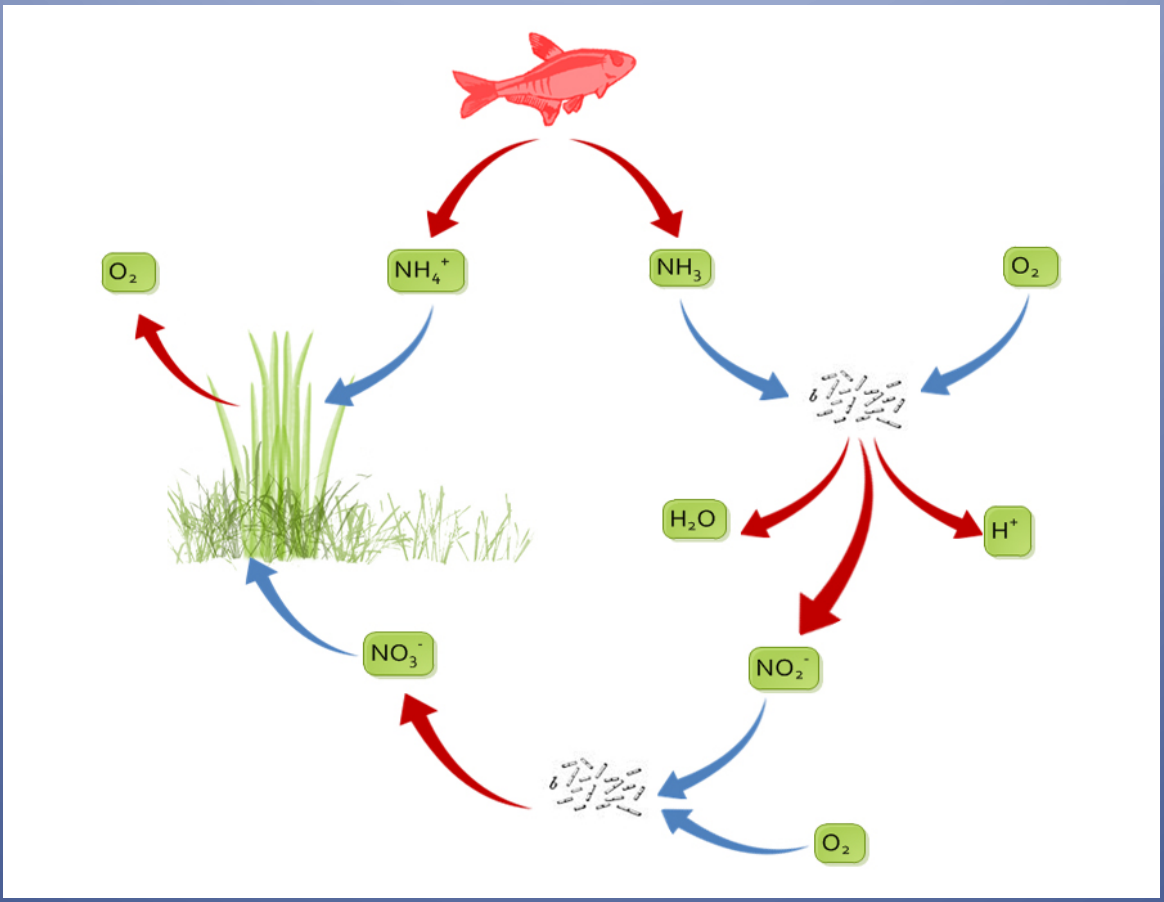

The Nitrogen Cycle in the Planted Aquarium

Raymond Wise

The nitrogen cycle in the aquarium as related to a balanced aquatic ecosystem.

What is the Nitrogen Cycle?

The nitrogen cycle is simply the process in which various chemical forms of nitrogen are converted amongst one another. The reason the nitrogen cycle is so important within an ecosystem is that nitrogen is a component in all amino acids – the building blocks of life. Nitrogen is used in the photosynthesis process by plants' chlorophyll molecules within the chloroplasts. Chloroplasts are responsible for not only photosynthesis, but also fatty acid synthesis and immune response.

Nitrogen in the Aquarium

Nitrogen is present in various forms within the aquatic ecosystem.

1. Nitrogen gas (N_2) is not normally present in useful quantities in the aquarium because it is in gaseous form which escapes the aquatic system.
2. Ammonia (NH_3) is present in the aquarium due to fish waste, decaying organic matter, or possibly through contaminated water. This is the unionized form of ammonia and is toxic to both fish and plants.
3. Ammonium (NH_4^+) is the ionized form of ammonia and is not toxic to fish and plants. This form has an additional hydrogen atom in it, absorbed from free hydrogen present in acidic water. This form of ammonia is only found in aquatic ecosystems where the pH value is acidic.
4. Nitrite (NO_2^-) is ammonia which has been oxidized, or goes through a reaction that causes it to lose electrons and then binds with oxygen. This form is considered toxic to life.
5. Nitrate (NO_3^-) is the result of oxidation of nitrite. Nitrate in the aquarium refers specifically to Nitrate Nitrogen (NO_3^- N). This form is considered least toxic to life.

Ammonification

Ammonification is the conversion of ammonia to nitrite in the following reaction:

$$2NH_3 + 3O_2 \rightleftarrows 2NO_2 + H_2O + 2H^+$$

This process is performed by the aerobic bacteria genus Nitrosomonas. This bacterium processes the ammonia to fulfill its energy needs and results in the production of nitrite.

