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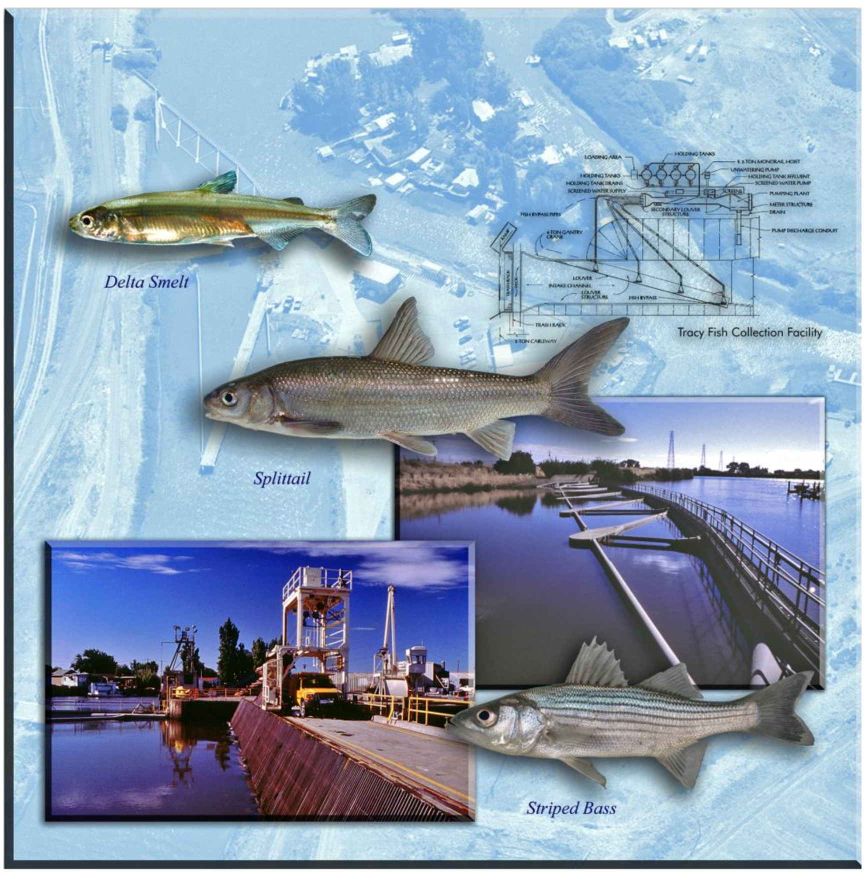
Laboratory Design and Testing of an Electrical Crowder for Predator Reduction at the Tracy Fish Collection Facility



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14. ABSTRACT
A rolling electrical crowder was designed and tested in a laboratory to deter large predator fish (greater than 300 mm FL) from taking up residency in the Tracy Fish Collection Facility while minimizing impacts to smaller fish. The crowder consisted of an electrical sequencer, electrofisher unit, and series of electrodes. The electrical crowder moved fish through avoidance rather than taxis, so injury was minimized. Small flume tests showed that most striped bass (285–590 mm FL) avoided the electrical crowder, swimming quickly out of the field. Juvenile Chinook salmon and rainbow trout (88–108 mm FL) displayed twitch or slight movement when exposed to the field. Lighting conditions affected behavioral response. Nineteen of 20 fish crowded through a 15.2-cm-wide (6-in-wide) bypass on the first pass when the bypass was light. When the bypass was dark, only 3 of 20 fish crowded on the first pass, although an additional 14 fish were driven through after multiple attempts at crowding. In large laboratory flume tests where electrode spacing (2.4m) was set to approximate a real world application, 300 volts was needed to maintain a field strength similar to that of the small flume. Although only 60 percent of adult striped bass were crowded, no fish experienced taxis. To minimize harm to fish, the crowder can be operated at the lowest possible settings on an intermittent basis with the goal of reducing predator populations over time.

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Laboratory Design and Testing of an Electrical Crowder for Predator Reduction at the Tracy Fish Collection Facility

Tracy Series Volume 48

by

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EXECUTIVE SUMMARY

Federal and state fish screening facilities in the south Sacramento-San Joaquin Delta provide favorable habitat for predator fish, primarily striped bass (*Morone saxatilis*). At the Tracy Fish Collection Facility (TFCF), striped bass are frequently found residing upstream, downstream, and within the facility. The goal of this study was to design and test a rolling electric crowder to safely and effectively deter large predator fish from taking up residency in the TFCF while minimizing impacts to smaller bodied fish. An electric crowder drives fish through avoidance rather than taxis, so injury to fish is minimized.

Stationary tank tests at a water conductivity of 400 µS/cm and a constant frequency of 7.5 Hz showed that striped bass (254–368 mm FL) exhibited twitch between 0.05 and 0.3 V/cm, moderate taxis between 0.3 and 0.75 V/cm, strong taxis between 0.75 and 1.5 V/cm, and tetanus above 1.5 V/cm. In the laboratory, a rolling crowder was developed using an electrical sequencer, electrofisher unit, and a series of electrodes. Tests conducted in a 76-cm-wide (30-in-wide) flume showed that striped bass (285–590 mm FL) avoided the electric crowder, swimming quickly out of the field. When the electric field was rolled multiple times through the full cycle, most upstream swimmers would swim downstream on a successive cycle of the crowder. Channel velocity did not affect behavioral response.

At the small model scale, the lowest electrofisher settings for voltage (50 V peak), frequency (7 Hz), and pulse width (1.2 ms) at 320 µS/cm were sufficient to move most adult striped bass downstream. Small-bodied fish (juvenile rainbow trout, *Oncorhynchus mykiss* and Chinook salmon, *O. tshawytscha*) in the size range of 88–108 mm displayed only twitch or slight movement when exposed to the electric crowder at these settings. Lighting conditions had a significant effect on behavioral response. Nineteen of 20 fish crowded on the first pass when the bypass was light. When the bypass was dark, only 3 of 20 fish crowded on the first pass, although an additional 14 fish were driven through the bypass after multiple attempts at crowding.

In a large laboratory flume with channel dimensions similar to the TFCF secondary channel, an electric field with 2.4 m (8 ft) spacing between electrodes was capable of producing striped bass avoidance. Since voltage gradients were high directly next to the electrodes, it is recommended that PVC covers with slots be installed to prevent fish from directly contacting electrodes. Pulsed DC with a peak voltage of 300 V, pulse width of 1.2 ms, and frequency of 7 Hz was the preferred operating condition in this flume at water conductivity of 320 µS/cm. Although only 60 percent of adult striped bass were crowded, no fish experienced taxis. If minimizing harm to large fish is a management objective, the crowder should be operated at the lowest possible settings on an intermittent basis to reduce predator populations over time.

INTRODUCTION

Striped bass (*Morone saxatilis*) were introduced to the Sacramento River system in 1879 for the purpose of establishing a fishery (Kohlhorst 1999). Striped bass populations prospered for many years, but over the last 30 years a significant decline in striped bass populations has been attributed to pumping plant exports and ecosystem changes (Kimmerer *et al*. 2000, Feyrer *et al*. 2007, Sommer *et al*. 2007, Thomson *et al*. 2010). Striped bass remain an important sport fishery in the system and future management actions will have to take this into account. Once striped bass reach two years of age, they become predominately piscivorous. Striped bass predation has been implicated in the decline of several species in the Delta, but large scale impacts to populations of prey species have been brought into question. Striped bass are largely opportunistic predators and many of the prey species in question occur in low numbers, only making up a small proportion of the total prey base. However, it is clear that that striped bass can have a potential impact on the population of prey species in the Sacramento River System.

One area where predation could potentially be significant is at federal and state fish screening facilities in the south Sacramento-San Joaquin Delta. Because of their designs, these facilities provide favorable habitat for predator fish, primarily striped bass (Gingras 1997, Bark *et al*., in draft). Hydraulic conditions in and around fish screening facilities tend to concentrate predators where water velocities are lower (Liston *et al.* 1994, Bark *et al*., in draft). At the Tracy Fish Collection Facility (TFCF), striped bass are frequently found residing upstream, downstream, and within the facility (Bark *et al*., in draft). During a 2008 study under the Vernalis Adaptive Management Program (VAMP), a large number of striped bass tagged in the area tended to remain within the detection range of the receiver placed near the trashracks at the TFCF (Vogel 2010). During a series of fish removals at the TFCF, 1,866 and 4,683 striped bass were captured in 1991 and 1992, respectively (Liston *et al*. 1994). On average, stomachs from 36 percent of the salvaged striped bass contained fish. These studies indicate striped bass are present in numbers large enough to significantly impact the number of smaller fishes salvaged at the facility.

There are two primary areas within the TFCF that predators can be found in large numbers. The first is in the primary channel, which encompasses the area from the trashrack downstream to the first set of louvers. This area has zones of variable flow and average velocities are well within the swimming speeds of most sub-adult and adult striped bass. Louvers in the primary channel guide fish to one of four 15.2-cm-wide (6-inch-wide) primary bypasses. The bypasses transition into pipes which carry the fish and flow into a secondary channel where feeding stripers congregate in significant numbers. A secondary set of louvers guide fish through another fish bypass and into a holding tank area. Within the secondary channel, predator fish removal is conducted periodically by lowering the water level and manually removing predators. High flows are released through the fish bypasses to force predators out of the bypass pipes where they can be netted and removed. Carbon dioxide (CO_2) has also been used to force predators through the bypass pipes. Predator removal has been more difficult in the primary channel due to the large channel width, large water depth, and the inability to dewater the channel. Gill nets and hook-and-line are the current options for predator removal in the primary channel. These methods catch limited numbers of fish, and nets may produce a significant risk to the facility under higher flows if they get caught on the louver array.

According to the National Marine Fisheries Service's 2009 Biological Opinion on the Long Term Coordinated Operation of the Central Valley Project and State Water Project, Reclamation is required to complete studies that evaluate methods for removal of predators in the primary channel, using physical and non-physical removal methods (*e.g*., electricity, sound, light, and CO_2), with the goal of reducing pre-screen predation loss of exposed salmonids to 10 percent or less (National Marine Fisheries Service 2009). The goal of this study was to investigate the potential for using electricity as a safe and effective way of deterring or preventing large predator fish from taking up residency in the TFCF.

