Aquarium Carrying Capacity: When "One More Fish" is One too Many

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What is considered a safe number of fish in an aquarium and what factors (existing or potential) can determine/limit that number? This is a very common dilemma facing anyone who has ever kept (or plans to keep) tropical fish. From beginners to even the most advanced aquarists, there seems to exist in us all that universal urge--that innate inner prompting--to add just a few more fish to a tank, especially when all has been going great for weeks.

Carrying capacity, the number of fish (or the weight of those fish) in the aquarium, is the subject of this month's discussion. The objective of such an examination? To establish a framework from which we can: 1) better understand the bio load factors affecting fish selection; and 2) enhance the operative success of your aquarium based upon this understanding.

Over the years, a few guidelines have been developed that are now treated as "laws" to be passed down to the new hobbyists. The most common is the "1 inch of fish per gallon of water," a variation of which is the "one inch of fish per square foot of tank surface area" maxim. In reality, these laws are simply not very useful. What is a standard fish inch? Does "per gallon" mean with gravel and rocks and plants, or without? Can you compare a guppy to an adult Red Devil? How?

The single most critical factor in determining the carrying capacity of an aquarium is not the fish, not the filter, not the aquarium. It is the aquarist. The aquarist alone is responsible for feeding the fish, servicing and cleaning the filter, and changing the water. These are the critical processes that determine water quality and, thus, carrying capacity.

Consider this...an aquarium filtration system is not really filtering so many gallons of water, but is, instead filtering the waste products of the organisms in the tank. The waste products are the result of the amount of feed given to the inhabitants. A filter that may be adequate for a 30 gal tank with a fish population of 30 zebra danios can be wholly inadequate for the same tank if it contains 10 large fancy goldfish. Why? The 10 goldfish are producing a lot more waste than the 30 danios because they are eating much more.

Let's now examine the filtration of a heavily loaded aquarium in a couple of different ways. Initially, let's say that the water in the aquarium is perfect for the fish and is completely replaced every hour with new fresh water. Aquaculturists consider this an open system. Water is used once, flows out of the tank and is replaced by new water. This environment is relatively stable as long as the incoming water does not change. There is little ammonia build-up (it is flushed out of the tank). Because a biofilter is not necessary, nitrite and nitrate are not produced. The pH is stable and the oxygen needs of the fish are met by vigorous aeration. This type of tank can support a heavy load of fish, but it is not realistic for a home aquarium.

Now consider the same tank in the other extreme: the unlimited water supply is eliminated. The water initially used to fill the tank is all that it gets. This is a closed system. No new water enters the tank. Therefore, the tank water must be recycled through a filter. The filter's projected function is to remove particulate material, dissolve pollutants and maintain low ammonia levels. If the filter were 100% effective, it would return the water to the state it was in when it first entered the tank. The carrying capacity (fish load) would be similar to that in the first example.

These filtration systems work wonderfully in a perfect world. But, of course, filters (and the World) are not perfect; the water does not re-enter the aquarium in the same state as it first did. The water is changed by the filtration process, and it is these changes that limit increased fish numbers.

The first limiting factor in a fish system is not the presence of ammonia, nitrite or even pH (more about them later), but oxygen. Fish must have oxygen to breathe. The more fish in the water, the more oxygen that must be supplied. But fish are not the only consumers of oxygen in an aquarium. Bacteria also consume a major portion of the oxygen. As fish numbers increase, there is more ammonia to oxidize, more waste to mineralize, and more bacteria needed to perform these tasks. More bacteria and increased bacterial activity require yet more oxygen. Fortunately, oxygen is relatively easy to provide in aquariums. The most effective oxygen-generating methods create a lot of water surface agitation which is where gas exchange takes place.

Surface agitation is important because it helps get rid of carbon dioxide--another fish-limiting factor. Carbon dioxide is more soluble in water than oxygen, so vigorous surface agitation is needed to drive the carbon dioxide from the water. As with humans, fish respiration produces carbon dioxide. And because it can be toxic to fish (and also lowers the pH), carbon dioxide must be controlled. It always astonishes hobbyists that a fish can die of carbon dioxide poisoning (suffocate) even in water that is saturated with oxygen. Some aquarists rely on plants to consume carbon dioxide and produce oxygen, but this will not work well in a heavily stocked tank. At night, when the plants are not photosynthesizing, they start to consume oxygen. This creates an even greater demand for oxygen.

