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An assessment of total ammonia nitrogen concentration in Alabama (USA) ictalurid catfish ponds and the possible risk of ammonia toxicity

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ABSTRACT

An assessment of total ammonia nitrogen (TAN) concentration was conducted for 31 ictalurid catfish ponds on six farms, in the Blackland Prairie region of Alabama (USA). Five farms that provided production data had average annual feed inputs and harvest weights of 15,579–21,739 kg ha^{-1} and 8104–12,344 kg ha^{-1}, respectively. Concentrations of TAN were measured 26 times (weekly June through September and less frequently other months) between May 2013 and May 2014. The farm average, annual TAN concentrations were 1.05–1.78 mg L^{-1} at five farms and 4.17 mg L^{-1} at the other. Correlations were not found ($P > 0.05$) when pond average TAN concentration was regressed individually against feed input, weight fish harvested, and aeration rate. Nearly half of the TAN concentrations were <1 mg L^{-1}, the majority were <5 mg L^{-1}, but some ranged from 5 to 15 mg L^{-1}.

Analysis of the literature on ammonia toxicity to channel catfish suggested that the no-observed-effect level (NOEL) is around 1.0 mg L^{-1} NH_3-N in ponds with pH of 7.5 and above where NH_3-N concentration fluctuates greatly because of daily change in temperature and especially pH. Based on the daily pH fluctuation of 7.5 to 9.5 observed in ponds, and typical monthly average water temperatures, the NOEL for NH_3-N was often exceeded. At pH 8.5–8.9, depending upon the month, up to 14.5% of ponds exceeded the NOEL for NH_3-N. The NOEL was exceeded by up to 31.5% of pond at pH ≥ 9.0. The findings reveal that TAN concentrations in Alabama ponds often are at chronically toxic levels for ictalurid catfish. There is usually no practical emergency treatment for reducing NH_3-N (or TAN) concentration in ponds exceeding the NOEL. Thus, good management practices for avoiding excessively high TAN concentrations in ponds — efficient feed management, adequate aeration to promote nitrification, and treatments for maintaining buffering capacity in pond water should be applied.

1. Introduction

In feed-based aquaculture, 20 to 40% of nitrogen contained in protein of feed applied to ponds is recovered in harvested biomass. The rest of the nitrogen enters the pond in uneaten feed and feces or is excreted as ammonia nitrogen by the culture species. Nitrogen in uneaten feed and feces is released into the water as ammonia nitrogen by bacteria and other decomposer organisms (Boyd and Tucker, 2014).

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

$$NH_3 + H_2O = NH_4^+ + OH^- \qquad K_b = 10^{-4.74}. \tag{1}$$

Biological membranes are more permeable to NH_3 than to NH_4^+, and ammonia toxicity is attributed primarily to NH_3. Nevertheless, high NH_4^+ concentration in the water interferes with the outward movement of ammonia through the gills (Liew et al., 2013). Thus, NH_4^+ has some degree of toxicity, but much less than that of NH_3.

The ratio NH_3:NH_4^+ increases with greater pH as obvious from Eq. (1). Moreover, examination of K_b of Eq. (1) for different temperatures (Bates and Pinching, 1949) shows that the NH_3:NH_4^+ ratio also increases with rising temperature.

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. The concentrations of each of the two forms can be calculated with Eq. (1) using the measured pH and the appropriate K_b for the observed water temperature. However, convenient tables for estimating the percentage of TAN present as NH_3-N at different pHs and water temperatures are available (Trussell, 1972; Emerson et al., 1975), and even more convenient NH_3-N calculators are available on-line — an excellent one can be found at http://www.hbuehrer.ch/Rechner/Ammonia.html.

Concern over possible toxic effects of ammonia in aquaculture systems has increased in recent years, because of the intensification of production by greater use of feeds. For example, in ictalurid catfish farming in the southern United States, average production in ponds has increased from less 2000 kg ha^{-1} in the 1960s to over 5000 kg ha^{-1} in recent years (Hanson and Sites, 2012). Annual production at some farms in Alabama has exceeded 10,000 kg ha^{-1} in recent years. Such

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high production results in greater nitrogen input that favors higher TAN concentration. Nitrogen and phosphorus that enter water as a result of feeding stimulate phytoplankton productivity, and greater photosynthesis often increases pH during the day, increasing the proportion of NH_3-N (Boyd and Tucker, 2014).

There seems to be reason for concern over possible negative effects of ammonia in ictalurid catfish ponds and other types of intensive pond aquaculture. Nevertheless, a careful analysis of the situation has not been made despite there being considerable information on the toxicity of ammonia to aquaculture species including channel catfish *Ictalurus punctatus*. The 96-hr LC50 to channel catfish ranged from 1.50 to 3.30 mg L^{-1} with an average of 2.28 mg L^{-1} (Hargreaves and Kucuk, 2001).

Water temperature and pH fluctuate daily in ponds with highest values typically occurring in early to mid-afternoon (Boyd and Tucker, 2014). In order to investigate the effect of daily fluctuations in NH_3-N, Hargreaves and Kucuk (2001) exposed channel catfish in laboratory systems for 22 to 43 days to pH regimes that mimicked those in ponds. Exposure of fish to a daily maximum NH_3-N concentration of 0.91 mg L^{-1} NH_3-N did not influence growth compared to the control, while a 42% reduction in growth occurred at a maximum daily NH_3-N concentration of 1.81 mg L^{-1} NH_3-N. They concluded that in ponds, a daily high maximum NH_3-N concentration would persist for no more than 5 to 10 days, while the high daily concentration persisted throughout their trial. They suggested that in ponds, an effect on growth might not be elicited at as low of a NH_3-N concentration as observed in their study.

