North American Journal of Aquaculture 74:160–163, 2012
© American Fisheries Society 2012
ISSN: 1522-2055 print / 1548-8454 online
DOI: 10.1080/15222055.2012.678565

ARTICLE

Effects of Abrupt pH Increases on Survival of Different Ages of Young Channel Catfish and Hybrid Catfish

Charles C. Mischke*
Mississippi State University, Thad Cochran National Warmwater Aquaculture Center, Box 197, Stoneville, Mississippi 38776, USA

Nagaraj Chatakondi
U.S. Department of Agriculture, Agriculture Research Service, National Warmwater Aquaculture Center, Box 38, Stoneville, Mississippi 38776, USA

Abstract
A previous study showed that fry of channel catfish *Ictalurus punctatus* are sensitive to pH increases but tolerant of pH decreases. This study determined the tolerance of channel catfish and hybrid catfish (female channel catfish × male blue catfish *I. furcatus*) sac fry, swim-up fry, and fingerlings to abrupt pH increases. Sac fry, swim-up fry, and fingerlings of channel catfish and hybrid catfish are sensitive to abrupt pH increases and become more tolerant with age or size. Hybrid catfish sac fry were more tolerant than channel catfish sac fry at lower pH increases, as evidenced by their higher 24-h LC10 (0.38 and 0.13 pH unit increases, respectively) and 24-h LC50 (0.48 and 0.36 pH unit increases, respectively). However, the 24-h LC90 for hybrid catfish sac fry (0.62 pH unit) was much lower than that for channel catfish (1.03 pH unit), showing that at higher pH increases hybrids are less tolerant. Channel catfish swim-up fry were more tolerant of pH increases (24-h LC50 = 1.28 pH units) than were hybrids (24-h LC50 = 0.83 pH units), but hybrid catfish fingerlings (24-h LC50 = 1.54 pH units) were more tolerant of pH increases than channel catfish fingerlings (24-h LC50 = 1.33 pH units). When comparing fish acclimated to different starting pH levels, lethal concentration values increased correspondingly. This indicates that pH sensitivity is due to upper lethal pH limits rather than abrupt pH changes.

It is a typical practice in the aquaculture industry to hold fry of channel catfish *Ictalurus punctatus* in the hatchery for 7–14 d after hatching and before stocking into nursery ponds (Tucker and Robinson 1990). Catfish hatcheries are generally single-pass flow-through systems that provide a stable, high-quality environment for eggs and fry. However, conditions in nursery ponds can vary considerably. Over a 24-h period, water temperature can vary by 10°C or more and pH can change by more than 3 units (Mischke and Wise 2008).

Even with careful temperature monitoring, acclimation, and proper pond fertilization (Mischke and Zimba 2004), fry-to-fingerling survival in the catfish industry is variable and not well documented. Estimated survival rates of fry after stocking into nursery ponds range from 55% (Hatch et al. 1987) to 80% (Moore and Waldrop 1994). Some mortalities can be traced to specific causes such as dissolved oxygen depletion or disease occurrence, but a number of mortalities occur from unknown causes. Unknown mortalities are estimated to be about 20% (Tucker and Hargreaves 2004) and are presumed to occur early in the production cycle when fry are small and mortalities are difficult to detect.

According to Mischke and Wise (2008), a possible explanation for poor and variable fry survival is the abrupt change in environmental conditions when fry are transferred from the hatchery to the nursery ponds. Specifically, they showed that channel catfish swim-up fry are highly sensitive to abrupt increases in pH. With a pH increase of 0.7 units, 10% mortality

*Corresponding author: cmischke@drec.msstate.edu
Received April 27, 2011; accepted November 22, 2011
Published online April 2, 2012

occurs in 24-h, and an increase of 1.4 units causes 50% mortality (Mischke and Wise 2008).

Gradual water exchanges are less effective in changing the pH of hauling water than in moderating changes in water temperature, and no practical methods of pH acclimation are currently available. Mischke and Wise (2008) recommended monitoring pH in stocking ponds that have large fluctuations in pH early in the morning when pH is lowest. Although fry are typically stocked at 7–14 d post hatch, it may be that different life stages of young fish would be more tolerant of abrupt pH increases (i.e., sac fry versus swim-up fry versus fingerlings) or that hybrid catfish (female channel catfish × male blue catfish *I. furcatus*) may be more tolerant of abrupt pH increases. The purpose of this study was to determine the relative tolerance of channel catfish and hybrid catfish sac fry, swim-up fry, and small fingerlings to the abrupt increases in pH that may occur when stocking nursery ponds.

