# Unit 4: Ecosystems // Section 4: Biogeochemical Cycling in Ecosystems

Along with energy, water and several other chemical elements cycle through ecosystems and influence the rates at which organisms grow and reproduce. About 10 major nutrients and six trace nutrients are essential to all animals and plants, while others play important roles for selected species (footnote 3). The most important biogeochemical cycles affecting ecosystem health are the water, carbon, nitrogen, and phosphorus cycles.

As noted earlier, most of the Earth's area that is covered by water is ocean. In terms of volume, the oceans dominate further still: nearly all of Earth's water inventory is contained in the oceans (about 97 percent) or in ice caps and glaciers (about 2 percent), with the rest divided among groundwater, lakes, rivers, streams, soils, and the atmosphere. In addition, water moves very quickly through land ecosystems. These two factors mean that water's residence time in land ecosystems is generally short, on average one or two months as soil moisture, weeks or months in shallow groundwater, or up to six months as snow cover.

But land ecosystems process a lot of water: almost two-thirds of the water that falls on land as precipitation annually is transpired back into the atmosphere by plants, with the rest flowing into rivers and then to the oceans. Because cycling of water is central to the functioning of land ecosystems, changes that affect the hydrologic cycle are likely to have significant impacts on land ecosystems. (Global water cycling is discussed in more detail in Unit 8, "Water Resources.")

Both land and ocean ecosystems are important sinks for carbon, which is taken up by plants and algae during photosynthesis and fixed as plant tissue. Table 2 compares the quantities of carbon stored in Earth's major reservoirs.

**Table 2.** Global carbon storage. **Source:** NOAA, www.pmel.noaa.gov/co2/gif/globcar.png.

| **Location** | **Amount (gigatons carbon)** |
|---|---|
| Atmosphere | 750 |
| Land plants | 610 |
| Soil and detritus | 1,500 |
| Surface ocean | 1,020 |
| Intermediate and deep ocean | 37,890 |
| Sediments | 78,000,000 |

Carbon cycles relatively quickly through land and surface-ocean ecosystems, but may remain locked up in the deep oceans or in sediments for thousands of years. The average residence time that a molecule of carbon spends in a terrestrial ecosystem is about 17.5 years, although this varies widely depending on the type of ecosystem: carbon can be held in old-growth forests for hundreds of years, but its residence time in heavily grazed ecosystems where plants and soils are repeatedly turned over may be as short as a few months.

Human activities, particularly fossil fuel combustion, emit significant amounts of carbon each year over and above the natural carbon cycle. Currently, human activities generate about 7 billion tons of carbon per year, of which 3 billion tons remain in the atmosphere. The balance is taken up in roughly equal proportions by oceans and land ecosystems. Identifying which ecosystems are absorbing this extra carbon and why this uptake is occurring are pressing questions for ecologists.

Currently, it is not clear what mechanisms are responsible for high absorption of carbon by land ecosystems. One hypothesis suggests that higher atmospheric $CO_2$ concentrations have increased the rates at which plants carry out photosynthesis (so-called $CO_2$ fertilization), but this idea is controversial. Controlled experiments have shown that elevated $CO_2$ levels are only likely to produce short-term increases in plant growth, because plants soon exhaust available supplies of important nutrients such as nitrogen and phosphorus that also are essential for growth.

Nitrogen and phosphorus are two of the most essential mineral nutrients for all types of ecosystems and often limit growth if they are not available in sufficient quantities. (This is why the basic ingredients in plant fertilizer are nitrogen, phosphorus, and potassium, commonly abbreviated as NPK.) A slightly expanded version of the basic equation for photosynthesis shows how plants use energy from the sun to turn nutrients and carbon into organic compounds:

$CO_2$ + $PO_4$ (phosphate) + $NO_3$ (nitrate) + $H_2O$ → $CH_2O$, P, N (organic tissue) + $O_2$

Because atmospheric nitrogen ($N_2$) is inert and cannot be used directly by most organisms, microorganisms that convert it into usable forms of nitrogen play central roles in the nitrogen cycle. So-called nitrogen-fixing bacteria take inert nitrogen ($N_2$) from the atmosphere and convert it to ammonia ($NH_4$) nitrate ($NO_3$) and another nitrogen compounds, which in turn are taken up by plants. Some of these bacteria live in mutualistic relationships on the roots of plants, mainly legumes (peas and beans), and provide nitrogen directly to the plants; farmers often plant these crops to restore nitrogen to depleted soils. At the back end of the cycle, decomposers break down dead organisms and wastes, converting organic materials to inorganic nutrients. Other bacteria carry out denitrification, breaking down nitrate to gain oxygen and returning gaseous nitrogen to the atmosphere (Fig. 9).

