locked up in the soil and in organisms' tissues, when riparian forests are cut down for lumber, phosphorous in the soil is exposed and swept away by runoff, leaving the land virtually barren of phosphorous. Even more phosphorous is removed from the riparian ecosystems when the lumber is transported away. The trees that are removed from the riparian ecosystem take with them the phosphorous in their tissues instead of being left to decompose and return that phosphorous to the soil. In agricultural areas, intact riparian forests can absorb phosphorous from the adjacent agricultural runoff; however, in agricultural areas where riparian forest buffers are disrupted, high concentrations of phosphates wash into waterways, resulting in algal blooms and subsequent eutrophication. Human land use practices that exacerbate erosion, such as the cutting down of riparian forests, worsen phosphorous depletion in terrestrial ecosystems and phosphorous overabundance in aquatic ecosystems because most phosphate is attached to sediment that is washed away during erosion.

References

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