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The Private Practitioner's Guide to Water Quality for Freshwater and Marine Tropical Fish

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During the four years of vet school, fish are one of the species that is overlooked. Thus, it is understandable when veterinarians shrug their shoulders when clients ask questions regarding their fishtanks. These clients, without their veterinarian to turn to, often resort to seeking advice from pet store employees and fish suppliers.

Veterinarians should learn how to answer these questions. Aquarium hobbyists provide a clientele market that has been virtually untapped by most practitioners. Hobbyists commonly have a great deal of money invested in their tanks and would likely pay for a consultation and recommendation on treatment for a problem they are encountering.

The purpose of this paper is to provide a basic guide to water quality for freshwater and marine tropical fish. Water quality is considered one of the most important factors in aquatic medicine due to the fact that fish cannot escape their environment and are extremely sensitive to any changes that occur. Physiologically and anatomically, fish are adapted to the environment in which they live. A change in the water's chemical composition can cause direct damage to organs. Chronic exposure to poor water quality can cause physiologic stress which will act to suppress immunity and inhibit the ability to resist infectious disease and parasites. Therefore, when clients comes to a veterinarian with a question about their sick fish, the quality of the water should be thought of first and foremost. The parameters that should be considered include nitrogen, pH, salinity, hardness, chlorine, copper, hydrogen sulfide, oxygen, and temperature.

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** Nitrogen

Ammonia is present in two forms in water: the non-ionized form, ammonia (NH₃), which is highly toxic to fish and the ionized form, ammonium (NH₄⁺), which is non-toxic to fish. Ammonia accumulates in aquaria because it is the major end product of nitrogen catabolism and is excreted via the gills of freshwater fish. Salt water fish excrete urea, but urea is quickly hydrolyzed to ammonia and carbon dioxide in the water. Heterotrophic bacteria also contribute ammonia to the system through the decomposition of organic matter. The ratio of ammonia to ammonium depends primarily on pH. At a high pH, there is more ammonia than ammonium due to chemical equilibrium. The maximum safe level for ammonia is not known, but levels of 0.02 mg/L are known to be detrimental to fish health after chronic continual exposure.

Removal of ammonia is accomplished by biological nitrification performed by the aerobic autotrophic bacteria *Nitrosomas* spp. and *Nitrobacter* spp. These bacteria colonize the gravel bed and act as a biological filter. *Nitrosomas* converts ammonia to nitrite (NO₂⁻). *Nitrobacter* then transforms nitrite to nitrate (NO₃⁻). Nitrite is the second least desirable form of nitrogen which accumulates quickly in new tanks that have premature biofilters which cannot break down ammonia completely. Test kits that measure ammonia and nitrate are available from pet stores. Ammonia toxicity should be suspected when fish exhibit signs of respiratory distress secondary to gill damage. Fish with respiratory distress will gill (breathe) with an irregular pattern which progresses to spasticity with fins extended. Tetany occurs prior to death. Microscopically, the ammonia causes gill hyperplasia, aneurysms, telangiectasis, and corrosion of gill epithelium.

Lowering the pH of the tank is one method of decreasing toxic levels of ammonia but this method may not be feasible for the marine aquarist due to the alkaline pH saltwater tanks require. Individually
affected fish may benefit from diluted vinegar baths. The best treatment however is prevention. The use of charcoal or zeolite media in the filter in addition to having a mature biological filter will help keep the ammonia levels under control. The media and the biofilter are only effective if the organic load does not surpass their ability to break down nitrogenous waste. Overloading a tank with fish is a common mistake of inexperienced aquarists. The recommendation of fish per tank is one inch of fish per gallon of water. Weekly water changes of 4% of the tank's volume helps to decrease the volume of organic waste to be broken down by heterotrophic organisms. Excess food will supply heterotrophic bacteria with excess organic matter to break down and should be avoided.

Nitrite is taken up by gill membranes and absorbed into the blood where it causes the formation of methemoglobin resulting in brown blood disease. Clinical signs include mud colored gills and severe respiratory difficulty. Fish commonly hang in the water in a vertical position about two inches off the bottom with their heads up. This is often followed by convulsions, coma, and death. Treatment consists of adding sodium chloride to the water. The chloride disassociates from sodium and competes with nitrite ions for absorption across the gills. Saltwater fish are not susceptible to nitrite poisoning because of the high salt content of their environment. Prevention of nitrite toxicity is possible by advising clients not to add any fish to their tank until the biofilter is mature. A new tank may be “seeded” with gravel from an established tank or with freeze-dried starter kits containing Nitrobacter spp. and Nitrosomas spp.. Maturation of the bacteria takes four to six weeks and during this time, no fish can be added. When seeding a tank with gravel, the recommendation is to use one liter of gravel from an established tank per ten gallons of water and choose a tank that has been disease free in the past so infectious agents and parasites are not transmitted.