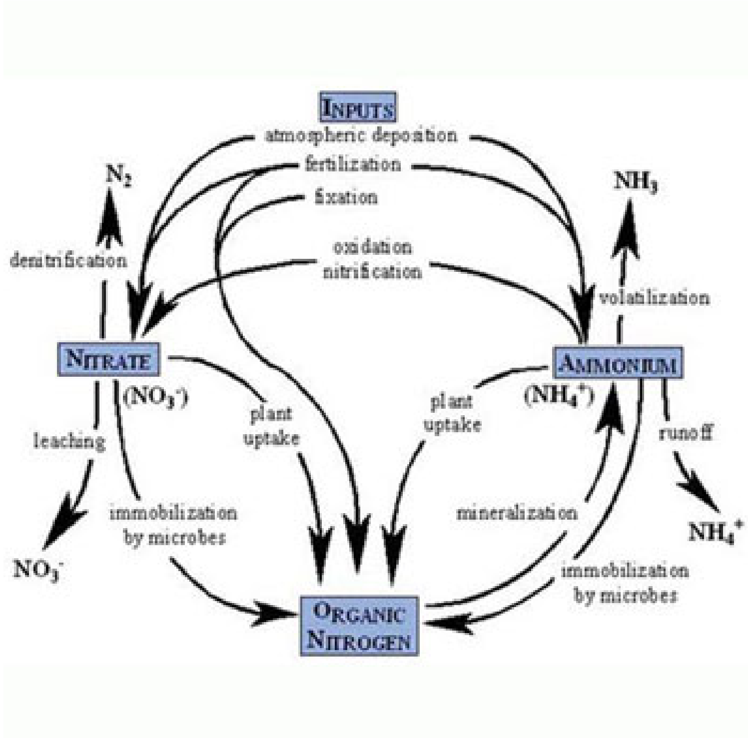


**Figure 10.** The nitrogen cycle
See larger image

**Source:** � U.S. Department of the Interior, National Park Service.

Human activities, including fossil fuel combustion, cultivation of nitrogen-fixing crops, and rising use of nitrogen fertilizer, are altering the natural nitrogen cycle. Together these activities add roughly as much nitrogen to terrestrial ecosystems each year as the amount fixed by natural processes; in other words, anthropogenic inputs are doubling annual nitrogen fixation in land ecosystems. The main effect of this extra nitrogen is over-fertilization of aquatic ecosystems. Excess nitrogen promotes algal blooms, which then deplete oxygen from the water when the algae die and decompose (for more details, see Unit 8, "Water Resources"). Additionally, airborne nitrogen emissions from fossil fuel combustion promote the formation of ground-level ozone, particulate emissions, and acid rain (for more details, see Unit 11, "Atmospheric Pollution").

Phosphorus, the other major plant nutrient, does not have a gaseous phase like carbon or nitrogen. As a result it cycles more slowly through the biosphere. Most phosphorus in soils occurs in forms that organisms cannot use directly, such as calcium and iron phosphate. Usable forms (mainly orthophosphate, or $PO_4$) are produced mainly by decomposition of organic material, with a small contribution from weathering of rocks (Fig. 11).

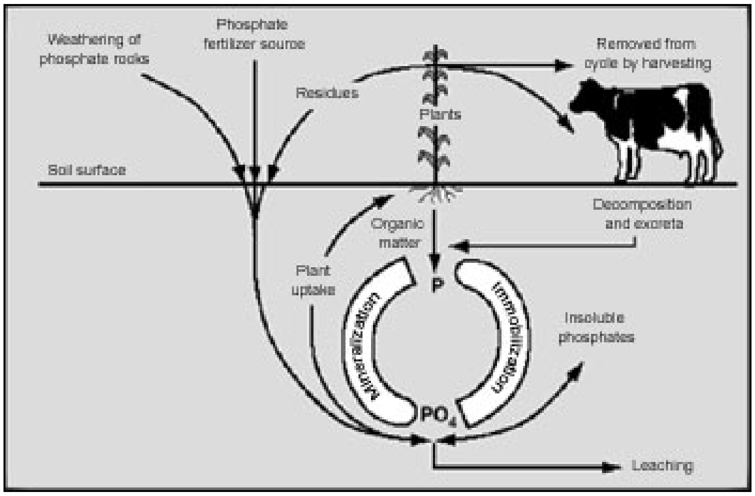


**Figure 11.** The phosphorus cycle
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**Source:** � United States Environmental Protection Agency.

The amount of phosphate available to plants depends on soil pH. At low pH, phosphorus binds tightly to clay particles and is transformed into relatively insoluble forms containing iron and aluminum. At high pH, it is lost to other inaccessible forms containing calcium. As a result, the highest concentrations of available phosphate occur at soil pH values between 6 and 7. Thus soil pH is an important factor affecting soil fertility.

Excessive phosphorus can also contribute to over-fertilization and eutrophication of rivers and lakes. Human activities that increase phosphorus concentrations in natural ecosystems include fertilizer use, discharges from wastewater treatment plants, and use of phosphate detergents (for details, see Unit 8, "Water Resources").