

5. Bacteria in aquaponics

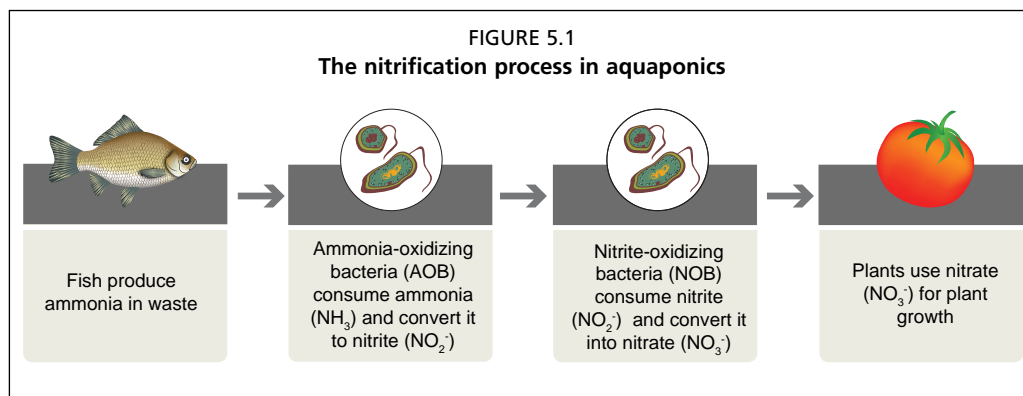
Bacteria are a crucial and pivotal aspect of aquaponics, serving as the bridge that connects the fish waste to the plant fertilizer. This biological engine removes toxic wastes by transforming them into accessible plant nutrients. Chapter 2 discussed the nitrogen cycle, especially the critical role of nitrifying bacteria, and outlined the essential parameters for maintaining a healthy colony. Chapter 4 discussed the aspects of biofilter materials that host these same bacteria. This brief chapter serves as a review of the bacteria, including details of the important bacterial groups. Heterotrophic bacterial activity is more fully discussed in terms of its role in the mineralization of solid fish waste. Unwanted bacteria are discussed, including: denitrifying bacteria, sulphate-reducing bacteria and pathogens. Finally, the timeline of bacterial cycling is discussed in regard to the establishment of a new aquaponic system.

5.1 NITRIFYING BACTERIA AND THE BIOFILTER

Chapter 2 discussed the vital role of nitrifying bacteria in regard to the overall aquaponic process. The nitrifying bacteria convert the fish waste, which enters the system mainly as ammonia, into nitrate, which is fertilizer for the plants (Figure 5.1). This is a two-step process, and two separate groups of nitrifying bacteria are involved. The first step is converting ammonia to nitrite, which is done by the ammonia-oxidizing bacteria (AOB). These bacteria are often referred to by the genus name of the most common group, the *Nitrosomonas*. The second step is converting nitrite to nitrate is done by the nitrite-oxidizing bacteria (NOB). These are commonly referred to by the genus name of the most common group, the *Nitrobacter*. There are many species within these groups, but for the purposes of this publication, the individual differences are not important, and it is more useful to consider the group as a whole. The nitrification process occurs as follows:

- 1) AOB bacteria convert ammonia (NH_3) into nitrite (NO_2^-)
- 2) NOB bacteria then convert nitrite (NO_2^-) into nitrate (NO_3^-)

Nitrification and, therefore, a healthy bacterial colony is essential to a functioning aquaponic system. Nitrifying bacteria are relatively slow to reproduce and establish colonies, requiring days and sometimes weeks, and therefore the patience of the farmer is one of the most important management parameters when establishing a new aquaponic system. Many aquariums and aquaponic systems have failed because too many fish were added before the colony of bacteria was fully developed. There are several other key parameters to support nitrifying bacteria. Generally, bacteria require



a large, dark location to colonize with good water quality, adequate food and oxygen. Often, nitrifying bacteria form a slimy, light brown or beige matrix on the biofilter, and have a distinctive odour that is difficult to describe, but does not smell particularly foul which could indicate other micro-organisms.

