Effectiveness of an Electrical Barrier in Blocking Fish Movement

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Abstract: Electrical barriers were successful in blocking movements of gizzard shad (*Dorosoma cepedianum*), golden shiners (*Notemigonus crysoleucas*), rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), and largemouth bass (*Micropertus salmoides*) stocked in a 24-m long canal during simulated modes of pumped hydropower operation. Blockage rates were highest during nongeneration (95%–97%) and generation (94%–97%), and lowest during pumping (83%–84%). These results indicate an electrical barrier may be useful in blocking fish from migrating into areas around hydropower projects where they are vulnerable to being entrained.

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Fish entrainment is a major concern for regulatory agencies that deal with licensing of hydropower projects. These agencies routinely require project owners to conduct extensive studies to document the numbers of fish entrained and to mitigate for the loss of these fish. Because of the high costs associated with standard mitigation measures (e.g., installation of a permanent screen, modification of plant operation, or cash payments for fish killed), behavioral barriers have recently received considerable attention from hydropower owners as a cost-effective way to reduce fish entrainment (Electric Power Res. Inst. 1990).

Effective behavioral barriers rely on the natural response of fish to be repelled or attracted by some external stimulus. While sound (Haymes and Patrick 1986, Loeffelman et al. 1991, Dunning et al. 1992, Nestler et al. 1992, Ross et al. 1993, Knudsen et al. 1994) and lights (Martin et al. 1991, Electric Power Res. Inst. 1992, Nemeth and Anderson 1992) have proven successful as behavioral barriers, they generally do not elicit responses from a wide variety of fishes. Inasmuch as hydropower projects entrain numerous fish species, sound and light barriers provide only limited fish protection for most projects. Thus, there is a need for a behavioral barrier that will provide protection for multiple fish species.

Electrical barriers have been used to block fish movements in a variety of circumstances (Halsband 1967, Hartley and Simpson 1967, Palmisano and Burger 1988). Even though Hartley and Simpson (1967) reported that electrical barriers have been used in England and Scotland since the 1950s to reduce fish entrainment at hydropower projects, little or no attention has been given to using them for this purpose in the United States. It is possible this type of behavioral barrier could be especially useful at pumped storage hydroelectric stations where several projects have entrained large numbers of fish (Liston et al. 1981, Richards et al. 1986). The objective of this study was to test the effectiveness of an electrical barrier in blocking the movements of several species of fish during simulated modes of pumped hydropower operation.

We are grateful to David Smith, Smith-Root, Inc., for supplying the pulsators used in this study and his assistance, and that of Paul White, Michael Pollard, and Montgomery Smith, Duke Power Company, for the set-up and operation of this equipment.

Methods

Evaluation of the graduated field fish barrier (GFFB) manufactured by Smith-Root, Inc., (Vancouver, Wash.) took place in a plastic-lined canal (24 m long × 2 m wide × 1 m deep). The GFFB electrode array consisted of 4 5-mm diameter stainless steel electrodes (spaced 1.1 m apart) that were attached to a 6.0-m long × 4.1-m wide piece of canvas. This array was placed on the bottom center of the canal so that the electrodes were positioned perpendicular to water flows through the canal (Fig. 1). Ground wires (3 mm diameter, stainless steel) were installed on each side of the array to restrict the electrical field to the area above the array. The array was activated

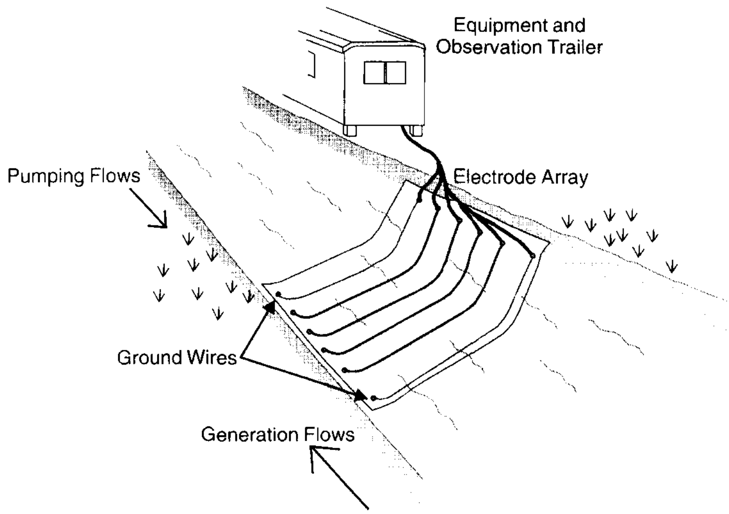

Figure 1. Diagram of setup used to evaluate the effectiveness of electrical fish barriers.

using 3 pulsators (Model GFFB 0.5), each capable of producing up to 400 volts (3–4 amperes) of pulsed direct current. The pulsators were housed in a small house trailer parked parallel to 1 end of the canal. This trailer also served as the observation area for recording fish distributions in the canal during testing.

