Nutrient Cycles

Energy flows through ecosystems (one way trip). Unlike energy, however, nutrients (P, N, C, K, S…) cycle within ecosystems. Nutrients are important in controlling NPP in ecosystems. "Bottom-up" control.

Nutrients – elements required for the development, maintenance, and reproduction of organisms.

Nutrient cycle – transformation, movement, and reuse of nutrients in ecosystem.

1) nutrients have physiological importance and are scarce in ecosystems, 2) nutrients control NPP, 3) creation, movement and transformation of pollutants are linked to nutrient cycles, and 4) nutrient cycles are involved in global biogeochemical processes that affect the Earth's climate and atmospheric chemistry.

Important nutrient cycles are:

Carbon cycle
Nitrogen cycle
Phosphorus cycle
Hydrologic cycle
Sulfer cycle

The availability of Nitrogen and Phosphorus control many aspects of global biogeochemistry - often limit rates of primary production on land and in sea.
C, N, P, and S (+ others) are essential components of life – enzymes, DNA, ATP, cellular membranes, structural compounds…
Thus nutrient cycles are linked to energy flow through ecosystems (control on NPP).
Changes in the availability of, for example, N and P through geologic time have controlled the size and activity of the biosphere.

General points about cycles:

Storage reserviors, transfer, transformation:

Abiotic reserviors - atmosphere, water (hydrosphere), rocks and sediments (lithosphere)
Biotic reserviors - aquatic and terrestrial ecosystems.

Organisms obtain many nutrients (eg, Phosphorus) from weathering of rock (lithosphere).
Carbon and Nitrogen derive mainly from atmosphere.
Sulfer comes from both atmosphere and lithosphere.
Hydrologic cycle is involved many of the processes.

Example with Nitrogen cycle:

Collectively, these microbial reactions drive the global cycle of Nitrogen.

Storage reserviors: The global Nitrogen cycle is characterized by a relatively small biogeochemical cycle with rapid turnover (50 yrs) that is coupled to a giant global pool of N_2 gas in the atmosphere that has a very slow turnover rate.

The large atmospheric storage reservior (pool) of N is linked to the N cycle by the processes of N_2 fixation (to ecosystem from atm.) and denitrification (from ecosystem to atm.) controlled by microbes in aquatic and terrestrial ecosystems.

Biological N_2 Fixation - N_2 is fixed and transformed to NH_3 by cyanobacteria in soil and aquatic env., 2) bacteria associated with roots of leguminous plants, 3) some fungi associated with roots of woody plants like Alder (*Alnus*).

Abiotic N_2 fixation - lightning N_2 to NO_3^-.

This is about 15% of the nitrogen that is needed for plants on land each year.

Most organisms, however, obtain N from uptake from soil solution or from ingestion.

Transformations: A large number of biochemical **transformations** of N are possible.

Valence of -3 (in NH3) and +5 (in NO3-)

Various microbes capitalize on the potential for chemical transformations of Nitrogen, and use the energy released by these transformations to maintain their life processes.

These microbial reactions drive the global cycle of Nitrogen.

Ammonification (mineralization) - type of transformation.

Nitrogen in decomposing plant and animal material undergoes a process called **ammonification** (mineralization) to form NH_4^+.

Rate of decomposition of organic material is influenced by temperature, moisture, and chemical composition of litter.

Figure 16.7 from textbook. C:N , Lignin:N

Figure 16.8 from textbook. Higher decomposition where AET is higher.

NH_4^+. is oxidized to NO_3^- by chemoautotrophic bacteria (*Nitrosomonas, Nitrobacter*) through a process called **nitrification**.

Denitrification: Other microbes return N_2 to the atmosphere by a process called denitrification

Denitrification takes place when NO_3^- is converted to N_2O or N_2 by bacteria *Pseudomonas* under anaerobic conditions. NO_3^- is used by these bacteria as the final electron acceptor in energy metabolism (rather than O_2 under aerobic conditions). Denitrification returns the N_2 to the atmosphere.

Human impact on terrestrial nutrient cycles is huge!

Carbon cycle:

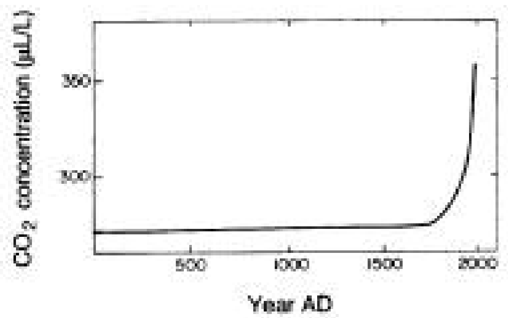

FIG. 3. Concentrations of CO_2 in the atmosphere over the past 2000 yr, determined by analysis of air bubbles trapped in the Greenland and Antarctic ice caps (Raynaud et al. 1993). Redrawn from Webb and Bartlein (1992).