5.1.1 High surface area

Biofiltration material with a high specific surface area (SSA) is optimal to develop extensive colonies of nitrifying bacteria. SSA is a ratio defining the surface area exposed from a given volume of media, and is expressed in square metres per cubic metres (m^2/m^3). In general, the smaller and more porous the particles of the media, the greater is the surface available for bacteria to colonize. This results in more efficient biofiltration. There are many such materials used in aquaponics, either as growing media or for biofiltration, e.g. volcanic gravel, expanded clay, commercial plastic biofilter balls, and plant roots. The volcanic tuff and Bioballs® considered in this manual have, respectively, $300 \text{ m}^2/\text{m}^3$ and $600 \text{ m}^2/\text{m}^3$, which is an adequate SSA to enable bacteria to thrive. Further characteristics and SSA of the different media used in aquaponics are summarized in Table 4.1 and Appendix 4. If the biofilter material is not ideal and has a lower surface area to volume ratio, then the biofilter should be larger. An oversized biofilter cannot harm an aquaponic system, and although overly large biofilters would add unnecessary expense, excess biofiltration capacity has saved many systems from collapse.

5.1.2 Water pH

Nitrifying bacteria function adequately through a pH range of 6–8.5. Generally, these bacteria work better at higher pH, with the *Nitrosomonas* group preferring a pH of 7.2–7.8, and the *Nitrobacter* group preferring a pH of 7.2–8.2. However, the target pH for aquaponics is 6–7, which is a compromise between all of the organisms within this ecosystem. Nitrifying bacteria function adequately within this range, and any decrease in bacterial activity can be offset with a larger biofilter.

5.1.3 Water temperature

The optimal temperature range for nitrifying bacteria is 17–34 °C. This range encourages growth and productivity. If the water temperature drops below this range, the productivity of the bacteria will tend to decrease. In particular, the *Nitrobacter* group is less tolerant of lower temperature than is the *Nitrosomonas* group, and as such, during colder periods nitrite should be more carefully monitored to avoid harmful accumulations.

5.1.4 Dissolved oxygen

Nitrifying bacteria need adequate levels of DO in the water at all times to grow healthily and maintain high levels of productivity. Nitrification is a reduction/oxidation (redox) reaction, where the bacteria derive the energy to live when oxygen is combined with the nitrogen. Optimum levels of DO are 4–8 mg/litre, which is also the level required for the fish and the plants. Nitrification does not occur if the DO concentration drops below 2 mg/litre. Ensure adequate biofiltration by dedicating aeration to the biofilter, either through flood-and-drain cycles in media beds, air stones in external biofilters, or cascading water return lines to the canals and sump tanks.

5.1.5 UV light

Nitrifying bacteria are photosensitive until they fully establish a colony, and sunlight can cause considerable harm to the biofilter. Media beds already protect the bacteria from sunlight; but if using an external biofilter, be sure to keep it shaded from direct sunlight.

5.1.6 Monitoring bacterial activity

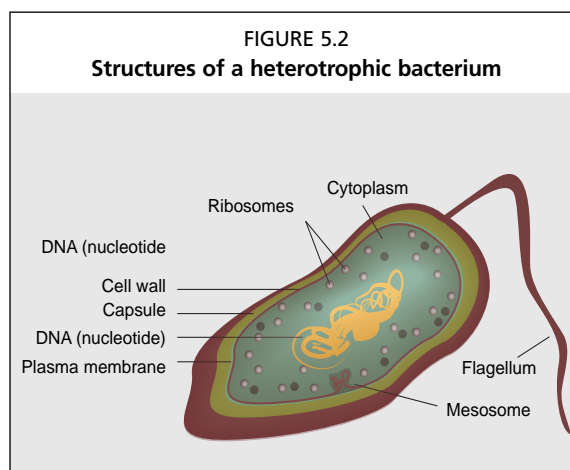
If all of these five parameters are respected, it is safe to assume that the bacteria are present and functioning properly. That said, bacteria are so important to aquaponics that it is worth knowing the overall health of the bacteria at any given time. However, bacteria are microscopic organisms, and it is impossible to see them without a microscope. There is a simple method to monitor the bacterial function; testing for ammonia, nitrite and nitrate provides information on the health of the bacterial colony. Ammonia and nitrite should always be 0–1 mg/litre in a functioning and balanced aquaponic unit. If either is detectable, it indicates a problem with the nitrifying bacteria. There are two possible, common reasons for this to occur. First, the biofilter is too small for the amount of fish and fish feed. Therefore, there is an imbalance and there are too many fish. To rectify, either increase the biofilter size or reduce the number of fish, or the fish feeding regime. Sometimes, this problem can occur when the system started out balanced when the fish were smaller, but gradually became unbalanced as the fish grew and were fed more with the same size biofilter. Second, if the system is balanced in size, then the bacteria themselves may not be functioning properly. This could indicate a problem with the water quality, and each parameter listed above should be checked. Often, this can occur during winter seasons as the water temperature begins to fall and bacterial activity slows.