**Alkalinity and pH**

Alkalinity and buffering capacity are terms used synonymously when describing the pH of water. Alkalinity is the term used to describe the forms of carbon dioxide in the water. Carbon dioxide is found naturally in water and becomes hydrated to form carbonic acid which dissociates into bicarbonate and carbonate ions:

\[ H_2O + CO_2 = H_2CO_3 = H^+ + HCO_3^- = CO_3^{2-} + H^+ \]

Bicarbonate and carbonate ions are the primary buffers in water. Alkalinity is thus an expression of the buffering capacity. It is expressed in terms of equivalent calcium carbonate in fresh and saltwater. In addition to calcium carbonate, saltwater is buffered by the bicarbonate-borate system \( \text{H}_2\text{BO}_3 \). This causes saltwater to be more basic at a pH of 7.6-8.3 as compared to freshwater which has a pH of 6.0-7.5.

The availability of bicarbonate and carbonate ions is the key to maintaining a desirable pH. In aquariums, the trend is for these buffers to be continually utilized and for the pH to decrease. Bicarbonate and carbonate ions are utilized by the acids formed during the nitrification process of ammonia to nitrate, and the pH will fall if ammonia levels are high. Aquariums are eutrophic systems in which carbon dioxide production exceeds precipitation and reduction to bicarbonate and carbonate ions. As bicarbonate and carbonate increase and the supply of the ions decreases, carbonic acid levels rise and cause the pH to fall.

The range of tolerance for freshwater fish is pH 6-9. For saltwater fish the range is pH 7.5-8.5. Test kits and pH papers are available through pet stores. Chronic exposure to pH levels out of normal ranges causes skin inflammation resulting in excess mucus production. The gill epithelium erodes and gill hemorrhage is seen. Skin hemorrhage can occur, but more commonly the fish appear to be in excellent condition and show bright color patterns prior to death. Signs of acidosis are darting movements, swimming in circles, and attempts at jumping out of the water. Respiratory rates will be increased and fish may gulp air at the surface. Signs of alkalosis include pale gills, areas of skin erosions, excess mucus production, bluish-white turbidity of the skin, and occasional fin necrosis.

The most effective way to combat a fluctuating pH is to change the water frequently to reduce the accumulation of nitrogenous wastes and to dilute the hydrogen ion concentration. The time frame for water changes is the same recommendation for reducing nitrogen build-up. If a water change cannot be performed and the pH is falling, addition of one teaspoon of sodium bicarbonate per twenty gallons of water is recommended. Vigorous aeration of the water will help to blow off excess carbon dioxide and increase the pH. If the pH becomes too basic, acidification of the water can be achieved by filtering the water through peat moss. To aid in maintaining a basic pH in saltwater aquariums, the use of calcareous gravel containing a high percentage of calcium carbonate, which dissociates into calcium and carbonate, is recommended.
Salinity

Salinity is a measure of the total amount of inorganic solids (salts) in seawater. It is difficult to measure this parameter directly, and instead, it is calculated by using the water's specific gravity. The specific gravity can be measured using a hydrometer or a refractometer. When using a hydrometer, a chart can be used to translate specific gravity to salinity (see Table 1). As the temperature changes, the salinity changes. Warm water is less dense than cold water. Most hydrometers are calibrated to read specific gravity at a certain temperature. If the temperature of the tank is not equal to the calibration temperature, the chart will adjust the value. When using a refractometer, subtract one from the specific gravity and multiply by 1250 to approximate salinity readings in parts per thousand (ppt). The optimum salinity for marine aquariums is 30-32 ppt.

It is important to monitor salinity due to the osmotic regulatory systems of marine fish. Marine fish are hypoosmolar (have a lower osmotic pressure than seawater) and must combat water loss to the environment. If the water osmolarity is out of the optimum range, either a hyperosmolar or hypoosmolar state occurs resulting in stress on the renal system and its eventual failure.

Hardness

Hardness is a term used to describe the mineral content of water. Magnesium, calcium bicarbonate, and calcium sulfate salts comprise a large majority of the mineral content, and when measured represent the total hardness of water. One degree of total hardness (dh) is equal to 10 mg of calcium or magnesium oxide per liter of water (10 ppm). There is a second measure of hardness which takes into consideration sodium, potassium, and other cations in addition to calcium and magnesium salts. This second measure is called the degree of carbonate hardness (dKH).

