FRI-UW-9306
April 1993

FISHERIES RESEARCH INSTITUTE
SCHOOL OF FISHERIES
UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON 98195

SYNOPSIS AND ANNOTATED BIBLIOGRAPHY ON ELECTROFISHING WITH SPECIAL REFERENCE TO COLUMBIA RIVER SQUAWFISH CONTROL

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Approved

Submitted 2 April 1993 ____________________
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ACKNOWLEDGMENTS

This project was funded by Bonneville Power Administration, William Maslen, Project Manager (Contract #DE-BI79-90BP07084) as part of the Squawfish Control Program administered by Oregon Department of Fish and Wildlife, Franklin Young, administrator. Chuck Willis, C.P. Cramer and Associates, coordinated all activities within this program.

We would like to thank Dave Ward, Oregon Department of Fish and Wildlife, Clackamas, Oregon; Tom Poe, U.S. Fish and Wildlife Service, Cook, Washington; Darell Schneider, Colorado State University, Fort Collins, Colorado; and Jim Williams, Alaska Cooperative Fishery Research Unit, Fairbanks, Alaska, for reviewing and commenting on previous drafts of this report.

We would especially like to thank Marcus Duke and Abby Simpson for their patience and efforts in editing this report and presenting a legible product.

KEY WORDS

electrofishing, injury, mortality, sampling methodology

INTRODUCTION

This report has two objectives: (1) to provide an introduction to electrofishing theory and practical application and (2) to review the existing electrofishing literature, emphasizing how the knowledge and experience of previous studies could be applied to squawfish removal efforts on the Columbia River. Some general principles and guidelines are provided for the understanding, construction, and application of safe, efficient, boat-based electric fishing equipment.

This review heavily relies on information from the following authors: Reynolds (1983) on principles of electrofishing, Koltz (1989) electricity and its application in electrofishing, Lazauski and Malvestuto (1990) on electrofishing and safety, Lamarque (1990) on fish response to electric shock and factors affecting electrofishing efficiency, Novotny and Priegel (1974) on electric fields and electrofishing equipment, Smith (1989) and D. Snyder (Colorado State Univ., Ft. Collins, pers. comm.) on the principles and techniques of electrofishing, and Zalewski and Cowx (1990) on factors affecting electrofishing efficiency.

HISTORY

Electric fishing is a well-established research and management tool for fisheries biologists. The history of electric fishing is surprisingly lengthy. The first patent for an electric fishing machine was granted in London, England, in 1863. The most important developments in the theory and application of boat based electric fishing occurred in the early 1970s.

At the University of Wisconsin, Novotny and Priegel (1974) developed a boat-mounted, multi-anode, boom-array electric fishing system, which was the forebearer of today's commercially available electrofishing units. In the past most electric fishing equipment was "home made" by biologists with limited electrical engineering backgrounds. For today's fisheries biologist, there exists a wide inventory of field-tested, dependable, commercially available electric-fishing equipment. The developments in today's electric-fishing gear have been directed towards reducing harm to fish, saving time and money, reducing the possibility of serious injury to fishery workers, and increasing catch-per-unit-effort.

BASIC ELECTRICITY

All matter consists of charged particles that attract or repel each other because of the positive or negative charges they bear. Electricity is the form of energy that results from this attraction or repelling of particles. Electricity can be defined as the force that moves electrons (Smith 1989). A circuit is a closed path along which an electric charge moves. The rate of flow or intensity that moves the charge is the current, which is measured in amperes. The electromotive force that moves the current is voltage and is measured in volts. Voltage may also be defined as the potential force available to move electrons through the circuit. The restriction of electron flow in the circuit is resistance and it is measured in ohms. Electrical power is the rate at which electrical work is done and is measured in watts. One watt of power results when a current of one ampere flows through a resistance of one ohm under the force of one volt. The relationship between current, voltage, and resistance in a closed circuit is given by Ohm's Law:

Current (amperes) = voltage (volts) / resistance (ohms)

The current in a circuit is directly proportional to the applied voltage and inversely proportional to the circuit resistance. That is:

$$I = V/R$$

where I = current in amperes (amount of electron flow),
V = voltage in volts (amount of charge causing electron flow), and
R = resistance in ohms (restriction of electron flow).

The flow of current in a circuit is like the flow of water in a pipe. The pressure (voltage) drives the flow (current) through the pipe (circuit). The amount of flow the pipe can handle depends on its size and material (resistance). As the flow reaches the end of the pipe, it releases energy to do work at some rate (power).

Only two of the three Ohm's Law quantities are needed to calculate power:

$$W = VI,$$
$$= V^2/R, \text{ and}$$
$$= I^2R.$$

Wattage is simply the product of voltage and amperage.

When electrofishing, the Ohm's Law parameters are redefined in three-dimensional terms. In electrofishing, a closed circuit is created by passing electric current between two submerged electrodes through the water and fish. Current of sufficient densities will either frighten, lead, stun, or kill fish. As current flow leaves the electrodes, passing through the water, it spreads out in all directions forming a field pattern. Ohm's Law parameters for water now become voltage gradient, current density, and resistivity:

Resistivity (ohms/cm^3) = voltage gradient (volts/cm)/current density (amps/cm^2).

Current density can be visualized as a measure of intensity of electron flow (current) at a given point in the water. The voltage gradient is the voltage between two closely spaced points causing the electron flow between the two points. Resistivity is the measure of the quality of the water as an electrical conductor. Resistivity is often referred to as conductivity and is the inverse of resistance (Smith 1989).

ELECTROPHYSIOLOGY

The basic principle of electric fishing is the transfer of electrical current into the water via electrodes and through the fish at high enough current densities to produce a desired effect (taxis, repulsion, or death). It is possible to stimulate or catch fish with any kind of electrical current (of a sufficiently strong field), but in order to maximize catch-per-unit-effort (CPUE), to avoid causing injury to the fish, or to fish under adverse physical conditions, the proper choice of electrical parameters and current is important. There are three types of current: alternating current (AC), pulsed direct current (PDC), and constant direct current (DC).

It is well established that AC can efficiently tetanize (immobilize) fish. A serious side effect of AC is the potential to kill a high percentage of affected fish. Unlike DC, current direction is changing every half cycle. In an AC field, the fish faces the cathode and anode successively as many times as the current alternates (Lamarque 1990). Above a certain field strength, this continuous reversing of current polarity quickly overwhelms the fish's nervous system. Constant DC has the desirable characteristic of producing anodic galvanotaxis (forced swimming toward the anode) with less harm to the fish. However, constant DC has a more limited effective range and generally large and inefficient power requirements.

At the same peak power, AC, DC, and PDC will have similar or equivalent fields in terms of size and intensity. However the response threshold levels of fish are higher for DC, thereby reducing the 'effective zone.' Also for DC, peak power = average power, whereas for PDC and AC average power, which determines the size of the generator, is much less (D. Snyder, Colorado State Univ., Ft. Collins, pers. comm.). The effects of pulsed DC are intermediate between that of AC and DC. Pulsed DC is most commonly used in boat-based electric fishing.

In choosing the appropriate electric parameters, we need to understand the behavior of fish in electric fields (electrophysiology). Unfortunately, fish electrophysiology is generally not well documented nor understood. Galvanotaxis is believed by some to be a result of direct stimulation of the central and autonomic nervous systems that control the fishes voluntary and involuntary reactions.

Many authors have classified fish reactions in electric fields, attempting to fully explain their causative mechanisms (Halsband 1967, Lamarque 1967, Vibert 1967, Sternin et al. 1972, Edwards and Higgins 1973). A general agreement of the results has proven difficult to achieve. The one matter that most scientists agree on is that AC is more harmful than DC. Pulsed DC can produce the desirable effects of both AC and DC while limiting the negative side effects (Lamarque 1990).

Fish may exhibit four general responses to induced electric fields (i.e., PDC at 60Hz), avoidance, taxis, narcosis, and tetany. These responses depend on the total duration and level of current density experienced. When electrofishing, it is necessary to establish an electric field of sufficient current density to achieve the desired response from fish. The field established is defined by three zones of increasing density: the perception zone, effective zone, and danger zone. If the perception zone is too large, fish are frightened and avoid capture. The desirable effect of taxis (forced swimming) occurs within the effective zone. If fish are not removed in a timely manner, narcosis (an induced relaxation of the body) occurs. Fish exposed to the danger zone will experience seizure or tetany. Tetany is the rigid immobilization of all musculature. Fish become tetanized by the increased levels of current densities. Tetany most often causes death by asphyxiation. Ideally an electrofishing unit produces the smallest perception zones, largest effective zone and no danger zone.

A fish's first reaction to AC is to take up a transverse position to the electric field lines: oscillotaxis (Koltz and Reynolds 1989). The fish then repeatedly attempts to face the anode and cathode until the threshold current is reached, causing the fish to be tetanized on the spot. Some authors also describe movements toward, as well as away from the electrodes (Lamarque 1990). Little agreement on results was apparent in our literature review of electrophysiology.

In DC electrofishing, electric current flows continuously from the negative cathode to the positive anode. The actual mechanism for electron flow is electrolysis, that is the movement through water of ions that collect electrons at the cathode and release them at the anode (electron flow). The reaction of fish to DC is quite different than to AC. The first reaction observed in a DC field is a quivering of fish body muscles or fins; this occurs as the fish enters the perception zone. What happens after a fish enters the perception zone depends on a number of factors: the fish's orientation to the electric field (facing anode or cathode), species electrophysiological characteristics (resistance, fatigue), and current density. Assuming the fish does not flee (the perception zone), it then moves into the effective zone. As the fish moves through the effective zone it experiences increasing current densities, causing inhibited swimming followed by galvanotaxis. If the fish is not removed from the increasing field densities, it will continue its forced swimming toward the anode until relaxation of all its muscles is induced (galvanonarcosis). With prolonged exposure to DC, a second forced swimming occurs, which sends the fish into the area of highest current densities, the danger zone. Here tetany occurs, often followed by death (Lamarque 1990). If a fish is removed from the danger zone in time and allowed to recover under optimal conditions, death from tetany may be averted (D. Snyder, Colorado State Univ., Ft. Collins, pers. comm.).

Strong anodictaxis is possible with pulsed direct current. Lamarque (1990) suggests that the mechanisms of taxis are quite different for DC and PDC. PDC is produced by interrupting a steady DC current flow with an electronically controlled switch. The switch gives the number of ON-OFF pulses per second (frequency). Research has shown a species-specific reaction to frequency and pulse width. In general, pulse shapes with a fast rise and slow decay enhance anodictaxis. With PDC, no narcosis or second swimming towards the anode occurs. In the effective zone, fish are drawn more directly from a greater distance than DC toward the anode, generally becoming immobilized before reaching the danger zone.

The establishment of the perception, effective, and danger zones in AC, DC, and PDC depends on field strength, water conductivity, and electrode size. In review, DC produces galvanotaxis, inducing tetanus only near the electrode and after prolonged exposure, and is the least harmful to fish. However it has the most limited effective range and highest power requirements. PDC produces strong galvanotaxis, and has a large effective zone and greatly reduced power requirements. PDC does tend to immobilize a large portion of the catch farther away from the anode than DC. AC has the greatest effective range but little or no taxis, with the potential for tetanizing fish, resulting in the death and loss of capture.

INJURIES TO FISH

At its worst, electric fishing can kill or produce strong muscle fatigue. Normally a head to tail voltage gradient from 0.1 to 1 volts/cm of fish is required to safely collect fish with an electric current (Halsband 1967). The degree of injury depends on voltage gradient experienced across the fish's body (Stewart 1962), exposure time (Chmielewiski et al. 1973, Whaley et al. 1978), current form (Lamarque 1967), and species and size of fish (Stewart 1962, Chmielewiski et al. 1973).

The most common damage caused by electric fishing involves vertebral malformations, recovery from which is long term if not impossible. The rate of mortality following electric fishing capture has a wide range depending on the particular study. For trout mortality, rates ranged from <5% to 90% (Hauck 1949, Pratt 1954, McCrimmon and Bidgood 1965, Hudy 1985, Holmes et al. 1990, Fredenberg 1992, Newman 1992, Reynolds et al. 1992), and warm-water species ranged from 0% to 28% (Spencer 1967, Holmes et al. 1990, Newman 1992). Hauck (1949) also reported internal damage and bleeding from gill filaments in electrofished trout. Mortalities from electrofishing may be broken into two broad groups, those caused by injuries and those due to asphyxiation.

Electric fishing induces the typical changes in blood lactate levels normally observed when fish are stressed. Schreck et al. (1976) observed changes in lactate levels in the blood of rainbow trout (*Oncorhynchus mykiss*) after shocking (DC current). The lactic acid levels in the blood doubled immediately after the fish were shocked, remained high for 1 hr, and recovered to pre-shock levels after approximately 3 hr (Schreck et al. 1976).