5.2 HETEROTROPHIC BACTERIA AND MINERALIZATION

There is another important bacteria group, as well as other micro-organisms, involved in aquaponics. This bacteria group is generally called the heterotrophic group. These bacteria utilize organic carbon as its food source, and are mainly involved in the decomposition of solid fish and plant waste. Most fish only retain 30–40 percent of the food they eat, meaning that 60–70 percent of what they eat is released as waste. Of this waste, 50–70 percent is dissolved waste released as ammonia. However, the remaining waste is an organic mix containing proteins, carbohydrates, fats, vitamins and minerals. The heterotrophic bacteria metabolize these solid wastes in a process called mineralization, which makes essential micronutrients available for plants in aquaponics (Figure 5.2).

These heterotrophic bacteria, as well as some naturally occurring fungi, help decompose the solid portion of the fish waste. In doing so, they release the nutrients locked in the solid waste into the water. This mineralization process is essential because plants cannot take up nutrients in solid form. The wastes must be broken into simple molecules in order to be absorbed by plants' roots. Heterotrophic bacteria feed on any form of organic material, such as solid fish waste, uneaten fish food, dying plants, dying plant leaves and even dead bacteria. There are many sources of food available for these bacteria in aquaponic units.

Heterotrophic bacteria require similar growing conditions to the nitrifying bacteria especially in high levels of DO. The heterotrophic bacteria colonize all components of the unit, but are especially concentrated where the solid waste accumulates. Heterotrophic bacteria grow much faster than the nitrifying bacteria, reproducing in hours rather than days. In media beds, the wastes collect on the bottom, permanently wet zone and many heterotrophic bacteria are found here. In other systems, the main colonies are found on the filters and separators, and in the canals. Mineralization is important in aquaponics because it releases several micronutrients that



are necessary to plant growth. Without mineralization, some plants may experience nutrient deficiencies and would need supplemental fertilizer.

Heterotrophic bacteria are aided in the decomposition of solid waste by a community of other organisms. Often, earthworms, isopods, amphipods, larvae and other small animals can be found in aquaponic systems, especially within media beds. These organisms work together with the bacteria to decompose the solid waste, and having this community can prevent accumulation of solids.

5.3 UNWANTED BACTERIA

5.3.1 Sulphate reducing bacteria

Nitrifying and mineralizing bacteria are useful to aquaponic systems, but some other types of bacteria are harmful. One of these harmful groups of bacteria is the sulphate-reducing group. These bacteria are found in anaerobic conditions (no oxygen), where they obtain energy through a redox reaction using sulphur. The problem is that this process produces hydrogen sulphide (H_2S), which is extremely toxic to fish. These bacteria are common, found in lakes, saltmarshes and estuaries around the world, and are part of the natural sulphur cycle. These bacteria are responsible for the odour of rotten eggs, and also the grey-black colour of sediments. The problem in aquaponics is when solid wastes accumulate at a faster pace than the heterotrophic bacteria and associated community can effectively process and mineralize them, which can in turn lead to anoxic festering conditions that support these sulphate-reducing bacteria. In high fish density systems, the fish produce so much solid waste that the mechanical filters cannot be cleaned fast enough, which encourages these bacteria to multiply and produce their noxious metabolites. Large aquaponic systems often contain a degassing tank where the hydrogen sulphide can be released safely back to the atmosphere. Degassing is unnecessary in small-scale systems. However, even in small-scale systems, if a foul odor is detected, reminiscent of rotten eggs or raw sewage, it is necessary to take appropriate management action. These bacteria only grow in anoxic conditions, so to prevent them, be sure to supply adequate aeration and increase mechanical filtration to prevent sludge accumulation.