The intensity of ictalurid catfish culture in ponds in the United States has increased, and farmers sometimes measure TAN concentrations of 10 mg L^{-1} with ammonia analysis kits. A few such high TAN concentrations have been verified by laboratory analyses at the Alabama Fish Farming Center in Greensboro. The major concern about the high TAN concentration is that disease outbreaks have been noted during or after these episodes (William Hemstreet, Alabama Fish Farming Center, personal communication). The present study was conducted to determine the range in TAN concentration in Alabama catfish ponds, and to ascertain if the concern over high TAN concentration is justifiable.

2. Materials and methods

Six commercial catfish farms in the Blackland Prairie region of west-central Alabama that have high production were selected, and a total of 31 ponds – five each on five farms and six at the other – were chosen because they had the highest stocking densities on the farms. The ponds had total alkalinity and total hardness concentrations ranging from 85 to 128 mg L^{-1} and from 91 to 142 mg L^{-1}, respectively.

The ponds were watershed-type ponds maintained by runoff. Pond water surfaces varied (Table 1), and catfish ponds in Alabama are typically about 1.5 m in average depth (Boyd et al., 2000). The ponds were stocked with channel catfish (*I. punctatus*), hybrid catfish (*I. punctatus* ♀ × *I. furcatus* ♂), or a combination of both. Management was similar among farms. Fish were produced by the multiple-batch system (Boyd et al., 2000) in which marketable-size fish are harvested by a tractor-drawn grading seine at intervals determined by the manager, and advanced fingerlings are stocked as replacements. Ponds usually are drained about twice over a 15-yr period.

Fish were provided with 32% crude protein, floating, pelleted ration daily by truck-mounted feeders that propelled the feed over the water surface around the sides of the pond. Feed usually was applied to apparent satiation, often resulting in more feed being offered than consumed. Floating, electric, paddlewheel aerations in each pond (Table 1) were operated – mainly at night – between May and October.

Water samples were collected from the ponds by dipping surface water with a dipper attached at the end of a 3-m plastic rod. Samples were placed in 1-L plastic bottles and held on ice in insulated chests during transport to the laboratory at Auburn University. Samples were collected weekly from May to September 2013 (late spring and summer), twice weekly in October, and once per month until May 2014. Water samples were filtered by gravity through Whatman No. 42 paper, and TAN concentrations in filtrates were measured by the salicylate method (Bower and Holm-Hansen, 1980; Le and Boyd, 2012).

Fluctuations in water temperature and pH were measured over a 24-hr period in two ponds each with light [Secchi disk (SD) visibility > 40 cm], medium [SD visibility 15–30 cm], and dense [SD visibility < 15 cm)] phytoplankton abundance at Farm K. This farm was chosen because there were six ponds that met the desired phytoplankton abundance categories. Some of these ponds, however, were not included in monitoring of TAN concentration. Surface and bottom water samples were collected every 3 hr and measurement of temperature and pH were attained with a handheld Waterproof pHTestr® 30 (Oaklon Instruments, Vernon Hills, IL, USA).

Data on water surface areas, total feed input, and total weights of harvested fish were attained from farm owners or managers.

The nitrogen input to ponds was calculated by the equation:

$$N_i = (F_i)(N_f/100) \quad (2)$$

where N_i = nitrogen input in feed (kg ha^{-1}), F_i = feed input (kg ha^{-1}), and N_f = nitrogen concentration in feed (%).

The nitrogen waste load to ponds (feed nitrogen–fish nitrogen) was estimated for each pond as follows:

$$N_w = N_i - (B)(N_b/100) \quad (3)$$

where N_w = nitrogen waste load (kg ha^{-1}); B = harvested biomass (kg ha^{-1}); and N_b = nitrogen concentration in harvested biomass (kg ha^{-1}). Live channel catfish contain 2.38% nitrogen (Boyd et al., 2007).

The nitrogen waste load as equivalent TAN concentration was estimated with the equation:

$$TAN_{eq} = \frac{N_w \times 10^{-3}}{D \times 10^4} \quad (4)$$

where TAN_{eq} = TAN equivalent (g m^{-3} = mg L^{-1}), D = average pond depth (1.5 m was used), and 10^{-3} = kg g^{-1}, 10^4 = m^2 ha^{-1}.

Table 1
Average pond size, feed input, production, aerator use, and nitrogen waste load over a 1-year period for catfish farms of this study. (Means were tested by Tukey's Studentized Range (HSD) test; entries indicated by the same letter in a column do not differ at P = 0.05).

Farm	Average pond area (ha)	Average production (kg/ha)	Average feed input (kg/ha)	Average aerator use (kw/ha)	N waste load (mg/L)
W	2.53	9560 ± 4630 a	19,680 ± 1890 a	7	52 ± 10.8 a
A	2.83	8010 ± 2641 a	15,580 ± 4540 a	6	40 ± 12.2 a
D	3.89	12,340 ± 5124 a	2174 ± 1980 a	17	55 ± 12.7 a
R	2.53	11,250 ± 3490 a	21,390 ± 3960 a	10	55 ± 11.6 a
K	4.17	13,650 ± 5900 a	18,070 ± 5690 a	5	40 ± 15.7 a
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* Data were not supplied by farm manager.