Ammonia Toxicity Degrades Animal Health, Growth

An NH_3-N concentration of 0.45 mg/L reduced the growth of five species of penaeid shrimp by about 50%.

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Summary:
Ammonia nitrogen occurs in aquaculture systems as a waste product of protein metabolism by aquatic animals and degradation of organic matter, or in nitrogen fertilizers. Exposure can reduce growth and increase susceptibility to diseases in aquatic species. Ammonia nitrogen concentrations vary with time of day, water depth and temperature, and increase as biomass and feed input increase. The best management is conservative stocking and feeding rates that minimize ammonia nitrogen and avoid excessive phytoplankton blooms that cause high pH.

Ammonia nitrogen consisting of un-ionized ammonia (NH_3) and ammonium ion (NH_4^+) occurs in waters of aquaculture production systems as a waste product of protein metabolism by aquatic animals and degradation of organic matter by bacteria and other microorganisms. Ammonia nitrogen also reaches ponds in nitrogen fertilizers such as ammonium sulfate, ammonium phosphate and urea that hydrolyze to produce ammonia nitrogen.

The proportion of ammonia nitrogen existing as NH_3 increases as water temperature and especially pH increase (Table 1). Salinity decreases the proportion of NH_3 at a given pH and temperature, but the effect is not great. For example, at pH 8 and 25° C, the contributions of un-ionized ammonia nitrogen (NH_3-N) to ammonia nitrogen at different salinities are: freshwater, 4.90%; 5 ppt salinity, 4.93%; 10 ppt, 4.78%; 15 ppt, 4.63%; 20 ppt, 4.48%; 25 ppt, 4.34%; 30 ppt, 4.20%; 35 ppt, 4.07%.

Most of the waste nitrogen in aquatic animals is transported in the blood to the gills, where it diffuses into the water as NH_3. When NH_3 concentration is low in the surrounding water, there is a high concentration gradient to facilitate loss of ammonia from animal blood to the water. An increase of NH_3 in the water decreases the gradient, resulting in a higher concentration of NH_3 in the blood and leading to adverse physiological consequences that can be lethal if the NH_3 concentration becomes excessive.

Toxicity Of Ammonia Nitrogen

The toxicity of ammonia nitrogen to aquatic animals results almost entirely from NH_3, because NH_4^+ is relatively non-toxic. Thus, NH_3 toxicity is highly dependent upon pH and is more likely in waters with pH above 8. Of course, in pond culture, water pH typically fluctuates daily, with lowest values in the early morning hours and highest values in the afternoon. In some weakly buffered, low-alkalinity waters with dense phytoplankton blooms, and in high-alkalinity waters, pH can be high throughout the day.

There has been much research on ammonia toxicity to aquaculture species under controlled conditions in the laboratory. Toxicity data have commonly been reported as the concentration of ammonia (reported as NH_3-N) lethal to 50% of the test organisms (LC50). The duration of tests have varied, but many were for 96 hours. Typical 96-hour LC50s found in the literature are presented in Table 2 for several aquaculture species.

The LC50s for NH_3 typically are less than 1.0 mg/L for coldwater species and 1.0-3.0 mg/L for warmwater species. There is not much difference in the 96-hour LC50 range for freshwater and marine species. Some of the reported variation in LC50s resulted from species differences in susceptibility to ammonia. However, much of the variation was the result of different conditions in the toxicity tests – especially water temperature, pH and salinity.

Table 1. Decimal fractions of ammonia nitrogen existing as un-ionized ammonia at various pH values and water temperatures.

	Temperature (° C)								
pH	16	18	20	22	24	26	28	30	32
7.2	0.004	0.005	0.006	0.007	0.008	0.009	0.011	0.012	0.015
7.6	0.011	0.013	0.015	0.017	0.020	0.023	0.027	0.031	0.036
8.0	0.028	0.033	0.038	0.043	0.049	0.057	0.065	0.075	0.087
8.4	0.069	0.079	0.090	0.103	0.117	0.132	0.149	0.169	0.194
8.8	0.157	0.178	0.200	0.223	0.248	0.276	0.306	0.339	0.377
9.2	0.319	0.352	0.386	0.420	0.454	0.489	0.526	0.563	0.603

Table 2. Examples of 96-hour LC50s for NH_3-N to common aquaculture species.

Species	96-Hour LC50
Freshwater	
Channel catfish	0.74-3.10
Tilapia	2.88
Rainbow trout	0.32-0.93
Cutthroat trout	0.50-0.80
Fathead minnows	0.20-3.4
Freshwater prawns	2.00-2.50
Marine	
Striped bass	0.64-1.10
Spotted sea trout	1.72
Southern white shrimp	0.69-1.20
Pacific white shrimp	1.20-2.95
Black tiger prawns	1.04-1.69
School prawns	1.39

A study on rainbow trout reported LC50s of 0.32-0.66 mg/L at temperatures of 10 to 13° C, but at 16 to 19° C, LC50s were 0.86-0.93 mg/L. This revealed that NH_3 was more toxic at lower temperature. This is somewhat unusual, because the LC50s of many toxins decrease with increasing water temperature, indicating greater toxicity in warmer water.