5.3.2 Denitrifying bacteria

A second group of unwanted bacteria are those responsible for denitrification. These bacteria also live in anaerobic conditions. They convert nitrate, which is the coveted fertilizer for plants, back into atmospheric nitrogen that is unavailable for plants. These bacteria are also common throughout the world, and are important in their own right (see Figure 2.4). However, within aquaponic systems, these bacteria can decrease efficiency by effectively removing the nitrogen fertilizer. This is often a problem with large DWC beds that are inadequately oxygenated. A problem could be suspected when plants show signs of nitrogen deficiencies despite the system being in balance, and when there is a very low nitrate concentration in the water. Investigate possible areas within the DWC canals that are not circulating properly, and further increase aeration with air stones.

Some large aquaponic systems deliberately use denitrification. The feed rate ratio balances the nutrients for the plants but usually results in high nitrate levels. This nitrate can be diluted during water exchanges (suggested in this publication for small-scale systems). Alternatively, controlled denitrification can be encouraged in the mechanical filter. This technique requires careful attention and off-gassing, and is not recommended for small-systems. More information can be found in the section on Further Reading.

5.3.3 Pathogenic bacteria

A final group of unwanted bacteria are those that cause diseases in plants, fish and humans. These diseases are treated separately in other parts of this publication, with

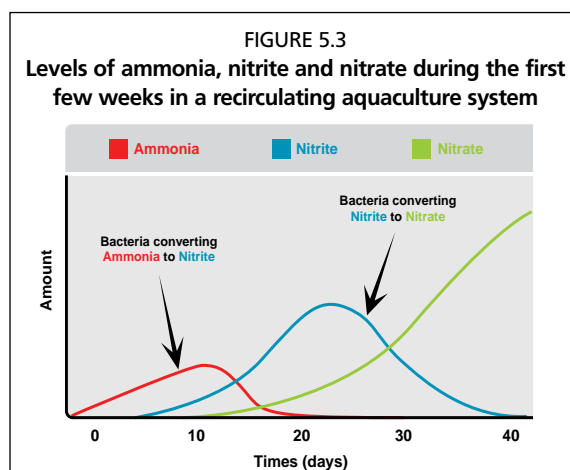
Chapters 6 and 7 discussing plant and fish disease, respectively, and Section 8.6 discussing human safety. Overall, it is important that there are good agricultural practices (GAPs) that mitigate and minimize the risk of bacterial diseases within aquaponic systems. Prevent pathogens from entering the system by: ensuring good worker hygiene; preventing rodents from defecating in the system; keeping wild mammals (and dogs and cats) away from aquaponic systems; avoiding using water that is contaminated; and being aware that any live feed can be a vector for introducing alien micro-organisms into the system. It is especially important not to use rainwater collection from roofs with bird faeces unless the water is treated first. The major risk from warm-blooded animals is the introduction of *Escherichia coli*, and birds often carry *Salmonella* spp.; dangerous bacteria can enter the system with animal faeces. Second, after prevention, never let the aquaponic water come into contact with the leaves of the plants. This prevents many plant diseases as well as potential contamination of fish water to human produce, especially if the produce is to be eaten raw. Always wash vegetables before consumption, aquaponic or otherwise. Generally, common sense and cleanliness are the best guards against diseases from aquaponics. Additional sources for aquaponic food safety are provided throughout this publication and in the section on Further Reading.

5.4 SYSTEM CYCLING AND STARTING A BIOFILTER COLONY

System cycling is a term that describes the initial process of building a bacterial colony when first starting any RAS, including an aquaponic unit. Under normal circumstances, this takes 3–5 weeks; cycling is a slow process that requires patience. Overall, the process involves constantly introducing an ammonia source into the aquaponic unit, feeding the new bacterial colony, and creating a biofilter. The progress is measured by monitoring the nitrogen levels. Generally, cycling takes place once an aquaponic system is built, but it is possible to give the biofilter a head start when creating a new aquaponic system. It is important to understand that during the cycling process there will be high levels of ammonia and nitrite, which could be harmful to fish. Also, make sure all aquaponic components, in particular the biofilter and fish tank, are protected from direct sunlight before starting the process.