METHODS

All channel catfish fry were obtained as sac-fry from commercial producers and transported to the Thad Cochran National Warmwater Aquaculture Center, Stoneville, Mississippi, and held in the hatchery until the appropriate testing age. Hybrid catfish were obtained from the U.S. Department of Agriculture, Agriculture Research Service, Catfish Genetics Research Unit, Stoneville, Mississippi.

The fish used in the tests were as follows: sac fry of both species (1–2 d posthatch [dph], 11.3 ± 0.20 mm [mean ± SE]), hybrid catfish swim-up fry (7 dph, 14.0 ± 0.23 mm), channel catfish swim-up fry (7 dph, 13.9 ± 0.29 mm), hybrid catfish fingerlings (10.0 ± 0.22 cm), and channel catfish fingerlings (7.1 ± 0.20 cm). Short-term (24 h) acute toxicity tests using pH unit increases as the dose were conducted for channel catfish and hybrid catfish sac fry, swim-up fry, and fingerlings. For each test, aquaria were set up by using 4 L of the same hatchery water the fish were held in (pH 9.0, alkalinity 393 mg/L as $CaCO_3$, hardness 156 mg/L as $CaCO_3$, temperature 20°C, and total ammonia 0.0 mg/L). For each life stage, three replicate tanks (4 L of water) were used for each pH value (range tested, 9.0–11 at 0.1 pH unit increases) and three tanks were used as controls (no pH change). In the test tanks, pH was increased by additions of dissolved sodium hydroxide. Fish for each test were moved to the laboratory in hatchery water and acclimated to the laboratory temperature over 4 h by holding fish in aquaria with aerated hatchery water until water temperature and ambient air temperatures were equal. Thirty fish were then transferred by net from the hatchery water to each of the aquaria without acclimation. After 24 h, mortalities were determined from each aquarium.

Because of the high ambient pH of our source water, a second experiment was conducted on channel catfish sac fry. The second study compared the tolerances of fry to the abrupt pH increases after acclimation to three different pH levels (8.0, 8.7, and 9.0). The same methods were used as previously described, but fish were acclimated to the different starting pH values for 24 h before testing.

Probit analysis was used to determine the 24-h LC10, LC50, and LC90 values (the concentrations lethal to 10, 50, and 90% of the test fish, respectively) by using PoloPlus statistical software (LeOra Software Company 2002). Lethal pH change ratios were calculated to detect significant differences ($P < 0.05$) among the different tests (Robertson et al. 1995).

RESULTS AND DISCUSSION

Sac fry, swim-up fry, and fingerlings of both channel catfish and hybrid catfish were sensitive to abrupt pH increases. With both species, fish became more tolerant with age or size (Table 1). Hybrid catfish sac fry were more tolerant than channel catfish sac fry at the lower pH increases as evidenced by their higher 24-h LC10 and LC50 values. However, the 24-h LC90 for hybrid catfish sac fry was much lower than for channel catfish, showing that at higher pH increases, hybrids are less tolerant. Many characteristics of hybrid fish are attributed to paternal predominance (Dunham et al. 1982), and it is possible that lower pH tolerance in hybrid catfish was affected disproportionately by the blue catfish male parent. Channel catfish swim-up fry were more tolerant of pH increases than were hybrids, but

TABLE 1. Acute toxicity (24 h) of abrupt pH increases to channel catfish and hybrid catfish sac fry, swim-up fry, and fingerlings. The numbers represent the estimated pH unit increases from 9.0 (the ambient pH) that will kill 10, 50, and 90% of the fish (LC10, LC50, and LC90, respectively); 95% confidence intervals are given in parentheses. Different letters within a lethal concentration column denote significant ($P < 0.05$) differences among the age and species of fish tested.

Fish stage	24-h LC10	24-h LC50	24-h LC90
		Channel catfish	
Sac fry	0.13 (0.055–1.99)v	0.36 (0.248–0.469)v	1.03 (0.786–1.557)x
Swim-up fry	1.04 (0.863–1.137)y	1.28 (1.177–1.362)y	1.58 (1.476–1.773)z
Fingerlings	1.10 (0.924–1.195)y	1.33 (1.232–1.413)y	1.61 (1.499–1.832)z
		Hybrid catfish	
Sac fry	0.38 (0.296–0.432)w	0.48 (0.421–0.542)w	0.62 (0.551–0.738)w
Swim-up fry	0.63 (0.397–0.738)x	0.83 (0.69–0.92)x	1.11 (0.992–1.402)y
Fingerlings	1.38 (1.200–1.454)z	1.54 (1.466–1.608)z	1.73 (1.650–1.930)z

TABLE 2. Acute toxicity (24 h) of abrupt pH increases to channel catfish sac fry acclimated to a pH of 8.0, 8.7, or 9.0. The numbers represent the estimated pH unit increases from the starting pH that will kill 10, 50, and 90% of the fish (LC10, LC50, and LC90, respectively); 95% confidence intervals are given in parentheses, and the last number in each set is the actual resulting pH value.