In general AC, DC and PDC can produce mortality. The worst currents are condenser or burst form charges: AC at 50-60 Hz and 1/2 wave rectified AC at 50-60 Hz (Lamarque 1990). Currents that tend to draw fish towards the anode are least harmful. Mortality results from physical injury or asphyxiation brought on by physiological stress. The most common injuries are broken or ruptured vertebrae resulting from electrically induced, violent muscle contractions. The frequency and severity of vertebral injury is increased in spawning fish owing to decalcification (Stewart 1962). Other observed injuries include damage to internal organs and burst blood vessels in the gills and brain.

With salmonids, one can determine if vertebrae are damaged by examining the skin. Dark spots or bands will appear in proximity to the damaged vertebrae. While such marks typically represent vertebrae injury, they are not always present when spinal injury has occurred (D. Snyder, Colorado State Univ., Ft. Collins, pers. comm.). This discoloration is thought to be caused by the excitation of skin chromatophores when the sympathetic nerve fibers are damaged (Lamarque 1990). Also such discoloration could be caused by hemorrhages of damaged tissue near the skin surface; if a fish actually touches an electrode it will be burned (D. Snyder, Colorado State Univ., Ft. Collins, pers. comm.). The degree of vertebrae dislocation largely depends on the current type, water conductivity, operator ability, and exposure time. AC tends to cause breaks while DC results in compressions or misalignment of the vertebrae (Stewart 1962). Presently, numerous authors (Holmes et al. 1990, Fredenberg 1992, Reynolds et al. 1992) are closely examining the electrofishing-induced harm caused by PDC.

Physiological stress occurs when the fish has been overexposed to a tetanizing current. Death usually results from respiratory failure brought on by radical increases in fish blood lactate levels, critically reducing the oxygen carrying capacity (Black 1958, Schreck et al. 1976, Emery 1984). Once the lactic acid reaches a certain level, a fish will not fully recover. Such a fish may appear fine at release; however, it will eventually die, usually within 1–3 days. The complex physiological processes experienced by fish have been investigated by (Black 1958, Black et al. 1960, Sternin et al. 1972, Schreck et al. 1976, Wood et al. ·83, Holeton and Heister 1983, Emery 1984). Emery (1984) succinctly explains these physiological processes.

In a successful electric fishing operation, an electrotaxic current is desirable, i.e., a current that attracts a fish to the anode but does not tetanize it. Some commonly used electrotaxic currents are as follows: constant DC, 3-phase fully rectified AC at 30 Hz, and PDC square wave currents at 30-60 Hz and 10-50% duty cycles, rectangular pulsed DC at 400 Hz on 10% duty cycle and Complex Pulse System (CPS™). The key to a successful electric fishing removal operation (e.g., squawfish control on the Columbia River) is flexibility in current form (AC, PDC, DC) and shape (square, sine, smooth, CPS™), and minimal harm caused to fish. An electric fishing unit must have the ability to adapt to the variable physical conditions (conductivity, water temperature, and water velocity) of a selected sampling site. Fortunately, modern commercially available electric fishing units offer such a range of electrical current parameters.

SYSTEM COMPONENTS

Basically the function of an electric fishing system is to produce an appropriate electrical stimulus in fish near the electrodes to permit easy capture by netting or to cause fish to stay in areas where nets, trawls, or traps can be readily used (Novotny 1990). Any electric fishing system requires some minimum effective value of current density produced from the electrodes. The minimum value will vary with water conductivity, temperature, and target fish. This current level establishes the perception, effective, and danger zones in the electric field surrounding the anode.

The components of an electric fishing system can be classified into six subsystems according to function. These are (1) power supply to provide the electrical energy to the system, (2) power conditioner to condition (or modify) the raw electric energy to meet the requirements of the specific application, (3) instrumentation to provide knowledge of the electrical performance of the system, (4) interconnection systems to safely carry the conditioned power to the electrodes, (5) electrodes to properly couple the conditioned electrical power to the water, and (6) auxiliary equipment to provide the peripheral functions necessary for successful electric fishing (nets, lights, pumps, aerators, rubber gear, etc.) (Novotny 1990).

When electrofishing, it is advantageous to produce a galvanotaxic current (PDC or DC). DC generators, however, are prohibitively large for boat-based operations. A three-phase AC generator is generally preferred for most boat-based electric fishing applications because it is smaller and lighter (for the same power rating) and better suited as a supply source for most power conditioners (Novotny 1990). AC generators are more flexible in their output parameters than DC generators and, therefore, more adaptable to a wider range of fishing conditions and water conductivities.

Raw, AC-generated electric power is modified via power conditioners. The function of the power conditioner is to provide the appropriate voltage level and wave form (DC, AC, PDC, CPS™, etc.) to suit the specific electric fishing application. A major advantage of modern power conditioners (i.e., Coffelt VVP-15, Mark 22, or Smith-Root GPP 7.5) is the flexibility they afford in terms of wave form, voltage level, pulse rate, and duty cycle. This flexibility enables a single electric fishing system to be used in a wide range of applications. Modern electric fishing systems may employ a combination of transformers, rectifiers, filters, and choppers in their power conditioners.

The individual components of the electric fishing system must be electrically interconnected in order to form the complete system. The interconnection system provides the following functions: (1) the main disconnection switch between the power supply and the rest of the system, (2) circuit protection devices, preferably circuit breakers, (3) suitable meters and instrumentation, (4) appropriate safety (dead man) switches and, most importantly, (5) proper electrical bonding of the cases of all the components to each other and to any metallic parts of the supporting structures. The bonding ensures that no two external metallic parts of the entire system (including the boat or other support structures) can ever have a potential voltage between them (Novotny 1990). The interconnection system should be carefully checked by qualified personnel in order to avoid a potentially dangerous situation.

The requirements of an effective electrode system include (1) establishment of a large effective zone while minimizing the perception and danger zones, (2) flexibility to meet variable water conductivities, (3) ability to negotiate weeds, obstructions and current while producing as little physical disturbance as possible, (4) ease of safe assembly (Novotny 1990). Commonly used electrode configurations that incorporate these principles are Coffelt's Wisconsin Ring, Smith-Roots UAA-6, and various sphere anode arrays.

The two basic electrode shapes are spherical and cylindrical. Spherical electrodes have generally superior electrical properties but have many mechanical disadvantages. The most effective electrode arrays combine the positive aspects of both electrode shapes. Cylindrical electrodes, arranged into a circular shape, achieves this. The best example of such a design is the commercially available Wisconsin Ring array. This design utilizes the desirable properties of spherical shapes (limited perception zone, no danger zone, large effective zone), while maintaining the advantageous mechanical properties of the cylindrical electrodes (ease of negotiating obstacles, little physical disturbance, and larger overall effective range).

Two guiding principles with electrodes are (1) always use the largest electrodes possible within the limitations imposed by the physical constraints and electrical limits imposed by the generator and electrical control system (Novotny and Priegel 1974); and (2) if possible, mechanically shield the anodes so fish can not come in direct contact with them (Holmes et al. 1990).

FACTORS AFFECTING EFFICIENCY

The parameters that regulate electric fishing efficiency are numerous: choice of current (AC, DC, PDC), electrical output, electrode shape and size, turbidity, water conductivity, temperature, depth, habitat, operator ability, fish species, behavior, and size. The most important parameter under the control of the electric unit operator is choice of current. To succeed at electrofishing, one must understand the actual electrical output characteristics (voltage, current, pulse rate, etc.) expected in the field. Operators also must understand the widely varying sampling conditions and be able to control current, voltage, and pulse shape to properly manipulate the electric fishing equipment, thereby maximizing catch-per-unit-effort.

The knowledge of electrical parameters and the components of an electric fishing system must be integrated with the understanding of all the biotic and abiotic external factors affecting catch rate. The most important factors are detailed below (adopted from Lamarque 1990).

Water conductivities in fresh water are divided into three groups. Low conductivity waters, 5-30 microsiemens per cm (µS/cm), are represented by mountain streams and lakes or areas associated with high rain runoff. Medium conductivity waters range from 30-500 µS/cm; the Columbia River is of medium conductivity ranging from 80-250 µS/cm. High conductivity waters have values greater than 500 µS/cm; these are mainly estuaries, brackish lagoons, and the sea.

Different fishing strategies must be adopted for each conductivity range. Fishing low conductivity waters is difficult, but good results may be achieved by using very large electrodes (anode diameter >60 cm) and high peak voltages (800-1,650 volts). Best results in medium conductivity waters are achieved with a combination of large anodes and galvanotaxic current. In high conductivity water, PDC (rectangular waves of either 400 Hz or 100 Hz at 10% duty cycle) and smaller electrodes are needed to reduce energy requirements (Lamarque 1990).

Fish behavior in electric fields (electrophysiology) has a measurable effect on CPUE. The physical characteristics of the sampling habitat also play an important role in determining fishing success.

Predator fish (e.g., Salmonidae, Percidae, Centrarchidae) are more easily caught than prey species. Spawning or territorial fish are less likely to be frightened out of an area, thus allowing the boat to come in close. Bottomfish and poor swimmers are relatively difficult to catch. Thick-scaled fish like carp seem to be more electrically resistant than thin-scaled fish such as trout. Many fish build up a tolerance to subsequent electric fishings. Schooling species are easily frightened out of a fisher's effective zone by physical disturbances in the water. Smaller fish have less body size for a voltage difference to develop across, making them harder to catch than larger fish. Vegetation and cover can hide stunned fish from capture.

Fishing over a gravel substrate produces the best results. Electrode contact with muddy bottoms can short-circuit the field, causing a decrease in resistance, which can lead to overloading of the generator. In strong current, tetanized fish often are not visible and, therefore, are washed away from the netters. Turbid water allows a close approach towards fish but reduces catching efficiency through poor visual contact. In general, electrofishing efficiency decreases in moderately fast waters deeper than 10 ft.

The following table summarizes the factors affecting the efficiency of electric fishing.

ENVIRONMENTAL	BIOLOGICAL	TECHNICAL
1. Abiotic a. Conductivity b. Water quality c. Water clarity	1. Community structure a. Species diversity b. Species composition	1. Personnel a. Size of crew b. Experience c. Motivation
2. Habitat a. Habitat structure b. Habitat dimensions c. Substrate d. Water velocity	2. Population structure a. Density b. Size distribution c. Age structure	2. Equipment a. Design b. Maintenance
3. Seasonality a. Temperature b. Weather	3. Species specific a. Behavior b. Physiology c. Morphology	3. Organization a. Site selection b. Standard effort

(Adapted from Zalewski and Cowx 1990.)

SAFETY

Safety should be a primary consideration in all electric fishing operations. All personnel involved in electrofishing operations should be instructed as to the fundamentals of electricity, and understand and observe the safety requirements associated with electrofishing. The single most important factor in both electrofishing efficiency and safety is the training and experience of the crew. Regardless of the safety precautions given, the capability of the crew in adhering to those guidelines and good common sense in handling unforeseen circumstances, is of cardinal importance (Smith 1989). It is recommended that crew leaders attend the U.S. Fish and Wildlife Services' Fisheries Academy Course, "Principals and Techniques of Electrofishing." For further information on this course, contact Alan J. Temple, Chief Fisheries Management Training, Fish and Wildlife Service Office of Technical Fisheries Training, Route 3, Box 49, Kearneysville, WV 25430; telephone number (304) 725-8461, ext. 370.

A standard set of safety practices are listed below along with two daily field check lists concerning boat and electric fishing equipment. Safety practices should include the following (adapted from Lazauski H.G. and Malvestuto, 1990)

1. All United States Coast Guard safety equipment for the operation of a 28 ft. boat should be used.
2. Red Cross first aid and CPR training should be provided for all members of the electric fishing boat crew.
3. All members of the crew should be familiar with the electrical system of the boat.

4. All dip netters should wear rubber gloves, rubber boots, life vests and noise arresters if needed.
5. Boat operators should wear life vests, rubber boots and noise arresters if needed.
6. Electric fishing runs should be kept under 1 hr to avoid netter fatigue.
7. A strict check, via checklists, should be made of all electrical systems before each day's work in the field.
8. All fishing should cease at the first sign of lightning, rain, high winds, or dip netter fatigue.
9. Alcohol should never be allowed on an electric fishing boat.
10. Never touch the water or an electrode while the current is on.
11. Refuel the generator after engine has sufficiently cooled.
12. The boat driver should not make sudden turns or changes in boat speed.
13. No unauthorized passengers should ever be allowed on an electric fishing operation.
14. Know the range of your electric field. Avoid public recreation areas. Do not electrofish near people or animals.
15. Avoid all unprofessional conduct (horse play).
16. Carry appropriate spare equipment for the particular boat.
17. Carry a first aid kit.