Ammonia is a third limiting factor. Ammonia is excreted by the fish in proportion to the amount of feed they are given. It is also produced by bacteria when they degrade (convert) organic matter--a process called mineralization. High levels of ammonia are acutely toxic; exposed fish will die in a very short time. Even constant low levels of ammonia are harmful because they limit fish growth. An old adage says that fish will only grow to the size of the aquarium. This is wrong; they will only grow to the size (and efficiency) of the filtration system. A university study done on channel catfish showed that as little as 0.5 mg/L unionized ammonia caused a 50% decrease in fish growth compared to fish grown in tanks with no ammonia. A concentration of nearly 1.0 mg/L unionized ammonia resulted in no growth of the catfish.

Ammonia is removed by nitrification: the bacterial oxidation of ammonia to form nitrite and then nitrate. But nitrification also produces hydrogen ions, thus lowering the pH. As the pH drops, nitrification slows because nitrifying bacteria do not work as efficiently at lower pH values. This causes ammonia to increase. As the pH drops and the ammonia increases, the fish become stressed and more susceptible to disease.

Thus, pH itself can be a limiting factor. In general, freshwater fish can tolerate a wider range of pH values than can saltwater fish. For most however, a pH value near or below 6 starts to cause stress. This situation leads to a malady that could be called "New Fish Death Syndrome." It occurs when one tries to add a new fish to an old established tank that has not been well-maintained. The new fish dies after just a day or two. The reason? Fish in the tank have slowly acclimated to the decreasing pH. The new fish, coming from water of a much higher (and more normal) pH, is dropped into the aged aquarium and must immediately cope with a pH value 2 - 3 levels lower then it has been accustomed to. The fish goes into shock and dies.

As explained above, pH drops due to nitrification. Because it is critical to maintaining a zero ammonia level, nitrification cannot be eliminated. The rate at which the pH drops depends upon the natural alkalinity (buffering) of the water and how much nitrification is taking place. Nitrification is determined by feeding amount which is, in turn, determined by the number of fish.

By now you probably have the picture. The chemistry and biology of a fish aquarium are irrevocably intertwined. Changing one factor means that, in effect, all the others will change as well.

An additional limiting factor is the build-up of dissolved organic material technically referred to as Dissolved Organic Carbon (DOC). This organically based material is generated via a host of biological activities in the aquarium, most of which are the result of microbial processes. Studies have shown that high levels of DOC inhibit nitrification. Activated carbon and foam fractionation are two ways to reduce DOC levels.

Nitrite, nitrate and phosphate are not limiting factors in fish tanks. Nitrite is toxic but, generally, it only occurs in high concentrations during the break-in period of a new aquarium. Nitrate and phosphate are not toxic, but may contribute to algae blooms and make the aquarium aesthetically unappealing.

Continual adding of fish to an established aquarium initiates a pattern: more fish means more feed, means more ammonia, means more nitrification needed, means a rapid drop in pH. The pattern will occur whether there are a few fish or dozens of fish. Granted, it will take longer to complete in the tank with a few fish, but it will inevitably take place.

The best, easiest and most effective way to break this destructive pattern is through regular partial water changes. The filtration system does not prevent it from occurring. Filtration removes particulate material (mechanical filtration), reduces the DOC (chemical filtration), and controls ammonia (biological filtration). Water changes restore alkalinity to the aquarium water. They help maintain a stable pH. They remove DOC and prevent it from accumulating. They also remove nitrate and phosphate from the system.

This brings us back to my opening statement. The aquarist is indeed, the ultimate limiting influence governing the number of fish in an aquarium. The more fish, the more water changes needed. The aquarist is an integral part of the filtration system. The greater the bio load, the more the filtration system will have to be serviced. The hobbyist who sticks to a situation-appropriate schedule of water changes and servicing will be able to successfully keep and maintain aquariums with a larger carrying capacity than those who are unable or unwilling, to perform the necessary water changes and servicing. Each hobbyist must determine for themselves the level of effort they are willing to expend on their fish tanks and adjust the fish population accordingly. This will result in both healthier fish and greater enjoyment for the hobbyist.

Originally published in Aquarium Fish Magazine, Nov. 1995