Electric fish barrier design typically involves submerging two or more metal electrodes in a fixed location and applying a voltage between them. Electrical current passes between the electrodes, forming an electrical field in the water. Fish coming into contact with the electrical field can experience a reaction such astwitch, taxis, and tetanus. Twitch produces fluttering of the gills or tail, slight changes in swimming position, or swimming avoidance. Avoidance refers to voluntary non-directional movement of fish in response to electricity. If avoidance is directional, this action is called crowding. Generally, taxis is defined as the behavioral response by an organism to a directional stimulus. Specifically, galvanotaxis is the directional movement of motile cells in response to an electric field. Galvanotaxis produces uncontrolled muscular contractions that involuntarily force fish to swim toward the anode. Galvanotaxis is simply referred to as taxis in electrofishing and electric barrier literature. Tetanus is full paralysis or immobilization. This can occur when the field strength is too strong or when fish are close to the electrodes. When pulsed direct current (DC) is used, response levels of twitch, taxis , or tetanus depend on peak voltage, peak current, pulse width, frequency, and duration of the applied electrical field.

While striped bass need to be removed from the facility, there is also a desire to minimize mortality to allow reintroduction of striped bass into the sport fishery at another location in the Delta. Studies must also ensure that smaller fishes of interest such as steelhead in the 200–250 mm range, salmon smolts, and Delta smelt remain relatively unaffected by any deterrence method. At the TFCF the target size class for predator removal is fish larger than 300 mm. Large fish are generally more susceptible to the electrical field than smaller fish; however, effects of the field on an individual depend on the specific location of the fish in the field. Maintaining field intensity low enough to avoid tetanus in larger fish should allow smaller fish to pass through the field unharmed. Real-time monitoring will be needed to determine if species of interest are present so that electrical crowding does not occur, further minimizing the chances of negatively impacting non-target species.

Electric fish barriers are commercially available and have been used in a variety of situations. In certain circumstances, electric barriers have been shown to be effective as a behavioral tool in controlling fish movement during upstream passage or movement into flow (Clarkson 2004). However, only limited testing has been conducted to document the effectiveness of electrical fields as a behavioral barrier during downstream movement of fish (Sechrist *et al*., in draft). There exists little data on the use of electricity to drive fish to a desired area.

Potential alternatives using electricity for predator control at the TFCF are reviewed in this report. Laboratory tests were conducted at Reclamation's Hydraulics Laboratory in Denver, CO to answer some of the fundamental questions about the efficacy of using electricity to reduce populations of striped bass in the primary and secondary channels of the TFCF. Experiment questions include:

1. What pulsed DC levels are needed to produce different response levels in striped bass?

2. Are small-bodied fish affected by the electric field gradients that affect striped bass?

3. Can rolling electrical fields be used to move striped bass of varying size classes downstream while not impacting small-bodied fish?

4. Does water velocity affect fish response to the electrical field?

5. Will striped bass successfully enter a 6-in-wide bypass in order to avoid the electric crowder?

6. Do light and dark conditions affect fish reaction to the bypass?

Results from these laboratory experiments will be presented to the Tracy Technical Advisory Team (TTAT) and resource agencies. Recommendations for potential installations of an experimental electrical array at the TFCF will be provided.

Review of Predator Removal Options Using Electricity

Several predator removal options using electricity at the TFCF were considered. Permanent electrical installations may be more costly to design, install, and maintain, but may require less set-up time and less physical labor each time the system is run. Temporary installations are beneficial in that equipment can be moved around to find the most productive predator removal locations and then removed from the primary channel during regular operations. Costs would likely be lower, but more physical labor may be involved. For any type of installation, cathodic protection against galvanic action must be considered and safety training and signage would be required.

Automated Harvesting Techniques

Electrified nets or long electrode strands controlled from hoists or cranes could be used to produce localized electric fields. The nets could be permanently installed on the facility deck, but would be removed from the water when not operational. After a taxis response is induced in large-bodied fish, automated nets would be used to collect fish. The electrodes could be moved along the louvers or trashrack to cover more area in the primary channel, however only predators within range of the electrodes would be affected. Since a taxis response is needed to move large fish close enough for removal, it is possible that similarly sized fish could be affected by voltage gradient levels.

Localized Fish Crowder Installation

Permanent electrodes could be mounted to the downstream end of the right sidewall in the primary channel or at another select location with a high density predator population. A rolling electric field could be used to move predators out of these areas and into the final bypass for collection, but only predators within range of the electrical field would be affected. A small installation at a targeted location would be less expensive than a full-scale installation, but would not be as effective at reducing predator numbers facility-wide.

Full Scale Fish Crowder Installation

Full coverage of the primary channel could be achieved by installing rows of buoy lines at 3.0 m (10 ft) spacing. Electrode drops could be placed every 3.0 m (10 ft) across the buoy line such that electrodes hang near the channel invert during low tide. A rolling pulsed DC field could be used to move large-bodied fish downstream in the primary channel and into the facility bypasses or out of the system through the louvers or trashrack. In the 2.4-m-wide (8-ft-wide) secondary channel, electrodes could be attached to the sidewalls rather than installing electrode drops. A rolling electric field could move large fish into the holding tanks for collection. A relatively low voltage gradient level would be required, since an avoidance response to the electrical field would produce downstream movement of predators rather than a taxis response. This type of installation could be highly effective at reducing the overall predator load at the TFCF, but may be expensive to design, install, and maintain.

Electric Barrier Upstream of Trashrack

An electric barrier located upstream of the trashrack would limit the passage of large-bodied fish into the facility. Limiting the influx of new fish could allow the predator population within the facility to be better controlled. However, placing a fixed barrier in front of the trashrack may cause predator fish to simply hold a further distance outside the facility and result in no net reduction in predator loads. Secondly, it is suspected many predators enter the facility as younger fish and reside and grow within the facility itself. The barrier, designed to have minimal impact on small fish, may not be able to prevent this influx. Another concern is that all net flow in the area is into the facility, so any fish stunned by the electrical field would be impinged on the trashrack or moved downstream into the facility. Finally, there are public safety concerns with installing a barrier in front of the trashrack in an area with general public access. Even though the electric barrier would be installed downstream of the trash boom, additional physical access barriers and signage would be necessary.

Electric Barriers on End of Bypass Pipes

Electric fields can be activated at the ends of the bypass pipes, like a culvert barrier, to prevent predators from swimming upstream during predator removals. Although this technique may be effective, activation of an electric barrier in a confined space causes worker safety concerns if personnel are in the secondary channel performing a predator removal while the electricity is turned on.

Boat Electrofishing

Boat electrofishing allows personnel the flexibility to seek out predators throughout the primary channel and remove predators in place. However, removals are localized and may not be effective at collecting large numbers of predators. Boat electrofishing is time-intensive and requires training and rigorous safety precautions for the personnel involved. Since the primary channel varies from approximately 4.3–6.7 m (14–22 ft) deep, the electrodes will not affect predators deep in the water column, since standard electrofishing boats reach maximum depths of 2–3 m (6.6–9.8 ft). Electrofishing is not as effective in flowing water as it is in still water since fish can be swept away from the electric field (Smith-Root guidance, brochure). Velocities of 1m/s (3 ft/s) or greater occur during maximum pumping at the C.W. “Bill” Jones Pumping Plant.

Summary of Predator Removal Options

Table 1 contains a comparison of predator removal alternatives using electricity based on permanence, worker safety, public safety, operational ease, scale (area of facility affected), fish response required, predator removal, and implementation cost.

All options involving electricity incur some level of risk. However, with proper training and signage, risk can be minimized in most situations. Alternatives where elevated risk to personnel or the public cannot be reasonably mitigated were eliminated from further analysis. Boat electrofishing and electric barriers on the bypass pipes and upstream of the trashrack pose unique safety concerns. Limiting the amount of power applied to the water is important in minimizing impact on smaller bodied fish or other large-bodied fish with less predatory impact. Therefore, automated harvesting and boat electrofishing alternatives were abandoned in favor of lower voltage alternatives. The scale of the installation affects the ability of the system to have a broad impact on predator populations. Localized crowding and electric barriers on the end of bypass pipes only affect small areas of the facility. Predators are removed and hauled away from the facility in all cases except for the electric barrier upstream of the trashrack. In this case, predators may simply relocate to an upstream location where they may continue to impact fish survival.

After reviewing options, more research is warranted to determine if a fixed rolling DC electrical field can be used to remove large predator fish from the TFCF.

LABORATORY STATIONARY TANK STUDY

Model Set-up

The purpose of the laboratory stationary tank study was to classify the biological response of striped bass to various electrical field strengths. Threshold levels needed to produce a certain response were determined. Responses were classified as twitch/avoidance (minor muscle contraction or voluntary swimming avoidance), taxis (involuntary forced swimming toward the anode), and tetanus (immobilization with contracted muscles).

Table 1.—Comparison of predator removal options using electricity. Avoidance is defined as general non-directional movement of fish in response to electricity. If avoidance is directional, this action is defined as crowding. Taxis causes involuntary forced swimming toward the anode.

	Permanence	Worker Safety	Public safety	Operational Ease	Scale	Fish Response Required	Predator Removal	Implementation Cost
Automated Harvesting	Permanent, removed from water	Moderate risk	No risk	Moderate effort	Mid-size area	Taxis	Predators removed & hauled	$$
Localized Crowder	Permanent, in water	Low risk with training & signs	No risk	Low effort	Small area	Avoidance	Predators removed & hauled	$$
Full Scale Crowder	Permanent, in water	Low risk with training & signs	No risk	Low effort	Large area	Avoidance	Predators removed & hauled	$$$
Barrier Upstream of Trashrack	Permanent, in water	Low risk with training & signs	Moderate risk with barriers & signs	Low effort	Mid-size area	Avoidance	Predators not removed	$$$
Barrier at End of Bypass Pipes	Permanent, in water	High risk	No risk	Moderate effort	Small area	Avoidance	Predators removed & hauled	$
Boat Electrofishing	Temporary	High risk	No risk	High effort	Large area	Taxis	Predators removed & hauled	$

A 71-cm-wide by 135-cm-long by 71-cm-deep (28-in-wide by 53-in-long by 28-in-deep) rectangular test tank with a viewing window was used for the experiments (Figure 1). A 0.32-cm-thick (1/8-in-thick) flat plate metal electrode was installed on each sidewall of the tank at a distance of 123 cm (48.5 in) apart. A Smith-Root voltage gradient meter was used to map the electrical field at three depths and four lateral locations in the test tank. Aside from higher voltage gradient readings directly adjacent to the electrodes, a near-uniform voltage field existed in the tank.

