NRAC Fact Sheet No. 170-1993

Northeastern Regional Aquaculture Center

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An Introduction to Water Chemistry in Freshwater Aquaculture

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The major water quality factors that are important in freshwater aquaculture systems and methods to monitor them are described in this publication. Water quality determines not only how well fish will grow in an aquaculture operation, but whether or not they survive. Fish influence water quality through processes like nitrogen metabolism and respiration. Knowledge of testing procedures and interpretation of results are important to the fish farmer.

Some water quality factors are more likely to be involved with fish losses such as dissolved oxygen, temperature, and ammonia. Others, such as pH, alkalinity, hardness and clarity affect fish, but usually are not directly toxic. Each water quality factor interacts with and influences other parameters, sometimes in complex ways. What may be toxic and cause mortalities in one situation, can be harmless in another. The importance of each factor, the determination method and frequency of monitoring depends upon the type and rearing intensity of the production system used.

Water Quality Variables

Temperature

All biological and chemical processes in an aquaculture operation are influenced by temperature. Fish adjust their body temperature and metabolic rate by moving into cooler or warmer water. Each species has a preferred or optimum temperature range where it grows best. At temperatures above or below optimum, fish growth is reduced. Mortalities may occur at extreme temperatures.

Dissolved Oxygen

The minimum dissolved oxygen (DO) level that fish can safely tolerate depends upon temperature and to a certain extent the species. Volubility of oxygen increases as temperature decreases. In ponds, DO can change dramatically over a *24* hour period. During the day oxygen is produced by photosynthesis, the process by which green plants convert water and carbon dioxide in the presence of light, to oxygen and carbohydrates. During the night and day oxygen is consumed by respiration, the process by which plants and animals use oxygen to produce carbon dioxide as they burn carbohydrates, but in the day photosynthesis usually produces more oxygen than is used. Typically, oxygen levels are lowest just before dawn and highest in the late afternoon.

DO in a culture system must be maintained above levels considered stressful to fish. Warmwater fish (species that grow best at temperatures above 80°F) can tolerate lower DO concentrations than coldwater fish (species that grow best at temperatures below 60°F). As a rule of thumb, DO should be maintained above 3.0 ppm (parts per million; frequently used interchangeably with milligrams per liter, mg/L) and 5.0 ppm for warm and coldwater fish, respectively. Prolonged exposure to low, non-lethal levels of DO constitutes a chronic stress and will cause fish to stop feeding, reduce their ability to convert ingested food into fish flesh, and make them more susceptible to disease. Intensive fish production in ponds, cages, flow-through, and recirculating systems requires aeration or oxygenation to maintain DO at safe levels.

Nitrogenous Wastes

Most fish and freshwater invertebrates excrete ammonia as their principle nitrogenous waste. Analytical methods are used to determine total ammonia-nitrogen (TAN). The proportion of TAN that exists in ionized and un-ionized form varies with pH and temperature. As pH and temperature increase, the amount of TAN in the toxic un-ionized form increases (see figure 1). Fish continuously exposed to more than 0.02 ppm of the un-ionized form may exhibit reduced growth and increased susceptibility to disease.

When fish are cultured intensively and fed protein-rich feeds they can produce high concentrations of ammonia in the water. Ammonia and other metabolic wastes are gradually removed by natural processes in ponds or through the use of biological filters in recirculating and reuse systems. Ammonia is removed by bacteria that initially convert it into nitrite and subsequently into nitrate. Nitrite is toxic to fish and causes "brown blood" disease. Concentrations of 0.5 ppm have reduced growth and adversely affected fish. Fish can tolerate nitrate to several hundred ppm. Removal or detoxification of ammonia is facilitated by providing and maintaining an optimal environment for the appropriate bacteria (pH between 7-9; temperature approximately 75-85° F).

