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Electroshock-Induced Injury and Mortality in the Spotfin Chub, a Threatened Minnow

F. MICHAEL HOLLIMAN* AND JAMES B. REYNOLDS

Alaska Cooperative Fish and Wildlife Research Unit[1] *and School of Fisheries and Ocean Sciences, University of Alaska–Fairbanks, Post Office Box 757020, Fairbanks, Alaska 99775-7020, USA*

THOMAS J. KWAK

U.S. Geological Survey, North Carolina Cooperative Fish and Wildlife Research Unit,[2] *Campus Box 7617, North Carolina State University, Raleigh, North Carolina 27695-7617, USA*

Abstract.—The effects of AC and pulsed DC (PDC) electroshock on mortality and injury (vertebral damage and hemorrhage) of spotfin chub *Cyprinella monacha*, a threatened minnow, were evaluated in a laboratory experiment. Groups of 18–20 captive-reared fish were either designated as a control or exposed for 3 s to one of five electrical treatments (60-Hz AC at a peak-to-peak voltage gradient of 1.7, 2.5, or 3.3 V/cm or 60-Hz PDC at a peak voltage gradient of 2.5 or 5.0 V/cm). Immobilization, which renders fish susceptible to capture during electrofishing, was the predominant response evoked in the groups exposed to electroshock, with the exception of the 1.7-V/cm AC group. No injury was detected in any fish in the experiment. Mortality was 10% or less in groups exposed to AC, regardless of voltage gradient. There was no significant variation in mortality among the groups exposed to AC (P = 0.487–1.00). Mortality varied significantly in the groups exposed to 60-Hz PDC (2.5 V/cm [0%] versus 5.0 V/cm [25%]; P = 0.047). Our results indicate that electroshocking with 60-Hz AC and 60-Hz PDC may be safe for capturing spotfin chub when voltage (thus, voltage gradient) is limited to the immobilization threshold and the exposure period to 3 s. However, AC should be used only in low-conductivity waters (e.g., <80 μS/cm).

The spotfin chub *Cyprinella monacha* is a federally designated threatened species. Although the species was once endemic to the Tennessee River drainage in Alabama, Georgia, North Carolina, Tennessee, and Virginia, discontinuous populations are now found only in the Duck, Emory, and Little Tennessee rivers, and the North Fork of the Holston River (USFWS 1983), all of which are oligotrophic streams in the southern Appalachian Mountains. The U.S. Fish and Wildlife Service is charged with monitoring and development of recovery plans that include objective, measurable population criteria for each threatened and endangered species under the U.S. Endangered Species Act of 1973. Effective, but nonlethal, sampling techniques must be used during population assessments to minimize ''take,'' as defined by the Endangered Species Act.

Electrofishing is used extensively to sample the populations of many freshwater fishes for monitoring, assessment, and research (Reynolds 1996). Several deleterious, and in some cases lethal, effects of electrofishing have been reported for salmonids (Nielsen 1998; Reynolds and Holliman 2000). However, information on the effects of electroshock on nongame and imperiled fishes is sparse (Cowdell and Valdez 1994; Cooke et al. 1998). In response, we previously evaluated electroshock-induced injury and mortality in the Cape Fear shiner *Notropis mekistocholas*, an endangered minnow endemic to the mesotrophic rivers of the North Carolina piedmont region; those results indicated electrofishing was a viable sampling technique for that species (Holliman et al. 2003, this issue).

Successful electrofishing is dependent upon evoking electroshock-induced fish behaviors (e.g., forced swimming and immobilization) that lead to capture. Environmental conditions, which influence electrofishing efficiency (Zalewski and Cowx 1990; Reynolds 1996), can dictate electrical output and the electrode configurations required for fish capture. For example, DC and AC voltages effective for capturing fish in moderately to highly con-

* Corresponding author: fffmh@uaf.edu

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ductive waters (80–800 μS/cm) are rendered ineffective in more resistive waters (<80 μS/cm; Hudy 1985; Habera et al. 1996). Direct current may be ineffective for capturing salmonids in weakly conductive waters, even at high voltages (Habera et al. 1996). Consequently, pulsed DC (PDC) or AC electrofishing is typically employed to collect fish in highly resistive waters (Hudy 1985; Hollender and Carline 1994; Habera et al. 1996).

Our goal in this study was to provide guidance to federal and state agencies for the use of electrofishing in spotfin chub (and, by implication, other small cyprinids) population assessments. Our objective was to quantify the consequences of electroshock, in terms of injury and mortality, in spotfin chub exposed to 60-Hz AC or 60-Hz PDC. To avoid jeopardizing wild stocks of this protected species, we conducted a controlled laboratory experiment with captive-reared spotfin chub.

Methods

Electroshock-induced injury and mortality were evaluated in a tank experiment conducted at the North Carolina Cooperative Fish and Wildlife Research Unit, North Carolina State University, Raleigh, on 17–18 October 2000. Spotfin chub used in this experiment were captive stock reared at the Tennessee Aquarium in Chattanooga, Tennessee. Experimental animals were transported to the research facility immediately prior to the experiment; all fish were in good condition upon arrival.