Sea water has 35 ppm dissolved mineral salts and is considered to be very hard. Freshwater has less than 75 ppm of dissolved mineral salts and is considered to be soft. Distilled and deionized water have no dissolved mineral salts and are considered to be the softest water. Tap water contains many mineral salts and is considered hard water. Most freshwater tropical fish require soft water to thrive.

Table 1

Conversion of Specific Gravity (SG) to Salinity (0/00)

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degrees range. African cichlids are the exception and require hard water of 10 degrees or higher. The dKH for most freshwater fish ranges from 2-8 dKH.2

Test kits for hardness are available from pet stores. Hardness should be evaluated for freshwater tropical fish that are failing to thrive. If the water tests hard, softening can be achieved by placing peat moss in the filter. Remember that peat moss is also used to lower the pH, and the client should be advised to test pH more often. For homes with chronic hard water problems, installation of a water softener is advised. In addition, the use of distilled or de-ionized water at water changes can be beneficial.2 Starting a tank with the sole use of de-ionized or distilled water is not recommended. A degree of hardness is needed for fish to thrive. Calcium and magnesium compete with toxic heavy metals such as copper and zinc at gill branchial absorption sites. Calcium also decreases the toxicity of ammonia by decreasing plasma sodium efflux at the gills.2

Chlorine

Chlorine is added to public water supplies for its disinfectant and oxidizing properties. It is added as a gas (Cl2) or as salts: sodium hypochlorite (NaOCl) or calcium hypochlorite (Ca(OCl)2). The salts dissociate to the hypochlorite ion ([OCl]−). The gas reacts with water and forms hypochlorous acid (HOCl). The sum of the concentrations of chloride, hypochlorite, and hypochlorous acid are expressed in milligrams per liter of Cl2.2

Levels of 0.1 ppm or higher are common in public water supplies. This level is toxic and fatal to most species of tropical fish.2 Aquarists using public water supplies must treat the water prior to the addition of fish to the system. Water can be dechlorinated simply via aeration and aging the water for a few days.1 Many chemical products are available to dechlorinate and take moments to work. The measurement of chlorine levels can be done using commercial test kits.

Fish affected by chlorine toxicity lose color and develop signs of respiratory difficulty due to damage to the gill epithelium. Immediate death of all fish can occur if levels are 0.5 ppm or higher. A lower level of exposure causes sporadic losses. Sunken eyes are seen grossly on necropsy and gill branchial epithelial hyperplasia is seen microscopically. There is no treatment available for chronic chlorine exposure. For accidental chlorine exposure, immediate addition of sodium thiosulfate to the water will rapidly decrease chlorine levels by reducing chlorine to chloride. Prevention of high chlorine levels by proper tank aging, aeration, or treatment with chemical dechlorination products is essential to fish health.2

Copper

Copper is present in public water supplies, and in homes with copper piping, copper can reach levels that are toxic to fish. The toxicity of copper is dependent on its ionic form. In freshwater, copper is present in the free cupric state and is toxic to fish. In saltwater, copper becomes bound to organic/inorganic ligands and chloride ions to form stable divalent negatively charged soluble complexes. These complexes break down and precipitate out in the alkaline pH of saltwater rendering copper non-toxic to fish.2

Fish affected by copper toxicity will show abnormal behavior, anorexia, edema, disorientation, and protruding scales.2 Systems affected include renal, hepatic, immune, nervous, and respiratory. The kidney loses its osmoregulatory function, the liver undergoes vacuolar degeneration, there is a decreased amount of immunoglobulin production, and the mechanoreceptors of the lateral line are disabled. Gill lamellae become blunt and thickened and the capillary channels become congested. The mucous cells at the base of gill filaments become dilated resulting in excess mucus production.2 Toxicity progresses in five characteristic stages: first, lethargy with correct posture and some avoidance to capture; second, indifference with correct posture but no capture avoidance; third, incoordination with partial loss of normal posture; fourth, moribund with complete loss of normal posture; and finally, death. If these clinical signs are seen, testing the water with a commercial kit is indicated.