After the canal was filled with water (10 C and 60 µmhos/cm) from Lake Norman, North Carolina, 6 gizzard shad, 50 golden shiners, 20 rainbow trout, 20 brown trout, and 8 largemouth bass were released into it. These fish ranged in total length from 150 to 250 mm, 40 to 80 mm, 160 to 220 mm, 170 to 200 mm, and 250 to 310 mm, respectively.

Preliminary tests with various pulsator settings and no water flow indicated 10 pulses/sec at settings of 200 volts, 200 volts, and 300 volts (for the 3 pulsators) provided an electrical field that produced the best fish blockage without inducing tetanus in the fish. Thus, these settings were selected for additional testing. Voltages across the GFFB (as measured with a hand-held probe and an oscilloscope) were 0.0–0.5 volts/cm between the ground wire and the first electrode (nearest the trailer), 1.6–2.0 volts/cm between the first and second electrodes, 1.5–3.0 volts/cm between the second and third electrodes, 1.0–1.7 volts/cm between the third and fourth electrodes, and 0.0–0.8 volts/cm between the fourth electrode and the second ground wire.

Testing consisted of concentrating all fish at the end of the canal in front of the trailer and then recording the percentages of fish that remained there or redistributed themselves either over the electrode array or to the opposite end of the canal at 15-minute intervals during a 2-hour test period, when the GFFB was not activated (control) during simulated periods of nongeneration (no flow through the canal), generation, and pumping. Generation and pumping flows were created by pumping 1.1 m^3 of water/minute through the canal from opposite directions (Fig. 1). This volume of water produced velocities of 0.2 m/sec across the GFFB. Each test was repeated twice (with a minimum of 2 hours between tests) and the average percentages of fish located in the 3 areas of the canal were calculated. Chi-square tests (Sokal and Rohlf 1969) were used to determine if differences existed in the distributions of fish in the canal (mean percentage of fish distributed in the canal near the trailer, over the array, or on the end of the canal opposite the trailer) measured at 15-minute intervals with and without the barrier activated during the 3 modes of operation. Differences were considered significant when $P < 0.05$.

After the above tests were completed, a second series was conducted to evaluate the effectiveness of a single electrical field in blocking fish movements. This testing was similar to that reported above, except only 1 pulsator was used (pulse rate of 20 pulses/sec and a 400-volt setting) to create the electrical field and the tests were not repeated. Measured voltages during these tests were 0.5–0.8 volts/cm between the ground wire and the first electrode (nearest the trailer) and 1.0–1.2 volts/cm between the first and second electrodes. Zero voltage was measured between the remaining electrodes. Chi-square tests were again used to determine if fish distributions in the canal differed with and without the barrier operational for the 3 modes of operation and if fish distributions using only a single pulsator differed from those observed during the tests with the GFFB.

Results

Fish distributions in the canal varied considerably depending on the mode of operation and whether or not the electrical barriers were activated. During nongeneration control tests, fish that were initially concentrated in the canal near the trailer immediately began to redistribute themselves either over the electrode array or at the opposite end of the canal (Fig. 2). This movement continued until the end of the tests