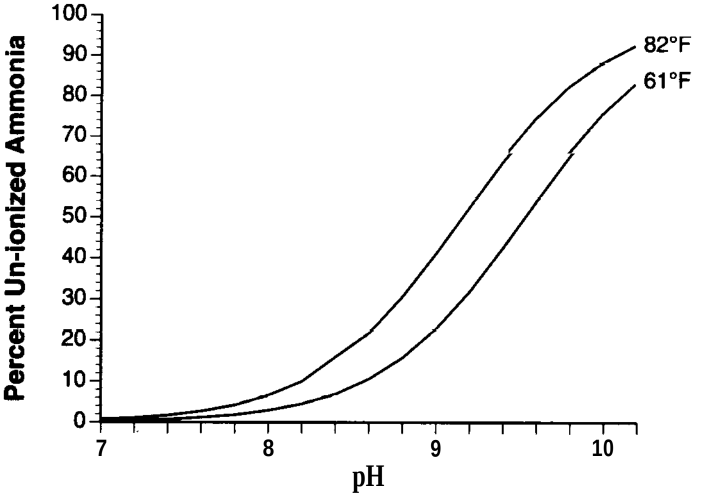

Figure 1. Relationship between pH, temperature, and un-ionized ammonia at 61°F and 82°F

pH

The concentration of bases and acids in the water determines its pH. A low pH is acidic and a high pH is basic; a pH of 7 is neutral. Fish survive and grow best in waters with a pH between 6-9. If pH readings are outside this range, fish growth is reduced. At values below 4.5 or above 10, mortalities occur.

In well-buffered ponds (with alkalinity over 50-100 ppm, see next section), pH typically fluctuates one or two units daily. In the morning, carbon dioxide levels are high and pH is low as a result of respiration during the night (carbon dioxide forms a mild acid when dissolved in water). After sunrise, algae and other green plants produce carbohydrates and oxygen from carbon dioxide and water by photosynthesis. As carbon dioxide is removed from the water, its pH increases. The lowest pH of the day is typically associated with the lowest level of dissolved oxygen. The highest pH of the day is typically associated with the highest level of dissolved oxygen.

In recirculating systems, vitrification and respiration of both fish and biofilter bacteria decrease pH. Frequently, a buffer such as sodium bicarbonate is added to prevent the pH from falling too much.

Alkalinity

The buffering capacity of culture water, expressed as ppm calcium carbonate, is its alkalinity. Alkalinity is a measurement of carbonate and bicarbonate ions (ions are atoms or groups of atoms with a negative or positive charge) dissolved in the water. As the amount of carbon dioxide fluctuates, the pH of water changes. The magnitude of this shift is determined by the water's buffering capacity or its ability to absorb acids and/or bases. Photosynthetic activity in a poorly buffered pond can cause pH to increase, perhaps from as low as six in the morning to nine or more by late afternoon. In a pond with higher alkalinity, the pH shift is reduced. For instance, the daily shift in a well buffered pond might be from a pH of seven in the morning to eight by late afternoon. A suitable range of alkalinity is 20 to 300 ppm. Alkalinity in excess of 300 ppm does not adversely affect fish, but it does interfere with action of certain commonly used chemicals (e.g., copper sulfate). Alkalinity remains relatively constant in ponds, but decreases steadily in nonsupplemented, recirculating systems. Alkalinity can be increased by adding agricultural limestone to ponds or sodium bicarbonate to recirculating systems.

Hardness

Calcium and magnesium ions comprise hardness. Test procedures usually determine both ions as "total hardness," expressed as ppm calcium carbonate. In most waters the concentrations of alkalinity and hardness are similar, but they can differ vastly as alkalinity measures negative ions (carbonate, bicabonate) and hardness measures positive ions (calcium, magnesium). Hardness is important, especially in the culture of several commercial species such as striped bass and catfish. If hardness is deficient, these species do not grow well. Hardness should be above 50 ppm; low hardness can be adjusted by the addition of lime or calcium chloride.

