Biological Filtration: Understanding the Nitrogen Cycle in Aquariums

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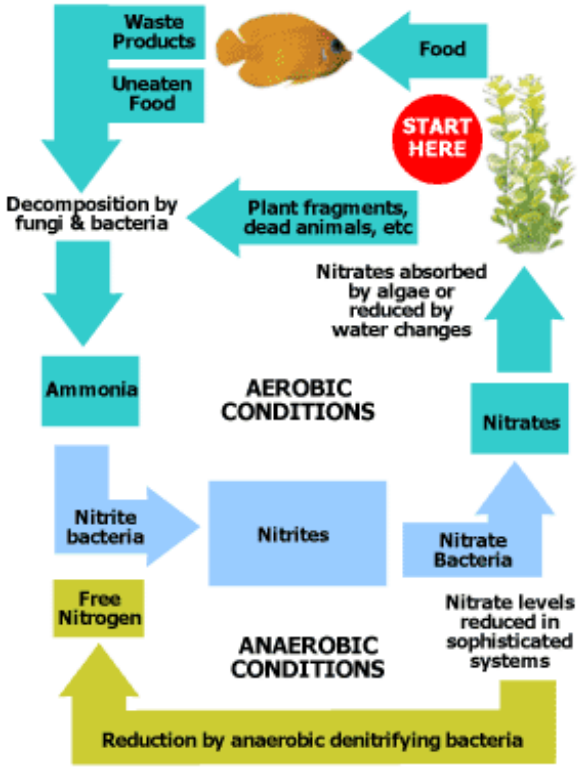
Understanding the nitrogen cycle is an important part of keeping a successful aquarium. The nitrogen cycle is responsible for the biological filtration within the system. It keeps the water free of toxic compounds that are a result of the respiration of the inhabitants, and the decay of any matter such as waste products and uneaten food. When we understand this cycle, we can anticipate situations that may cause damage to this process, and prevent or avoid these situations that may lead to livestock loss.

What is the nitrogen cycle?

In the nitrogen cycle, the waste products of the fish, plants, and invertebrates, along with any dead organisms or uneaten food, are broken down by bacteria and fungi into the resulting chemical, ammonia. Ammonia is extremely toxic to all of the aquarium inhabitants. It is broken down by an oxygen-loving bacteria, *Nitrosomonas*. The *Nitrosomonas** bacteria feed on both oxygen and ammonia, and with their biological activities, they excrete a chemical called nitrite. Although nitrite is not as toxic as ammonia, even at low concentrations in the aquarium, it can be harmful to fish and invertebrates. Another bacteria *Nitrobacter**, which also utilizes oxygen in its respiration, acts in a similar way as *Nitrosomonas*, and essentially changes the nitrites into a relatively harmless chemical called nitrate. The bacteria that will feed on nitrates are anaerobic, meaning they grow in areas of little or no oxygen. They require low-oxygenated stagnant water, and can be found in more elaborate filtration systems and within live rock. Here they breakdown nitrates into free nitrogen.

*** Note:** Recent research by one of the leading companies in the aquatics industry has found that other bacteria (some of which are still unnamed) are involved in the nitrogen cycle. The company has isolated these strains of bacteria in the freshwater systems and will be marketing them in a product to be used as a cycling aid. A product containing the saltwater strains is still in development, but is expected to be available in the near future. In this article, I have used the names of the bacteria commonly referred to in current textbooks and journals, understanding these names may be added to or changed as we learn more. For home aquarists, the names of the specific bacteria are not as important as understanding the process and what may affect its efficiency.

Figure 1. The nitrogen cycle



Adapted from: *Mills, D. The Marine Aquarium. Salamander Books LTD. 8 Blenhein Ct., Brewery Rd. London N79NT; 1987.*

The nitrogen cycle in new aquariums

Newly-set-up aquariums lack the colonies of bacteria that are necessary to perform the biological filtration. Because of this, the aquarium must be "cycled." "Cycling" refers to the process of establishing and maturing the biological filtration. In order to establish the system, we need to provide a source of ammonia for the *Nitrosomonas* bacteria in the filtration system so they can live, reproduce, and colonize. To provide an ammonia source, it is best to add a few hardy fish that can withstand the presence of ammonia and nitrites. Then we need to seed the aquarium with bacteria. There are commercially available cycling aids that contain the bacteria. Otherwise, when purchasing the hardy fish, request a small amount of gravel from the aquarium where the fish were held. This gravel should then be placed in the new aquarium along with the fish, and will provide the bacteria that are necessary to seed the system. Figure 2 illustrates the process that occurs in an aquarium during the biological filter maturing process.

