CHEMICAL: NITROGEN AND PHOSPHORUS
(read pp239-250 in Dodson)

BACKGROUND

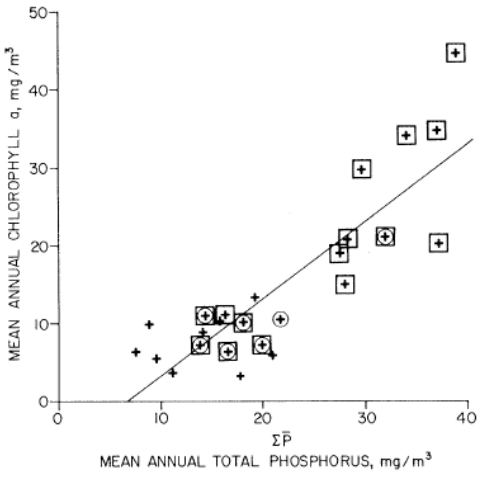
Lakes are often classified according to trophic status, specifically how much energy or food is available for the lake food web.

- Oligotrophic—Low rates of primary productivity. These lakes usually have few nutrients and are relatively "pristine". These lakes are generally characterized by having low light attenuation, low nutrients, and orthograde oxygen curves.
- Mesotrophic—Intermediate rates of primary productivity.
- Eutrophic—high rates of primary productivity. This is generally caused by high levels of nutrient loading. Eutrophic lakes are generally characterized by having high nutrients, rapid light attenuation, and clinograde oxygen curves.

- *Cultural eutrophication*—One of the major human perturbations of freshwaters is eutrophication. Eutrophication refers to a lake becoming more productive and exhibiting characteristics of this type of lake (rapid light attenuation, high rates of primary productivity). Excess nutrient inputs (generally P) drive eutrophication.

PHOSPHORUS

- Phosphorus is usually the limiting nutrient in freshwaters. Thus, understanding the Phosphorus cycle has proved critical in management and conservation of freshwater systems. Excess phosphorus is the leading driver of eutrophication.
- There are several lines of evidence that demonstrated that P is the main driver of lake productivity.
    - Whole-lake experiment by D.W. Schindler (1977).
    - Surveys of many lakes that found strong relationships between TP and lake production.



(Graph: D.W. Schindler. 1977. Science)

Forms of Phosphorus

- Soluble Reactive Phosphorus (SRP)—Dissolved forms of phosphorus that are available for uptake by primary producers. Includes organic and inorganic forms (e.g., Orthophosphate). Generally around 10% of TP.
- Orthophosphate—Inorganic form of phosphate (PO_4^{3-}). Orthophosphate is a key form of SRP.
- Dissolved organic phosphorus (DOP)—Released by organisms (living/dead), includes ATP.
- Particulate organic phosphorus (POP)—Phosphorus locked up in living or dead plant and animal matter.
- Particulate inorganic phosphorus (PIP)—Orthophosphate that has been locked up by other molecules such as calcium, iron (Fe), or magnesium. Relatively inert (inactive) form of P.