Uniform electric fields were generated in a fiberglass tank (168 × 42 cm; filled with water to a depth of 13 cm) by applying voltage to two parallel, fully cross-sectional, steel-plate electrodes separated by 125 cm. Water in the test tank had an ambient conductivity of 75 μS/cm at 22°C, similar to that of the fish's native habitat (NCDENR 2000). A Smith-Root (Vancouver, Washington) backpack electrofishing control unit powered by 120-V AC was used to supply PDC to the test tank. Commercial AC was supplied to the test tank with a variable transformer in series with an isolation transformer.

The 118 captive-reared spotfin chub available for experimentation were exposed to 60-Hz AC or 60-Hz PDC or were used as controls. Individual fish were assigned to experimental groups of 18–20 fish, which were randomly assigned to treatments, including the control designation. All fish within an experimental group were confined in a nylon-mesh dip net during treatment and received treatment simultaneously. Electrical treatments were applied for 3 s. Fish in the control group were subjected to the same experimental procedures as those in the electrical treatment groups except for electroshock. The predominant behaviors elicited in the experimental groups during treatment were observed and recorded.

Voltages of AC and PDC (thus, voltage gradients) were selected to simulate the electrical field of an electrofishing operation, for which immobilization (complete cessation of movement) occurs in fish near an electrode and unbalanced swimming occurs in those farther away. A calibrated digital oscilloscope was employed to verify voltage waveforms and amplitude applied to the electrodes in each treatment. Spotfin chub receiving 60-Hz AC electrical treatments were exposed to peak-to-peak (pk–pk) voltage gradients of 1.7, 2.5, or 3.3 V/cm (applied voltages of 200, 300, or 400 V_{pk-pk}). The PDC waveform was a series of 6-ms-duration square waves pulsed at 60 Hz (36% duty cycle). Those fish receiving 60-Hz PDC treatments were exposed to peak voltage gradients of 2.5 or 5.0 V/cm (300 or 600 V).

We observed the treatment groups immediately posttreatment, at 5–10-min intervals for the first hour after treatment, and at 2, 6, 18, and 36 h posttreatment to evaluate swimming behavior and determine numbers of dead or incapacitated fish in each group. Surviving fish were subjected to an overdose solution of MS-222 (tricaine methanesulfonate) at the conclusion of the 36-h observation period. Both dead and surviving fish were measured for total length (mm) and examined for electroshock-induced injuries via radiography and necropsy. Dorsoanterior and lateral projection radiographs were taken with mammography film and screens. The mammography film and screen system provides greater detail than conventional radiography. During necropsy, fillets were removed from the fish by use of surgical scalpels. The vertebral column and lateral fillets were examined via microscopy under transmitted and reflected light. Counts and percentages were used to quantify relationships between treatments and fish behavior, injury, and mortality. Differences in mortality between treatments were evaluated for statistical significance with Fisher's exact test (SAS 1999).

Results

Spotfin chub in the experiment were 35–57 mm total length (mean ± SD, 44 ± 5 mm). The spotfin chub vertebrae were too small to allow use of radiographs for identifying injury to individual vertebrae. However, radiographs were capable of

TABLE 1.—Elicited responses and mortality (%) in groups of spotfin chubs exposed to 60-Hz AC or 60-Hz pulsed DC (PDC) at various voltage gradients.

Treatment group	*N*	Behavioral response to treatment: Unbalanced swimming	Behavioral response to treatment: Immobilization	Mortality
60-Hz AC				
1.7 V/cm	20	50	50	5
2.5 V/cm	20	10	90	10
3.3 V/cm	20	0	100	0
60-Hz PDC				
2.5 V/cm	20	10	90	0
5.0 V/cm	20	10	90	25
Control	18			0

identifying gross misalignment in the vertebral column. None of the fish exhibited detectable misalignment. No other electroshock-induced injuries to the lateral musculature or vertebral column were detected by necropsy or radiography, and no abnormal external coloration (e.g., brands or bruising) was apparent.

Immobilization was the predominant behavioral response evoked in the groups of spotfin chub exposed to AC (Table 1). The group exposed to 1.7-V/cm AC displayed unbalanced swimming and immobilization in equal numbers. In contrast, 90% of the fish in the 2.5-V/cm AC treatment group and all of the fish in the 3.3-V/cm AC group were immobilized.

Several fish in the AC treatment groups had an abnormal vertical and lateral curvature of the body (a corkscrew appearance) immediately after treatment, a condition that usually subsided within the first minute posttreatment. Some fish in this condition lay at the bottom of the holding cages, while others swam abnormally in the water column. All surviving fish were swimming normally at the conclusion of the 36-h observation period. No abnormal curvatures were observed in dead fish.