Check lists should be developed for all phases of electric fishing operations. These should include items that are used daily, such as boat launching and electrical connections. An example of an electric fishing boat unit inspection sheet is given in Table 1.

A detailed instruction guide or manual should accompany each electric fishing apparatus to assist the operator. The operator should be familiar with both the unit and manual before fishing begins. A log book should also be available to record dates and times of use, maintenance, problems, and repairs.

An important emergency procedure is to have a pre-determined plan in the event of an accident. A documented route to medical facilities and procedures to follow is essential.

These safety procedures should be adhered to by all project personnel at all times. The safety check list and log book should be filled out every day. Also, all operational parameters (control box settings and meter readings) should be recorded with field data and any observations of abnormal appearance, behavior, or mortality. This data will help refine parameters for future trips, avoid undesirable effects, and add to the data base on such effects (D. Snyder, Colorado State Univ., Ft. Collins, pers. comm.). All members of the fishing crew should be familiar with the checklist material and compliance procedures.

Table 1. Daily check sheet for electric fishing boat safety inspection (adapted from Goodchild 1990).

Boat #____________________ Date____________
Crew leader____________________ Time____________
Crew members____________________
Location____________________
Log Book up to date Y/N
Manual present Y/N

BOAT

__ Hull integrity
__ Safety railings intact and sturdy
__ Decks clean, free of excess water/bilges dry
__ Adequate mechanical protection of wiring
__ Adequate connectors and interlocking (integral with hull)
__ All metal equipment in boat electrically bonded to hull (check with volt/ohm meter)
__ Batteries fully charged-properly enclosed and vented
__ Communication gear working (where applicable)
__ Boat clean—equipment neatly stored
__ Auxiliary motor present and working (where applicable)
__ Oars/paddles present
__ Anchors/bailers present
__ Controls and gauges operational
__ hv output checks done
__ Adequate mechanical protection of wiring
__ Audible tone generator working
__ hv flashing light working
__ All foot switches working
__ 'KILL SWITCH' working
__ Operators safety switch working

GENERATOR/ALTERNATOR

__ Unit electrically bonded/connected to hull
__ Exhaust directed away from operator
__ All electrical connections secure and protected
__ Oil level O.K.
__ Gas topped off

BOAT MOTOR

Inboard
__ Oil level O.K.
__ Components secure
__ Belts O.K.
__ Visual inspection O.K.
__ Proper venting of exhaust
__ No gas leaks
__ Auxiliary motor working
__ Bilge blower working

Outboard
__ Fastened securely—safety chain
__ Adequate gas supply

ANCILLARY EQUIPMENT

__ Fire extinguisher present—fully charged
__ First aid kit and flash light present
__ Communication gear working
__ Lights working

PERSONNEL/CREW MEMBERS

__ Each crew member briefed on boat operations
__ Minimum number of crew trained in CPR and basic electronics
__ Crew wearing PFD's
__ Crew wearing rubber gloves (long arm)
__ Crew wearing rubber boots
__ Crew wearing protective hearing gear
__ Each crew member has a dead man switch
__ Safety procedures covered
__ Local arrangements covered, i.e., police, etc.
__ Hospital route outlined

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ELECTROFISHING GLOSSARY*

GENERAL

Alternating current: cyclic current, the mean value of which is nil during a total period. An alternating current is characterized by a sequence of positive and negative waves that are equal, usually sinusoidal, and follow each other alternatively at regular time intervals.

Anode: the positive electrode, usually hung from a boom extending away from the electrofishing vessel.

Aperiodic impulses: impulses following each other at varying time intervals.

Bonding: the permanent joining of metallic parts to form an electrically conductive path that ensures electrical continuity, with the capacity to safely conduct current.

Branch circuit: the circuit conductors between the final overcurrent device protecting the circuit and the electrical load(s).

Cathode: the negative electrode, usually located on the hull of the electrofishing vessel.

Circuit breakers: a device designed to open and close a circuit by a non-automatic means, and to open the circuit automatically on the predetermined overcurrent without damage to itself when properly applied within its rating.

Complex pulse system (CPS™): a complex pulse train or burst form of pulsed direct current by Coffelt Manufacturing, Inc., developed in response to recently detected high mortality rates caused by commercially available PDC wave forms.

Condenser discharges: current composed of a steady sequence of exponential discharges.

Conductivity: the ratio of the density of the unvarying current in a conductor to the voltage gradient that produces it; the common unit of measurement is the µsiemen/cm = µmhos/cm.

Conductance: the measure of the ability of a component to conduct electricity, the reciprocal of resistance: the unit of measurement is the siemen (mho).

Current: the rate of electrical charge flow in a circuit; the practical unit is the ampere (amps), which is one coulomb per second.

Current shape: the geometric shape of the current during one cycle; usually this refers to the rate of growth and decay of an impulse.

Cycle: one full revolution of a periodic phenomenon.

Deadman switch: a switch that requires constant pressure to supply electrical current to the circuit.

Direct current (continuous, galvanic): unidirectional constant current.

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*Adapted from Cowx, I.G. and P. Lamarque. 1990. Fishing with Electricity. Applications in Freshwater Fisheries Management; and Koltz, A.K. 1989. A Power Transfer Theory for Electrofishing.

Effective fish conductivity: the apparent conductivity of live fish as determined by statistically fitting electroshock response data to the theoretical curve developed for the concept of constant power.

Electrical charge: a fundamental property of matter that can be classified as a fundamental physical quantity; the practical unit is the coulomb. The electron, the smallest charge identified in nature, has a magnitude of 1.6 x 10–19 coulomb.

Electrofishing: the use of electricity to provide a sufficient electrical stimulus in fish to permit easy capture by netting.

Frequency: total number of cycles per time unit measured in hertz; 1 Hz equals one cycle per second.

Ground: a conducting connection between an electrical circuit or equipment and the earth, or to some conducting body that serves in place of the earth.

Half-wave rectified current: current composed of a sequence of half sine waves in the same direction, separated by pauses of equal duration. This is obtained by passing an alternating current through a rectifier.

Impulse: electric phenomenon of short duration compared with the period.

Interrupted direct current: unidirectional current interrupted by periodic pauses. See pulsed direct current.

Isolation transformer: a transformer inserted into a system to separate one section of the system from undesired influences with other sections.

Mismatch ratio: the ratio of either the two resistance values or two conductivity values determined for adjoining media. For electrofishing, this is the ratio of conductivity of the water to the effective conductivity of the fish.

Multiphase current: the number of phases, the whole of n being alternating currents originating from the same source and out of phase with each other by 1/n of a period (1/3 of a period with three phase current).

Netter: the individual who nets the captured fish during electrofishing operations.

Pause duration: interval between two electric phenomena.

Period: time interval between two identical stages in an electric sequence.

Power: the rate of doing work or the energy-per-unit-of-time; the practical unit is the watt (W), which is one joule per second.

Applied power: incidental power at an electrical interface separating two mediae.

Constant transferred power: the constant value of transferred power desired under all conditions of mismatch.

Maximum output power: the maximum available power delivered to an external load from a power source having an internal resistance equal to that of the external load.

Reflected power: the portion of applied power that is not transferred to the second medium.

Transferred power: the portion of applied power transferred from the first medium to the second medium.

Power control circuit: the circuit that interconnects and adjusts the power from the pulsator or generator to the electrodes.

Power density: the power or energy-per-unit-of-time dissipated in a given volume of material. The unit measurement is watts per cubic centimeter (W/cm^3).

Applied power density: power density available for transfer to a fish at a particular location in the water.

Power density in fish: the desired constant value of power density to be transferred to a fish. Also, the threshold of in vivo power density required to produce a specific electroshock response at a specific conductivity.

Pulse duration (pulse length): duration of an impulse.

Pulsed current (pulsating AC or DC): unidirectional current composed of a sequence of cyclic impulses.

Quarter-sine wave current: a special kind if current electronically obtained from alternating current, usually from V-max to zero.

Rectified alternating current: current composed of an uninterrupted sequence of half sine waves in the same direction, and obtained from an alternating current by means of a four-way bridge rectifier. Also called, full-wave rectified current.

Resistance: the ability to react to the flow of AC or DC with an opposition to the flow of current. Also, the ratio of the applied voltage to the induced current that it produces; the unit of measurement is the ohm.

Resistivity: the reciprocal of conductivity; the common unit of measurement is the ohm-cm.

Smooth rectified current: direct current derived from alternating current by using rectifiers and a suitable capacitance inductance filter. When insufficiently filtered, the current shows weak sinusoidal variations and is called 'partly smoothed rectified current,' or ripple current, or undulating current.

Square wave (syn. rectangular pulses): cyclic waveform with steep rise and fall time, with flat top and bottom.

Variable voltage pulsator electroshocker: the device used to deliver the pulsed electric current.

Volts or Voltage: the energy-per-unit-of-electrical-charge; the volt (V) is the unit of measure where one volt is one joule per coulomb.

Voltage gradient: the rate of change of voltage with distance. Also, the force-per-unit-of-electrical-charge; the common unit of measurement is volts per centimeter (V/cm).

ELECTRIC FIELD CHARACTERISTICS

Anode (or cathode) field: in electric fishing, field around the electrode beyond which the values of potential gradient are unimportant.

Conductivity (of water): conductance of 1 cm^3 of water. Conductivity is the inverse of resistivity.

Critical zone of current density: in electric fishing, current density area around the electrode in which a fish is shocked.

Current lines (flow lines, equiflux): imaginary lines that represent direction of current flow perpendicular to equipotential surfaces.

Density (of current): current intensity passing through one unit of cross-sectional area perpendicular to the current lines of an electric field.

Equipotential surface: a surface on which all points are at the same electrical potential. Equipotential surfaces are perpendicular to the direction of the current flow.

External resistance: electrical resistance between electrodes.

Heterogeneous field: field in which current density and potential gradient decrease as a function of the distance from electrodes.

Horizontal field: see vertical field.

Isolines: lines of equal potential gradient.

Moving field (syn. movable field): field in which surfaces of equal relative potential (related to the supply voltage) are displaced as a function of time (rotating field, intersecting field, etc.).

Potential gradient: potential difference in an electric field-per-unit-length on the direction perpendicular to the equipotential surfaces; this gradient is measured in volts per centimeter (V/cm).

Resistivity (of water): resistance of 1 cm^3. Resistivity is the inverse of conductivity.

Stationary field: field in which surfaces of equal potential (related to the supply voltage) are steady.

Vertical field: field in which the potential gradient is lower on a ground plane than on a vertical plane, so that a fish swimming horizontally into the field will be subject to a body voltage much lower than if the field were horizontal itself at the same distance from the electrode.

BEHAVIOR AND PHYSIOLOGY

Anelectrotonus: decrease of nerve excitability on the anode side.

Anodic (cathodic) curvature: curving of the fish body towards the anode (cathode) under the influence of a unidirectional current, when the fish is perpendicular to the current lines.

Ascending current: according to conventional direction of current (from + towards -), electric current ascending into the system from the periphery towards the fish nervous centers, occurring when the fish is facing the cathode.

Autorhythm: excitability of nerve and muscle provoked and sustained by a constant continuous current.

Body voltage: measured potential difference between head and tail of a fish in an electric field.

Catelectrotonus: increase of nerve excitability on the cathode side of a shocked fish.

Closing of the circuit reaction: nerve or muscle excitation produced by closing the circuit.

Descending current: electric current going down into the system from nervous centers towards the periphery (see ascending current), as in the case of fish facing the anode.

Electrotaxis: fish swimming induced by any kind of electric current.

Fixation: state of immobility of fish resulting from tetanus under the action of electric current, distinct from galvanonarcosis.

Forced swimming (first swimming towards the anode): a very fast swimming motion towards the anode, induced by a constant current.

Frightening effect: fish escape from an electrode under the action of current.

Galvanonarcosis: state of immobility of fish resulting from muscular slackening, under pulsating direct current.

Inhibition of swimming: slowing down of swimming movements; produced by a low and constant continuous current when a fish faces the anode.

Narcosis: state of immobility resulting from muscular slackening.

Opening of the circuit reaction: nerve or muscle excitation produced by opening the circuit.

Oscillotaxis: swimming artificially induced by an alternating current.

Pseudo-forced swimming (second swimming towards the anode): out of balance swimming produced by a strong and constant continuous current. Occurs when a fish faces the anode.

Rheobase: minimal intensity of current indefinitely maintained to release the excitation of nerve of muscle.

Spatial summation: cumulative effect produced on a neuron by means of several simultaneous stimuli.