Carbon Dioxide

Only when using groundwater, transporting fish at high densities, or in recirculating systems are carbon dioxide problems likely to develop. At high concentrations, carbon dioxide causes fish to lose equilibrium, become disoriented and possibly die. Testing groundwater before use and aerating it, if necessary, will reduce carbon dioxide to acceptable levels. Careful planning, aeration or oxygenation, and buffering of water will keep carbon dioxide at acceptable levels when large numbers of fish are hauled extended distances or cultured in recirculating systems.

Salinity

The total concentration of all ions in the water is its salinity. Freshwater fish exhibit a range in salinity tolerance. Many commercially important species (e.g., channel catfish, *Ictalurus punctatus;* largemouth bass, *Micropterus salmoides;* tilapia, *Tilapia* sp.) survive and grow well in slightly salty water. After they smelt, salmon and trout can tolerate salt water. Salinity not only affects osmoregulation it also influences the concentration of un-ionized ammonia. During the planning stage of an aquaculture operation, salinity should be measured and the water's appropriateness determined.

Iron

Many groundwaters contain elevated levels of dissolved iron. When exposed to the air, this iron interacts with oxygen, becomes insoluble, and forms a red deposit. Small clumps of iron are produced that can settle on fish gills, causing irritation and stress. Problems can be avoided if the iron-bearing water is exposed to air and the resultant clumps of iron removed by settling or filtration before the water enters the culture system.

Chlorine

To control bacteria, municipal water supplies are typically treated with chlorine at 1.0 ppm. If municipal waters are used to culture fish, residual chlorine must be removed by aeration, with chemicals such as sodium thiosulfate, or filtration through activated charcoal. Chlorine levels as low as 0.02 ppm can stress fish.

Hydrogen Sulfide

Ponds with oxygen-poor bottoms and accumulated organic material can release hydrogen sulfide when seined or disturbed. Substratum beneath heavily fed cages/net pens can accumulate wastes (e.g., uneaten food, feces) and produce hydrogen sulfide gas if oxygen becomes deficient. Hydrogen sulfide gas has a rotten egg odor and is extremely toxic to fish. Any detectable odors or levels should be avoided and extreme care should be taken when handling fish in an afflicted pond. Ponds can be drained, exposed to air and/or excavated to correct the problem.

Water Clarity

In pond and cage culture, water clarity can affect fish. If fish that prefer turbid waters (e.g., bullhead, catfish, walleye) are cultured in relatively clear water they will experience stress; survival and growth will be adversely affected. Accumulation of suspended solids and discoloration of culture water occur in recirculating systems which can irritate fish and precipitate disease. Some suspended and dissolved materials can cause off-flavor in fish. Filtration and flocculent can be used to remove solids and reduce discoloration.

Monitoring Methods

A variety of methods are available to monitor water quality (see Table 1). In pond, cage, and low intensity culture, the high precision of sophisticated analytical methods (e.g., APHA 1989) is not needed to make informed management decisions (see Boyd 1990). However, intensive culture in recirculating and reuse systems requires frequent and sophisticated monitoring.

If fish are maintained at high densities, then temperature, dissolved oxygen, ammonia, nitrite, and pH should be monitored daily or more frequently (e.g., continuous monitoring of dissolved oxygen in recirculating systems). Water clarity, alkalinity, and hardness can be measured less frequently, perhaps one or two times per week, as they do not fluctuate as rapidly. Salinity, iron, and chlorine should be determined when a potential water source is first examined so corrective measures may be incorporated into the production system during the design or planning stage. Carbon dioxide should be measured when first using a new groundwater source and routinely in recirculating systems. When hydrogen sulfide and carbon dioxide problems are likely, systems should be monitored closely and the means to correct problems should be readily available.

At lower stocking densities, water quality parameters can be monitored less frequently or not at all. Regardless of the frequency, monitoring should be conducted at a standard time and depth where fish are located. Time of measurement and observed values should be recorded; good record keeping is essential to successful aquaculture. In pond and cage culture it is preferable to monitor dissolved oxygen early in the morning, when conditions stressful to fish are most likely to occur (e.g., low oxygen). Conversely, temperature and pH in ponds are best measured during the late afternoon.