Nitrification

Nitrification is the conversion of nitrite to nitrate in the following reaction:

$$2NO_2^- + O_2 \rightleftarrows 2NO_3$$

Once again we see oxidation or the loss of an electron. In the aquarium this process is performed by aerobic bacteria genus Nitrobacter and Nitrospira. These bacteria cannot be present without the presence of the Nitrosomonas to produce the nitrite substrate in which these bacteria utilize for their energy.

Biological Filtration

In the non-planted aquarium, this is where the nitrogen cycle will normally break. Once these two types of beneficial bacteria are present in the aquarium, nitrate will build up and can be removed via partial water changes before it becomes toxic.

Anaerobic Conditions

While anaerobic conditions are detrimental (toxic) to the ecosystem that we strive for in the aquarium, there are two interesting processes within the nitrogen cycle that occur only when oxygen needs exceed oxygen supply and anaerobic bacteria begin to appear.

Denitrification

This anaerobic process is the conversion of nitrate to nitrogen gas in the following reaction:

$$2NO_3^- + 10e^- + 12H^+ \rightleftarrows N_2 + 6H_2O$$

This is a reduction reaction, or the gaining of an electron. The bacteria that perform this reaction are from the genus Pseudomonas or Clostridium that utilize nitrate for their energy.

Anaerobic Ammonium Oxidation

This is a rarely seen condition in saltwater where bacteria oxidize ammonium and nitrite to nitrogen gas:

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

Bacteria from phylum Planctomycetes can perform this function in anaerobic conditions mostly seen in the world's oceans.

Ammonium to Ammonia

As the pH increases in an aquarium, the equilibrium of free hydrogen shifts and ammonium (non-toxic) will give up hydrogen and become ammonia (toxic) in the following reaction:

$$NH_4^+ + OH^- \rightleftarrows NH_4OH \rightleftarrows NH_3 + H_2O$$

This is important to note as we move on to the utilization of nitrogen by plants and how it affects the nitrogen cycle.

Nitrogen in the Planted Aquarium

Nitrogen is a requirement for life in any ecosystem. In the planted aquarium, plants utilize nitrogen for the production of amino acids and growth within the plant structure. Plants can utilize most chemical forms of nitrogen in the aquarium.

Ammonia and Plants
Ammonia is toxic to plants, but plants can and will utilize ammonia for a nitrogen source because they cannot stop it from diffusing freely across their cell membranes. Excess ammonia will build up quickly and hinder plant growth, as well as harm fish, as they cannot stop ammonia from diffusing freely across their cell membranes.

Nitrite and Plants
Nitrite is toxic within the aquarium, but it does contain nitrogen that can be used by plants. It is unlikely that plants will choose toxic nitrite for nitrogen over non-toxic alternatives.

Ammonium and Plants
Ammonium, on the other hand, is not toxic and is a charged ion. This allows plant cells to process and store the ammonium's nitrogen for use in growth and development, both removing it from the water and decreasing the risk of ammonium to ammonia reaction. In the planted aquarium, *most* plants prefer to receive nitrogen from ammonium as it takes the least amount of energy to procure.

Nitrate and Plants
Due to biological filtration, nitrate is the most common form of nitrogen available in the aquarium for plants to utilize. Plants, however, must expend energy converting nitrate to ammonium for proper utilization in the following nitrate reduction reaction:

$$NO_3^- + H_2O\ 2H^+ \rightleftarrows NH_4^+ + 2O_2$$

As is displayed with this reaction, plants must convert the nitrate to ammonium to properly utilize the nitrogen within it.

Nitrogen Assimilation in Plants
While plants can utilize any of the previous chemical forms of nitrogen, it has been shown that many plants prefer ammonium to nitrate. Ammonia is constantly used, but is not preferred. Nitrite can be used, but if nitrite is present, most likely nitrifying bacteria are also present which would produce nitrate. Nitrate would be preferred to nitrite due to toxicity, though scientifically, this is not readily proven.

When plants utilize nitrate for nitrogen, they must use energy for conversion to ammonium, so if ammonium is present, it is more likely to be preferred over nitrate for energy conservation.

Biological Filtration and Plants
As noted, ammonium is preferred over nitrate by many plants, but not all plants. Biological filtration utilizes bacteria for ammonification (if NH_3 is present) and nitrification (if NO_2^- is present). These bacteria are competing with plants for nitrogen.

If conditions exist where ammonium is present, the ammonium will be utilized by plants for growth. When plants use ammonium for growth, acids are released which will sustain conditions for ammonium to remain ammonium and not convert to ammonia.

If pH increases and ammonium becomes ammonia, this can result in ammonia toxicity for plants and fish, especially if biological filtration is not present to ultimately convert the ammonia to non-toxic nitrate.

Another issue that may arise out of relying on plants for biological filtration is other limiting factors such as light or carbon. As these sources are depleted, the plants' need for nitrogen decreases, which may lead to build up of chemical forms of nitrogen.

Conclusion

As we strive for a balanced ecosystem in our aquarium, we need to note that certain conditions are met within the nitrogen cycle:

1. Bio-load must not be too high. As ammonia from fish or decaying organic matter builds up, plants will not detoxify the ammonia as quickly as needed to avoid ammonia toxicity.
2. The pH will be optimal when lower than 6.5. Many fish and plants prefer slightly acidic water, but some do not. Be sure your stock selection matches your needs for the ecosystem you are creating.
3. Biological filtration may not be needed in the planted aquarium. As has been shown, it's possible to have no beneficial bacteria and have the plants assimilate nitrogen to detoxify ammonia. In certain conditions, the presence of beneficial bacteria may be detrimental to plant growth. In any heavily planted aquarium, the need for biological filtration will be less than that of a similar aquarium with no plants.

When striving for balance in your aquatic ecosystem, be sure to understand the nitrogen cycle and monitor nitrogen levels to ensure balance and health for both your fish and your plants.