Figure 1.—Laboratory test tank with flat plate metal electrodes covering the full dimension of the side of the tank.

Since water conductivity affects the flow of current in the water and thereby the amount of power transferred to the fish, the conductivity in the laboratory was maintained at a level similar to the field. A seven-year water conductivity chart from the TFCF shows seasonal and daily variability in water conductivity (Figure 2). Based on this seven-year data, the average water conductivity is approximately 400 µS/cm. Water conductivity was raised in the test tank and monitored with a Hydrolab DS5 multiprobe to maintain water conductivity at approximately 400 µS/cm for all experiments. When water conductivity equals the conductivity of the fish (typically 100–150 µS/cm), maximum power transfer occurs (Kolz and Reynolds 1989). Very low or high water conductivity makes it difficult to transfer enough power to produce sufficient fish response. Power transfer theory can be used to correlate the amount of power required to elicit a specific response at a specific water conductivity to another water conductivity (Kolz and Reynolds 1989).

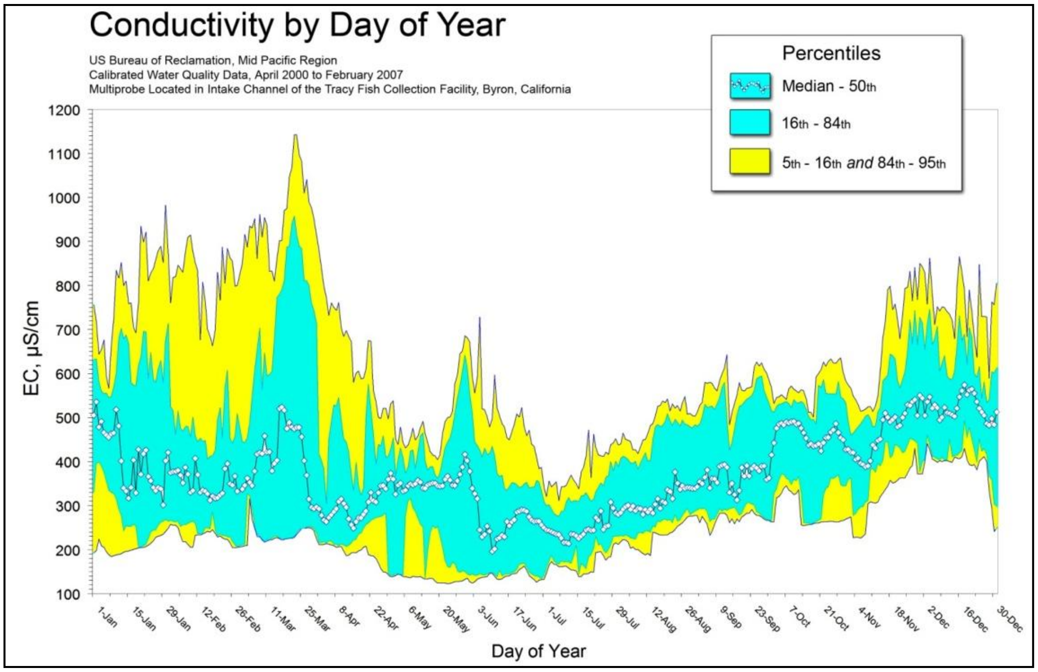

Figure 2.—Water conductivity record from April 2000 to February 2007 at the TFCF (TFCF 2012).

An available Smith-Root model GPP 9.0 gas powered electrofisher unit capable of generating AC, DC, and pulsed DC waveforms was used for this portion of the study (Figure 3). Pulsed DC is made by interrupting steady DC with an electronically controlled switch which triggers several on-off pulses per second. A Tektronix model 2246 oscilloscope showed that the GPP unit altered a fraction of the half-wave of an AC sine wave, rather than producing a true DC square wave (see Miranda and Spencer 2005 for detailed information about the output from Smith-Root GPP unit). The peak voltage, the number of pulses per second (pulse frequency), and the on-time (pulse width) have different effects on different species of fish and can be fine-tuned to differentially affect certain species.

Test Procedure

Twenty-six striped bass with a fork length (FL) of 254–368 mm (average 315 mm) were placed in the test tank one at a time. Peak voltage and pulse width were varied, while pulse frequency and test duration were held constant for this portion of the study. Peak voltages ranged from 1 to 260 V and pulse width varied from 1.25 to 2.9 ms. Frequency was maintained at a constant 7.5 Hz after a preliminary test showed that 30 Hz produced a strong taxis response in test fish even at low voltage. The electric field was applied for 5 or 10 seconds. Fish response was observed and recorded during and after exposure to the electric

Figure 3.—Smith-Root GPP 9.0 electrofisher unit with gas powered generator.

field. Fish were anesthetized with MS-222 to measure length and weight (Figure 4). Following tests, fish were observed for 72 hours to measure short-term survival. Tests with small bodied fish could not be completed due to availability of fish.

Figure 4.—Striped bass were measured for length and weight.

Results and Discussion

At a frequency of 7.5 Hz, very little voltage was required to elicit a response from striped bass 254–368 mm in length. Muscle twitch, from fin or tail fluttering to repetitive muscle contractions, occurred between 0.05 and 0.3 V/cm. Striped bass displayed moderate forced swimming toward the anode between 0.3 and 0.75 V/cm. Strong, fast movement toward the anode with some fish physically contacting the anode plate was observed between 0.75 and 1.5 V/cm. Above 1.5 V/cm, fish displayed a tetanus response with completely rigid muscles and loss of swimming ability. In the tetanus response range, when the duration of the electrical field was increased from 5 to 10 sec, fish turned sideways or upside down. Although fish were swimming after the current was removed, they could be easily handled without being anesthetized. After 72 hour evaluation, there was no mortality or visible signs of damage to any test fish after the experiment.

Results of all tests are shown in Table 2. Figure 5 graphically depicts the responses of test fish to pulsed DC electrical stimulus. Table 3 provides a summary of threshold levels to achieve certain responses. Overall, larger bodied fish experience more voltage drop (volts per unit length) across their bodies than smaller fish and therefore elicited greater response to the same stimulus.

Based on this initial study, it appeared that responses in the range of strong twitch to weak taxis, or a voltage gradient of 0.2 to 0.5 V/cm at 400 µS/cm, would likely produce an avoidance response to the electric crowder, minimize the chance of tetanus, and limit overall mortality. The results of this study were used to set up initial parameters for a rolling electric crowder. The objective of using a rolling crowder is to move large fish through avoidance of electricity rather than producing taxis or tetanus.

ROLLING ELECTRIC CROWDER: SMALL FLUME STUDY

Model Set-up

The rolling electric crowder flume study built on results from the laboratory stationary tank tests. The primary objective of this study was to determine whether a rolling electric field can drive striped bass greater than 300 mm through a flume with little impact on fish 200 mm and smaller. Specific objectives include:

1. Determine whether a rolling DC electrical crowder can drive striped bass greater than 300 mm downstream through avoidance without causing immobilization. Determine 72-hour survival of the exposed fish.

2. Determine whether smaller-bodied fish show any noticeable response (twitch, taxis, tetanus) to a rolling DC electrical crowder of sufficient power to move striped bass downstream. Determine 72-hour survival of the exposed fish.

Table 2.—Electrical properties and biological responses observed during stationary laboratory tank tests at 400 µS/cm water conductivity

Electrical Properties							Biological Properties		
Peak Voltage (V)	Voltage Gradient (V/cm)	Current (A)	Pulse Width (ms)	Frequency (Hz)	Test Duration (sec)	Output Voltage Setting (V)	Fish Size (mm FL)	Fish Weight (g)	Response
1	0.01	0.01	1.25	7.5	5	85*	335	530	No response
3	0.02	0.03	1.25	7.5	5	85*	302	335	No response
9	0.08	0.10	1.25	7.5	5	85*	348	550	Weak twitch
17	0.16	0.19	1.25	7.5	5	85*	272	250	Weak twitch
17	0.16	0.19	1.25	7.5	5	85*	365	575	Twitch
24	0.22	0.27	1.25	7.5	5	85*	280	260	Twitch
32	0.28	0.36	1.25	7.5	5	85*	268	195	Weak taxis
32	0.28	0.36	1.25	7.5	5	85*	320	370	Weak taxis
41	0.41	0.46	1.25	7.5	5	85*	280	260	Weak taxis
41	0.41	0.46	1.25	7.5	5	85*	340	500	Moderate taxis
54	0.55	0.60	1.25	7.5	5	85	254	195	Moderate taxis
54	0.55	0.60	1.25	7.5	5	85	357	540	Moderate taxis
70	0.75	0.78	1.95	7.5	5	85	325	350	Strong taxis
90	0.94	1.00	2.6	7.5	5	85	320	365	Strong taxis
130	1.22	1.44	1.25	7.5	5	170	285	260	Strong taxis
130	1.22	1.44	1.25	7.5	5	170	290	270	Strong taxis
140	1.5	1.56	1.95	7.5	5	170	337	500	Taxis/tetanus
140	1.5	1.56	1.95	7.5	5	170	319	410	Tetanus
140	1.5	1.56	1.95	7.5	5	170	355	525	Tetanus
180	1.88	2.00	2.6	7.5	5	170	309	350	Tetanus
180	1.88	2.00	2.6	7.5	5	170	360	530	Tetanus
240	2.66	2.67	2.6	7.5	5	340	255	200	Tetanus
240	2.66	2.67	2.6	7.5	10	340	338	460	Tetanus
240	2.66	2.67	2.6	7.5	10	340	287	270	Tetanus
260	3.08	2.89	2.9	7.5	10	340	311	345	Tetanus
260	3.08	2.89	2.9	7.5	10	340	324	450	Tetanus

* Voltage reducer was used to obtain peak voltages less than the minimum value produced by the pulsator unit.

