Ammonia Nitrogen Management in Aquaculture Ponds

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*By Li Zhou and Claude E. Boyd**

Introduction

Ammonia nitrogen usually is the next most important factor after low dissolved oxygen concentration limiting the amount of fish that can be produced in a culture system. As a major component of protein and necessary nutrient for phytoplankton, nitrogen regulates the primary productivity and enhances the base of the food web culminating in cultured species. High concentrations of ammonia nitrogen, however, are toxic to aquatic animals and can cause sub-lethal or lethal effects on fish. Poor growth and feed conversion rates, reduced fecundity and fertility, and susceptibility to bacterial infections and disease have been reported in fish. Elevated ammonia nitrogen in water can cause gill damage, oxygen-carrying capacity reduction in the bloodstream, lack and depletion of adenosine triphosphate (ATP) in the brain, and liver and kidney malfunction. Moreover, ammonia nitrogen occurring with phosphorus when discharged to the environment contributes to the eutrophication of water bodies.

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Temperature, pH, and Ammonia Toxicity

Ammonia nitrogen occurs in water as un-ionized ammonia (NH_3) and the ammonium ion (NH_4^+):

$$NH_3 + H_2O = NH_4^+ + OH^-$$

The usual analytical procedures do not distinguish between ammonia and ammonium, and results are reported as total ammonia nitrogen (TAN) consisting of NH_3-N and NH_4^+-N. Biological membranes are more permeable to NH_3 than to NH_4^+, and ammonia toxicity is attributed primarily to NH_3. The NH_3:NH_4^+ ratio increases with greater pH and temperature, with pH being the more important influence (Table 1). Convenient convertors for estimating the percentage of TAN present as NH_3-N at different pHs and water temperatures are available on-line – an excellent one can be found at http://www.hbuehrer.ch/Rechner/Ammonia.html.

Water temperature and pH fluctuate daily in ponds, with highest values typically occurring in early to mid-afternoon and lowest in early morning. As a result, there is much variation in the proportion of the TAN concentration in NH_3-N form at different times of the day. For example, on a summer day when TAN concentration is 1 mg L^{-1}, a pH change from 8.0 to 9.0 with water temperature at a constant 28 °C will raise NH_3-N concentration from 0.066 to 0.412 mg L^{-1}. If pH remains constant at 8.0, a 1 °C increase in water temperature will increase NH_3-N concentration from 0.066 to 0.070 mg L^{-1}. Of course, both temperature and pH usually increase on a summer afternoon. In a pond where temperature and pH increase from 27 °C and 7.5 in the morning to 31 °C and 9.0 in the afternoon, NH_3-N concentration will rise from 0.020 to 0.463 mg L^{-1}.

Ammonia toxicity is usually reported as the 96-hr LC50 – the lethal concentration of ammonia (as NH_3-N) required to kill half of the test population in 96 hours. The tolerance of ammonia toxicity varies among different species. The LC50s for NH_3-N generally are 1.0 – 3.0 mg/L for warmwater species and less than 1.0 mg/L for coldwater species. The 96-hr LC50 to pacific white shrimp has been reported to range from 1.20 to 2.95 mg L^{-1} with an average of 2.08 mg L^{-1}; for channel catfish the range is from 1.50 to 3.30 mg L^{-1} with an average of 2.28 mg L^{-1}. In realty, however, producers are concerned over the sub-lethal

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effects of ammonia more than the LC50. The "safe" or no-observed-effect level (NOEL) of common toxins such as ammonia to aquatic animals often is considered to be 5% of the 96-hr LC50.

Concentrations and measurement

TAN concentrations in ponds tend to fluctuate greatly over time (Figure 2). Concentrations of TAN in ictalurid catfish farms in Alabama usually are less than 5 mg L^{-1}; but, concentrations between 5 and 15 mg L^{-1} also occur. Similar concentrations of TAN can be expected for intensive culture of other species. A recent study confirms that TAN concentrations high enough to be chronically toxic to ictalurid catfish occur rather commonly in ictalurid catfish ponds in Alabama.

