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Cold Shock Susceptibility of Blue Tilapia from the Susquehanna River, Pennsylvania[1]

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Abstract.—A population of blue tilapia *Oreochromis aureus,* a native species of Africa and southern Asia, became established in the Susquehanna River, Pennsylvania, after escaping from the Brunner Island Aquaculture Facility. It appears that blue tilapias are able to survive low water temperatures during winter by congregating in thermal effluents. The objective of this study was to determine the susceptibility of the Susquehanna River population to cold shock, and the conditions necessary to eliminate these fish from the thermal effluent at Pennsylvania Power and Light's Brunner Island Steam Electric Station. Blue tilapias were acclimated to 20° and 15°C and then exposed to sublethal and lethal temperatures under three patterns of temperature reduction—rapid cold shock or one of two rates of gradual temperature decrease (1°C/h or 3°C/h) to lethal temperatures—each test lasting 96 h and involving 20 fish per test group. Among fish acclimated to 20°C and immediately exposed to test temperatures, none died at the control (acclimation) temperature and at 14°C, 65% died at 11°C, and all died after 30 min at 8° and 5°C. A similar pattern occurred for fish acclimated to 15°C: 5% died at the control temperature, none died at 11°C, 95% died at 8°C, and all died at 5° and 3°C after 30 min. Exposure to gradually decreasing temperatures increased resistance times at test temperatures in all cases. Among fish acclimated to 20°C and cooled by 3°C/h, 100% mortality occurred within 14 h at 8°C and within 8 h at 5°C. Among fish acclimated to 15°C and cooled by 1°C/h, 95% mortality occurred after 96 h at 8°C and 100% mortality occurred within 20 h at 5°C. Among fish acclimated to 15°C and cooled by 3°C/h, 100% mortality occurred within 12 h at 5°C and within 6 h at 3°C. Among fish acclimated to 15°C and cooled by 1°C/h, 100% mortality occurred within 16 h at 5°C and within 14 h at 3°C. We recommend that the temperature be lowered to 5°C for at least 16 h to kill blue tilapias in the thermal effluent at Pennsylvania Power and Light's Brunner Island Steam Electric Station.

The blue tilapia *Oreochromis aureus*[2] is native to Africa and southern Asia. It was initially imported to the USA for aquacultural purposes, and subsequently it was tested for aquatic vegetation control. It has escaped captivity and populations have become established in Florida, Texas, Arizona, California, and North Carolina (Hensley and Courtenay 1980; Courtenay et al. 1986). Establishment of a reproducing population is a potential threat to native species. Members of the family Cichlidae, including the blue tilapia, are successful invaders both in the USA (Hensley and Courtenay 1980; Courtenay et al. 1986) and in other countries (Arthington and Mitchell 1986). Arthington and Mitchell (1986) discussed the characteristics of a successful invading species, particularly the species' ability to establish large populations quickly. Blue tilapias have spawned every 4–6 weeks in our laboratory. A second characteristic of a successful invader is a wide tolerance of environmental variables, including temperature, salinity, and dissolved oxygen (Arthington and Mitchell 1986). Blue tilapias can survive in aquaria at salinities ranging from 0 to 50‰. Their expansion to more northerly parts of North America has been limited because they are warm stenotherms. Chervinski and Lahav (1976) and Kindle and Whitmore (1986) determined that the species' lower lethal limit was between 8° and 11°C. Shafland and Pestrak (1982) found that the lower incipient lethal limit of blue tilapias from Florida was 6–7°C.

Attempts to control exotic fishes have had varied success. Control methods include chemicals, physical barriers, and biological agents. In all cases, it has been necessary to alter the environment to control the exotic. The situation in the Susquehanna River, Pennsylvania, is unique in that introduced blue tilapias apparently depend upon an artificial construct for survival: industrial thermal effluents along the river. Thus, it appears possible to eradicate this species from the river without adding other chemical or biological agents to the environment.

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[2] The names preferred by the American Fisheries Society for the *Oreochromis* species cited in this paper are *Tilapia aurea* and *T. nilotica.* The authors use the nomenclature of Trewavas (1983).—*Managing Editor.*

Blue tilapias were brought into Pennsylvania for culture at Pennsylvania Power and Light's (PP&L) Brunner Island Aquaculture Facility near Harrisburg. They escaped from this facility and were collected from the Susquehanna River in 1984 (Skinner 1984) and subsequently at several locations downstream of Harrisburg. Collections in the vicinity of the Brunner Island Aquaculture Facility indicated that blue tilapia was the most abundant species present in this portion of the river and that several size-classes were present. When brooding females were found (R. Denoncourt, York College, personal communication), it was hypothesized that this species was reproducing in the Susquehanna River, as well as escaping from the hatchery facility.