Taxis: artificial swimming induced by a stimulating agent.

Temporal summation: cumulative effect produced on a neuron by a series of stimuli.

Tetanus: state of muscular rigidity.

Threshold: minimal value of current parameter inducing a determined reaction.

Useful time: minimal time during which an electric current of a given value must be maintained to produce an excitation.

ANNOTATED BIBLIOGRAPHY

The following paper provides a review of current literature in electrofishing. Seventy five entries are indexed into four broad categories: (1) effects of electric fields on fish response and electrofishing efficiency (effects(E)), (2) gear design, construction and operations (techniques(T)), (3) applications, sampling design and analysis (applications(A)), and (4) safety, regulations and guidelines (safety(S)). A paper listed in one category often covers material that overlaps into another. This bibliography was prepared for a review of the existing electrofishing literature as it might pertain to our ensuing northern squawfish control efforts on the Columbia River. This work is intended to serve only as a quick reference and/or review, and not as a replacement to any of the cited literature.

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Adams, W.J., D.J. Behmer and W.O. Weingarten. 1972. Recovery of shocked common shiner, *Notropis conutus*, related to electric energy. Trans. Am. Fish. Soc. 101(3):553-555.

Common shiner (*Notropis conutus*), physiology, electrical parameters, pulsed direct current, electric fishing.

The time necessary for electroshocked fish to recover swimming equilibrium (recovery time) was evaluated for the common shiner under the controlled conditions of the laboratory. Halsband (1967) and Lamarque (1967) both established that it is the 'head to tail' potential voltage drop that determines just how much applied electric energy an electroshocked fish is actually exposed to. Larger fish experience more current through their bodies. Electric fishing is size selective and has a more pronounced effect on larger fish.

Adams et al. showed that after treatment with pulsed direct current (15 seconds duration), longer fish (total length) experienced a longer recovery time and greater mortality than similarly exposed shorter fish. Recovery time for all fish increased with an increase in exposure time to the current. Twenty-four hours was the suggested time necessary for a full physiological recovery in the laboratory. In the field it is suggested that retained electroshocked fish be held out of the applied electric field for minimum time needed to regain their swimming equilibrium, before release.

An attempt was made to establish which variable (voltage drop, current, duration, or power density) could be used to best define an expected electrical stimulus in fish. It was suggested that power density,

$$\text{Power Density} = E^2 / R \times (\text{Volume of a Fish})$$

E = Voltage and R = Resistance,

may be a more meaningful measure of experienced electrical stimulus than potential voltage drop.

The physiological effects to incidentals (salmon, walleye, and sturgeon) of electrofishing for squawfish in the Columbia River should be evaluated. The recommended observation period is from 24 to 72 hours. As long as practicality allows, non-game incidentals (sculpins, peamouth, suckers, etc.) should be held in electrically isolated holding tanks, at least until swimming equilibrium has been re-established, so as to reduce the loss of lethargic fish to predators. Unfortunately, the limitations of holding space and sampling time may greatly restrict this activity.

Amiro, P.G. 1990. Variation in juvenile Atlantic salmon population densities between consecutive enclosed sections of streams. Pages 96-101 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Atlantic salmon (*Salmo salar*), Nova Scotia, electric fishing, hand-held electrode, Coffelt VVP-2C, barrier nets, modeling.

The homogeneity of juvenile Atlantic salmon densities was tested for consecutive sections of wadeable streams. Densities were generally heterogeneous between sections for all size or age classes. This paper suggests that larger sampling areas and consolidating effort to suitable locations within an area (habitat pro-rating) may be required for meaningful comparisons of inter-site or inter-river fish densities.

Although the target species and sampling habitat detailed within are unique, the sampling procedures suggested here may also be employed in the removal of Columbia River squawfish.

Armstrong, M.C. and J.H. Mundie. 1983. Floating fish shocker. Prog. Fish Cult. 45(4):236-237.

Coho salmon (*Oncorhynchus kisutch*), Nanaimo, British Columbia, electric fishing, fish culture, habitat improvement.

This short paper describes construction and operational specifications for a floating fish shocker proven suitable for removing fish from channels and raceways. The shocker consists of a hand-held switch, 12 aluminum dropper electrodes suspended from an aluminum pipe made buoyant by six Styrofoam net floats, and a flexible ground electrode of four lengths of copper pipe, each one meter long.

This equipment could prove to be useful as an auxiliary piece of collection gear. The floating shocker could be used in areas inaccessible to an electric-fishing boat. It could also be used in collecting juvenile lampreys for squawfish longline bait.

Balayave, L.A. 1981. The behavior of ecologically different fish in electric fields. II. Threshold of anode reactions and tetanus. J. Ichthy. 21:134-143.

Baltic Sea, Black Sea, behavior, anodic reactions of various ocean fishes.

The behavior of 18 Black Sea and 4 Baltic species of fish in an electric field of rectified current was investigated. The fish were divided into three behavioral groups, strong anodic reaction (galvanotaxis), intermediate galvanotaxis, and no galvanotaxis. Galvanotaxis was characteristic of active swimming fishes. Sessile or bottom fish responded to the applied electric current by trying to hide or burrow into the bottom. The behavioral responses of the intermediate group, which consisted of active, migrating, and bottom species, were more difficult to label.

This paper concludes: (1) the presence or absence of galvanotaxis depends on the ecological stereotype of behavior; (2) irrespective of the presence or absence of galvanotaxis, all species can distinguish the anode from the cathode, preferring the anode; (3) narcosis or tetanus does not depend on the orientation of the fish in the electric field, but rather on field intensity.

This paper provides useful insight into the behavior of fish within a field of rectified current. Electrofishing for squawfish will employ various forms of rectified electric current. Squawfish may be classified as an active species. It is expected that squawfish will show strong galvanotaxis to an appropriately applied field, greatly increasing our catch potential.

Bird, D. and I.G. Cowx. 1990. The response of fish muscle to various electric fields. Pages 23-33 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Rainbow trout (*Oncorhynchus mykiss*), roach (*Rutilus rutilus*), European eel (*Anguilla anguilla*), physiology, electric stimuli, muscle stimulation, fatigue, inter-specific and intra-specific variability.

Electric fishing is a well-established technique for sampling fish populations in freshwater. Recently, the applications of methods to improve the efficiency and accuracy of the technique have received considerable attention. These developments, however, have been hindered by an incomplete understanding of the precise effects of electric fields on fish (electrophysiology).

In this study, the response of fish musculature to direct electrical stimulation was investigated. Individual variability in contractile performance was high in muscle preparation for each of the species tested. Negative linear relationships were found between fatigue resistance and pulse frequency for the three species examined. Therefore, the longer a fish is exposed to high-frequency current, the greater the chances are of that fish becoming tetanized, permanently damaged, and lost to a collection effort.

Bowles, F.J., A.A. Frake and R.H.K. Mann. 1990. A comparison of efficiency between two electric fishing techniques on a section of the River Avon, Hampshire. Pages 229-235 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Roach (*Rutilus rutilus*), coarse fish populations, Hampshire, United Kingdom, electric fishing, hand-held electrodes, boom-boat, stop nets, modeling, efficiency and cost comparisons.

A pilot survey was carried out to assess the most suitable electric fishing technique for a fish population study of the Hampshire Avon in the United Kingdom.

The initial technique was to adapt the traditional electric fishing boat technique by using three boats fishing in tandem downstream with two hand-held anodes on each, and to conduct a four-catch depletion survey. This method produced very low catches of fish. Catch efficiency was assessed by introducing a known marked population into an isolated section of stream and then fishing them.

This paper compares the catch rate and population estimates produced by the 'three boat' method on a known population of roach, with a second trial on the same section using boom-mounted equipment. The labor and equipment costs of each are compared.

The 'three boat' technique recaptured 11% of the 570 introduced roach after four catches. The boom boat caught a greater percentage of the stocked fish, 36% after three runs. Both methods of capture underestimated population size. The mean percentage caught was 3% for the 'three boat' and 13% for the boom boat. The boom boat was later chosen for the main survey since it caught a larger proportion of the introduced fish, gave a more accurate population estimate, and was more cost effective.

The squawfish removal effort on the Columbia River will employ boom-mounted electric fishing boats. The multi-anode arrays described in this paper differ in that the anodes are arranged in a straight line equidistant along the boom. For our effort, two Wisconsin Ring arrays, or Smith Root UAA-6 dropper arrays, will be used.

Cave, J. 1990. Trapping salmon with the electro-net. Pages 65-69 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Sport Fishing News, Blackwell Scientific Publications, Ltd.

Atlantic salmon (*Salmo salar*), electric gear, electric fences, electric fishing, fish culture, habitat improvement, comparison of catch methods.

An electric trammel net was developed to catch Atlantic salmon (*Salmo salar*) of Tyne River origin for stripping and rearing at a hatchery. The resultant progeny were restocked to replace the anticipated juvenile losses caused by a hydro-dam. With constant modification, the catch-per-unit-effort (CPUE) of the equipment increased sixteen times in four years. Rod catches per season improved five times in the same period. An increase of salmon on the spawning fjords was related to improvements in the estuaries' water quality.

This paper shows that the addition of electricity to some existing fishing gear increases those gears' efficiency. In future investigations on the Columbia, the CPUE of purse seining and Merwin Traps for squawfish could possibly be increased if so modified.

Cowx, I.G., A. Wheatly and P. Hickley. 1988. Development of boom electric fishing equipment for use in large rivers and canals in the United Kingdom. Aquacult. Fish. Manage. 19: 205-212.

Fishing gear research, fishery surveys, canals, rivers, British Isles, electric fishing.

The construction of a multiple-electrode fishing boom is described. The efficiency of the equipment was compared with more conventional hand-held electric fishing equipment and seine netting in a series of field trials.

The boom electric fishing equipment with a direct current output produced more consistent catches and is considered to be a good cost-effective method for sampling large slow-moving bodies of water. Hand-held electrodes are limited in their horizontal and vertical effective range. Seines were of limited use because of excessive current (>1 m/s), underwater obstacles, and large manpower requirements.

Multi-electrode boom arrays have been developed to overcome the problems associated with sampling large rivers and canals. Boom fishing is common practice in the United States. The results from this investigation show that the boom-mounted, pulsed direct current equipment caught 48.4% of a known population, compared with 24.6% for hand-held gear. Three advantages of boom fishing were low cost, increased maneuverability, and greater CPUE. This gear, however, still underestimated the known population size by 25.6%.

Cowx, I.G., G.A. Wheatly, P. Hickley and A.S. Starkie. 1990. Evaluation of electric fishing equipment for stock assessment in large rivers and canals in the United Kingdom. Pages 34-40 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publication Ltd.

Roach (*Rutilus rutilus*), electric fishing, multiple-electrode fishing boom, hand-held electrodes, assessment of efficiency of equipment under varied conditions.

In order to efficiently sample large rivers, canals and lakes in the United Kingdom, a cost-effective approach to boat-based electric fishing, similar to that used in the United States by Novotny, was developed. The Cowx boom differs from Novotny's Wisconsin Ring in that it is composed of ten pendant anodes spaced equidistant along a nine-meter boom made of reinforced polyester hydroglass tubing.

To overcome the excessive power demands required to fish high conductivity waters (>800 mhos), a pulsating direct current (PDC) control box was developed. It fires up to ten electrodes, energizing one at a time, beginning outward and progressing inward. This sequential firing system presents the electrode array as a single elongated anode with a field of more than nine meters. This system can successfully fish waters with conductivities of more than 4000 mhos. There may be some inadequacies to this system when it is used in very fast, deep, and wide rivers.

The squawfish removal effort will use commercially available equipment from either Smith-Root Inc. or Coffelt Manufacturing. This gear owes much to Novotny's original work.

Cowx, I.G. 1990. Developments in electric fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Physiology, fishing gear, CPUE, sampling, modeling, electric screens, safety, electric fishing.

A symposium 'Fishing With Electricity' was hosted by the Humberside International Fisheries Institute in Hull, England, 12-16 April 1988. The objective of this symposium was to advance the scientific basis of electric fishing and provide a medium for the dissemination and exchange of ideas. The main symposium was attended by 128 delegates from 23 countries. Fifty-five papers were organized into seven sessions. The presentations demonstrated that electric fishing has advanced considerably in equipment technology, safety, and sampling design; however, it has remained static in our understanding of electrophysiology, the response of fish to electric currents and factors affecting the efficiency of electric fishing.

This text contains forty-two selected papers from the symposium, and, along with its complement, Developments in Electric Fishing, should be considered a primary reference source and required reading for any electric fishing project.

Cowx I.G. and P. Lamarque. 1990. Fishing with electricity; applications in freshwater fisheries management. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Physiology, fishing gear, electric parameters, modeling, electric gear, electric screens, electric fishing, safety, text on the theory and applications of electric fishing.