A recent study also revealed that the salicylate method developed by Bower and Holm-Hansen in 1980 is the most reliable method for measuring TAN concentrations in aquaculture. The widely used Nessler kit for TAN determination provides considerably greater-than-actual concentrations. On the other hand, the YSI salicylate kit is accurate, and provides an alternative to the standard salicylate method for use at aquaculture facilities.

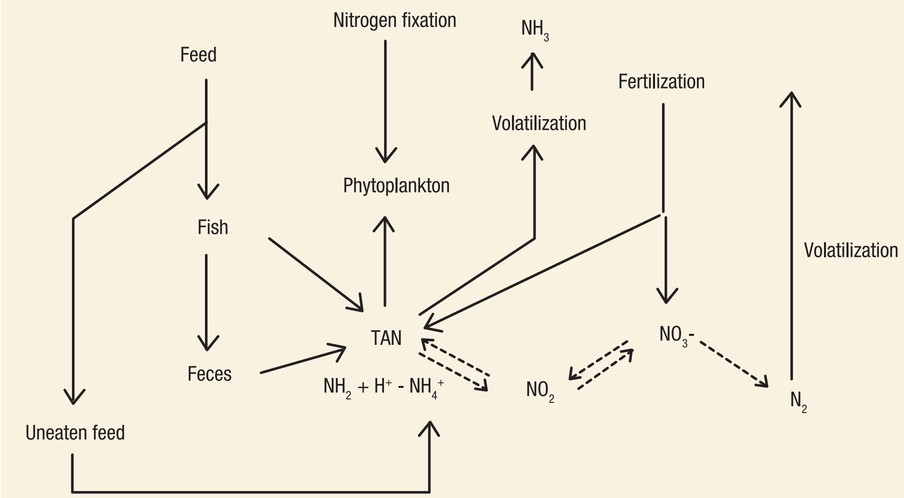
Table 1

Percentage of un-ionized ammonia nitrogen at different pHs and temperatures.

pH	Temperature (ºC)			
	10	20	25	30
7	0.0018	0.0039	0.0056	0.0080
7.6	0.0074	0.0156	0.0221	0.0311
8.2	0.0287	0.0592	0.0827	0.1132
8.8	0.1052	0.2004	0.2642	0.3370
9.2	0.2280	0.3863	0.4742	0.5607
9.8	0.5403	0.7148	0.7821	0.8356

Figure 1

Nitrogen cycle in aquaculture ponds.



Ammonia management

There are several ways to reduce ammonia nitrogen concentration. Although some are not long-term solutions or practical to use at production facilities, they are still worth mentioning. Measures such as adding an acid to lower pH, applying an algicide to lessen phytoplankton photosynthesis and reduce pH, or exchanging water in ponds to flush out ammonia nitrogen can be used as emergency treatments where the TAN concentration is too high. However, such treatments are expensive, they also have possible negative effects on water quality in ponds (acid and algicide treatment) and in water receiving aquaculture effluents (release nutrient-enriched or pathogen-contaminated water). They may also be difficult or impossible to implement at particular sites (water exchange).

Fertilizing ponds with phosphorus promotes algae growth, thereby decreasing ammonia nitrogen through algae uptake. However, adding additional phosphorus to ponds already receiving phosphorus input from feed may cause unacceptably dense phytoplankton blooms.

Adding a source of organic matter such as manure or chopped hay can reduce ammonia nitrogen. This result is because organic matter with an elevated C/N ratio promotes immobilization of the ammonia from the water by microorganisms of decay. This practice, however, requires large amounts of organic carbon and increases the oxygen demand.