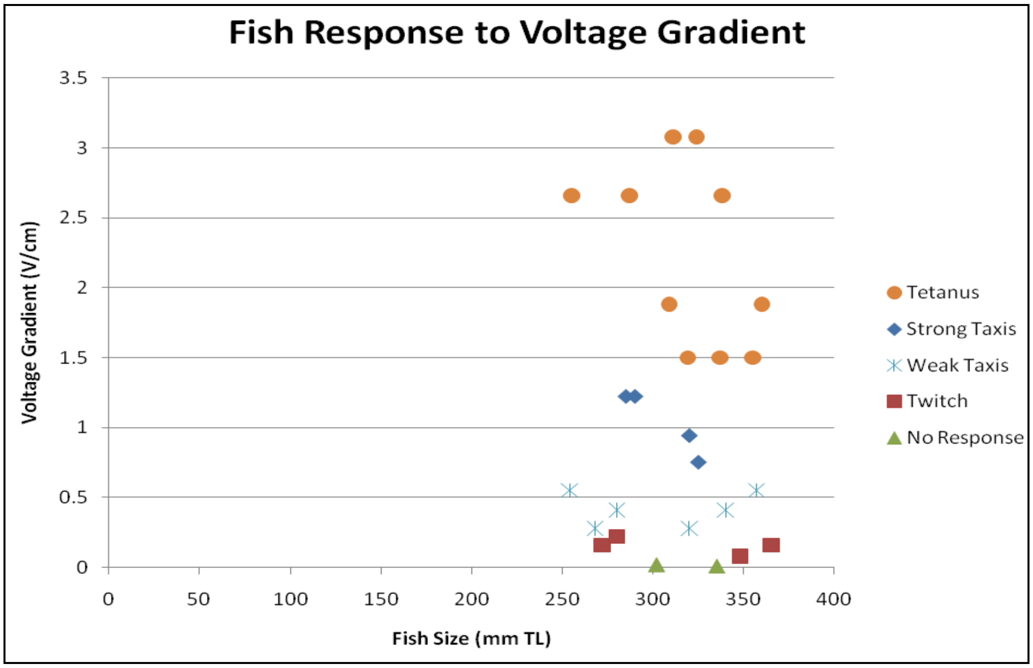

Figure 5.—Responses to pulse DC electrical stimulus.

Table 3.—Physiological response of striped bass to pulsed DC current at a pulse frequency of 7.5 Hz and pulse width in the range of 1.25–2.9 ms with water conductivity of 400 µS/cm

Striped Bass Response	Voltage Gradient (V/cm)
No response	< 0.05
Twitch	0.05–0.3
Weak taxis	0.3–0.75
Strong taxis	0.75–1.5
Tetanus	1.5–3.1

3. Determine if water velocity affects the response of striped bass to the electrical crowder at 0.46 and 0.76 m/s (1.5 and 2.5 ft/s).

4. Determine if striped bass enter a 15.2-cm-wide (6-in-wide) bypass to avoid the electrical field or if impingement occurs on the angled screen.

A 0.76-m-wide by 0.91-m-high by 4.88-m-long (30-in-wide by 36-in-high by 16-ft-long) acrylic flume was used to test the rolling DC electrical crowder concept. The flume contained a headbox with curved transition walls and a fish collection system in the tailbox. Black plastic was affixed to the bottom of the flume and draped over the sides to limit disturbance by outside activities. For some tests, black plastic was draped over the entire flume to mimic full dark conditions (Figure 6). A video camera system with four infrared illuminator-equipped remote cameras and a DVR digital recording device was installed underneath the cover to observe and document fish behavior during testing (Figure 7).

Figure 6.—For some tests, the flume was covered by black plastic to simulate dark conditions.

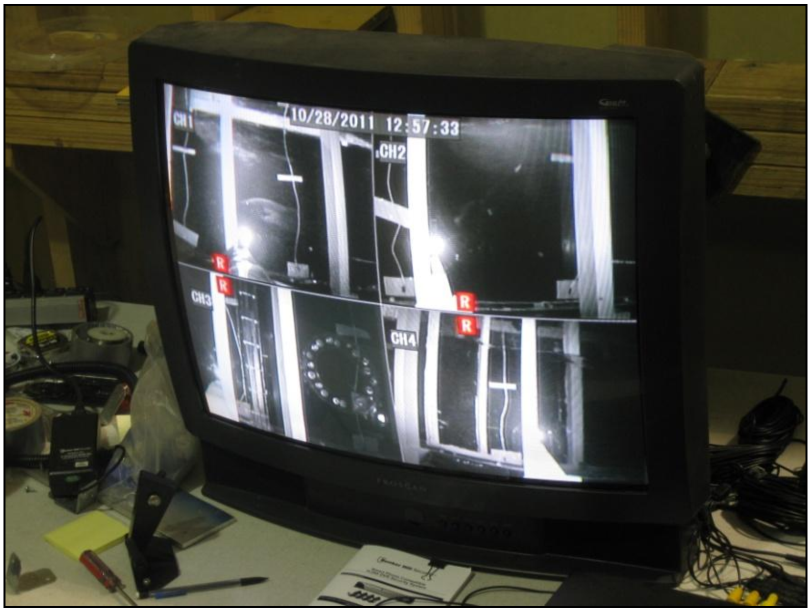

Figure 7.—Four remote infrared cameras were used to observe and document fish behavior.

Seven sets of electrodes (10 gage copper wire) were taped to the inside of the flume walls on opposite sides of the flume at 46 cm (18 in) spacing (Figure 8). A Smith-Root Model LR-24 Electrofisher unit (www.smith-root.com) transmitted pulsed DC to an electrical sequencer designed and built by an electrical engineer at Reclamation's Technical Service Center (Figure 9). The sequencer pulsed DC to successive electrode pairs. The operator adjusted whether the anode or cathode was the upstream electrode in the pair and how quickly the electrical field rolled down the flume. For example, the first set of electrodes was positive and the second set of electrodes was negative to create an electric field in the upstream section of the flume for a set period of time. Then, the electric field would move downstream when the second set of electrodes was positive and the third set of electrodes was negative, and so forth. The electrical field was set to roll through the seven sets of electrodes at a velocity slower than the measured water velocity so any stunned fish would drift out of the electric field.

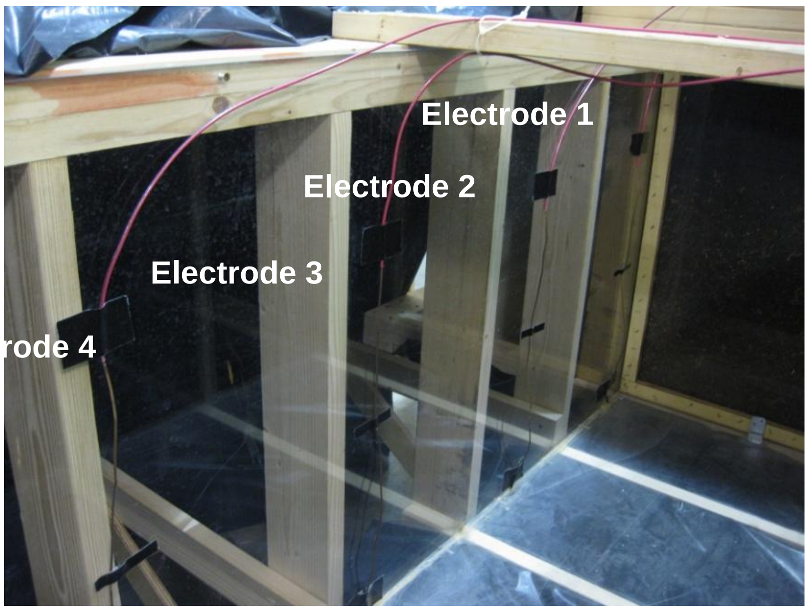

Figure 8.—Electrodes were installed at 46 cm (18 in) spacing over the full water depth.

Variables such as peak voltage, pulse width, and frequency were controlled independently by the electrofisher unit. Initial settings for the electrofisher unit were based on results of the stationary tank tests. Average water temperature and conductivity of the laboratory system was 19.0°C and 320 µS/cm. Since the laboratory conductivity was closer to the conductivity of the fish (typically 100–150 µS/cm), more power was transferred to fish at the same electrical settings as compared to the stationary tank test.

A Smith-Root voltage gradient meter was used to measure the strength and uniformity of the electrical field produced by an electrode pair at a peak voltage of 50 V. This voltage was the lowest setting available on the electrofisher unit.

Figure 9.—A sequencer was developed to move the pulsed DC field to successive electrodes at a specified speed.

The corresponding peak current was 0.4 A and peak power was 19 W. The pulse frequency was set to 7 Hz. Voltage gradients were mapped near the electrodes by rotating the voltage gradient meter at each location to determine the direction of maximum voltage (Figure 10).

Voltage gradients experienced by a fish depend on the location of the fish in the field and the orientation of the fish along voltage lines. Voltage gradients directly next to the electrodes were very high. Voltages upstream and downstream of the electric field dropped off quickly to 0 V/cm. The electric field extended across the 0.76 m (30 in) width of the flume with no dead spots as the electricity rolled between successive electrode pairs.

Test Procedure

The response of large bodied and small bodied fish to a rolling electrical crowder in moving water was documented (upstream/downstream avoidance, twitch, taxis, tetanus). Striped bass in the size range of 285–590 mm FL were tested in the model. This size range allowed researchers to observe a range of responses for large bodied predators. Juvenile Chinook salmon *(Oncorhynchus tshawytscha)*

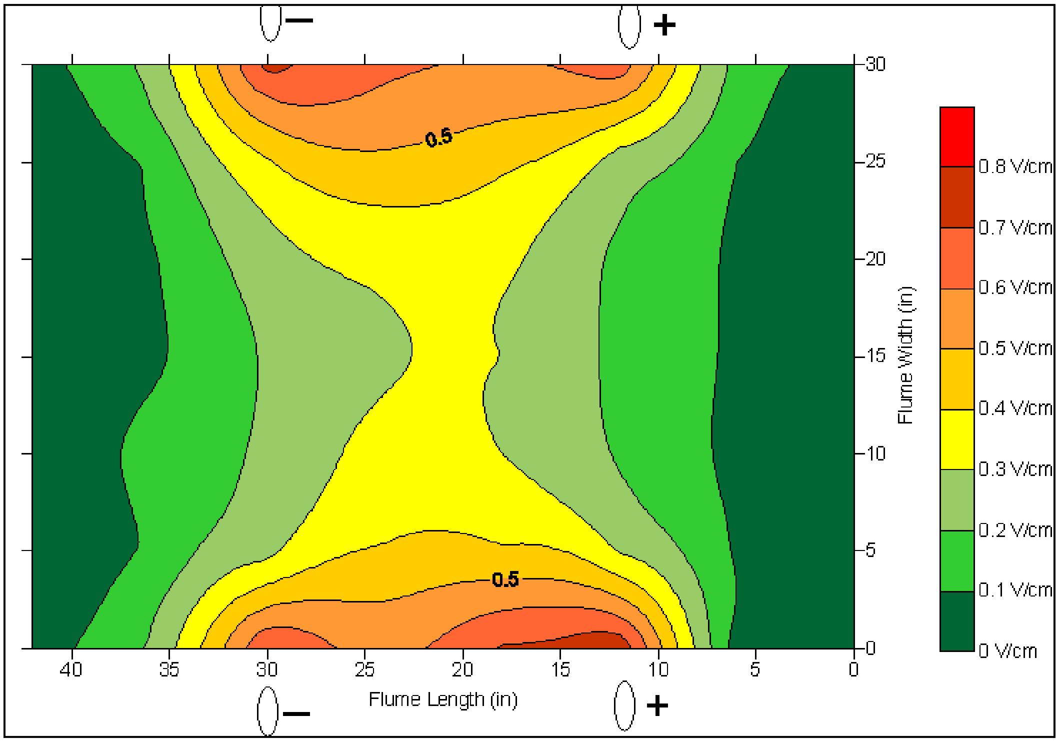

Figure 10.—DC voltage gradient map across two sets of electrodes at a peak voltage of 50V.