The Pennsylvania Fish Commission was concerned about any potential adverse effects the blue tilapia might have on native species and thus wanted to explore methods that could be used to eradicate this species. We felt that the most efficient method to eradicate blue tilapias was to subject them to cold temperatures. To minimize the economic loss to the power facility and to ensure eradication in the effluent, it was necessary to determine the resistance time for blue tilapias, which is the amount of time the fish can survive a given lethal condition. However, because of possible genetic or physiological adaptations to cold temperatures, it is possible that the population resident in the Susquehanna River may be more resistant to cold temperatures than those strains previously tested. Thus, the purpose of this study was to predict the temperatures to which the thermal discharge must be lowered, and the length of time these temperatures must be maintained, to eliminate the blue tilapia from the Susquehanna River. To achieve these objectives, we needed to determine the lower incipient lethal temperature (the temperature at which mortality occurred irrespective of acclimation temperature), the amount of time these fish can survive in their zone of resistance (temperatures lower than the lower incipient lethal temperature), and the rate of temperature change that was needed to kill these fish when they were acclimated to particular temperatures.

Methods

Blue tilapias were captured in the Susquehanna River in the vicinity of the Brunner Island Aquaculture Facility in September when water temperatures were about 22°C. Fish were collected by electrofishing and transported to laboratory facilities at The Pennsylvania State University. Collection temperature was maintained during transport and initial holding periods. Fish were held on a photoperiod of 12 h light:12 h darkness. Concentrations of dissolved oxygen were maintained at 95–100% of saturation and pH was 7.0–7.3. Fish were treated with a 3‰ salt solution for 3 d to control fungal infections. The holding temperatures were adjusted at a rate of 1°C/d to acclimation temperatures of 15° and 20°C. Fish were then held at acclimation temperatures for at least 5 d before tests began.

Duplicate tests (each with 10 fish) were conducted under three temperature exposure regimes: (1) instantaneous temperature decrease (cold shock) to 14°, 11°, 8°, and 5°C for fish acclimated to 20°C, and decreases to 11°, 8°, 5°, and 3°C for fish acclimated to 15°C; (2) temperature decrease of 3°C/h to 8° and 5°C for fish acclimated to 20°C, and to 5° and 3°C for fish acclimated to 15°C; and (3) temperature decrease of 1°C/h to the same exposure temperatures that were tested in regime (2). Control fish were handled like test fish, but were kept at their respective acclimation temperatures. Responses of fish exposed to temperature changes were monitored at least every 2 h for the first 24 h and every 6 h for the remaining 72 h. Fish were considered dead when there was complete cessation of opercular movement and there was no response to mechanical stimuli. We found that the criteria for death were not completely satisfactory, because some apparently dead fish revived when transferred to their original acclimation temperature. Therefore, to confirm death, a subsample of apparently moribund specimens from each test was transferred to the respective acclimation temperature and observed for 2 h.

The taxonomy of the blue tilapia introduced into North America is unclear. Blue tilapias first introduced into North America were originally misidentified as *O. niloticus*. Furthermore, tilapiine fishes are known to produce fertile hybrids; thus, introgression undoubtedly occurs. Therefore, we summarized morphometric and meristic data for 22 of our specimens, which are catalogued (number 2031) into The Pennsylvania State University Fish Museum; data are available upon request from the senior author.

Results

Instantaneous Temperature Decreases

Among blue tilapia acclimated to 20°C, then subjected to abrupt temperature decreases (Table

TABLE 1.—Numbers of blue tilapia acclimated to 20° or 15°C and surviving after immediate exposures to test temperatures. There were two trials per test temperature; each trial began with 10 fish.

Hours of exposure	Survivors by test temperature and trial: 14°C, 1	14°C, 2	11°C, 1	11°C, 2	8°C, 1	8°C, 2	5°C, 1	5°C, 2	3°C, 1	3°C, 2
Acclimation temperature = 20°C										
2	10	10	10	10	0	0	0	0		
12	10	10	7	10						
48	10	10	2	9						
96	10	10	1	6						
Acclimation temperature = 15°C										
2			10	10	10	10	0	0	0	0
12			10	10	10	10				
48			10	10	9	10				
96			10	10	0	1				

1), there was 100% survival of those exposed to 14°C. Of fish immediately exposed to 11°C, mortality commenced after 6 h in one group and after 40 h in the second group. After 96 h, survival in the two groups was 10 and 60%. Fish exposed to 8° and 5°C lost equilibrium within 10 min and all were dead after 30 min. All control fish survived.

Among blue tilapia acclimated to 15°C and cold-shocked (Table 1), there were no deaths of those exposed to 11°C. Mortality of fish immediately exposed to 8°C commenced after 42 and 56 h; after 96 h, survival was 0 and 10%. Fish exposed to 5° and 3°C lost equilibrium within 15 min and all were dead within 30 min. One of 20 control fish died.