As the fish in the new system are fed and begin to thrive, they will, through their biological activities, produce ammonia. The *Nitrosomonas* bacteria, in turn, will begin to feed upon that ammonia and will start populating the aquarium. Their population will be greatest in the media that contains the highest level of oxygen and surface area, which will normally be within the filtration system. At this point, because the numbers of bacteria are limited, they will not be able to convert all of the ammonia that is present in the system, so the ammonia levels will continue to rise. As the amount of ammonia increases, the population of bacteria will also increase, but at a much slower rate than the ammonia. The ammonia level will eventually reach a peak and then start to decline as the population of bacteria becomes large enough to break down the ammonia faster than it is being produced. Because there is still ammonia within the system, however, the bacteria will continue to live and feed on the ammonia until it reaches a level undetectable by testing. At this point, a balance has been achieved in which the rate of ammonia production equals the rate at which it is broken down by the bacteria. The number of bacteria, from this point

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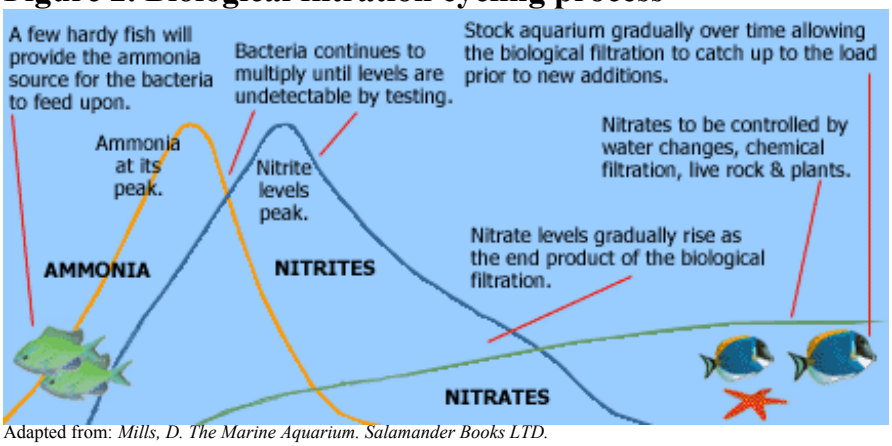
on, will change as the levels of ammonia (their food source) changes.

As we can see in Figure 2, the nitrites go through a very similar cycle as the ammonia. Nitrites are produced through the biological activities of the *Nitrosomonas* bacteria as they feed on the ammonia. As their numbers increase, so does the amount of their waste product, nitrites. The *Nitrobacter* bacteria, because of the increasing supply of nitrites, will multiply and increase in numbers. They, too, will be most densely populated in the area with the greatest surface area and oxygen content. The nitrite levels will rise until the number of bacteria has increased to the point at which they break down the nitrites faster than it is being produced. At this point, the peak level of nitrites has occurred, and the bacteria will continue to metabolize and feed upon the nitrites that are produced. The nitrite level will decrease until it becomes undetectable. As with the *Nitrosomonas*, the *Nitrobacter* will constantly alter their numbers as the amount of nitrites changes, keeping a balance at which the nitrites are undetectable.

Figure 2. Biological filtration cycling process



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The end product of this whole process is nitrate. Nitrates, in low to moderate concentrations, are not toxic to fish and invertebrates. Nitrates, however, can serve as a nutrient source for bacteria and plant life, and be the cause of other problems in the aquarium, such as excess algae. The anaerobic bacteria will break down the nitrates. Plants within the system will also feed on nitrates and are a good natural way of controlling this nutrient. Otherwise, the nitrate level needs to be controlled by chemical filtration and partial water changes.

The length of time required for this cycle to be completed in the new aquarium depends on many factors. These factors include: the amount of ammonia being produced during the cycling period; the efficiency of the biological filtration; and whether live rock or live plants are used in this process. The typical time period in most aquariums is going to be 3 to 6 weeks. It is important that if any of the fish used during this process perish, that they be replaced with another hardy fish in order to maintain the input of ammonia.

The nitrogen cycle in established aquariums

An established aquarium is one that the biological filtration has been matured. There are situations, however, that affect the nitrogen cycle in established aquariums, such as: adding livestock; unnoticed death in the aquarium; overfeeding; medicating the aquarium; and system maintenance.

Adding livestock

In the biological filter of an established aquarium, there are just enough bacteria to handle the biological load that is placed on the system at that time. When we add livestock to this system, we are increasing the amount of ammonia for the bacteria in the biological filter to metabolize. This situation brings us back to the cycling process (Figure 2), where the bacteria begin to multiply to make up for the extra biological load. How high the toxins will become in the system is going to depend both on the amount of livestock added to the aquarium at one time, and the size of the aquarium. If too much livestock is added at one time, it is possible for the ammonia and nitrites to reach dangerous levels, which may lead to livestock losses. It is important to minimize these levels by stocking the aquarium slowly over time, giving the biological filtration time to catch up to the load.