and juvenile rainbow trout (*Oncorhynchus mykiss*) from 88–108 mm FL were tested to observe the response of small-bodied fish. Striped bass were tested one at a time. Juvenile salmon and rainbow trout were tested in groups of five because individual juveniles were difficult to track in the model. Temperature and water conductivity were measured before each experiment with a Hydrolab DS5 multiprobe. Target water velocities of 0.46 and 0.76 m/s (1.5 and 2.5 ft/s) were measured with an acoustic Doppler SonTek FlowTracker. The target water depth of 51 cm (20 in) was measured with a staff gauge. Fish survival after 72 hours was recorded.

Control Tests

Control tests for striped bass were run before the treatment was applied. Six control fish were tested one at a time at 0.46 m/s (1.5 ft/s) and six control fish were tested at 0.76 m/s (2.5 ft/s) under the same transport, handling, testing, and collection procedures as fish experiencing the treatment. This allowed researchers to isolate the effects of the electrical crowder on fish response and survival from effects due to stress of capture and handling. All fish were acclimated in the model flume for 10 minutes before the treatment was applied, or in the case of the control tests, before fish were collected from the model. Control tests showed that there was no mortality from transport and handling alone for naïve fish.

Flume Tests

The objective of the initial round of tests was to qualitatively determine if a rolling electric field could drive striped bass in the downstream direction. A screen was placed at the downstream end of the model to keep fish in the test section. The location of the screen was far enough away from the downstream electrodes to provide fish refuge from the electric field. In all tests, fish were acclimated in the model for 10 minutes. Peak voltage of the DC square wave was 50 V, pulse frequency was 7 Hz, and electrical crowder field speed was 0.23 m/s (0.75 ft/s). DC pulse width and flume velocity were varied according to the following tests:

- 6 striped bass with DC pulse width 1.2 ms at velocity 0.46 m/s (1.5 ft/s)
- 6 striped bass with DC pulse width 10 ms at velocity 0.46 m/s (1.5 ft/s)
- 6 striped bass with DC pulse width 1.2 ms at velocity 0.76 m/s (2.5 ft/s)
- 6 striped bass with DC pulse width 10 ms at velocity 0.76 m/s (2.5 ft/s) (6 fish reused from previous tests)

Juvenile Chinook salmon and rainbow trout behaviors were also observed during initial testing of the electric crowder. The following tests were conducted:

- 6 sets of juvenile rainbow trout (5 count) with DC pulse width 1.4 ms at velocity 0.46 m/s (1.5 ft/s) (no juvenile salmon available)

- 6 sets of juvenile Chinook salmon (5 count) with DC pulse width 10 ms at velocity 0.46 m/s (1.5 ft/s)

Bypass Tests with Screen

The objective of the second round of tests was to determine whether striped bass volitionally move through a modeled bypass in order to avoid the rolling electrical field. A screen at a 15-degree angle with a 15.2-cm-wide (6-in-wide) bypass entrance was added to the model to mimic the louver and bypass geometry in the primary and secondary channels at the TFCF (Figure 11). Flume tests showed that 1.2 ms pulse width was sufficient at moving striped bass downstream and water velocity had no effect on striped bass behavior; therefore, bypass tests were only conducted at 1.2 ms pulse width and water velocity of 0.46 m/s (1.5 ft/s).

During the bypass tests, it became clear that light and dark conditions in the flume and bypass greatly affected fish behavior. When the bypass was light, some fish

Figure 11.—After testing fish in a rectangular flume, the model was modified to include a screen angled at 15 degrees and a 15.2-cm-wide (6-in-wide) bypass opening.

swam through the bypass before the electric field was even turned on. When the bypass was darkened, fish would stay in the test section. As a result of these observations, the following experiments were added to the study:

- Light Flume/Light Bypass: 10 striped bass with DC pulse width 1.2 ms at velocity 0.46 m/s (1.5 ft/s)

- Light Flume/Dark Bypass: 10 striped bass with DC pulse width 1.2 ms at velocity 0.46 m/s (1.5 ft/s)

- Dark Flume/Light Bypass: 10 striped bass with DC pulse width 1.2 ms at velocity 0.46 m/s (1.5 ft/s)

- Dark Flume/Dark Bypass: 10 striped bass with DC pulse width 1.2 ms at velocity 0.46 m/s (1.5 ft/s) (2 fish reused)

Results and Discussion

Laboratory observations showed that adult striped bass in the size range of 285 to 590 mm FL generally avoided the electric crowder, swimming quickly out of the field. Setting the upstream electrode as the anode and the downstream electrode as the cathode was the most effective orientation for downstream crowding. With this polarity, the fish were pushed downstream rather than pulled downstream by the field. When encountering the field, most fish swam downstream and away from the field; however, some swam upstream through the field. When the electric field was rolled multiple times through the full cycle, upstream swimmers would typically swim downstream following successive passes of the crowder. It was important to install the first electrode as far upstream as possible to eliminate electricity-free zones of refuge for fish. Fish that moved downstream initially either stayed downstream out of the influence of the crowder or started to swim upstream again until encountering the field, at which time they typically turned and headed back downstream.

The rolling electric crowder should be programmed for the lowest possible settings to produce the desired behavioral response. If electrical settings are too strong, the field could cause immobilization depending on the orientation of the fish with respect to electric field lines and distance from electrodes. Programming the crowder to move slower than the channel velocity allows any stunned fish to float out of the electric field.

Flume Tests

At this model scale and conductivity, the lowest electrofisher settings for voltage (50 V peak), frequency (7 Hz), and pulse width (1.2 ms) were sufficient to move most striped bass downstream during flume tests. At a pulse width of 10 ms, striped bass showed a stronger avoidance response than at 1.2 ms; however, overall results regarding directionality of movement were similar between the two settings.

Changing channel velocity from 0.46 to 0.76 m/s (1.5 to 2.5 ft/s) also did not affect behavioral response to the crowder. There was no mortality in naïve striped bass tested at 0.46 m/s (1.5 ft/s) with 1.2 and 10 ms pulse widths or in naïve striped bass tested at 0.76 m/s (2.5 ft/s) with 1.2 ms. Three of six striped bass did not survive tests at 0.76 m/s (2.5 ft/s) with 10 ms, likely because these fish were reused from previous tests due to fish availability. Based on observed mortalities of other fish in this study, it is likely that handling stress led to these mortalities. Since the exact cause of the mortalities can only be hypothesized, data from fish at 0.76 m/s (2.5 ft/s) and 10 ms were not used for any of the analyses. Conclusions regarding water velocity were based solely on observations made with 1.2 ms pulse width.

The biological response of juvenile rainbow trout and Chinook salmon in the size range of 88–108 mm was not greatly affected by the electrical crowder. At a pulse width of 1.2 ms, only twitch behavior occurred in juvenile rainbow trout. At 10 ms, juvenile salmon reacted with twitch or slight avoidance when experiencing the field. In either case, fish typically maintained their relative positions in the water column and exhibited no crowding behavior as was observed for the larger striped bass. No mortality in the 60 small-bodied test fish occurred within 72 hours.

Bypass Tests with Screen

By adding a screen and bypass system to the model, fish were given an opportunity to escape completely from the zone of influence of the crowder by volitionally entering a 15.2-cm-wide (6-in-wide) bypass. A more quantitative assessment of crowding success could be determined with this method. The bypass itself did not appear to deter fish movement through the bypass; however lighting conditions had a significant effect on behavioral response.

During daytime conditions with a lit bypass, 100 percent of striped bass swam through the bypass within 3 cycles of the crowder (Table 4). During nighttime conditions with a lit bypass, 100 percent of striped bass exited in the first cycle. When the bypass was dark, fish were reluctant to enter the bypass and would often encounter the electric field several times before exiting. During daytime conditions with a dark bypass, only 70 percent of fish exited through the bypass after 5 cycles of the crowder. Under nighttime conditions with a dark bypass, all 10 striped bass eventually swam through the bypass after 4 crowding cycles.

Table 4.—Bypass test results for striped bass during various lighting conditions.

Lighting Condition		Number of Times Fish Crowded Before Exiting Bypass							
Flume	Bypass	1x	2x	3x	4x	5x	Never Left	Total Fish Tested	Mortality
Light	Light	9	0	1	0	0	0	10	2*
Light	Dark	1	2	2	1	1	3	10	1**
Dark	Light	10	0	0	0	0	0	10	0
Dark	Dark	2	5	1	2	0	0	10	1**

* Mortality may have been caused by temperature difference between holding temperature (15.0°C) and experimental temperature (17.0°C) on this day.
** Reason for mortality unknown.

When the data are reduced to looking at the effects of a light and dark bypass versus whether fish crowded immediately or after multiple passes, there is a highly significant behavioral response to the bypass lighting condition (Fisher's exact test, $p < 0.001$). Nineteen of 20 fish crowded on the first pass when the bypass was light. When the bypass was dark, only 3 of 20 fish crowded on the first pass, although eventually an additional 14 fish were driven through the bypass after multiple attempts at crowding.

ROLLING ELECTRIC CROWDER: LARGE FLUME STUDY

Since the small study flume was considerably smaller than the actual channels at the TFCF, electric crowder properties will need to be scaled up for prototype installation. A model of the TFCF secondary channel was installed concurrently in the laboratory and became available for a short period of time. Since channel width and feature dimensions were similar to the TFCF secondary channel, the larger model was used to scale up electrical properties and to observe fish behavior in a setting similar to a field application.