In April 1988 the European Inland Fisheries Advisory Commission (EIFAC) held a symposium to analyze and evaluate the many improvements and applications of contemporary electric fishing in Europe and the United States. The results of this symposium are available in the form of two new books, Fishing With Electricity and Developments in Electric Fishing. Both texts should be required reading for any electrofishing personnel.

Fishing With Electricity details the following: Electrophysiology of fish in electric fields, electric fishing apparatus and electric fields, factors affecting the efficiency of electric fishing, electric fishing for sampling and stock assessment, electric screens and guides, electric fishing and safety, electric fishing in practice, and the future of electric fishing.

Cross, D.G. and B. Stott. 1975. The effect of electric fishing on subsequent captures of fish. Journal of Fish Biology 7:349-357.

Roach (*Rutilus rutilus*), gudgeon (*Gobio gobio L.*), Great Britain, modeling, bias in electrofishing population estimates.

This paper addresses the question of decreased catchability experienced during a series of replicated electric fishing passes and the resulting negative bias in various catch depletion population estimates. The experiments conducted clearly showed electrofishing can cause a decrease in catchability so that second and subsequent catches are made from reduced populations. This fact violates the equal catchability assumption associated with catch depletion methods, resulting in seriously low population estimates. The authors provide a method for adjusting population estimates for this factor of decreased catchability..

Dwyer, W.P. and D.A. Erdahl. 1992. Effects of electroshock voltage, wave form, and frequency on trout egg mortality [Abstract]. Page 13 *in* Western Division of The American Fisheries

Society, July 13-16, 1992, Colorado State University, Program abstracts [Annual meeting]. American Fisheries Society, Western Division, Fort Collins, Colorado.

Rainbow trout (*Oncorhynchus mykiss*), eggs, injury, mortality, electrofishing, Montana, DC, PDC, Coffelt Pulsed System (CPS).

This study raises the question of how much incidental harm is being done to salmonid eggs while in the redd if an electrofishing operation passes over them. Tests with trout eggs have shown that electrofishing may be having more detrimental effects than previously thought. When shocking over redds, it was shown that eggs in the laboratory can be killed during the sensitive period by electroshock. Tests in the field yield similar results. This paper reports the results of testing and defining the effects of continuous DC, PDC and CPS, at different voltages. Electrofishing should be avoided in spawning areas of any species of fish. The levels of incidental harm to eggs, larval and weakened adult fish, are too significant.

Edwards, J.L. and J.D. Higgins. 1973. The effects of electric currents on fish. Final Technical Report. Projects B-397, B-400 and E 200-301. Game and Fish Division, Department of Natural Resources. Atlanta, Georgia. 75 p.

Channel catfish (*Ictalurus punctatus*), bluegill (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides*), bowfin (*Amia calva*), behavior, electric field, teleostean, controlled conditions.

To improve the effectiveness of electrofishing techniques, an investigation into the physiological mechanisms responsible for the reaction of fish to electric currents of various types was performed. It is clear that the responses often involve the sensory and motor nerve system, but the mechanisms are complex and not completely understood.

Pulsed direct current at low current densities produces agitation or fright. At higher current densities, the fish move involuntary toward the anode. At still higher densities the fish are immobilized. If alternating current is used, there is no tendency to swim toward either electrode, and fish tend to take up a transverse orientation between the electrodes. At sufficiently high current levels the fish are immobilized.

This study had two goals: to investigate the possibility of selectively affecting a particular species or size of fish by choosing the appropriate wave form and other electrical parameters, and to investigate the possibility of reducing average power requirements through the use of pulsed shapes and frequencies to which fish exhibit a particular sensitivity.

Pulsed direct currents were the most effective at inducing temporary immobilization of fish. Rectangular and exponential pulse shapes were tested at frequencies up to 200 pulses per second (burst form). Various wave forms were compared at the value of peak field strength required to immobilize 75% of a similar group of fish. Twelve different wave forms were tested on six groups representing four species. No species variation could be discerned. The data showed that larger fish are generally more susceptible to electric shocks than small, because larger fish intercept more current.

Three techniques were demonstrated to be effective in reducing the required average power: reduction of duty cycle, use of exponentially decaying pulses, and periodic interruption of the pulse trains. Power reductions of 92% to 99% as compared with those required when using continuous DC were demonstrated.

Eloranta, A. 1990. Electric fishing in the stony littoral zone of lakes. Pages 91-95 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Bullhead (*Cottus gabio*), burbot (*Lota lota*), oligotrophic lakes, Finland, sampling, electric fishing.

The fish populations of stony littoral areas have been poorly known until recently. Although this habitat is quite open and easy to approach, the small size, night activity and benthic behavior of fish found there have made it difficult to use conventional capture methods. This paper deals with fishing strategy, effects of different catching conditions and results achieved from DC electric fishing in the Finnish Lake District.

Direct-current electric fishing worked well for catching night-active bottom-feeders from the stony littoral zone. Ideal conditions were when the weather was calm and light with few shadows or reflections on the water, shallow depth (< 1 M), good water clarity, a homogeneous gravel bottom, gently sloping shore and the lack of vegetation. Stop nets were used, but shown to be unnecessary; on average, less than 3% of the total catch migrated in or out of the sampling area.

Direct current worked well in low conductivities (30 to 50 μhos). Temperature ranged from 4 to 14 degrees Celsius. Moderate winds (5 to 7 m/s) disturbed fishing, especially on deep and exposed shores, and high waves made fishing impossible. Fishing was abandoned during rain.

This paper details procedural aspects that would be important to any electric fishing operation.

Eloranta, A., E. Jutila, and S. Kanno. 1990. Electric fishing and its safety requirements in Finland. Pages 340-343 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Safety, fishery research, electric fishing, fishery technology, Finland.

Finnish tradition in electric fishing is short. The method was not established in Finnish fisheries until the 1970s. This paper presents a review of the shortcomings observed in the electric fishing method and suggests some improvements.

In 1987, there were over forty electric fishing units operational in Finland. The majority were DC units powered by 0.5 - 2.0 KVA generators. All systems were made in Nordic countries, most less than ten years old. Most electrofishing was in small streams and rivers with backpack units.

Legal requirements of electric fishing are detailed along with a list of suggestions for improving fishing methods, with regard to electrical and other equipment and operating procedures. This list should be reviewed and used with the similar safety guidelines from Hickley (1990), McLean (1990) and Lazauski (1990) in order to produce a set of standard operating procedures for fishing with electricity.

Frankenberger, L. 1960. Applications of a boat-rigged direct-current shocker on lakes and streams in west central Wisconsin. Prog. Fish Cult. 22: 124-128.

Walleye (*Stizostedion vitreum*), Wisconsin, aquaculture, fishing gear, electric fishing, applications of experimental gear.

Many of the problems associated with AC electric fishing (stunning of fish out of sight, physical harm or death, high power requirements) may be overcome by using PDC to achieve electrotaxic effects on fish. The boat-rigged direct-current shocker described in this paper was effective because the fish are attracted to the grid suspended just below the water. This unit was developed primarily for use as a sampling and cropping device in walleye rearing ponds.

Detailed construction and operational specifications are given for an experimental pulsed DC boom-boat shocker. Much of this information is still applicable to a present-day electric fishing operation.

Fredenberg, W. 1992. Evaluation of electrofishing-induced spinal injuries resulting from field electrofishing surveys in Montana. Montana Dept. Fish, Wildl. Parks.

Electrofishing, PDC, rainbow trout (*Oncorhynchus mykiss*), injury mortality, Montana.

This paper, along with Holmes (1990), addresses the issues of potential electrofishing-induced injury that were raised by Sharber and Carothers' (1988) work. About nine hundred fish were examined during this research. Sampling was designed to evaluate the differences in injury rates due to various factors, including variability in electrical wave forms and electrofishing methods, as well as species and size of fish. The two primary wave forms compared were 60 Hz square PDC and smooth DC (Coffelt VVP15). Substantial evidence demonstrated that 60 Hz PDC results in excessive injury rates to both rainbow trout (60-98% injury) and brown trout (44-62% injury), regardless of wave form (rectified sine-wave), water conductivity (33-900 mhos/cm), and equipment design variables. Limited sampling of Arctic grayling, sauger, and shovelnose sturgeon did not reveal spinal injury problems with these species. A discussion of electrofishing efficiency and proposed guidelines for minimizing spinal injury are included.

Because of the unacceptable high injury rates to salmonids, all electrofishing with PDC 60Hz square wave has been halted in Montana. This same method of electrofishing has been used extensively in the Columbia River for population indexing, and the removal of northern squawfish. The results reported by Sharber and Carothers (1988), Holmes (1990), and Reynolds (1992) will need to be evaluated and applied to the ongoing northern squawfish electrofishing work on the Columbia River. In 1993, the University of Washington will propose to evaluate electrofishing-induced harm on resident fish.

Gatz, A.J., Jr. and S.M. Adams. 1987. Effects of repeated electroshocking on growth of bluegill x green sunfish hybrids. N. Am. J. Fish. Manage. 7:448-450.

Hybrid sunfish, bluegill (*Lepomis macrochirus*) x green sunfish (*Lepomis cyanellus*), physiology, laboratory, electrofishing, DC backpack electrofisher.

Gatz et al. (1986) reported that 2 to 7 exposures to electroshocking within a 12-month period significantly reduced the growth rate of wild rainbow trout. This follow-up paper showed that similar results could be obtained with hybrid sunfish (bluegill x green sunfish) that were electroshocked in the laboratory over a three-month period.

Hybrid sunfish that were shocked once a week for three months experienced a reduction in average growth rate as compared with less frequently shocked fish and unshocked fish. The reduced growth in the frequently shocked fish was attributed to fish having to expend a greater portion of their total energy reserves for tissue repair and respiration. Gatz et al. (1986) reported that the reduction in growth of wild rainbow trout was due to behavioral interactions between shocked and unshocked trout. Unshocked fish were able to dislodge shocked fish from prime feeding areas. Shocked fish tended to seek cover and show no interest in feeding following electroshock.

Repeated exposure to the voltages necessary to capture fish in the field will induce some negative behavioral and physiological response, the severity of which depends on the quality and amount of a particular electrofishing effort, habitat quality, food availability, and species of fish in question. Gatz suggests that repeated electrofishing at intervals of less than three months may be harmful to some species of fish.

Gatz, A.J., Jr., J.M. Loar, and G.F. Cada. 1986. Effects of repeated electroshocking on instantaneous growth of trout. N. Am. J. Fish. Manage. 6:176-182.

Rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), North Carolina, Tennessee, small streams, population estimates, growth, backpack electrofishing, PDC.

Electroshocking is a commonly used method for collecting fish in streams. Many fisheries management studies employ techniques that require multiple captures of fish. This paper explored the non-lethal side effects of repeated exposure to electroshocking and the possibility of any bias in population estimates that may result.

Instantaneous growth rates were calculated for age 1+, 2+, and 3+ wild rainbow and brown trout. The growth rates of individual trout that had been electroshocked 2 to 7 times within a 12-month period were shown to be lower than the average growth rate of similar age class unshocked fish. The reduced growth rates were attributed to fish expending energy reserves to repair damaged tissue, physiological and behavioral responses to handling stress, and especially, fish experiencing a loss of stamina (Horak and Kline 1967) resulting in shocked individuals being pushed out of prime feeding habitat by competing unshocked similar-sized trout. Decrease in growth rate happened more often and to a greater extent in age 1+ and 2+ trout than those 3 and older, and more frequently among trout that had been electroshocked within the last two and a half months than among trout that had three or more months to recover from their last electroshock.

The results reported here are of practical significance to fisheries studies that estimate growth of production in streams from a series of collections obtained by electrofishing. Researchers should be aware that their results could be negatively biased if more than a small fraction (e.g., >20%) of the total population is shocked repeatedly. Bias will be greatest on younger age classes. To avoid bias it is recommended that repeated electrofishing occur at intervals of greater than three months.

Hauck, F.R. 1949. Some harmful effects of the electroshocker on large rainbow trout. Trans. Am. Fish. Soc. 77:61-64.

Rainbow trout (*Oncorhynchus mykiss*), morphology, physiology, fish dissection, fisheries management, electric fishing.

The use of the electric shocker in the salvage of rainbow trout from an irrigation canal is described. An account is given also of physiological effects observed during shocking and the morphological effects determined by dissection.

Dissection of some specimens disclosed fractured vertebrae, ruptured arteries and veins, hemorrhaging, death of tissues, curvature of the spine, and extreme dilation of blood vessels in various parts of the body, including the brain.

