NUTRIENTS: DETAILED CONCEPTUAL MODEL NARRATIVE

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Algae and aquatic plants require nitrogen (N) and phosphorus (P) for photosynthesis. The availability of these nutrients often drives ecosystem productivity and determines trophic status. However, excessive amounts of P and N can have several negative effects on aquatic communities.

Model Format

The N and P conceptual models provided here depict relationships between human activities and processes that increase nutrient levels in surface waters, and the effect of nutrient enrichment on aquatic communities. Note that nutrient enrichment itself is not shown as a proximate stressor, but affects processes and states that lead to proximate stressors, such as changes in dissolved oxygen levels or alteration of food resources that have direct impacts on aquatic invertebrates and fish.

The nutrient conceptual model diagrams depict sources that introduce nutrients to streams, and land use and channel alterations that alter the delivery of nutrients to streams, near the top of the figure, leading down the diagrams to steps in the causal pathway, proximate stressors, modes of action, and eventually biological responses at the bottom. The role of light in influencing these relationships also is illustrated. This narrative generally follows the diagram from top to bottom, left to right. For more information on interpreting CADDIS conceptual model diagrams, see the Conceptual Model Library homepage.

Linking Sources to Proximate Stressors

Nutrients naturally occur in soils and vegetation and move throughout watersheds in regular cycles, but excess nutrient loadings to streams can adversely impact aquatic biota. Often these excess inputs of N and P are related to human activities and sources in the watershed, which influence in-stream nutrient concentrations via six dominant pathways: (1) by increasing the delivery of N and P from the watershed; (2) by increasing the amount of N and P in soils transported into streams; (3) by increasing the amount of N and P in surface runoff; (4) by increasing the amount of N and P in subsurface waters; (5) by increasing the amount of N and P in wet or dry deposition; and (6) by increasing the amount of N and P in discharged waters (i.e., point source effluents).

For example, many human activities (e.g., agricultural practices, residential and commercial development) lead to land cover alteration, with subsequent increases in surface runoff and watershed erosion; this land cover alteration can increase the mobilization of N and P bound to watershed soils, ultimately increasing nutrient delivery to streams. Decreases in vegetation and floodplain connectivity also may reduce N and P uptake and their retention on the floodplain, further increasing delivery to streams.

Other sources directly elevate N and P concentrations within the watershed. For example, one of the most significant ways in which humans increase nutrients in streams is through fertilizer use for agricultural, residential, and commercial purposes, thus increasing total nutrient levels in the watershed (top center). Waste inputs also are common sources of added nutrients, from both point source discharges (e.g., WWTP or industrial effluents discharged directly into streams) and non-point sources (e.g., leakage from septic tanks or diffuse inputs of animal wastes).

In general, potential sources of N and P are similar, although the relative importance of those sources may differ. For example, P binds much more easily to soil than N, so pathways involving soil adsorption (e.g., erosion pathways) are usually much more significant for P than for N dynamics. However, some sources only add significant amounts of N to systems, and thus are shown only in the N diagram. These include vehicle emissions and other combustion by-products, which emit N to the atmosphere and eventually deposit N into streams through air transport mechanisms. Nitrogen-fixing crops (e.g., legumes such as soybeans) also can increase N levels in soil by transforming atmospheric nitrogen gas into a biologically available form.

In streams, N and P are present in three main forms, based on size and chemical composition: dissolved organic N and P, dissolved inorganic N and P, and particulate N and P (center curved rectangles). These forms are dynamic, and many transformations and reactions occur which convert particulate to dissolved forms (and vice versa), and organic to inorganic forms. Only dissolved organic and inorganic forms can be taken up by microbes and primary producers directly.

Linking Proximate Stressors to Biological Impairment

Microbes (lower left) (e.g., bacteria, fungi) require nutrients for growth. They can obtain these nutrients directly from dissolved organic and inorganic forms and indirectly from plant-based detritus and exudates. Increased nutrients can stimulate increases in microbial biomass and production, which can directly affect biota via increased microbial infection of invertebrates and fish. Microbial increases also can increase organic matter quality and decomposition. Improved organic matter quality may benefit organisms that feed upon it (like shredders), but shifts from coarse to fine particulate organic matter may benefit organisms which feed upon smaller particles (e.g., collectors). Increased microbial production also may reduce dissolved oxygen concentrations due to increased heterotrophic respiration and decomposition.

Perhaps the most evident and common effect of increasing nutrient levels in streams is an increase in primary producer biomass or production; when more nutrients are present, more periphyton, macrophytes, and phytoplankton can grow (center of diagram), assuming light levels are adequate. This increase in plant material can influence other organisms via several pathways. First, plant photosynthesis and respiration both may increase. Enhanced photosynthesis can lead to supersaturated dissolved oxygen concentrations, which can cause gas bubble disease and adversely affect biota (especially fish). In contrast, increased respiration by plants will consume oxygen, and may drive dissolved oxygen concentrations below critical levels, especially at times when photosynthesis is limited (e.g, at night or on cloudy days). Ultimately, decreases in dissolved oxygen concentrations may lead to the loss of taxa intolerant of low DO levels and increases in tolerant species (see the dissolved oxygen model and module for a more detailed explanation of these pathways). Blooms of certain algal taxa also may result in increased production and release of toxins that can affect fish or invertebrates.

For N, increased photosynthesis may have an added adverse affect. Photosynthesis leads to an increase in pH, which may increase the amount of ammonium hydroxide present in streams. This compound can be extremely toxic to aquatic organisms, especially fish.

Increases in primary producers can directly affect both food quantity and food quality. Most obviously, increased plant production can mean increased food for herbivores and detritivores. However, plant responses to nutrient enrichment often are taxon-specific: based on the total and relative amounts of N and P present, certain plant taxa may increase while others decrease, leading to changes in plant assemblage structure (lower right). Thus, increases in plant production do not necessarily translate to increases in food availability. In the P diagram, for example, when excess P is supplied, the N:P ratio decreases. As a result, algae taxa capable of fixing N_2 gas may be favored, as they have a source of N not readily available to other taxa; many of these taxa may be less palatable or inedible. Filamentous algae may become more dominant with nutrient enrichment, and more prostrate forms may be shaded out. These shifts can lead to a decrease in overall algal richness or evenness, and ultimately may affect herbivore assemblages. Changes in plant assemblage structure also can affect habitat structure, for example by changing the availability of refugia or the trapping of fine organic matter particles.

In larger streams and rivers with significant phytoplankton communities, phytoplankton blooms (lower right) may have adverse consequences for biota. For example, increases in suspended organic matter can increase turbidity, which may reduce light penetration and benthic plant abundance. Turbidity increases also may lead to decreased visibility and potentially cause problems for visual predators. However, filtering organisms may benefit from increases in suspended organic matter.

Each of these pathways ultimately may contribute to biological impairment of stream biota. Total invertebrate richness or evenness may decline or specific taxa may be lost, and changes in any one population may indirectly affect other taxa.