**Nitrogen cycle**

It is the circulation of nitrogen in various forms through nature. Nitrogen, a component of proteins and nucleic acids, is essential to life on Earth. Although 78 percent by volume of the atmosphere is nitrogen gas, this abundant reservoir exists in a form unusable by most organisms. Through a series of microbial transformations, however, nitrogen is made available to plants, which in turn ultimately sustain all animal life. The steps, which are not altogether sequential, fall into the following classifications: nitrogen fixation, nitrogen assimilation, ammonification, nitrification, and denitrification.

Nitrogen fixation, in which nitrogen gas is converted into inorganic nitrogen compounds, is mostly (90 percent) accomplished by certain bacteria and blue-green algae. A much smaller amount of free nitrogen is fixed by abiotic means (e.g., lightning, ultraviolet radiation, electrical equipment) and by conversion to ammonia through the Haber-Bosch process.

Nitrates and ammonia resulting from nitrogen fixation are assimilated into the specific tissue compounds of algae and higher plants. Animals then ingest these algae and plants, converting them into their own body compounds.

The remains of all living things—and their waste products—are decomposed by microorganisms in the process of ammonification, which yields ammonia (NH3) and ammonium (NH4+). (Under anaerobic, or oxygen-free, conditions, foul-smelling putrefactive products may appear, but they too are converted to ammonia in time.) Ammonia can leave the soil or be converted into other nitrogen compounds, depending in part on soil conditions.

Nitrification, a process carried out by nitrifying bacteria, transforms soil ammonia into nitrates (NO3−), which plants can incorporate into their own tissues.

Nitrates also are metabolized by denitrifying bacteria, which are especially active in water-logged anaerobic soils. The action of these bacteria tends to deplete soil nitrates, forming free atmospheric nitrogen.

**Processes in the nitrogen cycle**

Five main processes cycle nitrogen through the biosphere, atmosphere, and geosphere: nitrogen fixation, nitrogen uptake through organismal growth, nitrogen mineralization through decay, nitrification, and denitrification. Microorganisms, particularly bacteria, play major roles in all of the principal nitrogen transformations. Because these processes are microbially mediated, or controlled by microorganisms, these nitrogen transformations tend to occur faster than geological processes like plate motion, a very slow, purely physical process that is a part of the carbon cycle. Instead, rates are affected by environmental factors that influence microbial activity, such as temperature, moisture, and resource availability.

**1. Nitrogen fixation**

Nitrogen fixation is the process wherein N2 is converted to ammonium, or NH4+. This is the only way that organisms can attain nitrogen directly from the atmosphere; the few that can do this are called nitrogen-fixing organisms. Certain bacteria, including those among the genus Rhizobium, are able to fix nitrogen (or convert it to ammonium) through metabolic processes, analogous to the way mammals convert oxygen to CO2 when they breathe. Nitrogen-fixing bacteria often form symbiotic relationships with host plants. This symbiosis is well-known to occur in the legume family of plants (e.g., beans, peas, and clover). In this relationship, nitrogen-fixing bacteria inhabit legume root nodules (Figure 2) and receive carbohydrates and a favorable environment from their host plant in exchange for some of the nitrogen they fix. There are also nitrogen-fixing bacteria that exist without plant hosts, known as free-living nitrogen fixers. In aquatic environments, blue-green algae (really a bacteria called cyanobacteria) are an important free-living nitrogen fixer.

In addition to nitrogen-fixing bacteria, high-energy natural events such as lightning, forest fires, and even hot lava flows can cause the fixation of smaller, but significant, amounts of nitrogen. The high energy of these natural phenomena can break the triple bonds of N2 molecules, thereby making individual N atoms available for chemical transformation.

Within the last century, humans have become as important a source of fixed nitrogen as all natural sources combined. Burning fossil fuels, using synthetic nitrogen fertilizers, and cultivating legumes all fix nitrogen. Through these activities, humans have more than doubled the amount of fixed nitrogen that is pumped into the biosphere every year (Figure 3), the consequences of which are discussed below.

**2. Nitrogen uptake**

NH4+ → Organic N

The ammonium (NH4+) produced by nitrogen-fixing bacteria is usually quickly taken up by a host plant, the bacteria itself, or another soil organism and incorporated into proteins and other organic nitrogen compounds, like DNA. When organisms nearer the top of the food chain (like us!) eat, we are taking up nitrogen that has been fixed initially by nitrogen-fixing bacteria.

**3. Nitrogen mineralization**

Organic N → NH4+

After nitrogen is incorporated into organic matter, it is often converted back into inorganic nitrogen by a process called nitrogen mineralization, otherwise known as decay. When organisms die, decomposers (such as bacteria and fungi) consume the organic matter and lead to the process of decomposition. During this process, a significant amount of the nitrogen contained within the dead organism is converted to ammonium. Once in the form of ammonium, nitrogen is available for use by plants or for further transformation into nitrate (NO3-) through the process called nitrification.

**4. Nitrification**

NH4+ → NO3-

Some of the ammonium produced by decomposition is converted to nitrate (NO3-) via a process called nitrification. The bacteria that carry out this reaction gain energy from it. Nitrification requires the presence of oxygen, so nitrification can happen only in oxygen-rich environments like circulating or flowing waters and the surface layers of soils and sediments. The process of nitrification has some important consequences. Ammonium ions (NH4+) are positively charged and therefore stick (are sorbed) to negatively charged clay particles and soil organic matter. The positive charge prevents ammonium nitrogen from being washed out of the soil (or leached) by rainfall. In contrast, the negatively charged nitrate ion is not held by soil particles and so can be washed out of the soil, leading to decreased soil fertility and nitrate enrichment of downstream surface and groundwater.

**5. Denitrification**

NO3- → N2+ N2O

Through denitrification, oxidized forms of nitrogen such as nitrate (NO3-) and nitrite (NO2-) are converted to dinitrogen (N2) and, to a lesser extent, nitrous oxide gas (NO2). Denitrification is an anaerobic process that is carried out by denitrifying bacteria, which convert nitrate to dinitrogen in the following sequence:

NO3- → NO2- → NO → N2O → N2.

Nitric oxide and nitrous oxide are gases that have environmental impacts. Nitric oxide (NO) contributes to smog, and nitrous oxide (N2O) is an important greenhouse gas, thereby contributing to global climate change.

Once converted to dinitrogen, nitrogen is unlikely to be reconverted to a biologically available form because it is a gas and is rapidly lost to the atmosphere. Denitrification is the only nitrogen transformation that removes nitrogen from ecosystems (essentially irreversibly), and it roughly balances the amount of nitrogen fixed by the nitrogen fixers described above.