Power was supplied via a portable gas-powered generator of 110 volt 60 cycle alternating current with a maximum output of 495 watts. Captured trout were transferred to a local hatchery and observed for 2 to 5 days. An output of 80 to 90 volts was sufficient to stun fish momentarily. The effective range was a radius of ten feet and to a depth of five feet. The water was alkaline, pH 7.5, and temperature was 58 to 70 degrees Fahrenheit.

Ten rainbow trout that exhibited representative symptoms of injury were selected for dissection. The total mortality of fish due to shocking was only 2% of the entire test group. Low mortality may have been attributable to low voltages applied, short observation time and the controlled conditions in the hatchery.

Hickley, P. 1985. Aspects of fishing electrode design. Aquaculture and Fisheries Management 1: 297-298.

Electric fishing, design, electrodes.

Two important aspects of equipment design are commonly ignored by manufacturers. Connectors are placed on the end of the anode pole so it can be quickly detached from the power cable. The cable from the electrode must be continuous from within the hollow electrode handle as far as to its terminal plugs used for connection to the control box. The mixing of high and low power tension in the same connector is not safe.

The fixing of separate high tension and low tension plugs onto the same piece of three-core anode cable is schematically detailed.

Hickley, P. and A. Starkie. 1985. Cost-effective sampling of fish populations in large bodies of water. J. Fish. Biol. 27(Supplement A):151-161.

Sampling, economics, lakes, fishery surveys, stock assessment, fishery management, British Isles, methodology.

The problems of estimating fish populations in large bodies of water are addressed. Case histories are presented showing how a range of large habitat types have been surveyed. The survey methods are discussed in terms of relative success and cost. (1) The status of the River Severn fish population was monitored by postal questionnaires addressed to contest fishermen, cost effectively collecting valuable data. (2) A predator cull and population estimate for a 35-hectare lake was made by sequential netting of sections. The population estimates arrived at were questionable and the results in general were poor. This sampling method proved to be very labor intensive and costly. (3) A boat-based electric fishing technique was used in estimating fish populations in large canals. The boat-based electric fishing unit and sampling methods used are described by Cowx:. The perpendicular, ten pendant, bow mounted anode array gave the most consistent catch-per-unit-effort, while operating at a cost-effective level.

This paper details alternative effective electric-fishing techniques for streams and rivers.

Hickley, P. and B. Millwood. 1990. The United Kingdom safety guidelines for electric fishing: its relevance and application. Pages 311-323 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Electric fishing, electric gear, construction, health and safety, fishery survey.

The United Kingdom, unlike the United States, has adopted legislation that strictly regulates the applications and procedures of electric fishing. This paper reviews recommendations for all aspects of working with electricity, from daily working procedure to equipment design. Established national safety guidelines are discussed in the context of their relevance, necessity, and suitability for application in the field.

All components of the electrical equipment must be suitable for exposure in a wet, outdoor environment, and particular attention should be given to standards of enclosure, robustness, construction, mounting of components, termination, plugs, and sockets--in short, a durable solid-state system is required.

In electrofishing operations, power supplies are restricted to those from portable generators or spill-proof batteries. Power must always be fed via a control box, the primary reason for this being operator protection when a high-tension generator is used. Generators must be modified so that they are not grounded internally and must be clearly labeled to this effect. The generator must be housed in an insulated, ventilated enclosure so as to prevent bodily contact with any person while the generator is running.

This paper provides a comprehensive review of safety requirements, along with a safety checklist of gear specifications for prospective purchasers. This information should be incorporated into any electric fishing operation.

Hollender, B. 1992. Injury of wild brook trout by backpack electrofishing [Abstract]. Page 13 *in* Western Division American Fisheries Society, July 13-16, Colorado State University Program Abstracts [Annual meeting]. Am. Fish. Soc., Western Div., Ft. Collins, Colorado.

Brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), brook trout (*Salvelinus fontinalis*), alternating current (AC), PDC, backpack electrofishing, injury, mortality, Pennsylvania.

The objective of this study was to assess internal injuries of wild brook trout that were captured with AC and PDC backpack electrofishing units in four small infertile streams. X-ray and autopsy were used to assess injury rate of 579 brook trout captured by electrofishing and 89 captured by angling. Injuries consisted of internal hemorrhages, and spinal-misalignment and fracture, or both. There were 74 hemorrhages and 91 spinal injuries. Injury rates were not significantly different between current types: 26% for AC and 22% for DC. It was concluded that even for relatively small trout in infertile waters, the incidence of electrofishing-induced injury can be significant.

A review of this and other papers contained in this synopsis makes it clear that the harmful effects of any type of electrofishing need to be evaluated (with standard evaluation protocols) on an individual project basis.

Holmes, R., D. McBride, T. Vivant and J.B. Reynolds 1990. Electrofishing mortality and injury to rainbow trout, Arctic grayling, humpback whitefish, least cisco, and northern pike. Fishery Manuscript 90-3. Alaska Dept. Fish Game, Anchorage. 95 p.

Electrofishing, PDC, rainbow trout (*Oncorhynchus mykiss*), Arctic grayling (*Thymallus arcticus*), northern pike (*Esox lucius*), humpback whitefish, (*Coregonus pidschian*), least cisco (*Coregonus sardinella*), injury, mortality, Kenai River, Alaska, Coffelt VVP-15.

The publication of Sharber and Carothers' (1988) work on the possible deleterious effects of PDC electrofishing on large rainbow trout in the Colorado River has stimulated ongoing debate and agency-wide re-evaluation of The Standard Principals and Field Practices of electrofishing.

Before their work, it was generally believed that PDC electrofishing presented limited incidental harm to fish. Sharber and Carothers reported a range of 44% to 67% spinal injury to large rainbow trout exposed to standard PDC. Holmes et al. took this information and set out to test the applicability of these results to Alaska's electrofishing efforts.

This paper examined the effects of PDC electrofishing on all species for which electrofishing was being used as a sampling method by the Alaska Department of Fish and Game. The huge injury and mortality rates for large rainbow trout were confirmed. Large rainbow trout are unique in their hypersensitivity to electric current. The paper addresses this by examining five different species of fish and evaluating the observed short-term mortality, and injury caused by electrofishing. Rainbow trout sustained the highest rate of mortality (13.9%) and injury (40.9%). Northern pike sustained zero mortality and an injury rate of 12.5%. Two species of whitefish had a short-term (7 days) mortality of 5.4% and 0% electrofishing-caused injury. The injury rates for Arctic grayling varied from 0% to 18.3%.

With this information in hand, the study then addresses the issue of establishing species-specific threshold power levels, and detailed methods for mechanically shielding the anodes, as ways to reduce harm from electrofishing. In order to make comparisons between different species and study sites, the capture methods, sampling protocols and sample test must be as uniform as possible. For this reason, this paper, along with Fredenberg's (1992), Reynolds' (1992), and Sharber Carothers' (1988), will establish the sampling program and research focus for the University of Washington's 1993 proposal to evaluate electrofishing-induced mortality and injury to fish species in the Columbia River.

Horak, D.L. and W.D. Klien. 1967. Influence of capture methods on fishing success, stamina, and mortality of rainbow trout in Colorado. Trans. Am. Fish. Soc. 96:220-222.

Rainbow trout (*Oncorhynchus mykiss*), Parvin Lake, Colorado, physiology, morphology, aquaculture, methodology, electric fishing, fly fishing.

Delayed mortality caused by various capture methods is of concern to fishery managers. Bouck and Ball (1966) encountered 87% delayed mortality within ten days after collecting hatchery rainbow trout with artificial lures. This paper evaluates effective capture techniques and their effects on 'put and take' fish populations.

The criteria used to evaluate the effect of capture methods were: (1) return to the creel of stocked trout before and after special fishing size limit regulations were imposed, (2) stamina evaluation of collection by electrofishing and fly fishing, and (3) mortality after collection by electrofishing and fly fishing.

Under the special fishery regulations (slot limits), fishermen harvested 37.7% of a known population of marked rainbow with subsequent returns of individual plantings ranging from 28.2% to 49.9%.

Two groups of hatchery trout were tested for stamina, one group collected by fly fishing, the second with a PDC electrofisher. Both capture methods resulted in reductions in individuals' swimming stamina (performance index). The higher an individual's performance index (P.I.), the greater its stamina. The control group performance index was 60 minutes, fly fishing P.I. was 54.7 minutes, and electrofishing P.I. was 35.2 minutes The low conductivity of the hatchery water may have introduced a negative bias on the electrofished group; 39% of shocked fish were visibly burned, indicating that excessive power may have been applied to the water.

Mortalities in the three groups were recorded over a five-week period. The control group had five delayed mortalities; fly fishing had five initial hooking mortalities and three delayed mortalities; and electrofishing suffered only two delayed mortalities over 35 days.

Hudy, M. 1985. Rainbow trout and brook trout mortality from high voltage AC electrofishing in a controlled environment. N. Am. J. Fish. Manage. 5:475-479.

Rainbow trout (*Oncorhynchus mykiss*), brook trout (*Salvelinus fontinalis*), physiology, morphology, alternating current, sampling, electrofishing.

Delayed mortality could: (1) bias population estimates (Pratt 1954), (2) limit spawning success (Maxfield et al. 1971), or (3) cause misinterpreted change in population level or structure. In moderate to high conductivity waters where low AC or DC current voltages are effective for stunning fish (Vibert 1976), mortality from electrofishing is negligible (Godfrey 1954, Horak and Kline 1967, Maxfield 1971). This paper presents data on immediate mortality, delayed mortality and vertebral injuries in hatchery rainbow and brook trout following electrofishing with high AC voltages.

The immediate, delayed, and total mortalities were low with no significant differences (analysis of variance, $p > 0.05$, $N = 12$) among treatment means for both rainbow and brook trout, or for the combined data from both species. Only 28 of 3,000 fish in the experiment died, 7 immediately and 21 delayed over a 15-day period. Rainbow trout represented 79% total mortality, while the brook trout accounted for the remaining 21% of the mortality. The combined total mortality was 0.0% for the control group (unshocked), 1.8% at 350 volts, 1.3% at 700 volts, and 0.5% at 760 volts.

The number of survivors with visible abnormalities (burns, erratic swimming) was low, 0.0% for the control group, 1.6% at 360 V, 2.4% at 700 V, and 0.8% at 760 V. Radiographs showed that only 21% (6 of 28) of the dead trout had fractured or dislocated vertebrae; 77% (27 of 36) of the abnormal surviving fish had fractured or dislocated vertebrae, the injury usually occurring between the 15th and 25th abdominal vertebrae.

Hudy, M. 1986. Comments: Mortality from high voltage AC electrofishing. N. Am. J. Fish. Manage. 6:134.

Rainbow trout (*Oncorhynchus mykiss*), brook trout (*Salvelinus fontinalis*), morphology, electric fishing, electrodes.

Hudy responds to Norman G. Sharber's criticism of his 1985 results, defending his conclusion that "high voltage AC electrofishing probably is acceptable for most management uses in low conductivity waters."

Jesien, R. and R. Hocutt. 1990. Method for evaluating fish response to electric fields. Pages 10-18 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Channel catfish (*Ictalurus punctatus*), controlled environment, physiology, electric gear, electric parameters, electric fishing.

Experimental apparatus designed to investigate fish response to electric fields induced by commercially available electric fishing units is described. The objective of the study was to determine threshold power densities to tetanize channel catfish over a range of conductivities, pulsed AC and 30 Hz and 120 Hz PDC were used. Fish were exposed to the field for one second. The threshold power densities increased with increasing conductivity. Peak power densities required to tetanize fish at 100 μS/cm ranged from 4.8 to 13.5 $\mu W/cm^3$ and at 10,000 μS/cm ranged from 81.0 to 515 $\mu W/cm^3$. Average power density to tetanus ranged from 0.5 to 2.4 $\mu W/cm^3$ at 100 μS/cm and from 8.7 to 53.0 $\mu W/cm^3$.

Fish were more sensitive to DC when facing the cathode and sensitivity became more apparent as conductivity increased.

Understanding electric parameters and fish electrophysiology will greatly increase the CPUE of the Columbia River predator control fishery.

Johnson, I.K., W.R.C. Beaumont and J.S. Welton. 1990. The use of electric fish screens in the Hampshire Test, Itchen, England. Pages 256-265 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Atlantic salmon (*Salmo salar*), Hampshire, England, experimental gear, electric screens, fish passage.

Electric fish screens provide an alternative method to mechanical devices for blocking upstream fish passage. Electric fish screens were used in conjunction with resistivity fish counters in an investigation of upstream migration of salmonids in the Hampshire test. Three sites of differing configurations are presently being used. The experimental design and the preliminary results from using the screens are discussed.