At this time there are no specific antidotes for copper toxicity. Treatment involves removing the exposure or correcting the source of copper.2 Aquarists with copper pipes should be advised to run the tap water for several minutes. This will remove the standing water in the pipes which is laden with heavy copper sediment due to gradual leaching. The use of cold water is also indicated since it will cause less copper to leach from the pipes.1

Hydrogen Sulfide

Anaerobic bacteria such as Desulfovibrio produce hydrogen sulfide in aquaria when there is a decrease in water circulation resulting in decreased oxygenation of the gravel bed.2 This problem occurs when filters malfunction or are dirty resulting in inadequate water circulation.5

Hydrogen sulfide interferes with the oxygen binding of hemoglobin and also has direct damage on the central nervous system. Respiratory distress is seen with gasping at the surface for air. The most
common clinical sign is sudden death. On necropsy, gills are a violet color due to cyanosis. If fish are exposed to chronic low levels, they will become irritable, anorexic, and show insufficient equilibrium. The exposure limit for hydrogen sulfide is less than 10 ppm. There are no commercial test kits available, but even at low levels a rotten egg smell can be detected. 

The best treatment is prevention. Filters should be kept clean of debris and gravel and gravel should be cleaned regularly. Chronically affected fish should be moved to a new tank. Baths of 0.1 ppm sodium nitrite or 25 mg/L of pyridoxine can also be used. The tank should be cleaned and aerated to drive off residual hydrogen sulfide. 

**Oxygen**

Oxygen is less soluble in water than in air and fish must ventilate ten to thirty times more than a terrestrial animal to obtain a similar amount of respired oxygen. Ventilatory rate depends on the amount of dissolved oxygen in the water. The amount of dissolved oxygen depends on water temperature, the oxygen demand of the aquarium’s inhabitants, and aeration devices. 

Cold water is more saturated than warm water, and at 30°C the oxygen concentration is equal to half the oxygen concentration at 0°C. Fish are not the only organisms utilizing oxygen in an aquarium. Plants, algae, and nitrifying bacteria of the biofilter also consume oxygen. It is important to remember that the oxygen consumption by the nitrifying bacteria of the biofilter may equal or exceed the oxygen consumed by the fish. 

The majority of oxygen exchange occurs at the air-water interface with small amounts provided by the bubbles rising in the water column from air stones. Air bubbles from aeration systems move water from the lower layers of the water column to the air-water interface for oxygen exchange and also serve to circulate water throughout the tank. It is important to watch for circulation currents in all areas of the tank to avoid oxygen depleted areas which can lead to hydrogen sulfide production as mentioned earlier. Airstones which produce small bubbles should be used since they transfer more oxygen to the water upon their ascent. The oxygen recommendation for aquariums is 1.5-2.0 liters of air per hour for each liter of water. This rate can be estimated by inverting a beaker over an airstone and measuring the fill time. 

At oxygen levels less than 3.5 ppm fish become stressed. Levels below 2.5 ppm are lethal. If the filter is black or a rotten egg smell is noticed, aeration of the tank or portions of the tank may be insufficient. Clinical signs of hypoxia are rapid gilling and gulping at the surface for air. Treatment is to correct the underlying problem by evaluating why the tank has become depleted. Possibilities include the following: decaying food on the bottom promoting increased activity by nitrifying bacteria and increased oxygen consumption, algae overgrowth, inadequate aeration system size in relation to tank size, a malfunctioning aeration system, or too many fish in the tank. 

**Temperature**

Maintaining a constant temperature is important since fish are poikilothermic. The temperature for freshwater tropical fish should be kept between 20-27°C (68-75°F) with temperature fluctuations made no faster than one to two degrees Celsius per hour. For marine tropical fish, the optimum temperature is 24-28°C (75-82°F). The rule of thumb for heaters is two to four watts per gallon of water. The location of the tank is important to prevent fluctuating temperatures. Tanks should be kept away from heating or air conditioning vents. Sunny spots are to be avoided since sunlight can quickly overheat a tank.

Clinical signs of hyperthermia are hyperactivity and hemorrhagic streaks on the body due to engorgement of blood vessels in the fins, skin, and subcutis. Death is thought to be due to osmotic stress resulting in a loss of ability to maintain serum ion and protein concentrations. Hypothermic fish are listless, pale, and have clamped fins. Loss of osmotic regulation is again thought to be the cause of death. Return to normal temperatures should be done slowly at a rate of two to three degrees per hour. 

**Conclusion**

The field of fish medicine is broad and may seem overwhelming. However, with a basic understanding of water quality the private practitioner can be well on his or her way to giving sound medical advice to fish owners. By having commercial test kits in house, water quality diagnoses can be made with a water sample from a problem tank. Alternatively, a veterinarian can set up an arrangement with local pet shops in which pet shop customers will be referred to the veterinarian who in turn sends these clients back to that store for medications or water testing supplies. As veterinarians begin to feel more confident answering questions about water quality, perhaps
confidence and interest in fish diseases and medicine will grow. Maybe one day, fish will enjoy the same status of health care that is provided to warm blooded, cuddly pets.

References