Starting pH	24-h LC10, pH value	24-h LC50, pH value	24-h LC90, pH value
8.0	1.8 (1.7–1.9), 9.8	2.3 (2.2–2.4), 10.3	2.9 (2.7–3.0), 10.9
8.7	1.3 (1.2–1.4), 10.0	1.6 (1.5–1.7), 10.3	2.0 (1.8–2.1), 10.7
9.0	0.7 (0.7–0.8), 9.7	1.0 (1.0–1.1), 10.0	1.3 (1.2–1.4), 10.3

hybrid catfish fingerlings were more tolerant of pH increases than channel catfish fingerlings. Hybrid catfish fingerlings were slightly longer than the channel catfish fingerlings (7 versus 10 cm), which could have contributed to the increased tolerance.

It was expected that sac fry may be more tolerant of pH increases than swim-up fry because of the physiological differences in the two life stages. With other stressors or toxins, such as copper, sac fry are more tolerant than swim-up fry. Straus (2008) found that sac fry of channel catfish were 1.3–8.6 times more tolerant of copper than swim-up fry. This was attributed to weakened swim-up fry after the physiological stress of yolk sac absorption. Also, increased metabolic rate, increased vascularization of the gill surface, and increased intestinal absorption in the swim-up fry were cited as contributing to the differences in toxicity. With pH, however, tolerance increased with age. High pH inhibits sodium uptake and ammonia excretion of fish (Scott et al. 2005). As pH increases, the ammonia–ammonium equilibrium is shifted towards un-ionized ammonia causing the partial pressure gradient across the gills to decrease (Wright et al. 1989). The inhibition of ammonia excretion leads to an increase in plasma ammonia, which may be the cause of mortalities. Channel catfish fry apparently become better equipped physiologically to deal with the partial pressure gradient disruption as they mature from sac fry to swim-up fry to fingerlings.

Previous investigations (Mischke and Wise 2008) into tolerance of channel catfish swim-up fry to abrupt pH increases yielded 24-h LC10, LC50, and LC90 values of 0.7, 1.4, and 2.2 pH unit increases, respectively. In comparison, values for swim-up fry were 1.04, 1.28, and 1.58 pH unit increases, respectively, in the present study. Differences in temperature, starting pH, and ammonia nitrogen concentrations and in relative health of fry would all affect the tolerance of pH increases (Boyd and Tucker 1998). In the present study, the initial hatchery pH was high (9.0). This may explain the lower tolerance of fry in this study to pH increases at the 24-h LC50 and LC90 levels. However, fry in this study showed higher tolerance at the LC10 level than in the Mischke and Wise (2008) study.

Our second experiment showed that starting pH does have an effect on tolerance of abrupt pH increases (Table 2). As the initial acclimation pH was lower, tolerance of abrupt pH increased. This indicates that the results may have been more influenced by approaching an upper lethal limit than the actual abrupt pH changes. Regardless of acclimation pH, the pH corresponding to a 24-h LC10, LC50, and LC90 were consistent and averaged 9.8, 10.2, and 10.6, respectively.

With species such as rainbow trout *Oncorhynchus mykiss*, gradual acclimation to higher pH can increase the maximum tolerated pH to 10.2 before mortalities occur (Murray and Ziebell 1984). However, this study indicated that acclimation by channel catfish to different starting pHs does not change the maximum pH that is tolerated before mortality begins.

Differences in pH between the hatchery and pond, or between ponds when moving fingerlings from pond to pond, should play a major role in management decisions in areas where pH is high to begin with. In attempts to reduce hatchery costs, there is some interest and success in stocking fry within 2 d after hatching (Tidwell et al. 1995; Weirich et al. 2001; Reigh et al. 2006). Because the sac fry are the most sensitive to increases in pH, extra monitoring of pH would be necessary, and fry should only be moved to equal or lower pH conditions when implementing this strategy. Mischke and Wise (2008) showed that fry are tolerant of substantial sudden pH decreases (from 8.8 to 4.8), so concerns should be with pH increases. Sometimes fingerlings are moved to a new pond to limit losses from proliferative gill disease (Wise et al. 2004, 2008). Because fingerlings also show sensitivity to abrupt pH increases, this strategy should only be used when fingerlings can be transferred to a pond of equal or lower pH.