Gradual Temperature Decreases

There was 100% mortality within 14 h among fish acclimated to 20°C and subjected to a temperature decrease of 3°C/h until a test temperature of 8°C was reached (Table 2). There was 100% mortality within 8 h among fish subjected to the same acclimation temperature and temperature decrease rate, but exposed to 5°C, a temperature reached 5 h after the test began. Among fish acclimated to 20°C and subjected to a temperature decrease of 1°C/h until a test temperature of 8°C was reached, there was 95% mortality within 96 h (Table 2). There was 100% mortality within 20 h among fish subjected to the same acclimation temperature and temperature decrease rate, but exposed to 5°C.

There was 100% mortality within 12 h among fish acclimated to 15°C and subjected to a temperature decrease of 3°C/h until a test temperature of 5°C was reached (Table 2). There was 100% mortality within 6 h among fish subjected to the same acclimation temperature and temperature decrease rate, but exposed to 3°C, a temperature reached after 4 h. Among fish acclimated to 15° and subjected to a temperature decrease of 1°C/h until test temperatures of 5° and 3°C were reached, there was 100% mortality after 16 and 14 h, respectively (Table 2).

Fish that appeared dead when exposed to 8°C for 6 h (20°C acclimation temperature) revived after being moved to warmer water. Fish held at 8°C for 12 h did not revive after being transferred to their acclimation temperature. No fish exposed to 5° or 3°C revived after being transferred to their acclimation temperature.

TABLE 2.—Numbers of blue tilapia acclimated to 20° or 15°C and surviving after exposures to temperatures that gradually decreased 3°C/h or 1°C/h to a steady test temperature. There were two trials per test temperature; each trial began with 10 fish.

Hours of exposure	Temperature decrease = 3°C/h: survivors by test temperature, trial: 8°C, 1	8°C, 2	5°C, 1	5°C, 2	3°C, 1	3°C, 2	Temperature decrease = 1°C/h: survivors by test temperature, trial: 8°C, 1	8°C, 2	5°C, 1	5°C, 2	3°C, 1	3°C, 2
Acclimation temperature = 20°C												
2	10	10	10	10			10	10	10	10		
8	9	5	0	0			10	10	10	10		
14	0	0					10	10	0	2		
48							5	4		0		
72							2	3				
96							0	1				
Acclimation temperature = 15°C												
2			10	10	10	10			10	10	10	10
6			7	5	0	0			10	10	10	10
12			0	0					10	10	0	3
24									0	0		0

Discussion

Our results agree with those of Chervinski and Lahav (1976) and Kindle and Whitmore (1986), who found that the lower lethal limit for blue tilapias was between 8° and 11°C. These results differ from the lower lethal temperature (6–7°C) predicted for the species by Shafland and Pestrak (1982). Differences among studies may be due to tolerance differences among populations of the blue tilapia or to differences in testing procedures (Stauffer 1986). Shafland and Pestrak (1982) tested fish by lowering the temperature 1°C/d; thus, the fish may have been in their zone of resistance (<8°C) for several days before they died.

Based on our data, we hypothesized that to kill blue tilapias that overwinter in thermal discharges, temperatures in the effluent must be reduced to at least 5°C and maintained for at least 16 h. If effluent temperatures can be reduced below 5°C and held at these low temperatures for a longer period of time, the probability of eliminating all of the blue tilapias within the vicinity of the plant would be increased.

On January 24, 1987, PP&L's Brunner Island Steam Electric Station experienced a temporary shutdown of two of the three generating units. This partial shutdown resulted in reduced output of heated water to the discharge canal, which developed a lateral temperature gradient. Water temperature in places along the east side of the canal fell below 8°C for 6 h; however, the average temperature of the east side was still slightly above 8°C. The temperature on the west side fell below 5°C (W. F. Skinner, PP&L, personal communication). Observations by PP&L personnel indicated that fish on the west side of the canal were moribund and, as a result, were flushed into the river; fish on the east side were weakened, but were able to maintain their position in the canal and to respond to mechanical stimuli (W. F. Skinner, personal communication). Several hundred dead blue tilapias were collected after this unscheduled shutdown.

In an attempt to eradicate blue tilapias from the effluent in February 1987, electrical output from the Brunner Island station was purposefully reduced to lower the temperature along both sides of the discharge canal below 5°C for at least 25 h. Blue tilapias throughout the canal were unable to maintain position in the current and were carried into the Susquehanna River (W. F. Skinner, personal communication). In spring and summer 1987, the canal and adjacent river were sampled and no blue tilapias were collected. These results were consistent with predictions from our laboratory experiments.

Although eradication efforts were successful at the Brunner Island site, it is possible that blue tilapias remain in the river because they have been collected as far as 78 km downstream from this site (Skinner 1984), and other thermal discharges presently occur along the river. Nevertheless, these results show that planned shutdowns of power plants can effectively eradicate warmwater, stenothermal species. However, such efforts are not likely to be successful when there are large inflows of groundwater or geothermally heated water.

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