Model Set-up

A 2.74-m-wide by 1.22-m-high by 19.51-m-long (9-ft-wide by 4-ft-high by 64-ft-long) flume was previously set up to test performance of a proposed traveling screen for the TFCF. When testing was complete, this flume was used to optimize electrical settings for a larger scale rolling electrical crowder by mapping electric fields and observing fish behavior. Striped bass were run through the model for a quick proof-of-concept assessment.

Due to time restraints, the model was not modified other than the addition of electrodes to the model sidewalls. The flume contained a headbox with curved transition walls and tailboards to control water depth (Figure 12). Four Hydrolox traveling screens were installed at a 15 degree angle across the width of the channel (Figure 13). A 15.2-cm-wide (6-inch-wide) bypass at the end of the screens passed water and fish into a circular fish collection tank. Each traveling screen was 2.0 m (6.5 ft) long with support structure between the screen sections.

Ten gage copper wire was initially installed in the model, but was replaced by sturdier 1.9 cm-diameter (¾-in-diameter) aluminum poles. Four electrodes were spaced 2.4 m (8 ft) apart along the sidewalls in the upstream section of the model (Figure 12) and four were spaced 2.0 m (6.5 ft) apart on the screen support structure in the narrower downstream section (Figure 13) to represent the likely

Figure 12.—Upstream view of flume showing the electrodes attached to the model sidewalls.

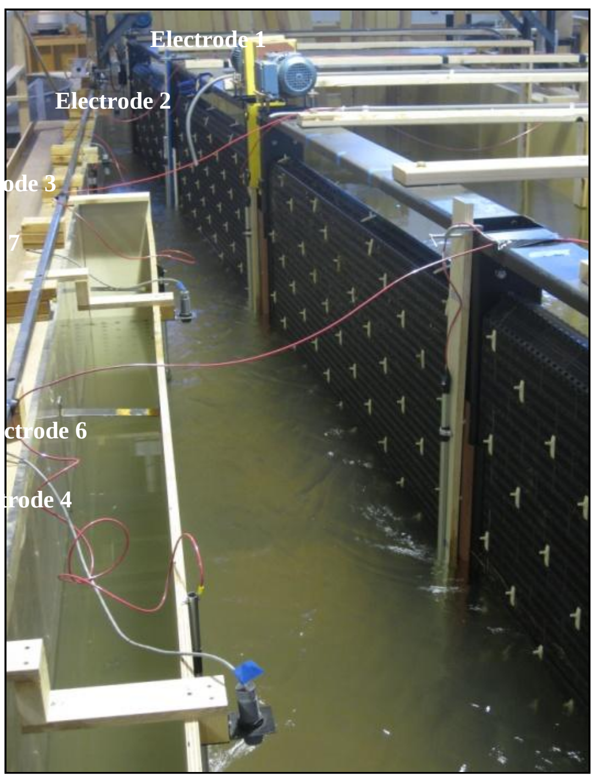

Figure 13.—Downstream view of flume showing the electrodes installed on the support structure between the screening sections.

geometry for an installation in the secondary channel. In the narrower section, electrode pairs were offset by 0.6 m (2 ft) to reduce the strength of the field between the electrodes. These eight sets of electrodes were connected to the same electrical sequencer and electrofisher unit described in the previous section.

Test Procedure

A Smith-Root voltage gradient meter was used to map the electric field between adjacent sets of electrodes at a peak voltage of 100 V, 200 V, and 300 V. Measurements were collected every 0.6 m (2 ft) in the streamwise direction and 0.3 m (1 ft) laterally with an additional measurement (0.15 m) 0.5 ft from the electrode. The meter was rotated at each location to determine the direction of maximum voltage. Temperature (average 17.9 °C) and water conductivity (average 320 µS/cm) were measured with a Hydrolab DS5 multiprobe. Water conductivity was similar to the small flume tests because the laboratory water source was the same.

Voltage maps were also produced next to the traveling screen where electrodes were spaced more closely together. Several electrode spacing configurations were mapped to identify the optimal way to space electrodes closer to the bypass.

1. Electric field between electrodes seven and eight was mapped. Electrodes were spaced 2.0 m (6.5 ft) with each pair offset by 0.6 m (2 ft).

2. Electric field between electrodes six and eight was mapped. Electrodes were spaced 4.0 m (13.0 ft) with each pair offset by 0.6 m (2 ft). Electrode seven was not energized.

3. Electric field between electrodes six and eight was mapped. Electrodes were spaced 4.0 m (13.0 ft) with each pair offset by 2.0 m (6.5 ft). Electrode seven was not energized.

The documented voltage gradient maps showed that peak electroshocker voltage levels would need to be between 200 and 300 V at this scale to produce a field similar in strength to that measured in the smaller flume, and to elicit an avoidance response from striped bass in the size range of 400 to 590 mm. Minimizing electrical exposure remained a goal during these tests. Due to fish availability, control tests were not conducted in the large flume. The same handling and transport procedures were employed and the collection procedure in the large flume was less stressful than the small flume. The larger flume was designed with a large circular holding tank to capture fish moving by the louvers.

Once experiments were completed, water levels were lowered and fish were easily netted out of the tank and transported back to the fisheries laboratory. The response of adult striped bass to the electric crowder was observed under three scenarios:

- 10 striped bass at 200V with DC pulse width 1.2 ms
- 10 striped bass at 200V with DC pulse width 10 ms
- 10 striped bass at 300V with DC pulse width 1.2 ms

As before, the striped bass were placed into the flume individually and acclimated for 10 minutes before running the crowder. Successfully crowded fish were collected in the circular holding tank after passing by the traveling screen and through the 15.2 cm (6 in) bypass. Due to model logistics and time constraints, experiments were only conducted with lighted conditions in the flume and bypass. A handheld video camera was used to document fish behavior during the tests.

During the experiments, some fish directly contacted the electrodes after going into taxis, in some cases causing tetanus. The electrical field increased quickly as the fish moved closer to the electrode, making it difficult to swim away. To try to minimize injury to fish, 5.1 cm-diameter (2-inch-diameter) PVC pipe covers were cut in half lengthwise and installed around the electrodes to prevent fish from directly contacting the electrodes. Two different pipe patterns, holes and slots, were fabricated and installed in the model (Figures 14 and 15). Voltage gradient fields were measured to determine if the insulating PVC covers affected voltage field strength or distribution.

Results

Voltage gradient maps at 100 V (1.0 A peak current), 200 V (2.5 A peak current), and 300 V (2.8 A peak current) are displayed in Figures 16, 17, and 18, respectively. Voltage gradients in the center of the electric fields were approximately 0.12 V/cm at 100 V, 0.29 V/cm at 200 V, and 0.40 V/cm at 300 V. Based on previous research, voltage gradients in the center of the electric fields at 200 and 300 V were sufficient to produce an avoidance response in adult striped bass. However, voltage gradients directly next to electrodes were high enough to produce taxis or tetanus in both cases.

Three electrode spacing configurations were mapped to identify the optimal spacing for electrodes in the narrow channel section next to the traveling screen. When electrodes were placed every 2.0 m (6.5 ft) and pairs were offset by 0.6 m (2 ft), voltage gradients at the center of the channel were high enough to cause taxis or tetanus in adult striped bass (Figure 19). When electrodes were placed

Figure 14.—PVC electrode cover with 2.5-cm-diameter (1-in-diameter) holes.

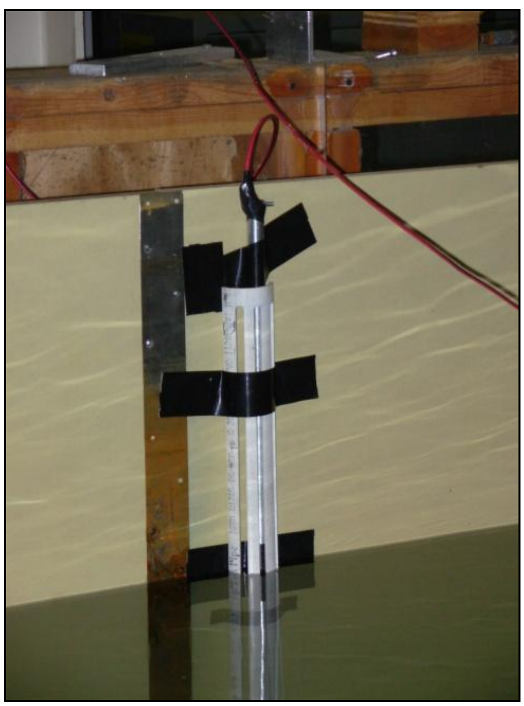

Figure 15.—PVC electrode cover with three 2.5-cm-wide (1-in-wide) slots.

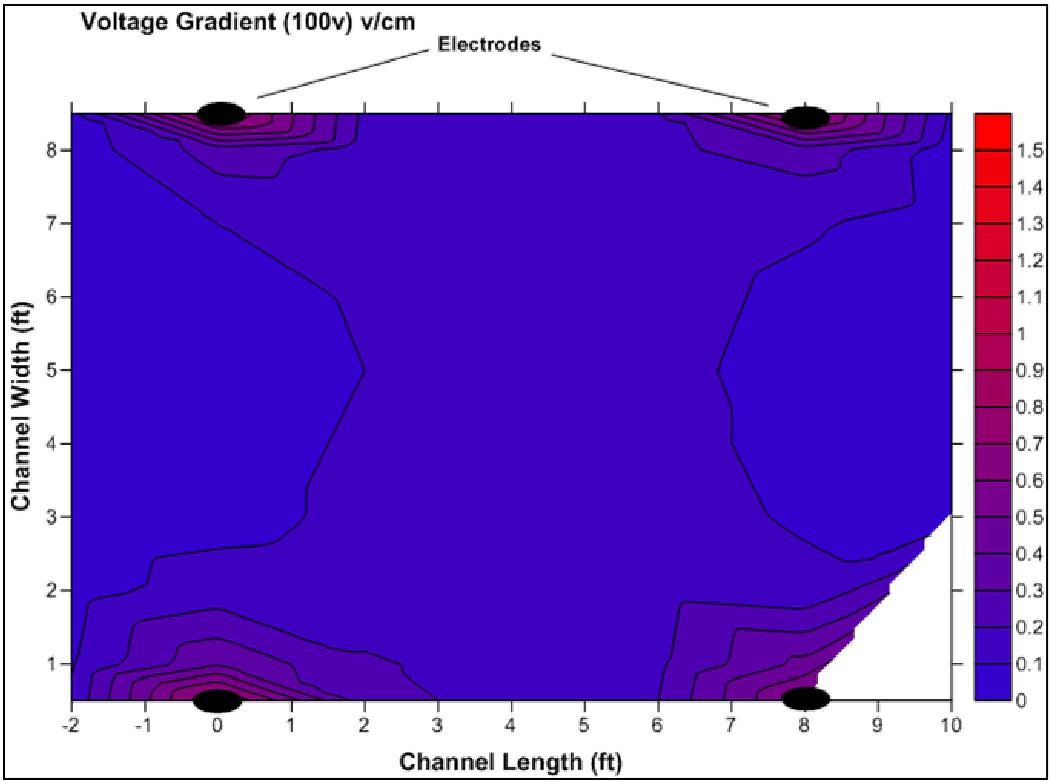

Figure 16.—Voltage gradient map between electrode pairs at a peak voltage of 100 V and peak current of 1.0 A. Voltage gradients in the center of the field were approximately 0.12 V/cm.

every 4.0 m (13.0 ft) and offset by 0.6 m (2 ft), some low voltage gradient zones existed (Figure 20). When electrodes were placed every 4.0 m (13.0 ft), but offset by 2.0 m (6.5 ft), some isolated points were high enough to cause taxis or tetanus, but most points were similar to voltage gradients elsewhere in the channel (Figure 21). If fish became stunned in this area, velocities were high enough to move stunned fish quickly through the bypass.