Immobilization was elicited in 90% of the minnows in each of the PDC treatments (Table 1); those not immobilized exhibited unbalanced swimming. Several fish in each PDC treatment demonstrated a tetanic curvature immediately after treatment: 5 of 20 in the 2.5-V/cm group and 4 of 20 in the 5.0-V/cm group. All surviving fish in the PDC treatment groups were swimming normally at the conclusion of the experiment.

All mortality occurred within 1 h of treatment. Dead minnows were removed from the holding pens 6 h after treatment. Pairwise comparisons (Fisher's exact test) of the incidence of mortality among the three experimental groups exposed to AC revealed no statistically significant differences among the three voltage gradients (P = 0.487–1.00). However, significantly higher mortality occurred in the group of spotfin chub exposed to 5.0-V/cm, 60-Hz PDC than in the group exposed to 2.5-V/cm, 60-Hz PDC (P = 0.047). No mortality occurred in the control group (Table 1).

Discussion

Fish response to electrified water is dependent upon introduced (in vivo) electrical energy (Kolz 1989) and is independent of the aquatic setting. Thus, fish response in laboratory studies can simulate electrofishing in the field. Most of the spotfin chub exposed to 2.5- and 3.3-V/cm, 60-Hz AC were immobilized, but those at 1.7 V/cm exhibited unbalanced swimming and immobilization in equal numbers. These results indicate that our selected range of voltages (hence, voltage gradients) produced the variety of capture-prone responses that would be seen during a typical electrofishing operation. Voltage gradients of 2.5- and 3.3-V/cm AC represented electrical field intensity near an electrode, whereas 1.7-V/cm AC produced an effect that would be seen farther away from an electrode but in the effective electrical field, nevertheless. Both levels of 60-Hz PDC, 2.5 and 5.0 V/cm, caused mostly immobilization, thus representing conditions near an electrode. Electrofishers should use the minimum voltage necessary to achieve a capture-prone response. For spotfin chub, voltage should be set at the threshold to achieve immobilization, or just below it to achieve a mix of capture-prone responses (e.g., immobilization and unbalanced swimming).

We detected no injury in the electroshocked fish in our experiment. Lack of vertebral damage in our study was consistent with results from other studies on small cyprinids (Cape Fear shiner: Holliman et al. 2003; juvenile humpback chub *Gila cypha* and bonytail *G. elegans*: Ruppert and Muth 1997). Electroshock can induce hemorrhage associated with the vertebral column in small fish (Ruppert and Muth 1997; Cooke et al. 1998). However, no hemorrhages occurred in Cape Fear shiners (Holliman et al. 2003) or in the spotfin chub in this experiment.

The ultimate test of electrofishing effects is fish mortality (Hollender and Carline 1994). In our experiment, no control fish died; thus electroshock, not handling, was responsible for the deaths of electroshocked spotfin chub. Although no clear relationship was demonstrated between AC voltage gradient and fish mortality in our experiment, mortality was low (10% or less) in all AC treatments. Mortality rate due to PDC shock significantly increased from 0% to 25% when voltage gradient was doubled (2.5–5.0 V/cm).

Historically, AC has been shown to cause excessive fish injury and mortality (McMillan 1928; Hauck 1949; Reynolds 1996), but recent studies (Hudy 1985; Habera et al. 1996) have demonstrated that injury and mortality of AC-shocked salmonids are low when water conductivity is very low (<30 μS/cm). We suspect that low water conductivity (<80 μS/cm) minimizes the power transfer from the electrical field to the fish (Kolz 1989). In these situations (low or very low conductivity), AC is successful (acceptable catch rates and low injury/mortality rates) because it is the waveform that best uses the very limited power available in small electrofisher units (e.g., backpack shockers). Pulsed DC reportedly has little or no value in these situations (S. Moore, National Park Service, Sevierville, Tennessee, personal communication) because, at the power levels available in small electrofisher units, it fails to elicit capture-prone responses in most fish. Despite the successful use of AC in these particular situations, we caution electrofishers against the general use of AC because of its well-documented risk to fish (Reynolds 1996).

All fish that died in our experiment did so within 1 h after a 3-s electroshock. After 36 h, all surviving fish looked and behaved normally. Because no fish were injured, we conclude that all deaths were stress related. If electrofishers observe that small cyprinids appear and behave normally within 1 h after electroshock and capture, they may conclude that stress is minimal and electroshock-induced mortality will likely be zero.

We have shown that spotfin chub may be electroshocked with 60-Hz AC and 60-Hz PDC, at voltages producing capture-prone responses typically seen in electrofishing operations, with no injury and low mortality. Low mortality rates in electrofishing samples translate to negligible effects in large, healthy populations (McMichael et al. 1998) but may be important when sampling small, threatened populations (Nielsen 1998). We conclude that electrofishing may be used for the safe capture of small cyprinids such as spotfin chub. However, we urge electrofishers to use the minimal voltage, regardless of waveform (AC, DC, or PDC), needed to immobilize and capture these fish, and to resort to the use of AC only when electrofishing in low-conductivity waters (<80 μS/cm).

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