It appears that mortalities in these studies may be related to approaching upper pH limits rather than toxicity due solely to abrupt pH changes. Based on channel catfish sac fry 24-h LC10 values, the upper limit of tolerable pH appears to be about 9.8.

ACKNOWLEDGMENTS

This is journal article J-11665 of the Mississippi Agricultural and Forestry Experiment Station (MAFES), Mississippi State University. This project is supported under MAFES project MIS-081115. Mention of trade names or commercial products is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

REFERENCES

Boyd, C. E., and C. S. Tucker. 1998. Pond aquaculture water quality management. Kluwer Academic, Boston.

Dunham, R. A., R. O. Smitherman, M. J. Brooks, M. Bechakan, and J. A. Chappell. 1982. Paternal predominance in reciprocal channel-blue hybrid catfish. Aquaculture 29:389–396.

Hatch, U., R. Dunham, H. Hebicha, and J. Jensen. 1987. Economic analysis of channel catfish egg, fry, fingerling, and food fish production in Alabama. Alabama Agricultural Experiment Station, Circular 291, Auburn.

LeOra Software Company. 2002. PoloPlus: probit and logit analysis, version 1.0. LeOra Software, Petaluma, California.

Mischke, C. C., and D. J. Wise. 2008. Tolerance of channel catfish fry to abrupt pH changes. North American Journal of Aquaculture 70:305–307.

Mischke, C. C., and P. V. Zimba. 2004. Plankton community responses in earthen channel catfish nursery ponds under various fertilization regimes. Aquaculture 233:219–235.

Moore, R. R. III, and J. E. Waldrop. 1994. Costs of raising channel catfish fry and fingerlings in the Delta of Mississippi. Mississippi Agricultural and Forestry Experiment Station Technical Bulletin 198.

Murray, C. A., and C. D. Ziebell. 1984. Acclimation of rainbow trout to high pH to prevent stocking mortality in summer. Progressive Fish-Culturist 46:176–179.

Reigh, R. C., M. B. Williams, J. M. Gillespie, and C. R. Weirich. 2006. Preliminary observations on the cost of producing fingerling channel catfish, *Ictalurus punctatus*, stocked as sac fry or as hatchery-fed swim-up fry. Journal of Applied Aquaculture 18:75–84.

Robertson, J. L., H. K. Preisler, S. S. Ng, L. A. Hinkle, and W. D. Gelernter. 1995. Natural variation: a complicating factor in bioassays with chemical and microbial pesticides. Journal of Economic Entomology 88:1–10.

Scott, D. M., M. C. Lucas, and R. W. Wilson. 2005. The effect of high pH on ion balance, nitrogen excretion, and behaviour in freshwater fish from an eutrophic lake: a laboratory and field study. Aquatic Toxicology 73:31–43.

Straus, D. L. 2008. Copper sulfate toxicity to channel catfish fry: yolk sac versus swim-up fry. North American Journal of Aquaculture 70:323–327.

Tidwell, J. H., S. D. Mims, C. D. Webster, J. A. Clark. 1995. Effects of direct stocking and hatchery feeding on growth and survival of channel catfish swim-up fry. Journal of Applied Aquaculture 5:61–68.

Tucker, C. S., and J. A. Hargreaves. 2004. Biology and culture of channel catfish. Elsevier, Amsterdam.

Tucker, C. S., and E. H. Robinson. 1990. Channel catfish farming handbook. Van Nostrand Reinhold, New York.

Weirich, C. R., C. C. O'Neal, B. C. Delbos, and C. G. Lutz. 2001. Effects of stocking sac-fry and hatchery-fed fry on production of fingerling channel catfish *Ictalurus punctatus*. Journal of the World Aquaculture Society 32:112–116.

Wise, D. J., A. C. Camus, T. E. Schwedler, and J. S. Terhune. 2004. Health management. Pages 444–502 *in* C. S. Tucker and J. A. Hargreaves, editors. Biology and culture of channel catfish. Elsevier, Amsterdam.

Wise, D. J., M. J. Griffin, J. S. Terhune, L. M. Pote, and L. H. Khoo. 2008. Induction and evaluation of proliferative gill disease in channel catfish fingerlings. Journal of Aquatic Animal Health 20:236–244.

Wright, P. A., D. J. Randall, and S. F. Perry. 1989. Fish gill water boundary layer: a site of linkage between carbon dioxide and ammonia excretion. Journal of Comparative Physiology B 158:627–63.