In this larger channel, a higher peak voltage was required to move striped bass toward the bypass. Fish that experienced the crowder at the upstream end of the flume often moved downstream, but stopped where the channel width narrowed and the velocity increased. When the crowder advanced to this point, fish either swam the rest of the way downstream through the bypass or swam upstream through the crowder. Some fish were drawn to an anode in taxis. Most fish were able to free themselves from the electrode, but occasionally a fish in taxis experienced tetanus when touching the electrode directly.

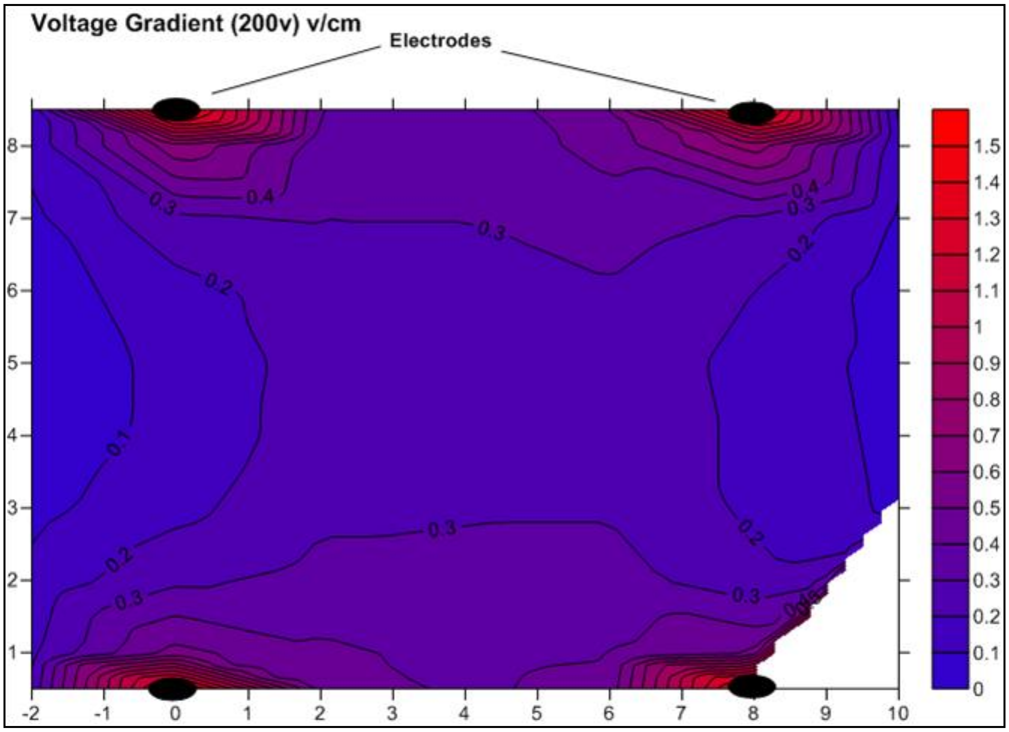

Figure 17.—Voltage gradient map between electrode pairs at a peak voltage of 200 V and peak current of 2.5 A. Voltage gradients in the center of the field were approximately 0.29 V/cm.

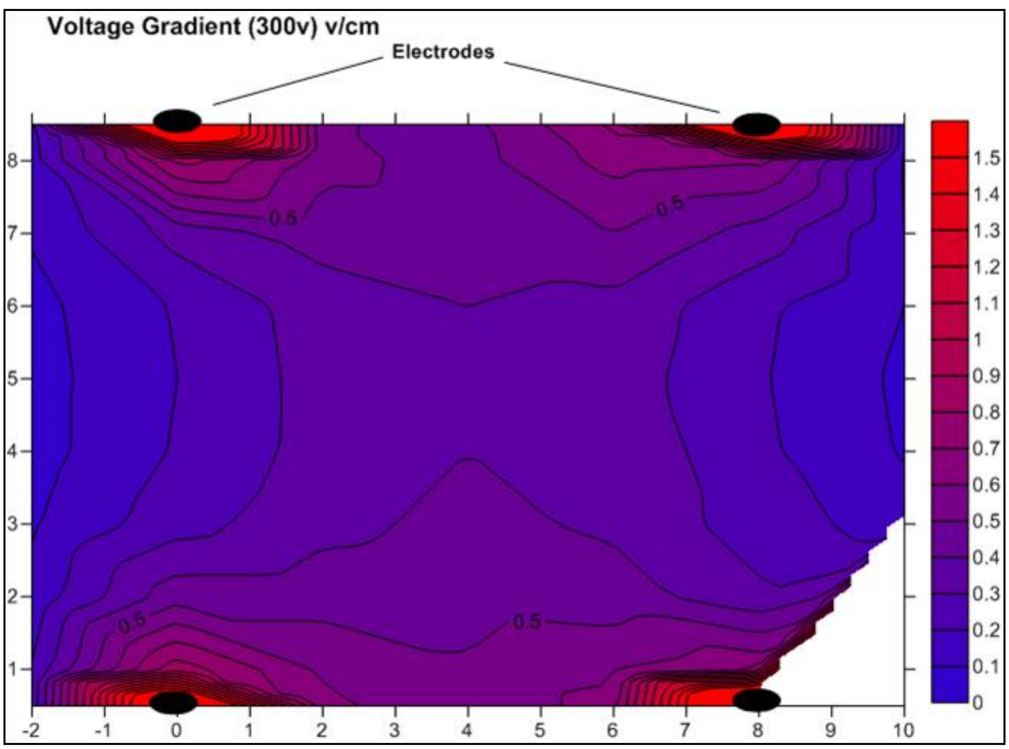

Figure 18.—Voltage gradient map between electrode pairs at a peak voltage of 300 V and peak current of 2.8 A. Voltage gradients in the center of the field were approximately 0.40 V/cm.

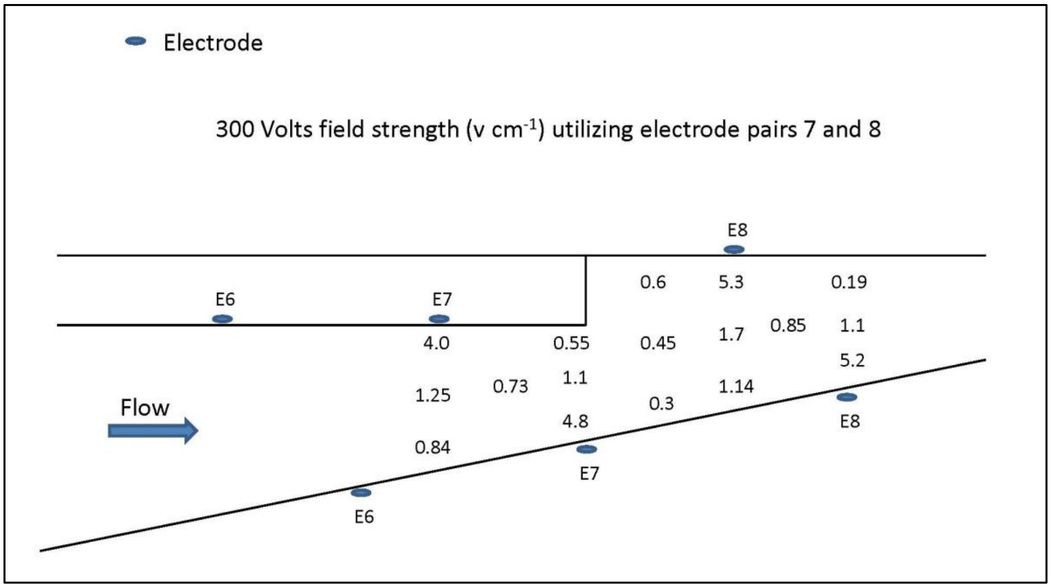

Figure 19.—Voltage gradient map between electrodes 7 and 8 at 300 V and 4.0 A peak. Electrodes were spaced at 2.0 m (6.5 ft) with each pair offset by 0.6 m (2 ft).