Sources of Supplies and Equipment

Several suppliers produce kits and materials to monitor water quality. Suppliers frequently have displays at trade shows and sources are listed in several trade journals including the Annual Buyer's Guide published by Aquaculture Magazine, P.O. Box 2329, Ashville, NC 28802.

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Acknowledgments

This work was supported by the Northeastern Regional Aquaculture Center through grants number 89-38500-4356 and 90-38500-5211 from the Cooperative State Research Service, U.S. Department of Agriculture. Any opinions, findings, or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the U.S. Department of Agriculture.

Table 1. Water quality factors, commonly used monitoring procedures, and preferred ranges for fish culture. Details for specific test procedures can be obtained from a commercial supplier or appropriate text (e.g., APHA 1989; Boyd and Tucker 1992).

Water Quality Factor	**Test Procedure**	**Preferred Ranges for Fish Culture**
Temperature	Thermometer, Telethermister	species dependent
Dissolved Oxygen[1]	Titrimetric (Modified Winkler) Polarographic meter Calorimetric kits	>4-5 ppm for most species
Total Ammonia-Nitrogen[2] (ionized and un-ionized)	Calorimetric kits (Nesslerization or Salicylate) Ion specific probes	NH_3<O.02 ppm
Nitrite[2]	Calorimetric kits (Diazotization) Ion specific probes	<1 ppm; 0.1 ppm in soft water
pH[3]	Calorimetric kits Electronic meter	6-8
Alkalinity	Titrimetric with pH meter Titrimetric with chemical indicator	50-300 ppm calcium carbonate
Hardness	Titrimetric kit	>50 ppm, preferably >100 ppm calcium carbonate
Carbon dioxide	Titrimetric	<10 ppm
Salinity[4]	Conductivity meter Refractometer Titrimetric	species dependent typically <0.5- 1.0 ppt (for freshwater fish)
Iron	Colofimetric kit Visible red precipitate	<0.5 ppm
Chlorine	Calorimetric kit	<0.02 ppm
Hydrogen sulfide	Calorimetric kit	No detectable level
clarity[5]	Secchi disk Turbidimeter	species dependent

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1. The Winkler method is relatively complicated and time consuming, but may be appropriate if the culture system is small and financial resources are limited. Dissolved oxygen meters are quick and convenient to use, but expensive and require regular maintenance to function correctly. Calorimetric samplers or kits are reasonably accurate and suitable for field analyses, but sometimes difficult to interpret at night with limited light. If multiple readings are frequently taken, a polarographic meter is the preferred method.

2. Ion-specific probes require expensive and sophisticated instrumentation; they are impractical in commercial situations. One possible exception is a computer monitored, intensive recirculating system. A variety of moderately priced calorimetric kits are available to monitor ammonia and nitrite. Greatest precision is obtained with a spectrophotometer. If fish are cultured at high densities, ammonia should be monitored by precise analytical methods (e.g., APHA 1989; Boyd and Tucker 1992).

3. Meters are available over a wide range of prices. Performance depends upon daily calibration and regular maintenance. Calibration is done with known standards called buffers. Calorimetric tests lack the precision of a meter, but are quick, economical, and adequate for field analyses.

4. Conductivity measures the water’s capacity to convey an electrical current; it is directly related to the concentration of ions in the water. Distilled water has a conductivity of 1 µmhos/cm; natural waters range from 20 to 1,500 µmhos/cm. Conductivity meters are widely available and relatively inexpensive. Refractometers measure the salinity of a water sample optically; they are expensive and most accurate in brackish or salt water.

5. A Secchi disk (metal plate 6“ in diameter with diagonal quadrants painted white and black) is lowered until it disappears, the depth of Secchi disk visibility. If a Secchi disk is not available, you can use your hand. In reuse and recirculating systems, a turbidimeter can be used and clarity expressed as Jackson Turbidity Units (JTU) or Nephelometric Turbidity Units (NTU).