SL171

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Nitrogen Cycling in Wetlands[1]

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Nitrogen (N) is an essential nutrient for plants and animals; however, excessive accumulation of nutrients can represent too much of a good thing, especially in water bodies such as lakes, streams and estuaries. Loading of nutrients to surface waters causes changes in ecological function, and often has undesirable environmental and economic consequences. Effective nutrient management, whether directed toward nutrient supply or abatement, requires a working knowledge of biogeochemical cycling; that is, the distribution and cycling of nutrients among living and non-living components of an ecosystem.

Wetlands perform many important biogeochemical functions in watersheds. Among these are sediment trapping; nutrient removal, storage and release; and transformation of inorganic nutrients to organic forms. The N cycle in wetlands plays an important role in transport, storage and biological availability of N in the surrounding watershed. An overview of the key physical, chemical and biological processes associated with N cycling in wetlands is presented here (refer to Figure 1).

Nitrogen can enter a wetland in several forms; for example, N carried in surface water may be in dissolved or particulate (suspended sediment) form, and may exist both as organic and inorganic compounds. Organic N compounds are in either dissolved or particulate form, while inorganic N is primarily in solution as nitrate (NO_3^-) or ammonium (NH_4^+).

Following is a summary of some major processes affecting retention, cycling and release of N in wetlands:

- *Diffusion*: Dissolved forms of N can be transferred from surface water to soil solution (porewater) and vice versa, through the process of diffusion. The driving force behind diffusion is the concentration gradient: a dissolved compound in the soil or water will diffuse from a region of high concentration to regions of lower concentration.
- *Plant uptake*: Inorganic forms of N (NH_4^+ and NO_3^-) are taken up by plants rooted in the soil or floating in the water (including algae).
- *Litterfall*: Dead plant tissue (e.g., leaves and stems) falls from the live plants and collects at the soil surface to form a litter layer, also known as detritus.

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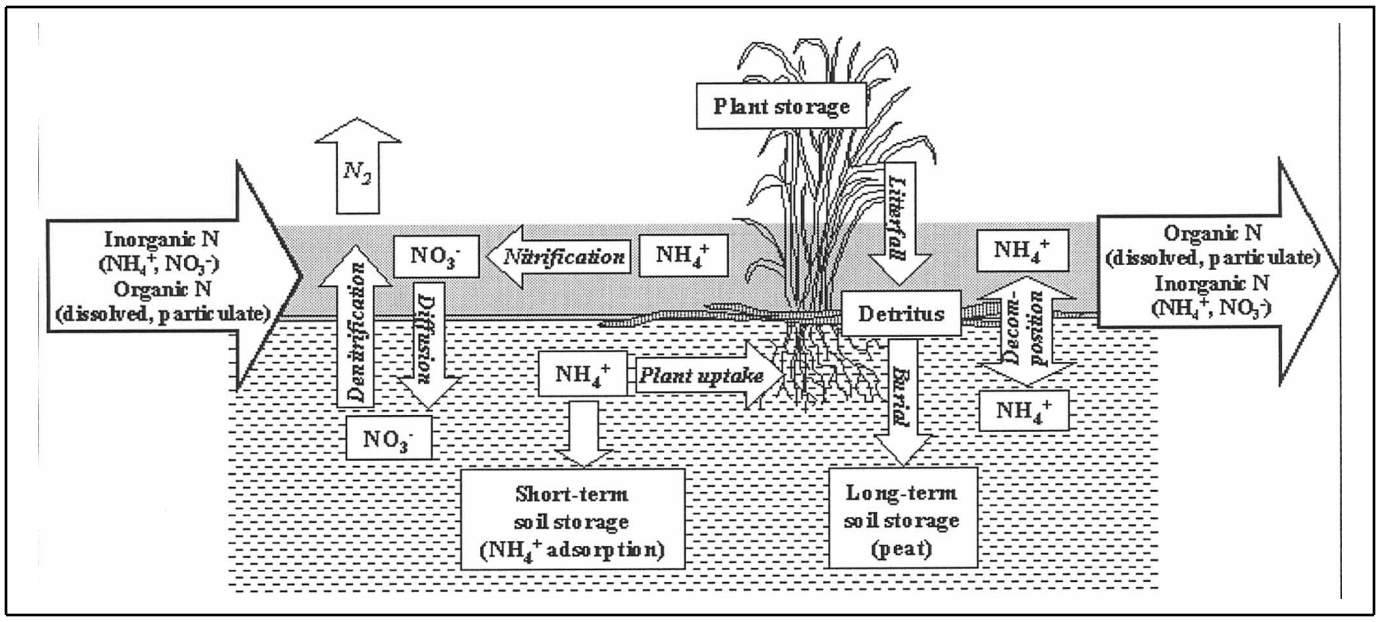

Figure 1. Summary diagram of the fate of nitrogen entering a wetland.