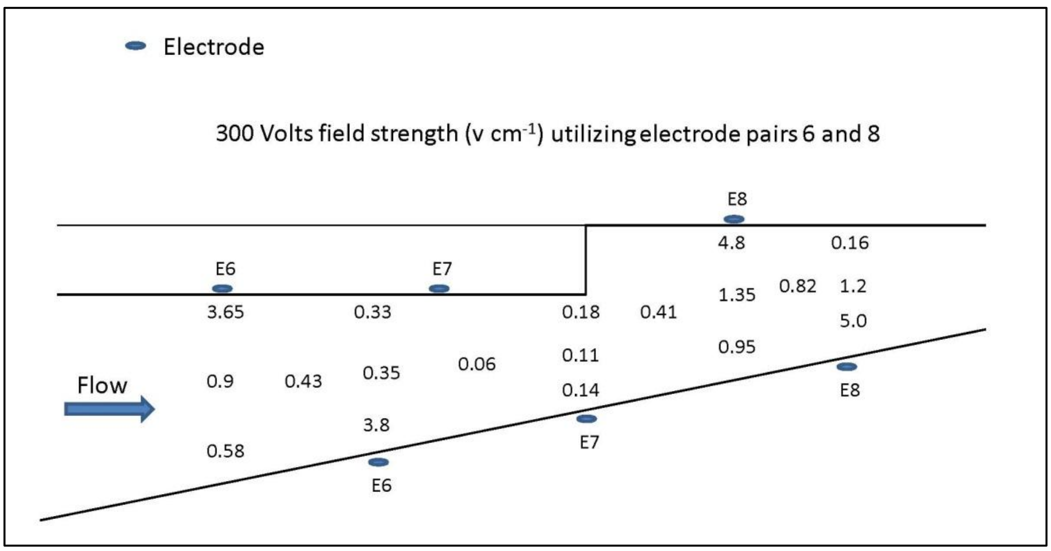

Figure 20.—Voltage gradient map between electrodes 6 and 8 at 300 V and 3.5 A peak. Electrodes were spaced at 4.0 m (13.0 ft) with each pair offset by 0.6 m (2 ft). Electrode 7 was not energized.

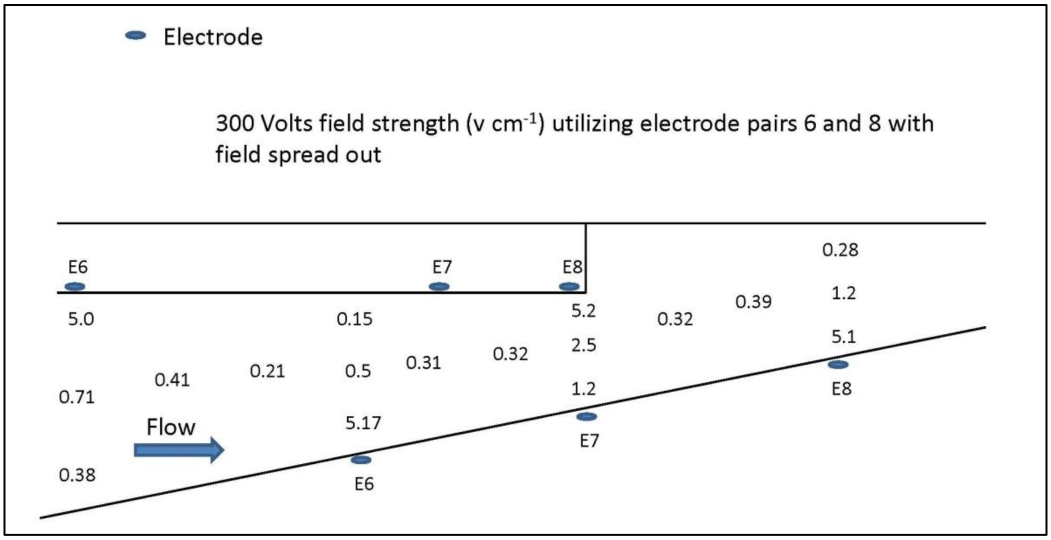

Figure 21.—Voltage gradient map between electrodes 6 and 8 at 300 V and 3.8 A peak. Electrodes were spaced at 4.0 m (13.0 ft) with each pair offset by 2.0 m (6.5 ft). Electrode 7 was not energized.

Fish tested at a peak voltage of 200 V and 1.2 ms pulse width did not show a very strong response to the crowder with only 60 percent successfully salvaged (Table 5). Although six fish exited the channel on the first two passes of the crowder, four fish did not leave the channel after multiple passes. When the pulse width was increased to 10 ms, fish response was much stronger, with some fish rising toward the water surface or even jumping when experiencing the field. Eighty percent of these fish were salvaged, but two experienced taxis strong enough to warrant turning off the crowder. With a peak voltage of 300 V and a 1.2 ms pulse width, similar results were obtained. Although the overall voltage gradient was higher in the flume, the fish did not exhibit the strong physiological response observed at 200 V and 10 ms.

Table 5.—Results of louver/bypass tests with striped bass in large flume

		Number of Times Fish Crowded Before Exiting Bypass							
Voltage (V)	**Pulse Width (ms)**	**1x**	**2x**	**3x**	**Taxis**	**Never Left**	**Total Fish Tested**	**Total Fish Salvaged**	**Lab Mortality**
200	1.2	5	1	0	0	4	10	6	1**
200	10	4	2	2	2	0	10	8	2*
300	1.2	5	2	1	2	0	10	8	1**

* Mortality in fish that directly contacted electrodes.
** Reason for mortality unknown.

When PVC covers were installed around the electrodes, the electric field distribution was the same, but the strength of the electric field slightly decreased. With a pattern of 2.5 cm (1 inch) holes drilled in the side of the PVC cover, voltage gradients were 12 percent lower than without covers. With 3 slots cut in the side of the PVC cover, voltage gradients were 10 percent lower. Although voltage gradient levels declined with PVC covers, the electric field should still be sufficient to crowd striped bass.

CONCLUSIONS

After reviewing alternatives for using electricity to reduce predator populations at the TFCF, the concept of a rolling electric crowder was recommended for further development. An electric crowder moves fish through avoidance rather than taxis, so injury to fish is minimized. In the laboratory, a rolling crowder was developed using an electrical sequencer, electrofisher unit, and a series of electrodes. The electrical sequencer pulsed DC to successive electrode pairs. The polarity of the field and the speed of the crowder were adjustable.

Stationary tank tests with water conductivity at 400 µS/cm and a constant frequency of 7.5 Hz showed that little voltage was required to elicit a response from striped bass in the size range of 254–368 mm. Striped bass exhibited twitch between 0.05 and 0.3 V/cm, moderate taxis between 0.3 and 0.75 V/cm, strong taxis between 0.75 and 1.5 V/cm, and tetanus above 1.5 V/cm.

Initial crowder tests in a 76-cm-wide (30-in-wide) flume showed that adult striped bass (285 to 590 mm FL) avoided the electric crowder, swimming quickly out of the field. When the electric field was rolled multiple times through the full cycle, most upstream swimmers would swim downstream on a successive pass of the crowder. Setting the upstream electrode as the anode and the downstream electrode as the cathode in each section produced better downstream crowding. The crowder should be moved more slowly than the water velocity so that stunned fish can drift out the electric field. Channel velocity did not affect behavioral response to the crowder. At the small model scale, the lowest electrofisher settings for voltage (50 V peak), frequency (7 Hz), and pulse width (1.2 ms) at 320 µS/cm were sufficient to move most adult striped bass downstream. Small-bodied fish in the size range of 88–108 mm were not greatly affected by the electric crowder at these settings. Only twitch or slight avoidance behavior was observed in juvenile rainbow trout and Chinook salmon.

Lighting conditions had a significant effect on behavioral response. When the bypass was dark, fish were reluctant to enter the bypass and would often encounter the electric field several times before exiting. A lighted bypass seemed to facilitate passage. When the flume and bypass were light, all adult striped bass exited within three cycles of the crowder. When the flume was dark and the bypass was light, all exited on the first pass. When the flume was light and the bypass was dark, 3 of 10 fish did not swim through the bypass after 5 cycles of the crowder. With a dark flume and dark bypass, all fish eventually swam through the dark bypass after four crowding cycles.

In a large laboratory flume with channel dimensions similar to the TFCF secondary channel, an electric field with 2.4 m (8 ft) spacing between electrodes was capable of producing striped bass avoidance. No electricity-free zones existed as long as electrodes were placed at the far upstream end of the flume. Voltage gradients were very high directly next to the electrodes. It is recommended that PVC covers with slots be installed around the electrodes to prevent fish from directly contacting the electrodes. Insulating PVC covers reduce voltage gradients by 10 percent, but the resulting electric field should still be strong enough to produce a strong avoidance response.

Pulsed DC with a peak voltage of 300 V, pulse width of 1.2 ms, and frequency of 7 Hz was the preferred operating condition in this flume at water conductivity of 320 µS/cm. Behavioral fish tests showed that 8 of 10 adult striped bass in the size range of 285 to 590 mm were successfully crowded through a 15.2-cm-wide (6-in-wide) bypass. Two test fish, however, experienced taxis and directly impacted the electrodes without PVC covers. At 200 V and 1.2 ms pulse width, 6 of 10 fish were successfully crowded and 4 fish did not leave the flume after several passes of the crowder. Although only 60 percent of adult striped bass were crowded, no fish experienced taxis. If harm to similarly sized fish is of large concern, these electrical settings should be considered.

RECOMMENDATIONS

From laboratory testing, it appears that a rolling electric crowder may be an effective way of reducing predator populations at the TFCF. The design is site specific and requires site-specific testing to identify optimal electrode spacing and field strength. A field test is recommended in the TFCF secondary channel after removal of the existing louvers and installation of the traveling screens. Pairs of 1.9-cm-diameter (¾-in-diameter) aluminum poles with PVC slotted covers should be attached every 2.4 m (8 ft) in the secondary channel. Along the traveling screen, electrodes should be installed every 4.0 m (13.0 ft) on the screen frame with electrode pairs offset by 2.0 m (6.5 ft). This spacing should minimize harm to fish encountering the electric field in the narrower section of the channel. If the electric crowder is operated during the daytime, it is recommended that lights be installed in the bypass to facilitate fish movement through the bypass during crowding. If it is not feasible to install lights, crowding should be accomplished during the evening, when there is less difference between the ambient light condition and bypass light condition.

In the secondary channel, the electric field can be measured for comparison to laboratory data. Tag-and-release experiments should be conducted with striped bass to determine predator collection efficiencies. Other fish collected during crowding will also be recorded. As seen during laboratory tests, it is anticipated that an electric crowder will not move all predators out of the channel. The concept behind the crowder is to reduce the predator load at the TFCF without harming fish. If the crowder were operated on an intermittent basis, predator populations would be reduced each time. It is expected that following this schedule would achieve a significant overall reduction in the number of predators present at any given time.

Before field tests can begin, the electric crowder concept and laboratory results will be presented to all interested federal and state agencies for comment and discussion. If approval for a field application is granted, permitting requirements will be discussed with regulatory agencies. A safety review will be conducted by Reclamation area office and regional office safety personnel to ensure that all government workers and the public are safe. A job hazard analysis will include necessary safety equipment and procedures for working near electricity. Cathodic protection and grounding issues will also be addressed before a field study can begin.

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