Biogeochemical Cycles

"Describe the flow of essential elements from the environment through living organisms and back into the environment"

'Fundamentals' of biogeochemical cycles

- All matter cycles...it is neither created nor destroyed...
- As the Earth is essentially a closed system with respect to matter, we can say that *all matter on Earth cycles* .

Biogeochemical cycles: the movement (or cycling) of matter through a system

by matter we mean: elements (carbon, nitrogen, oxygen) or molecules (water)

so the movement of matter (for example carbon) between these parts of the system is, practically speaking, a biogeochemical cycle

The Cycling Elements:

macronutrients : required in relatively large amounts

"big six": carbon , hydrogen , oxygen , nitrogen , phosphorous
sulfur

other macronutrients:

potassium , calcium , iron , magnesium

micronutrients : required in very small amounts, (but still necessary)

boron (green plants)
copper (some enzymes)
molybdenum (nitrogen-fixing bacteria)

The Nitrogen Cycle

- All life requires nitrogen-compounds, e.g., proteins and nucleic acids.
- Air, which is 79% nitrogen gas (N_2), is the major reservoir of nitrogen.
- But most organisms cannot use nitrogen in this form.
- Plants must secure their nitrogen in "fixed" form, i.e., incorporated in compounds such as:
    - nitrate ions (NO_3^-)
    - ammonium ions (NH_4^+)

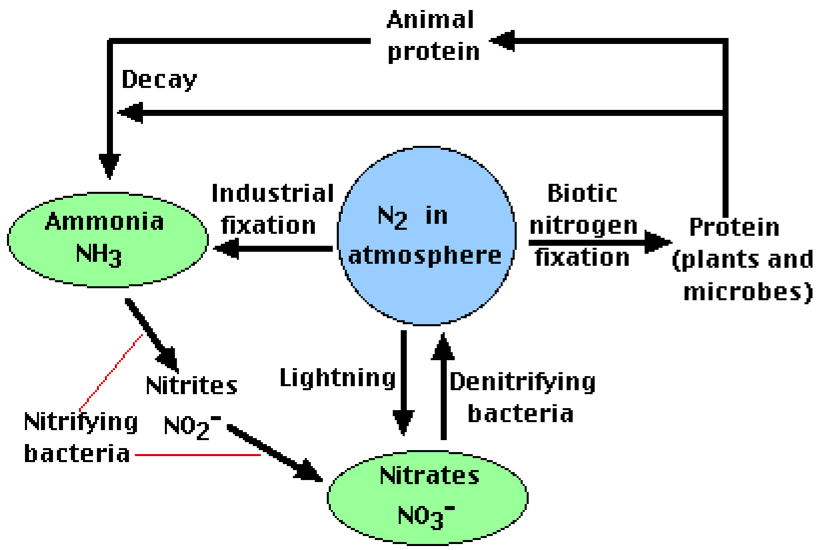
- urea $(NH_2)_2CO$

- Animals secure their nitrogen (and all other) compounds from plants (or animals that have fed on plants).

Four processes participate in the cycling of nitrogen through the biosphere:

- nitrogen fixation
- decay
- nitrification
- denitrification

Microorganisms play major roles in all four of these.



Nitrogen Fixation

The nitrogen molecule (N_2) is quite inert. To break it apart so that its atoms can combine with other atoms requires the input of substantial amounts of energy.

Three processes are responsible for most of the nitrogen fixation in the biosphere:

- **atmospheric fixation** by lightning
- **biological fixation** by certain microbes — alone or in a symbiotic relationship with some plants and animals
- **industrial fixation**

Atmospheric Fixation

The enormous energy of lightning breaks nitrogen molecules and enables their atoms to combine with oxygen in the air forming nitrogen oxides. These dissolve in rain, forming nitrates, that are carried to the earth.

Atmospheric nitrogen fixation probably contributes some 5– 8% of the total nitrogen fixed.