Situations may arise where it is advantageous to stock the aquarium at a faster rate than the biological filtration can handle. These situations include:

- Buying livestock through the mail: Because of the price of shipping, most aquarists will place large orders when purchasing their livestock through a mail order company. Although they may offset the shipping cost in doing this, they are also placing the new and existing livestock in jeopardy.
- Adding many aggressive fish at the same time: It is best to acclimate aggressive fish of the same species at the same time. Doing this will allow the fish to set their own territories prior to one individual taking over the entire aquarium.
- Transferring livestock to a hospital tank: The hospital tank is typically a small aquarium with minimal filtration. Levels of toxins must be monitored closely when any number of fish are added to this new system.

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Unnoticed death in the aquarium

It is possible in many aquariums, such as freshwater planted and saltwater reef aquariums, to have an inhabitant perish in a place where it cannot be seen. When this happens, the organism begins to decay, which places a large load on the biological filtration. Again, the nitrogen cycle can be thrown out of balance depending on both the amount of death in the system, and the size of the aquarium. Having a large aquarium, in this case, is advantageous because the ammonia being produced by the organism will be diluted by the large volume of water.

Overfeeding

When feeding the aquarium, it is important that the food that is added for the fish and invertebrates is consumed within a short period of time. After a few hours, any food that is left uneaten in the aquarium will begin to be broken down by the bacteria and fungi, resulting in ammonia added to the system. This ammonia in turn becomes part of the biological load and if the amount of decaying food is great enough, can cause an imbalance in the biological filtration. If the aquarium has been overfed, it is necessary to siphon out any uneaten food and to perform a 25% water change.

Medicating the aquarium

Many medications affect the ability of the bacteria to function in the biological filtration. For instance, anti-bacterial medications act in the way the name describes, by killing many types of bacteria. Unfortunately, the biological filtration is bacteria-based, and will be affected by these medications. Other medications such as copper, antibiotics, and ich treatments will also affect the filtration in different degrees. It is important, when treating an aquarium, to closely monitor both the ammonia and nitrite levels and to perform water changes or chemical filtration when necessary.

System maintenance

Water changes and filter maintenance will both affect the biological filtration to some degree. When performing water changes, it is important that the replacement water is free of any toxic chemicals such as chlorine. These chemicals can kill bacteria within the system and any water that is to be used, should be treated either by reverse osmosis, or by one of the many available liquid dechlorinators. Filter maintenance, if not done properly, can have a large effect on the biological filtration. Again, the beneficial bacteria responsible for the nitrogen cycle, populate in the greatest numbers where the water flow and oxygen content of the water are the highest. This is typically within the filter. When performing maintenance on the filter, it is ideal to leave the biological media untouched in order to preserve the bacteria. If there is no biological media within the filter, it is wise to change only ½ of the mechanical media at a time. The remaining media that is to be reused should be rinsed in water taken from the aquarium in order to preserve the bacteria colony.

Restoring the balance

All of the above situations can cause an imbalance in the nitrogen cycle, and make it necessary for us to monitor the level of toxins in the system whenever they occur. If any level of either ammonia or nitrites is detected, it is important to control these toxins either through partial water changes, or with one of the available toxin-absorbing resins.

When performing water changes, it is important to change no more than 25% of the aquarium water at a time. Changing more than 25% of the aquarium water can cause rapid changes in both temperature and pH, which can result in added stress to the aquarium inhabitants. Therefore, if toxins are present, it is best to perform small water changes frequently (even daily) rather than performing large water changes at less frequent intervals. Again, the makeup water that is used to replace the aquarium water should be treated by reverse osmosis, distillation, or at the very least using a liquid dechlorinator. It is ideal that the makeup water is at the same temperature as the aquarium, and has been aerated prior to adding it to the aquarium.

There are many chemical medias available on the market that will help control sudden increases in ammonia. By stopping the ammonia prior to it being broken down by the bacteria, we are reducing the biological load on the system. These products can be useful in the situations that have been described above. Again, it is important when using these products to monitor the water quality, and to perform water changes when any toxin levels are detected.

Know the warning signs

It is not practical to constantly test and monitor our water for ammonia and nitrites, but there are signs that we can see within the aquarium. These signs are the actions of the fish and invertebrates. When ammonia or nitrites are present in the water, the fish will show signs of stress. These signs can be in the form of erratic swimming behavior, gasping, or even laying on the substrate. These activities can also be the sign of disease, but our first reaction should be to test the water for ammonia and nitrites. Likewise, invertebrates such as corals will also show signs of distress. These signs are represented by the poor expansion of the coral, losses in coloration, and deterioration. If these signs do show themselves within the aquarium, it is then important to test the water for any amounts of ammonia or nitrites. If any levels are detected, then we must correct the situation by the methods that I have described above.

Conclusion

Maintaining a healthy aquarium starts with understanding the nitrogen cycle and its effect on the inhabitants. This cycle takes time to stabilize the water conditions both in the initial set-up, and after adding livestock. It is important to stock your new aquarium slowly and to allow the cycle to be completed prior to adding any new inhabitants. If you understand this process,

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pay attention to the warning signs, and take appropriate actions, there is no reason for catastrophic die offs in the aquarium due to ammonia or nitrites.

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