Electric screens may prove to be an effective method to frighten squawfish away from areas of high smolt concentration, such as the tailrace areas of dams.

Koltz, A.L. and J.B. Reynolds. 1990. A power threshold method for the estimation of fish conductivity. Pages 5-9 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Gold fish (*Carassius auratus*), physiology, controlled environment, electric fishing, electrical parameters.

Electric fishing is primarily a problem of transferring electrical power from water to fish. If a sufficient amount of power is transferred, a particular response, such as taxis or narcosis, can be achieved. The major deterrent to power transfer is the difference between the conductivities of water and fish.

Goldfish were exposed to various voltage gradients in a tank containing water of 10 to 10,000 mhos conductivity. The resultant power densities applied to the water in order to achieve various responses (twitch, galvanotaxis or narcosis), when plotted as a function of water conductivity, conformed to the theory of maximum power transfer, i.e., when conductivities of fish and water were equal, the applied power needed was at a minimum. The resultant estimates of fish conductivity proved to be 5 to 10 times lower than reported elsewhere.

Lamarque, P. 1990. Twenty years of electric fishing expeditions throughout the world. Pages 344-351 in I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Electric fishing, electric gear, electric parameters, sampling.

The parameters that regulate electric fishing efficiency are numerous: water conductivity, temperature, depth, current velocity, turbidity, vegetation, operator ability, electrode suitability, fishing methods, and fish species and size. Electric fishing conditions from site to site are rarely similar. Comparisons of like fishing techniques are scarce. There is no general agreement among users as to the single best method. There is only a quasi-general agreement: direct current is the most efficient method if conductivities permit its use.

This paper outlines the characteristics of successful electric fishing operations. In a successful electrofishing operation it is highly desirable to produce an electrotaxic current (i.e., a current which attracts fish to the anode but does not tetanize them). The most commonly used electrotactic currents are constant DC, 3-phase fully rectified AC, single phase fully rectified AC at 30 Hz, and rectangular pulsed DC at 400 Hz on 10% duty cycle. The key to a successful electric fishing operation is flexibility in current form and shape.

Water conductivities are divided into three groups: Low conductivity waters (5 to 30 µS/cm), such as mountain streams and lakes, or areas associated with high rain runoff; medium conductivity waters (30 to 500 µS/cm), such as the Columbia River, which ranges from 80 to 200 µS/cm; and high conductivity waters (values greater than 500 µS/cm), mainly estuaries, brackish lagoons, and the sea.

Different fishing strategies must be adopted for each conductivity range. Fishing low-conductivity waters is difficult, but good results may be achieved by using very large electrodes (anode diameter >60 cm) and high peak voltages (800 to 1650 volts). Best results in medium waters are achieved with the combination of large anodes and electrotactic current. In high-conductivity water, pulsed DC (rectangular waves of either 400 Hz or 100 Hz at 10% duty cycle) and smaller electrodes need to be used in order to reduce energy requirements.

In general, all pulsed current can produce some mortality. The worst currents are condenser charges, AC at 50 to 60 Hz and 1/2 wave rectified AC at 50 to 60 Hz. Currents with electrotactic characteristics are least harmful. Mortality is species dependent, being the result of synaptic exhaustion (violent shock) or dislocation of vertebrae, particularly if the fish is decalcified because of spawning or poor nutrition.

Predator fish (e.g., salmonids, Percidae, Centrarchidae, Esocidae) are more easily caught than prey species. Bottom fish and poor swimmers are also difficult to catch. Carp and tilapia seem to build up a tolerance to subsequent electric fishing. Many species are frightened out of a fisher's effective zone by physical disturbances in the water. Smaller fish tend to be more resistant than larger fish. Vegetation and cover can hide stunned fish from capture. Electrode contact with muddy bottoms causes a diminution effect in the field; this may cause an increase in resistance and lead to overloading of the generator. In strong current, tetanized fish often are washed away from the catchers. Turbidity allows a close approach towards fish but reduces catching efficiency through poor visual contact.

The experiences gained from Lamarque's twenty years of work in electric fishing should be applied to the removal effort for squawfish.

Latta, W.L. and G.F. Myers. 1961. Night use of a direct current electric shocker to collect trout in lakes. Trans. Am. Fish. Soc. 90:81-83.

Brook trout (*Salvelinus fontinalis*), lakes, Michigan, traps, electric fishing gear, electric fishing, gear efficiency.

Fishing was done at night from a small electrofishing boat. A Homelite DC generator (230 volts, 9.3 amperes) provided power both for underwater illumination and for the electrical field. The specifications on wiring and boat layout were detailed.

Eight hours of electrofishing at night in 1959 in a small lake produced 514 fish from a known population of 700 fish. Night shocking resulted in the capture of as many trout per hour as did 36 trap days (one trap day being equivalent to one submerged wire trap set for 24 hours). Similarly in Ford lake, night shocking yielded as many trout per hour as did 30 trap days.

The CPUE for squawfish collected by electrofishing during the day and night should be compared as are day and night Merwin trap catches. Such comparisons would establish the best times for catching squawfish.

Lazauski, H.G. and S.P. Malvestuto. 1990. Electric fishing: results of a survey on boat construction, configuration and safety in the United States. Pages 327-339 in I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Electric fishing, electric gear, methods, survey, United States.

The intention of this survey was to gather information pertaining to: (1) boat types and uses, (2) anode and cathode design, (3) boat construction, (4) formation of standards for electric fishing boat configuration, construction, and safety. The comprehensive standards detailed for boat construction, configuration and safety should be reviewed and adopted by any electrofishing operation.

The survey results showed that a combination of techniques (current types) was preferred over any one technique. Most agencies use both backpack and boat shocking. Population estimation, tagging, and specimen collection were the most common reasons that agencies electrofished. The majority of electric fishing is done in the 100 to 200 µS/cm conductivity range. Only a minority of agencies indicated that they had ever actually assessed the efficiency of their equipment. The most common electrode design closely followed that of Novotny and Priegel (1974), using their circular Wisconsin ring array. Many agencies used homemade electric boats (271 units). All commercial units were purchased from either Smith Root Inc. or Coffelt Electronics.

Loeb, H.A. 1958. Comparison of estimates of fish populations in lakes. New York Fish and Game 5:66-76.

Carp (*Cyprinus carpio*), New York, population estimates, fishing gear, traps, electric fishing, electric seine, rotenone.

Population studies involving a number of fish, primarily carp, were carried out in three lakes ranging from 30 to 800 acres in size. Different sampling techniques were used and the data analyzed by both the Schnabel method and direct proportion. Loeb showed clearly that electrofishing for some species was more effective at night than during the daylight hours. Often the increase in effectiveness of this tool when used at night is ignored.

CPUE data for electrofishing on squawfish during the day vs. nighttime needs to be assessed and incorporated into our sampling schedule.

Lui Q., W. Daming, X. Ronngong and L. Jiefu. 1990. A method of improving fishing efficiency in lakes by using a seine net with pulsed current. Pages 41-45 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Common carp (*Cyprinus carpio*), crucian carp (*Carassius auratus*), China, aquaculture, electric seine, electric fishing, fisheries management, efficiency comparison.

In ponds with uneven, heavily silted bottoms, it is difficult to harvest the bottom-living common carp and crucian carp. Capture efficiency using the traditional seine netting method was as low as 5%. Carp exhibit diving behavior once enclosed in a seine, often escaping capture. In order to improve catch efficiency, an electric seine-net equipped with pulsed current was developed. The foot rope of a 1200-m drag seine-net was bound to an electric wire with 20% of its insulation stripped off to act as an anode. The power output was three phase, 220 V, half wave rectified AC irregularly pulsed at a frequency of 10 Hz. This current can be controlled to drive, concentrate and seine the escaping fish. Capture efficiency increased, ranging from 20% to 30%. Because squawfish also exhibit diving behavior in a net, future seining efforts may test electric seining.

Lui, Q. 1990. Development of the model SC-3 alternating current scan fish driving device. Pages 46-50 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), aquaculture, electric gear, electric parameters, electric fishing, gillnets, physiology.

The response of silver and bighead carp to alternating current was studied. It was reported that frequencies of the order of 80 Hz appear to have the greatest long-term residual effects on fish, but above and below this value the effect is less traumatic. The threshold electric field intensity for the different responses decreased with elevated conductivity. Significant differences were also found in the threshold field intensity between continuous and intermittent alternating currents.

The SC-3 Alternating Current Scan Fish Driving Device was developed to catch silver and bighead carp in reservoirs. With use of this gear, the catching efficiency was of the order of 62%, increasing to a maximum of 92%.

The concepts explored here may prove useful to a future capture technique that could combine the congregating effects of electricity on fish with a purse or large beach seine.

Mann, R.H.K. and T. Penczak. 1984. The efficiency of a new electrofishing technique in determining fish numbers in a large river in Central Poland. J. Fish. Biol. 24:173-185.

Pilica River, Poland, fisheries management, sampling, electric gear, AC electric barrier, electric fishing.

A new method for determining fish populations in large rivers, which entailed electrofishing from boats downstream to an AC electric barrier, produced capture efficiencies ranging from 28% to 82%.

This study had two objectives: (1) to test a new electrofishing technique for estimating the numbers of fish in a large river, (2) to compare these catch results with those made before changes occurred in the management of the river.

A section of river to be sampled was divided into three subareas (A, B, C). A 220 V AC barrier was set across A, B, and C at the end of the fishing site. The subareas were fished simultaneously, each with boat-mounted pulsed DC equipment (3 Kw, 220 V, 50 Hz). Energy was delivered to the water via two hand-held anodes. The boats were steered downstream towards the AC barrier. Any fish not picked up by the boats were driven into the AC barrier and killed by the current. Most fish were recovered 25 m downstream of the AC barrier.

This sampling technique yielded good catch results. However, many of the captured fish were killed by the AC barrier. Therefore, this sampling technique would not be applicable in a project where incidental mortality is of concern.

Malvestuto, S.P. and B.J. Sonski. 1990. Catch rate and stock structure: a comparison of daytime versus nighttime electric fishing on West Point Reservoir, Georgia. Pages 210-218 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), West Point Reservoir, Georgia, CPUE, nighttime, daytime, size distribution, electric fishing.

A boom mounted electric fishing boat was used to sample shoreline areas of West Point Lake. A three phase, 120 to 240 V, 3.5 Kw, AC generator was used to supply pulsed DC via Coffelt model VVP-2C variable voltage pulsator. Catch rate (number of stock-sized fish caught per 45 minutes electric fishing sample) and stock structure (proportional stock density, PSD) were compared for daytime versus nighttime samples of largemouth bass >20 cm in total length and for bluegill >8 cm total length.

Six paired (day, night) samples were taken during fall, spring, and summer. Statistical analysis showed a significant difference ($p = 0.05$) between catch rate of bass captured during the day vs. night for the summer season only, with an increase of nine bass for sample at night. Bluegill catch rates were significantly greater during the night for all seasons.

Electrofishing at night is generally thought to be more effective than electrofishing during the day. This paper showed the importance of incorporating the seasonal and diel movements of the target species when establishing a sampling regime.

Maxfield, G.H., G.E. Monan and H.L. Garrett. 1969. Electrical installation for the control of the northern squawfish. U.S. Fish Wildl. Serv. Spec. Sci. Rep. No. 583. 14 p.

Squawfish (*Ptychocheilus oregonensis*), Cascade Reservoir, Idaho, electricity, trap, experiment to trap squawfish for the purpose of control.

Electricity was tested in Cascade Reservoir, Idaho, as a means to attract squawfish into traps during their spawning migration. Significantly more squawfish entered the traps when power (140 to 180 volts, AC) was on (354 fish) than off (110 fish). A variety of voltages, pulse durations and frequencies were tested. Other fish species were also captured in the traps.

This study demonstrated that electricity could be used to enhance catches of squawfish. However, electricity may not be useful for controlling squawfish throughout the Columbia River because of safety restrictions and the need for electrical generators when fishing away from a dam.

Maxfield, G.H., R. H. Lander and C.D. Volts. 1970. Laboratory tests of an electric barrier for controlling predation by northern squawfish. U.S. Fish Wildl. Serv. Spec. Sci. Rep. No. 611. 8 p.

Squawfish (*Ptychocheilus oregonensis*), salmon, Drano Lake, Columbia River, electricity, control of movements and predation of squawfish below hatcheries.

Preliminary laboratory results suggest that squawfish will avoid electrical fields, which could be used to reduce predation during releases of hatchery smolts. Although results may vary with water temperature and resistivity, these data suggest that electrodes placed 61 cm apart were most effective. Approximately 85%, 93% and 96% of the swimming squawfish were blocked by voltage gradients of 0.75, 1.00, and 1.25 volts, respectively. Electricity appears to have potential for blocking squawfish movements, although field testing is needed.