Once introduced into the unit, the ammonia becomes an initial food source for the AOB, a few of which are naturally occurring and recruit to the system on their own. They can be found on land, in water and in the air. Within 5–7 days after the first addition of ammonia, the AOB start forming a colony and begin to oxidize the ammonia into nitrite. Ammonia should be continuously, but cautiously, added to ensure adequate food for the developing colony without becoming toxic. After another 5–7 days the nitrite levels in the water will have started to rise, which in turn attracts the NOB. As the NOB populations increase, the nitrite levels in the water will start to decline as nitrite is oxidized into nitrate. The full process is illustrated in Figure 5.3, which shows the trends of ammonia, nitrite and nitrate in the water over the first 20–25 days of cycling.

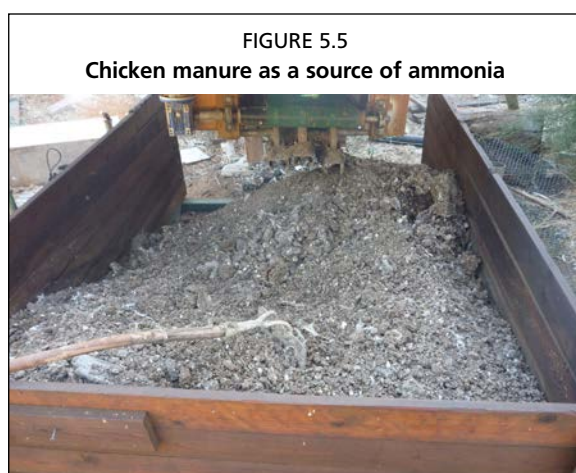
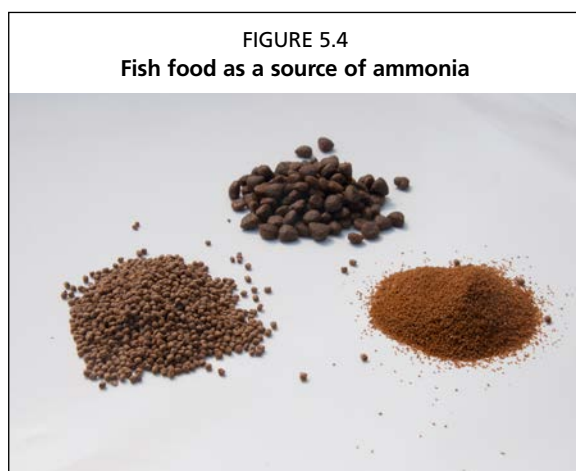
The end of the cycling process is defined as when the nitrate level is steadily increasing, the nitrite level is 0 mg/litre and the ammonia level is less than 1 mg/litre. In good conditions, this takes about 25–40 days, but if the water temperature is cool, complete cycling may take up to two months to finish. At this point, a sufficient bacterial colony has formed and is actively converting the ammonia to nitrate.



The reason this process is long is because nitrifying bacteria grow relatively slowly, requiring 10–15 hours to double in population. However, some heterotrophic bacteria can double in as little as 20 minutes.

Aquarium or aquaculture retailers sell various products containing living nitrifying bacteria (in a bottle). Once added to the unit, they immediately colonize a system thus avoiding the cycling process explained above. However, these products may be expensive or unavailable and ultimately unnecessary, as the cycling process can be achieved using organic means. Alternatively, if another aquaponic system is available, it is extremely helpful to share part of the biofilter as a seed of bacteria for the new system. This greatly decreases the time necessary for cycling the system. It can also be useful to separately start a biofilter medium by continuously trickling a solution containing 2–3 mg/litre of ammonia for a few weeks in advance. The media would then function as a primer by simply incorporating it into the new aquaponic biofilter. A simple trickling system can be built by suspending a wide plastic crate of medium above a small tank containing the ammonia solution that is being circulated by a small aquarium pump.