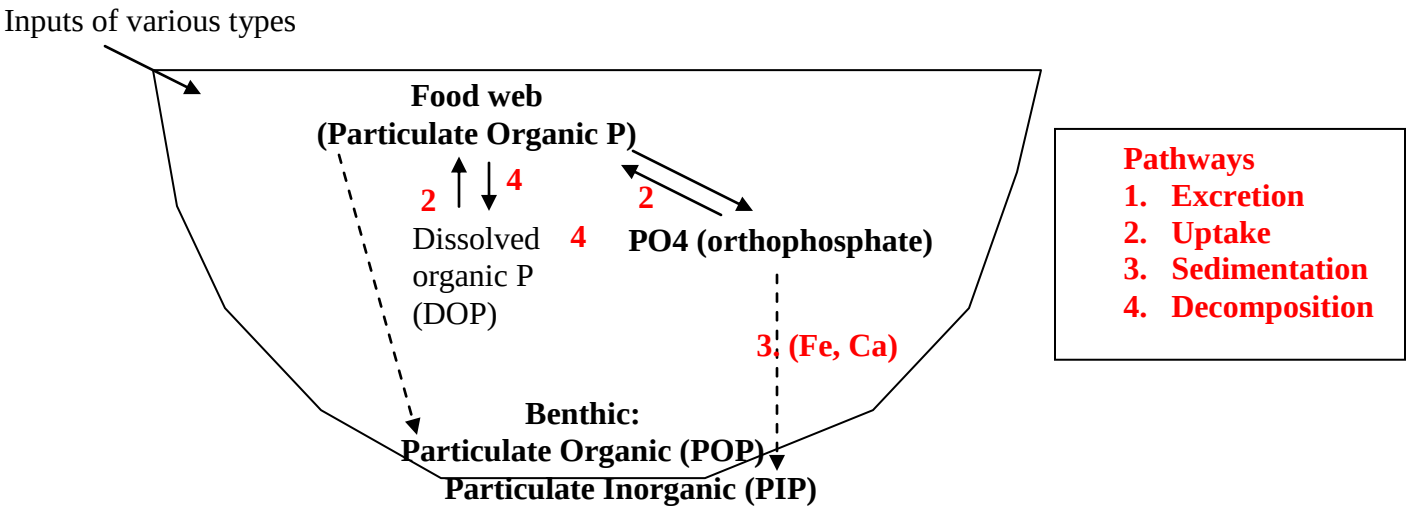
Reservoirs of Phosphorus

- Rocks and soil (lithosphere)—P is common in many rocks and soils. Often found as apatite (calcium phosphate). Most important reservoir.
- Biotic—Especially in freshwaters, a lot of P is found in plants and animals. Excretion is a major pathway by which accessible P becomes available.
- Freshwaters—See below. A lot P in freshwaters is found in the sediments or in living and dead animal and plant material.
- Ocean—A lot of P has been locked up and deposited in sediments of oceans. Thus, old ocean sediments are often P-rich, being an important landscape-level control of P.
- Atmosphere—Occurs generally as particulate matter in dust.

Stratification--Over the summer, available P (PO_4) is often depleted in the epilimnion. Thus, there can be pronounced stratification of P in some lakes.

Recycling--Animals play a huge role in cycling P in lakes. Fish and zooplankton eat particulate organic phosphorus (POP) and then excrete soluble P (DOP and PO_4).

Phosphorus cycle



NITROGEN

Nitrogen is the second most likely nutrient to limit primary production in a lake (after Phosphorus). Nitrogen limitation can develop in a lake when there is excess P input (such as due to sewage inputs)

Forms:

- Nitrogen gas (N_2): This gas makes up ~80% of the atmosphere. Thus, the atmosphere is a huge reservoir of Nitrogen. However, it is relatively inert, and only some bacteria (and lightning) can convert N_2 to more usable forms such as nitrogen oxides (NOx)or ammonia (NH_4).
- Nitrate (NO_3^-) and nitrite (NO_2^-): Nitrate can be used by plants. Nitrite can be toxic to life.
- Ammonia (NH_4): This form is created by nitrogen fixation (by bacteria or human industry). In addition, ammonium is often released as a waste product. When O_2 is present, Ammonia oxidizes to Nitrate. In water, NH_3 is ionized to produce NH_4^+.
- Organic nitrogen: Nitrogen is often found as part of organic nitrogen compounds such as amino acids ($R\text{-}NH_3$).

Reservoirs:

- Atmosphere: This is the dominant reservoir of nitrogen, where N2 gas composes ~80% of the atmosphere.
- Rocks: N can be found in rocks, but this is not as important as the atmosphere.
- Oceans: N is also found dissolved in ocean water.
- Freshwaters: N2 gas dissolves into water, but is inert unless transformed during N fixation.

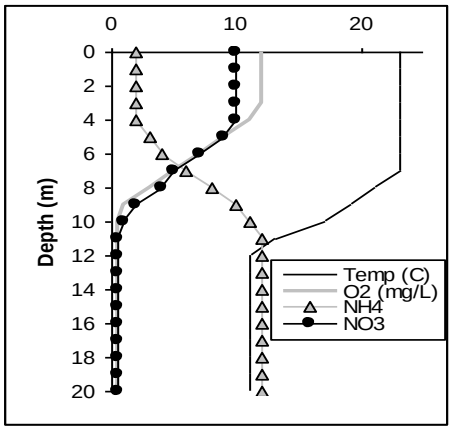
- Food webs: Like P, N is often found within the materials of plants and animals of aquatic food webs.

Processes that transform N:

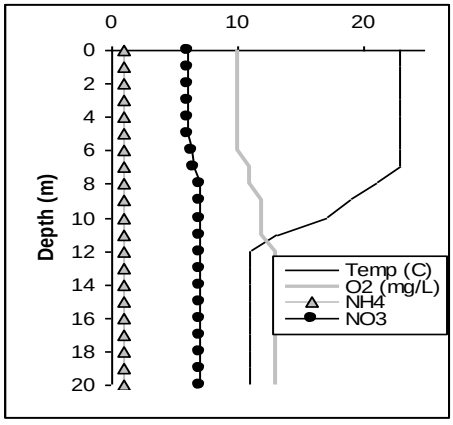
- N fixation: N2 → NH4 (Nitrogen gas to Ammonia). N fixation is performed by bacteria (alone or in symbiosis). Blue-green algae (aka., cyanobacteria) fix nitrogen with special enzymes that only work in the absence of oxygen. *Heterocysts* are morphological adaptations of many blue-green algae that allow this to happen—thick-walled cells without oxygen. N fixation is energetically costly, so generally only happens when nitrogen becomes limiting (often due to excess P inputs).
- Nitrification: NH_4→ NO_2 or NO_3 (Ammonia to Nitrate/Nitrite). Happens due to bacteria *only in the presence of Oxygen*.
- Denitrification: NO_3→N_2 (Nitrate to Nitrogen gas). Happens in the absence of Oxygen.
- Assimilation: NO_3→R-N. (Nitrate to organic matter). Algae and bacteria take up NH_4 (ammonia) and NO_3 (nitrate—shown above) to build matter (such as amino acids).
- Excretion: → NH_4 (ammonia) or $HN(CH_3)^2$ (urea). Organisms excrete nitrogen as a waste product of metabolism.

Vertical stratification of Nitrogen: There can strong seasonal stratification of Nitrogen, mainly depending on stratification of Oxygen (which in turn depends on primary production).

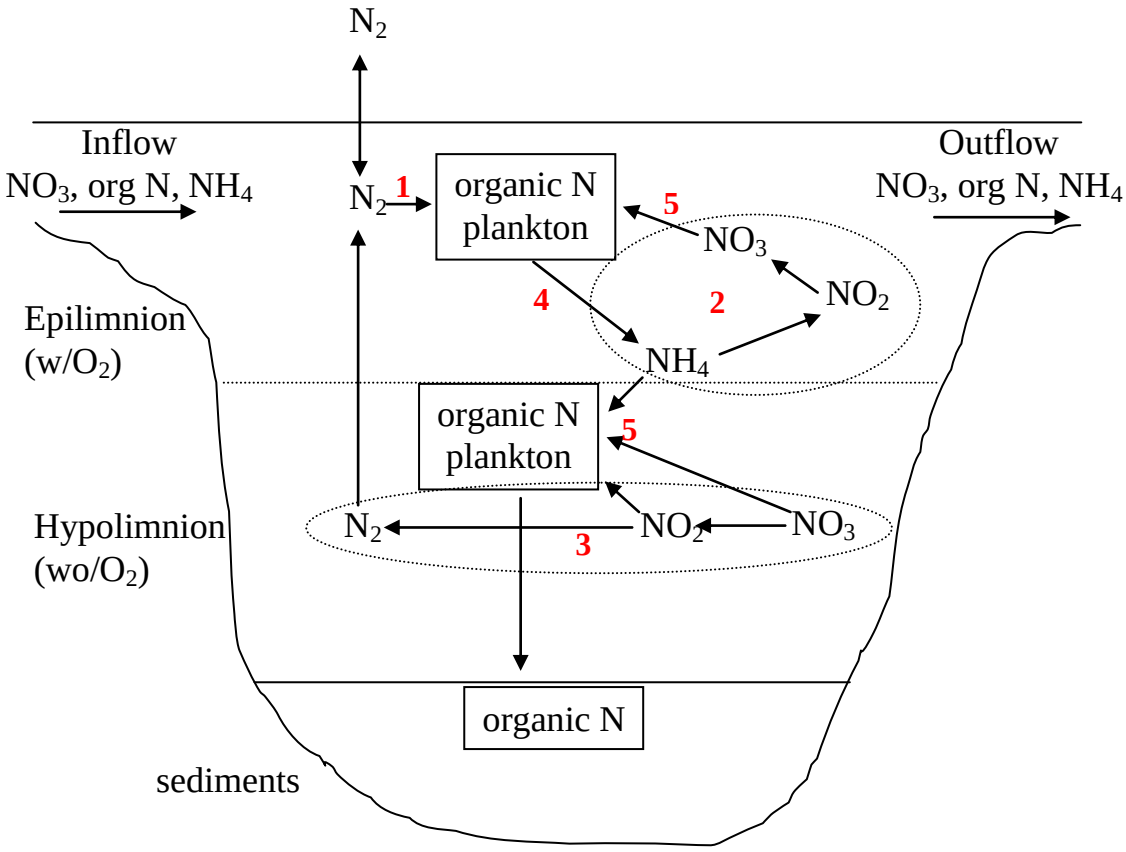
Eutrophic lake



Oligotrophic lake



The nitrogen cycle is complicated. Remember the key transformations and how those depend (or not) on the presence or absence of Oxygen.



1: N fixation 2: Nitrification 3: Denitrification 4: Excretion
5: Assimilation/Uptake