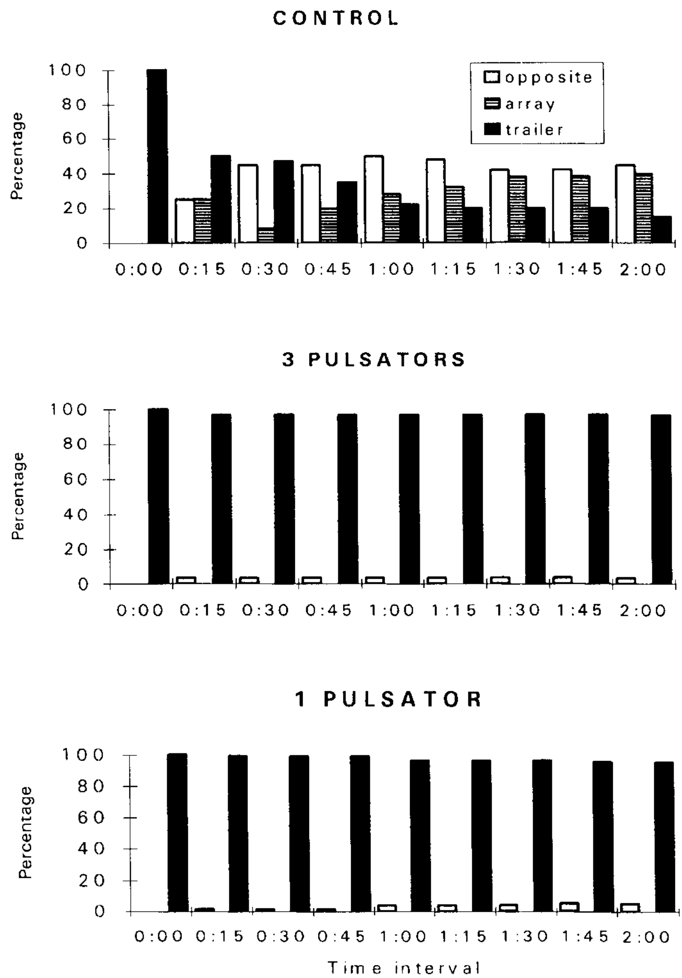

Figure 2. Percentages of fish distributed in the canal near the observation trailer, over the electrode array, and in the opposite end of the canal at 15-minute intervals during nongeneration with the electrical barrier not activated (control), activated using 3 pulsators (200 volts, 200 volts, and 300 volts), and activated using 1 pulsator (400 volts).

when 45% of the fish were located on the end of the canal opposite the trailer, 40% were over the array, and 15% remained on the end of the canal in front of the trailer. When the GFFB was activated during nongeneration, most of the fish remained on the end of the canal near the trailer (Fig. 2). However, a few fish did migrate through the electrical field to the opposite end of the canal. In general, this migration took place during the first 15 minutes of each test. Fish remaining in the canal near the trailer attempted to migrate across the electrical barrier, but were repeatedly stopped once reaching an area about halfway between the first ground wire and the first electrode. At the end of the tests, 97% of the fish that were originally in front of the trailer remained there. With only 1 pulsator activated during nongeneration, 95% of the fish that were originally in the canal near the trailer remained there (Fig. 2). In this test, fish also attempted to migrate through the electrical barrier, but they turned away once entering an area midway between the first ground wire and the first electrode. Mean fish distributions in both tests with the electrical barriers (GFFB and 1 operational pulsator) operational differed significantly from the mean distribution of fish observed when the barriers were not operational (χ^2 = 154.53 and 154.53, respectively). However, mean fish distribution in the canal during tests with electrical barriers created by the GFFB and only 1 operational pulsator were not significantly different ($\chi^2 = 0$).

Fish movements during generation control tests were somewhat different than noted during nongeneration control tests. After being concentrated in the canal near the trailer, fish immediately began to redistribute themselves (Fig. 3). However, few were observed over the array, and most moved to the opposite end of the canal from the trailer where generation flows were entering the canal. By the end of the tests, 70% of the fish were on the opposite end of the canal and no fish were over the array. When the GFFB was activated during generation, 94% of the fish remained in that portion of the canal near the trailer (Fig. 3). Of those that migrated across the GFFB to the opposite end of the canal, almost half did so during the first 15 minutes of the tests. With only 1 pulsator operational, similar results were noted (Fig. 3). Here, 97% of the fish remained in that portion of the canal near the trailer for the duration of the test. Mean fish distribution with both barriers operational (GFFB and 1 operational pulsator) differed significantly from that noted when the barriers were not operational (χ^2 = 119.70 and 128.74, respectively). However, no significant difference in mean fish distributions was observed when the GFFB and only 1 pulsator were operational ($\chi^2 = 1.04$). As noted in nongeneration tests with the GFFB and with only 1 pulsator activated, fish frequently attempted to migrate through the electrical barriers, but most were blocked between the first ground wire and the first electrode.