Deforestation, burning of fossil fuels, cement processing
CO_2 is a "greenhouse" gas

Nitrogen cycle:

Natural N fixation:
Total abiotically fixed N_2 deposited on land is about 10 Tg/yr (Tg=10^{12} g N)
Total biologically fixed N_2 on land is about 100 Tg/yr

Anthropogenic N fixation:

Fertilizer production through the Haber process (similar to lightning fixation- high temp and pressure) adds 80 Tg/yr.!
Combustion of fossil fuels that contain nitrogen adds 25 Tg/yr.!!! Most is deposited in wet deposition on land.
Leguminous crops that fix nitrogen add 30 Tg/yr above background N fixation on those lands.

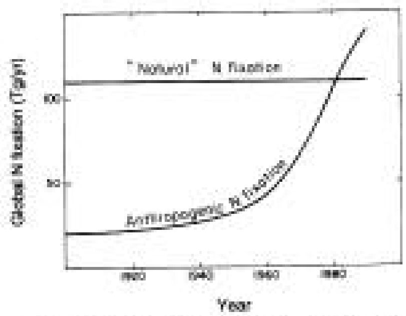

FIG. 6. Extent of human alteration of the global biogeochemical cycle of nitrogen. The "natural N fixation" line represents biological N fixation in natural terrestrial systems plus fixation by lightning; I assume that natural biological fixation has not changed recently, although it probably has declined due to land use change and increased N deposition. The "anthropogenic N fixation" line represents the sum of industrial N fixation for fertilizers, fixation during fossil fuel combustion, and fixation by leguminous crops (Smil 1991, Vitousek and Matson 1993). *Nitrogen biogeochemistry. The change reports the modern fractions for each source.*

Overall - humans have more than doubled the rate at which N enters biogeochemical cycle!!!

Consequences of altered N biogeochemistry

Where is this Nitrogen going??? Fixed N is transferred to rivers and streams or is volatalized as ammonium and tranported to other ecosystems as wet and dry deposition. This is pollution!

Many industrialized regions are experincing huge increases in deposition of Nitrogen, but deposition is raised globally.

Forest dieback in many regions of European industrialized areas can be attributed to increased Nitrate deposition (acid rain).

<u>At population and community level</u>:

Fertilization experiments show declining diversity to dominance by a few nitrogen demanding plant species (weeds).

Nitrogen demanding grasses in Europe have increased over this century just from deposition (not fertilization)

Diversity at larger scale may be decreasing as well as we lose N limited ecosystems that harbor unique species.

Increased N in tissues can be expected to alter relationships between consumers, decomposers and symbionts as well.

<u>Denitrification has likely increased as well</u>.

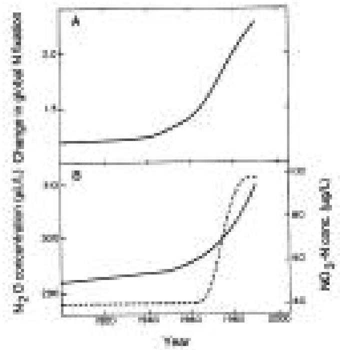

FIG. 9. Changes in global N fluxes during the 20th century. (A) Human alteration of global N fixation, as the ratio of anthropogenic to total (anthropogenic plus natural) N fixation (from Fig. 8). (B) Concurrent patterns in atmospheric concentrations of the greenhouse gas nitrous oxide (——) (Watson et al. 1992) and in nitrate concentrations at the mouth of the Mississippi River (- - -) (Turner and Rabalais 1991).

One of the products of denitrification is N_2O (nitrous oxide), which is a greenhouse gas and and a cause of ozone destruction in the stratosphere.

N_2O trace gas is increasing in atmosphere and may be related to human alteration of global N cycle.

Destruction of ozone in the stratosphere is exacerbated by N_2O. In fact Reaction with O3 in stratosphere is the only known process that gets rid of N_2O.

NO_2 is another by product of microbial action, but this is very reactive and will catalyze the **FORMATION** of ozone in the troposphere.

NO_2 + O2 <---> NO + O_3 Smog in Phoenix!!!

Thus – greater anthropogenic N fixation (tofu) >> greater N2O flux >> greenhouse warming

For further reading:

Vitousek, P. 1994. Beyond Global Warming: Ecology and Global Change, Ecology 75:1861-1876