The pH is not only important in determining the percentage of ammonia nitrogen in NH_3 form, it also affects the toxicity of NH_3. In a study of channel catfish, the LC50 at pH 6.0 was 0.74 mg/L, but at pH 8.8 was 1.91 mg/L. In rainbow trout, the LC50 increased from 0.13 mg/L at pH 6.5 to 0.66 mg/L at pH 8.9. Although there is a smaller proportion of NH_3 at lower pH, NH_3 is more toxic at lower pH.

In studies, tilapia growth declined progressively at NH_3-N concentrations above 0.068 mg/L.

Increasing salinity lessens the toxicity of NH_3. In Pacific white shrimp, the LC50 increased from 1.2 mg/L at 15 ppt salinity to 1.6 mg/L at 35 ppt salinity. Similar results were reported for other species of shrimp and fish.

The effect of dissolved-oxygen concentration on NH_3 toxicity is unclear. One study did not find an effect, but another study revealed that NH_3 was more toxic to black tiger prawns at a dissolved-oxygen concentration of 2.3 mg/L than at 5.7 mg/L.

Sub-Lethal Effects

In aquaculture, producers are usually more concerned over sub-lethal effects of a toxin than about the LC50. A number of studies have revealed that chronic exposure to NH_3 produces physiological changes, causes gill lesions, reduces growth and increases susceptibility to diseases.

A study with channel catfish found that growth decreased linearly over the NH_3-N concentration range of 0.048-0.989 mg/L. Growth reduction was 50% at 0.517 mg/L, and no growth occurred at the highest concentration. Tilapia growth also was shown to decline progressively at NH_3-N concentrations above 0.068 mg/L.

An NH_3-N concentration of 0.45 mg/L reduced the growth of each of five species of penaeid shrimp by about 50%. Rainbow trout exposed continuously to NH_3-N concentrations up to 0.073 mg/L did not show reduction in growth, but histopathological lesions were noted at 0.04 mg/L, and protozoan infections increased above 0.02 mg/L.

Most toxicity studies were conducted at relatively constant concentrations of NH_3-N. In culture systems, and especially in ponds, the NH_3-N concentration varies with time of day and depth. For example, in a freshwater pond, the pH might be 7.4 in the early morning, when water temperature is 26° C, and 8.8 in the afternoon, when the water temperature is 28° C. At an ammonia-nitrogen concentration of 1.0 mg/L, the NH_3-N concentration in the morning would be 0.015 mg/L, but in the afternoon, the concentration would be 0.306 mg/L – 20 times greater.

Nevertheless, daily fluctuations of NH_3-N up to 0.37 mg/L that occurred in ponds did not cause a measurable decline in tilapia growth. The authors of that study concluded that exposure to sub-lethal ammonia concentrations probably has minimal effects on fish growth.

Fish and shrimp exposed earlier to sub-lethal NH_3 concentrations were less affected by high NH_3 nitrogen concentration than were animals not previously exposed. Ammonia-nitrogen concentrations tend to increase over time in culture systems as biomass and feed input increase. This may allow the culture species to acclimate to greater ammonia-nitrogen concentrations.

Safe Concentrations

The safe concentration for long-term exposure to NH_3-N and several other common toxins often is estimated by multiplying 0.1 or 0.05 times the 96-hour LC50. Using 0.05 as the factor, safe NH_3-N concentrations would range 0.015-0.045 mg/L for coldwater species and 0.050-0.150 mg/L for warmwater species.

Because of the great variations in NH_3-N concentrations, pH and water temperature over time, however, these calculations should be considered more as general guidelines than absolute values. Frequent, repeated monitoring of NH_3-N in culture systems – especially in ponds – is therefore not necessary.

Besides, there is no sure method for reducing ammonia nitrogen short of using a high rate of water exchange to flush ammonia out of culture units or lowering feed inputs and hence production. The common practices of inoculation with nitrifying bacteria or application of zeolite may be of limited value, so probably the best approach to ammonia nitrogen management is to adopt conservative stocking and feeding rates that minimize NH_3-N input and avoid excessive phytoplankton blooms that cause high pH.

Enough aeration should be applied to avoid low dissolved-oxygen levels and encourage oxidation of ammonia nitrogen to nitrate by nitrifying bacteria. Disturbance of surface water by aeration also encourages NH_3 diffusion into the air. Pond bottoms should be dried out between crops, and acidic soil should be limed to encourage oxidation of organic matter between crops to lessen ammonia nitrogen release into the water during crops.