Many people use fish as the original source of ammonia in a new tank. However, these fish suffer the effects of high ammonia and high nitrite throughout the cycling process. Many new aquarists do not have the patience to allow a tank to fully cycle and the result is that the new fish die, commonly referred to as “new tank syndrome”. If using fish, it is recommended to use a very low stocking density ($\leq 1 \text{ kg/m}^3$). Instead of using fish, there are other sources of this initial ammonia to start feeding the biofilter colony. Some possible sources include fish feed, sterilized animal waste, ammonium nitrate fertilizer and pure ammonia. Each of these sources has positives and negatives, and some sources are far better and safer to use than others.



The best ammonia source is finely ground fish feed because it is a biologically safe product, and it is relatively easy to control the amount of ammonia being added (Figure 5.4). Be sure to use fresh, unspoiled and disease-free fish feed only. Chicken waste, despite being an excellent ammonia source, can be very risky and can introduce dangerous bacteria into the aquaponic system (Figure 5.5). *Escherichia coli* and *Salmonella* spp. are commonly found in chicken and other animal manure and, therefore, any manure must be sterilized before use. Household ammonia products can be used, but be sure that the product is 100 percent ammonia and does not include other ingredients such as detergents, colourants or heavy metals that could ruin the entire system. Once the ammonia source has been selected, it is important to add the ammonia slowly and consistently, and to monitor the nitrogen levels every 2–3 days (Figure 5.6). It is useful to record levels on a graph to track the process of the cycling. It is important not to add too much ammonia, and it is better to have a little bit too little than too much. The target level is 1–2 mg/litre. If ammonia levels ever exceed 3 mg/litre, it is necessary to do a water exchange to dilute the

ammonia in order to prevent it from inhibiting the bacteria.

5.4.1 Adding fish and plants during the cycling process

Plants and fish should be added only after the cycle is complete. Plants can be added a little bit earlier, but expect nutrient deficiencies in these early plants during this period because other nutrients take time to reach optimal concentrations (Figure 5.7).

Only once the ammonia and nitrite levels are below 1 mg/litre it is safe to start stocking the fish. Always start stocking the fish slowly. Once fish have been stocked, it is not uncommon to see a secondary and smaller ammonia and nitrite spike. This happens if the ammonia created from the newly stocked fish is much greater than the daily ammonia amounts added during the cycling process. Continue to monitor the levels of all three types of nitrogen, and be prepared to do water exchanges if ammonia or nitrite levels rise above 1 mg/litre while the system continues to cycle.

5.5 CHAPTER SUMMARY

- In aquaponics, ammonia must be oxidized into nitrate to prevent toxicity to fish.
- The nitrification process is a two-step bacterial process where ammonia-oxidizing bacteria convert ammonia (NH_3) into nitrite (NO_2^-), and then nitrite-oxidizing bacteria convert nitrite into nitrate (NO_3^-).
- The five most important factors for good nitrification are: high surface area media for bacteria to grow and colonize; pH (6–7); water temperature (17–34 °C); DO (4–8 mg/litre); cover from direct exposure to sunlight
- System cycling is the initial process of building a nitrifying bacteria colony in a new aquaponic unit. This 3–5 week process involves adding an ammonia source into the system (fish feed, ammonia-based fertilizer, up to a concentration in water of 1–2 mg/litre) in order to stimulate nitrifying bacteria growth. This should be done slowly and consistently. Ammonia, nitrite and nitrate are monitored to determine the status of the biofilter: the peak and subsequent drop of ammonia is followed by a similar pattern of nitrite before nitrate starts to accumulate. Fish and plants are only added when ammonia and nitrite levels are low and the nitrate level begins to rise.
- Ammonia and nitrite tests are used to monitor the function of the nitrifying bacteria and the performance of the biofilter. In a functioning system, ammonia and nitrite should be close to 0 mg/litre. High levels of either ammonia or nitrite require a water change and management action. Usually, poor nitrification is due to a change in water temperature, DO or pH levels.
- Another class of micro-organisms naturally occurring in aquaponics is that of heterotrophic bacteria. They decompose the solid fish waste, releasing some of the nutrients into the water in a process called mineralization.