Fish distributions in pumping control tests differed from those noted during both nongeneration and generation control tests. In these tests, about 50% of the fish that were initially in the canal near the trailer redistributed themselves to the opposite end of the canal during tests (Fig. 4). Once the GFFB was activated, only a few fish migrated to the opposite end of the canal. Of the fish that were originally near the trailer, 84% remained there for the duration of the tests (Fig. 4). With only 1 pulsator

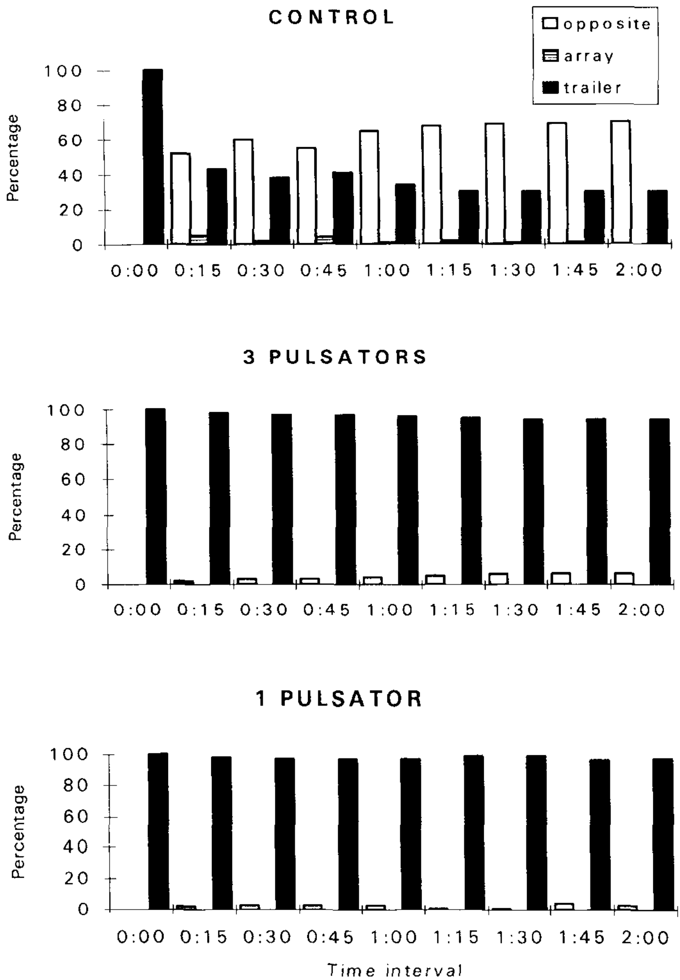

Figure 3. Percentages of fish distributed in the canal near the observation trailer, over the electrode array, and in the opposite end of the canal at 15-minute intervals during generation with the electrical barrier not activated (control), activated using 3 pulsators (200 volts, 200 volts, and 300 volts), and activated using 1 pulsator (400 volts).

activated during pumping, 83% of the fish in the canal remained near the trailer during the test (Fig. 4). Mean fish distribution (GFFB and only 1 operational pulsator) differed significantly from that noted when the barriers were not operational (χ^2 = 21.41 and 23.38, respectively). However, mean fish distributions observed with the GFFB and with only 1 pulsator operational were not significantly different ($\chi^2 = 0.09$). As observed in other tests, fish remaining near the trailer continually attempted to migrate across the electrical barriers, but were blocked prior to reaching the first electrode.