- *Sedimentation*: Particulate matter (inorganic and/or organic sediment) entrained in the water column settles out, due to the reduced water velocity, shallow water depth and filtering action of emergent vegetation, and collects on the soil surface.

- *Decomposition:* Organic matter, including plant detritus, organic sediments and peat, is broken down by a variety of microorganisms that utilize organic carbon as a source of energy. Organic N compounds, such as proteins and amino acids, are broken down to smaller organic molecules, both particulate and dissolved, and ultimately to ammonium (NH_4^+), which either may be utilized as a nutrient by the microorganisms or diffuse back into the soil or water.

- *Ammonia volatilization*: Under high-pH conditions in the wetland floodwater, concentration of the un-ionized form of ammonia (NH_3) becomes appreciable compared to NH_4^+, and may be released to the atmosphere as ammonia gas. This process is not usually a major factor for N cycling in most wetlands, but can lead to substantial N losses for poorly buffered waters with high photosynthetic activity (due to the associated daily increase in pH).

- *Nitrification*: Microbial conversion (by *Nitrosomonas* and *Nitrobacter* spp.) of reduced inorganic N (NH_4^+) to the oxidized nitrate form. This process occurs in aerobic, or oxygenated, regions of the wetland, usually confined to the surface water and the top few millimeters of the underlying soil.

- *Denitrification*: Microbial conversion (e.g., by *Pseudomonas* spp.) of nitrate to nitrogen (N_2) gas and, to a lesser extent, nitrous oxide (N_2O), which are lost to the atmosphere. The release of nitrous oxide is of particular concern, because of ozone-layer impacts. Denitrification occurs only in the anaerobic, or oxygen-depleted, regions of the wetland that typically exist below the soil surface.

- *Adsorption*: Retention of N in the soil through the process of cation exchange, whereby the ammonium ion (NH_4^+) is weakly bound to soil particles by electrostatic attraction. Most soil profiles are negatively charged, so the corresponding retention of nitrate (NO_3^-) is rare.

- *Burial and peat accretion*: Partially decomposed plant detritus and other organic matter is gradually buried and incorporated into the soil profile, with the buried material representing the portion of organic matter that is more resistant to decomposition. As this

material ages, it becomes highly decomposed and compressed, forming peat (i.e., peat accretion).

Denitrification represents an important N removal mechanism in wetlands, because it is rapid and results in gaseous losses of N from the ecosystem. Highly favorable environmental conditions for denitrification are commonly found in wetland soils. The existence of an aerobic- anaerobic interface near the wetland soil surface greatly facilitates the coupling of nitrification and denitrification, which allows removal of inorganic N as both nitrate and ammonium.

Although wetlands may remove and store substantial quantities of N, they also potentially release a significant quantity of N to downstream ecosystems. The vast majority of N in wetlands is in organic form, contained either in the vegetation (live plants), plant detritus, macrofauna, microorganisms, soil (soil organic matter or peat) or water (dissolved organic compounds or suspended sediments). Peat accretion potentially affords long-term storage of N in wetlands, although it is a relatively slow process and generally fails to offset high rates of N loading to a wetland. Living components of the wetland also provide storage of N, but subsequently release a large portion of this N during death and decomposition. Plants turn over their stores of N in a matter of months to years, while the turnover time for microorganisms, which may account for up to 5 to 10% of the soil organic matter, is substantially shorter. Turnover rates for soil organic matter (e.g., peat) are commonly measured in terms of decades, centuries or millennia. Nitrogen released from the biota is either recycled within the wetland or exported to downstream waters. Due to the rapid biological uptake of nutrients and extensive production of organic matter, wetlands generally export more organic N than inorganic N, even though nutrient inputs are often largely in inorganic form.

Biogeochemical cycling in wetlands represents an important function with respect to nutrient flow in watersheds. The transformation of inorganic nutrients to organic forms results in a more gradual release of N, and a general decrease in bioavailability for downstream waters, thus reducing the likelihood of algae blooms and other abrupt ecological changes. Coupled with their ability to buffer pulses of nutrients in the watershed by storing and slowly dispensing nutrients to downstream waters, wetlands provide a significant amount of ecological stability to associated aquatic systems.