Shrimp farmers in some Asian countries often apply zeolite to

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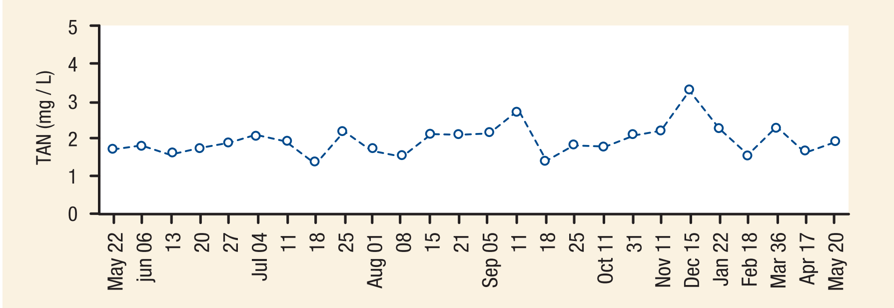
Figure 2

Fluctuations of monthly average total ammonia nitrogen between May 2013 and May 2014 in 31 commercial ictalurid ponds from West-central Alabama.



ponds in attempts to lower the ammonia concentration to which culture animals are exposed. This method is practical to use in transport containers for ornamental freshwater fishes, and in aquaria or water recirculating aquaculture systems, but it is not practical for large-volume fish ponds.

The practice of applying living bacterial amendments to ponds to lessen TAN concentration is popular in Asia and is now being used by some ictalurid catfish producers in the United States. However, there is no evidence that this practice is effective.

The best approach for avoiding high TAN concentration is to apply practices that minimize ammonia nitrogen input, increase nitrification, and lessen pH increase as follows:

1.Use a good quality feed with optimal crude protein concentration.

2.Use moderate stocking and feeding rates.

3.Feed slightly less than fish will eat to avoid overfeeding and uneaten feed.

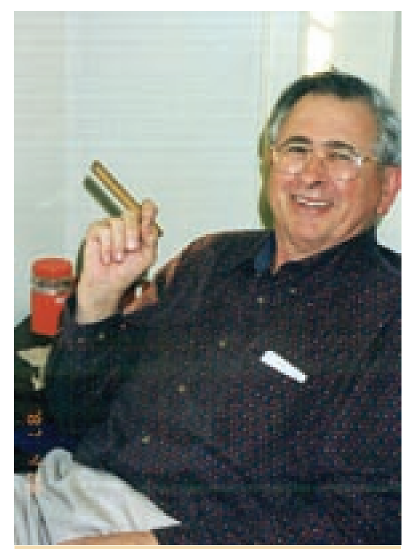
4.Use adequate mechanical aeration to prevent dissolved oxygen concentrations from falling below 4 mg L^{-1} at night – around 1 hp for each 10 kg ha-1 day-1 of feed usually is adequate. Aeration favors bacterial nitrification and enhances the diffusion of NH_3 from water to the air.

5.Avoid sources of ammonia nitrogen from watersheds. Livestock production on a watershed will substantially increase TAN concentration in receiving ponds.

6.Ponds with low alkalinity (< 40 mg L^{-1}) should be treated with agricultural limestone to increase alkalinity and buffer water against pH fluctuations.

7.Ponds with low total hardness but normal alkalinity should be treated with agricultural gypsum ($CaSO_4 \cdot 2H_2O$) to increase hardness and prevent high pH in response to high photosynthesis rates.

Adoption of moderate stocking and feeding rates will not appeal to many producers. But, even in ponds with high fish production, the other practices listed above can be beneficial in limiting the concentration of TAN.



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Dr. Zhou holds Bachelor's and Master's degrees from the Ocean University of China and Master's and a Ph.D. degree from Auburn University. Her prior experience includes work as a Research Assistant at Auburn University and the Ocean University of China and an internship at the Institute of Oceanology, Chinese Academy of Science. Dr. Claude Boyd received his B.S. and M.S. degrees from Mississippi State University and his Ph.D. from Auburn University, where he has worked for the past 44 years as a Professor in the Department of Fisheries and Allied Aquacultures.