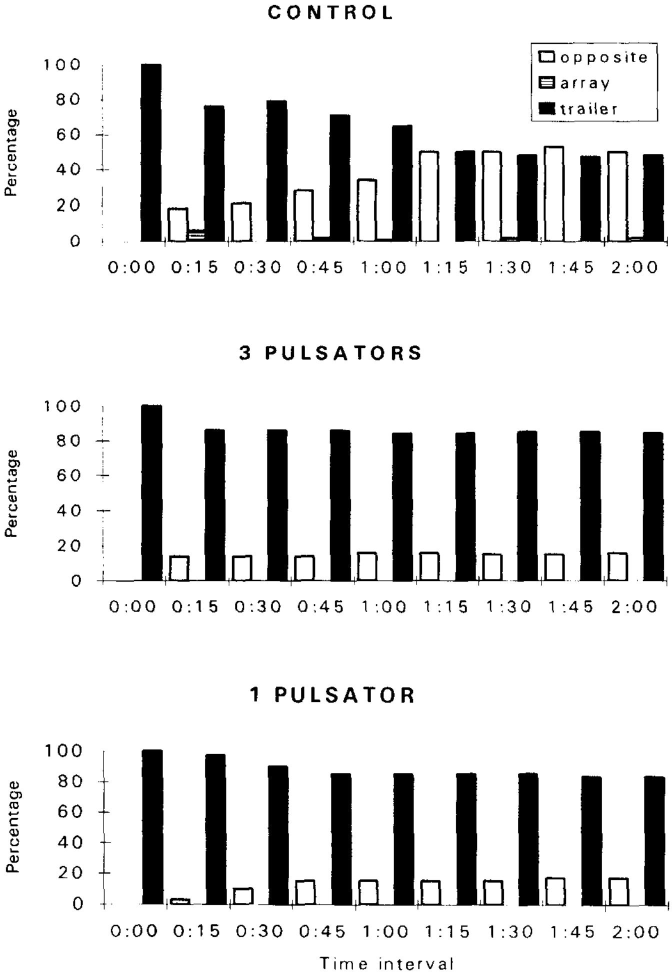

Figure 4. Percentages of fish distributed in the canal near the observation trailer, over the electrode array, and in the opposite end of the canal at 15-minute intervals during pumping with the electrical barrier not activated (control), activated using 3 pulsators (200 volts, 200 volts, and 300 volts), and activated using 1 pulsator (400 volts).

Discussion

The movements of all species of fish tested were restricted by use of the GFFB. This occurred even though a truly graduated electrical field (increasing in voltage from the first to the fourth electrodes) was not established across the electrode array. The plastic liner in the canal was apparently a poor insulating substrate and some of the current was lost to the ground. It was difficult to determine if this reduced the effectiveness of the GFFB, because most fish detected the electrical field between the first ground wire and the first electrode (where voltages ranged from 0.5 to 1.0 volt/cm) and did not actually swim into the interior of the electrical field. If a fish penetrated the electrical field beyond the first electrode, it generally became excited and continued across the barrier to the opposite end of the canal. This behavior may explain why an electrical field created with 1 pulsator was as effective as that created by the GFFB in blocking movements of fish under the flow regimes tested.

The effectiveness of the electrical barriers in blocking fish movements was best during nongeneration and generation modes of operation. Here, > 94% of the fish concentrated in that portion of the canal near the trailer remained there. Blocking effectiveness was apparently less for the electrical barriers during the pumping mode, but was still relatively high at 83%. Some reduction in effectiveness of the electrical barriers during pumping may have resulted from a fright response demonstrated by the fish as pumping commenced.

In all modes of operation, most of the fish that passed through the electrical field did so during the first 15 minutes of each test. During this time, the fish were excited by having been concentrated in the end of the canal near the trailer and some would immediately return to the opposite end of the canal by frantically swimming through the electrical field. With flows entering the canal near the trailer during pumping, the excitement level of the fish may have been enhanced by the surface agitation associated with the flows. This may have resulted in more fish swimming through the barrier during pumping than during either nongeneration or generation modes of operation. This enhanced level of excitement caused by concentrating fish in the end of the canal near the trailer, where pumping flows were entering, would not be present in field deployment of an electrical barrier and the blocking effectiveness during all modes of operation might be somewhat higher than noted in these tests.

The effectiveness of the electrical barriers in this study compared favorably with results reported in field tests for low frequency sound (Haymes and Patrick 1986, Loeffelman et al. 1991, Knudsen et al. 1994), high frequency sound (Ross et al. 1993), and lights (Electric Power Res. Inst. 1992) where 70%–95% blockage rates were generally reported. While sound and lights were generally species-specific in repelling fish, the electrical barriers tested in this study were effective in blocking a relatively large percentage of all species tested.

While field research is needed to fully evaluate the effectiveness of an electrical barrier in blocking fish movements, this type of behavioral barrier appears to have potential to block fish from migrating into intake areas of hydropower projects. An electrical barrier with a field of at least 1.5 volts/cm appears to be needed to provide effective blockage of fish. An electrical field of this voltage should result in little or no concern for public safety because we were able to place our hands in the center of the field with no discomfort. A major disadvantage of utilizing an electrical barrier at this time is the lack of an electrode array designed to create an evenly configured electrical field in water greater than 5 m deep. If this problem can be solved in a cost-effective manner, an electrical barrier may be a useful alternative for hydroproject owners with fish entrainment concerns.

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