Industrial Fixation

Under great pressure, at a temperature of 600°C, and with the use of a catalyst, atmospheric nitrogen and hydrogen (usually derived from natural gas or petroleum) can be combined to form ammonia (NH_3). Ammonia can be used directly as fertilizer, but most of its is further processed to urea and ammonium nitrate (NH_4NO_3).

Biological Fixation

The ability to fix nitrogen is found only in certain bacteria and archaea.

- Some live in a symbiotic relationship with plants of the legume family (e.g., soybeans, alfalfa).

- some establish symbiotic relationships with plants other than legumes (e.g., alders).
- Some establish symbiotic relationships with animals, e.g., termites and "shipworms" (wood-eating bivalves).
- Some nitrogen-fixing bacteria live free in the soil.
- Nitrogen-fixing cyanobacteria are essential to maintaining the fertility of semi-aquatic environments like rice paddies.

Biological nitrogen fixation requires a complex set of enzymes and a huge expenditure of ATP.

Although the first stable product of the process is ammonia, this is quickly incorporated into protein and other organic nitrogen compounds.

Decay

The proteins made by plants enter and pass through food webs just as carbohydrates do. At each trophic level, their metabolism produces organic nitrogen compounds that return to the environment, chiefly in excretions. The final beneficiaries of these materials are microorganisms of decay. They break down the molecules in excretions and dead organisms into **ammonia**.

Nitrification

Ammonia can be taken up directly by plants — usually through their roots. However, most of the ammonia produced by decay is converted into **nitrates**. This is accomplished in two steps:

- Bacteria of the genus **Nitrosomonas** oxidize NH_3 to **nitrites** (NO_2^-).
- Bacteria of the genus **Nitrobacter** oxidize the nitrites to **nitrates** (NO_3^-).

These two groups of autotrophic bacteria are called **nitrifying bacteria**. Through their activities (which supply them with all their energy needs), nitrogen is made available to the roots of plants.

Both soil and the ocean contain archaeal microbes, assigned to the Crenarchaeota, that convert ammonia to nitrites. They are more abundant than the nitrifying bacteria and may turn out to play an important role in the nitrogen cycle.

Many legumes, in addition to fixing atmospheric nitrogen, also perform nitrification — converting some of their organic nitrogen to nitrites and nitrates. These reach the soil when they shed their leaves.

Denitrification

The three processes above remove nitrogen from the atmosphere and pass it through ecosystems.

Denitrification reduces nitrates and nitrites to nitrogen gas, thus replenishing the atmosphere. In the process several intermediates are formed:

- nitric oxide (NO)
- nitrous oxide (N_2O)(a greenhouse gas 300 times as potent as CO_2)
- nitrous acid (HONO)

Once again, bacteria are the agents. They live deep in soil and in aquatic sediments where conditions are anaerobic. They use nitrates as an alternative to oxygen for the final electron acceptor in theirrespiration.

Anammox (anaerobic ammonia oxidation)

Under anaerobic conditions in marine and freshwater sediments, other species of bacteria are able to oxidize ammonia (with NO_2^-) forming nitrogen gas.

$$NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O$$

The anammox reaction may account for as much as 50% of the denitrification occurring in the oceans.

All of these processes participate in closing the nitrogen cycle.

Ecological Implications of Human Alterations to the Nitrogen Cycle

Many human activities have a significant impact on the nitrogen cycle. Burning fossil fuels, application of nitrogen-based fertilizers, and other activities can dramatically increase the amount of biologically available nitrogen in an ecosystem. And because nitrogen availability often limits the primary productivity of many ecosystems, large changes in the availability of nitrogen can lead to severe alterations of the nitrogen cycle in both aquatic and terrestrial ecosystems. Industrial nitrogen fixation has increased exponentially since the 1940s, and human activity has doubled the amount of global nitrogen fixation (Vitousek *et al*. 1997).