Maxfield, G.H., R.H. Lander and K.L. Liscom. 1971. Survival, growth, and fecundity of hatchery-reared rainbow trout after exposure to pulsating direct current. Trans. Am. Fish. Soc. 3:546-552.

Rainbow trout (*Oncorhynchus mykiss*), morphology, physiology, controlled environment, electric fishing.

Unshocked control and shocked test rainbow trout were held through spawning to determine the effects of electrical shock on the survival, growth, and fecundity of two year classes--young-of-the-year 1953 and yearlings of the 1952 year class--and on the survival of the eggs and fry of the exposed fish. The test fish were exposed for 30 seconds to one of two sets of electrical conditions. Exposure was longer than that usually encountered by fish during either electrical guiding or collection with a pulsating direct current shocker.

The survival, growth, and fecundity of the fish apparently were not affected by the electric shock, nor were the survival and development of their offspring. For the 1952 year class, cumulative survival percentages were 92.9 for the test fish and 89.6 for the controls. For the 1953 year class, the respective percentages were 90.1 and 84.0.

McCrimmon, H.R. and B. Bidgood. 1965. Abnormal vertebrae in the rainbow trout with particular reference to electrofishing. Trans. Am. Fish. Soc. 94:84-88.

Rainbow trout (*Oncorhynchus mykiss*), Great Lakes, laboratory experiments, morphology, gear comparisons, electric parameters, electric fishing, x-ray.

Rainbow trout collected by AC and DC electrofishing from four distinct Great Lakes watersheds were found, when x-rayed for taxonomic purposes, to include fish with abnormal vertebrae. Damage caused by electrofishing shock was compared with naturally occurring abnormal vertebrae in immature and mature fish.

Of 291 trout taken by electrofishing, 7.6% showed abnormal vertebrae. An examination of the vertebral columns of 80 hatchery-reared trout prior to shocking showed 3.8% abnormal vertebrae. A reexamination of the vertebral columns of the hatchery-reared fish following electrofishing showed no change in the incidence of abnormal vertebrae.

A total of 371 hatchery trout were shocked and examined by x-ray. The 371 trout examined had an average of 62.4 vertebra. In 23 of the 25 fish with damaged vertebrae, the damage was between the 17th and 44th vertebrae, the abdominal region between the dorsal and pelvic fins. There was an average of 6.2 damaged vertebrae. Dissection of the trout with abnormal vertebrae showed these vertebrae to be immovably and permanently fused together (25%-40% thicker than adjacent normal vertebrae). This fusion precludes any possibility that this condition was caused by electrofishing shock.

The prevalence of abnormal vertebrae among fish is well established (Gabriel 1944). Hauck (1947) reported on several types of injuries found in rainbow trout subjected to 80 to 90 volts AC, including damaged vertebrae. Unless fish are x-rayed prior to shocking, as done in this study, the extent of damage to the vertebral column actually caused by shocking may be difficult to assess.

The incidental damage to non-target species, salmonids especially, needs to be monitored. This paper presents useful information as to the type and frequency of naturally occurring vertebral damage.

McLean, I.A. 1990. Safety in electric fishing: a United Kingdom view. Pages 324-326 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Electric fishing, safety survey, United Kingdom.

In 1986, the Health and Safety Executive Board carried out a survey within the United Kingdom to examine present electric-fishing practices. The aim of the survey was twofold: (1) to examine the safety aspects of electric fishing equipment actually being used, (2) to examine safety procedures followed in electric fishing and compare those with existing national guidelines.

Safety in electrofishing should be a project's number one concern. All information regarding this topic should be given special consideration.

Mesa, M.G., and C.B. Schreck. 1989. Electrofishing mark-recapture and depletion methodologies evoke behavioral and physiological changes in cutthroat trout. Trans. Am. Fish. Soc. 118:644-658.

Cutthroat trout (*Oncorhynchus clarki*), Yamhill River, Oregon, hatchery, streams, behavior, physiology, electrofishing.

This paper evaluated electrofishing for use in population estimation studies. The effects of capture, handling, marking and multiple electro-shocks on normal behavior and physiology of cutthroat trout were described. Electrofishing and the procedures involved in estimating fish population size (capture, handling, marking) elicit a general stress response in fish. In a natural stream, cutthroat trout released after capture by electrofishing and marking showed distinct behavioral changes: fish immediately sought cover, remained inactive, did not feed, and were easily approachable by a diver. A 3-4 hour recovery time was required for 50% of the fish. In an artificial stream, hatchery-reared and wild trout decreased their rate of feeding and aggression. Hatchery fish appeared to return to normal after 2-3 hours, wild fish recovering in 24 hours. Hierarchical rank was affected only among the wild trout; socially dominant fish recovered faster than intermediate and subordinate fish. Physiologically, multiple electroshocks elicited the most severe stress response by elevating blood levels of lactate and cortisol. Plasma concentrations of cortisol and lactate returned to control levels by 6 hours after electroshock treatment.

The behavioral and physiological responses of fish to electrofishing affect the accuracy of catch depletion population estimates by violating key assumptions of the methods, especially the assumption of equal catchability of fish.

Newman, L.E. 1992. Spinal injury of walleye caused by PDC electrofishing [Abstract] Page 14 *in* Western Division of the American Fisheries Society, Program Abstracts [Annual meeting]. American Fisheries Society, July 13-16 1992, Western Division, Bethesda, Maryland.

Walleye (*Stizostedion vitreum*), electrofishing, PDC, injury, mortality, Wisconsin.

Walleye were taken by PDC electrofishing and analyzed by x-ray and autopsy for final injuries. Of the 30 fish examined, 9 (28%) had spinal injuries involving fractured vertebrae, and ruptured dorsal arteries. There was no difference in injury rate between 30 Hz and 120 Hz. Future work will include tests using larger sample sizes, controls, and egg viability.

Nigro, A. et al. 1985. Abundance and distribution of walleye, northern squawfish and smallmouth bass in John Day Reservoir. Annual progress report, 1985. Oregon Dept. Fish. Wildl. 162 p.

Squawfish (*Ptychocheilus oregonensis*), walleye (*Stizostedion vitreum*), smallmouth bass (*Micropterus dolomieui*), Columbia River, gillnets, trapnets, boat electrofishing, hook and line, radio tracking, angler survey, characteristics of salmon predator populations.

A variety of gear types were used to determine the distribution, abundance, and rates of growth and mortality of squawfish, walleye, and smallmouth bass in the John Day Reservoir. Radio tagging indicated that squawfish and walleye moved throughout the reservoir, although they tended to be close to the shore during periods of high water velocity. Squawfish were captured in greatest quantities during May to July. Abundance of squawfish (>250 mm), walleye (250 mm), and smallmouth bass was approximately 95,000, 16,000, and 11,000 fish, respectively.

Detailed records of catch data are given in an appendix and may be used for comparison in the squawfish control study. Greatest catch rates of squawfish were made by electrofishing (3 to 4 fish per hour) and the small-mesh bottom gillnet (1.34 fish per hour).

Novotny D.W. and G.R. Priegel. 1974. Electrofishing boats. Improved designs and operational guidelines to increase the effectiveness of boom shockers. Technical Bulletin No. 73. Department of Natural Resources. Madison Wisconsin. 49 p.

Electric gear, electric parameters, boat configurations, construction, safety, electric fishing.

The first segment of this report presents basic concepts and design guidelines for electrofishing boats, including a summary of problem areas, descriptions of the basic aspects of electricity, safety, and general design and operating guidelines.

Experimental and operational PDC, DC, and AC electrofishing boats designed during the project are described in detail in the second segment. Electrofishing performance and operating guidelines based on actual field operation as well as design information on power supplies, controls and electrode systems are presented. Supporting information on electrofishing safety, calculations of electrode resistance, wiring diagrams and lists of components used in newly designed electrofishing boats are included in the appendices.

This paper should be considered required reading for any persons working with electrofishing equipment. The material presented here has served as the baseline standard from which present-day commercially available electric fishing gear has evolved.

Paragamian, V.L. 1989. A comparison of day and night electrofishing: size structure and catch-per-unit-effort for smallmouth bass. N. Am. J. Fish. Manage. 9:500-503.

Smallmouth bass (*Micropterus dolomieui*), catch-per-unit-effort, modeling, Maquoketa River, Iowa, electrofishing, day vs. night fishing comparisons.

Catch-per-unit-effort and proportional stock density (PSD) of smallmouth bass were compared between day and night electrofishing samples. The data were collected from the Maquoketa River, Iowa, during the spring of 1978. CPUE for all size ranges of smallmouth bass was significantly higher for night fishing than for daytime. Smallmouth bass were captured with the aid of a boat-mounted, 230-V, AC, 3,000-W, 7.5-A electrofishing unit and two experienced dipnetters. The PSD from daytime catches was 27, whereas it was 33 for night, a 22% increase. Night electrofishing in rivers is recommended for this species to improve gear efficiency, reduce the time necessary to make population estimates, and increase sample size for determining length frequency distributions and age structures.

Squawfish are active nocturnal feeders. An electrofishing evaluation for potential removal programs should have a strong night fishing component to it.

Penczack, T., and H. Jakubowski. 1990. Drawbacks of electric fishing in rivers. Pages 115-122 in I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Large rivers, Poland, modeling, site characteristic vs. fishing efficiency, behavior, electric fishing.

In order to obtain an accurate picture of the fish community and population structure in large rivers, it is necessary to have not only an adequate sampling technique but also a knowledge of the biology of the fish species (Hunt and Jones 1974).

The number of a species caught is related to the importance of each species in the community structure and their migratory habits. Increased fishing effort (number of successive runs) on each sampling occasion can determine the importance of a species in a community, while repetition of electric fishing during each year is required to fully assess the contribution of migratory species. The relationship between site characteristics and catching efficiency for some species is well pronounced.

Squawfish exhibit a spawning migration and then form feeding aggregations. To be most effective, a removal effort should be aligned with these seasonal and behavioral patterns.

Pierce, R.B., D.W. Coble and S.D. Corley. 1985. Influence of river stage on shoreline electrofishing catches in the upper Mississippi River. Trans. Am. Fish. Soc. 114:857-860.

Bluegill (*Lepomis macrochirus*), drum (*Aplodinotus grunniens*), modeling, catch-per-unit-effort, upper Mississippi River, Illinois, boom electrofishing boats, electric fishing.

The numbers of fish and the species caught per unit of effort along main channel shorelines in pool areas of the upper Mississippi River were inversely related to river water level.

Fish were stunned with AC electrofishing gear. A boom shocker, described by Novotny and Priegel (1974), was initially operated at 9 to 11 amps with 320 V, and later at 7 to 9 amps with 230 V because of bleeding observed on shocked fish. A second catcher boat was used to pick up fish missed by the netting crew. A total of 5,652 fish of 50 species was caught. Sampling occurred in June, August and October in 1978 and 1979, and in June and August in 1980.

Lower catch-per-unit-effort at higher river stages could be caused by reduced fish abundance along shorelines, reduced electrofishing efficiency, or both. In general, electrofishing catches are inversely related to water level, but it varies for individual species--strong for some, no relation for others.

Squawfish catch rates may be low during the high flows of spring. Increased catch-per-unit-effort should be experienced after the Snake and Columbia River Dams cease spilling.

Pratt, S.V. 1954. Fish mortality caused by electrical shockers. Trans. Am. Fish. Soc. 84:93-96.

Brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), controlled environment, morphology, electric parameters, AC current verses DC current, electric fishing.

Under experimental conditions, legal-sized brook, brown, and rainbow trout were exposed to 110 volt AC and 230 volt DC. The average mortality was 6.4%. Immediate mortality was 4.3% and delayed mortality accounted for 2.1%. Of the trout exposed to AC, 11.1% died, whereas only 2.0% treated with DC were killed. Mortality appeared unrelated to species or size.

Hauck (1949), using 495 watt, 110 volt AC with hand-held electrodes, reported a 26% mortality in the rescue of large rainbow trout (average weight, 3.7 pounds) from an irrigation canal. Shelter (1947), using similar equipment on smaller trout in Michigan streams had a mortality rate of generally less than 1.0%. In Pratt's work, all of the fish that were killed immediately had been accidentally left in the electric field longer than the prescribed period (one foot away from an electrode for 15 seconds).

Incidental harm and delayed mortality to salmonids from electrofishing for squawfish need to be evaluated and kept at a minimum.

Pugh, J.R., G.E. Monan and J.R. Smith. 1970. Effects of water velocity on the fish-guiding efficiency of an electrical guiding system. U.S. Fish Wildl. Serv., Fish. Bull. 68(2):307-324.

Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), rainbow trout (*O. mykiss*), Yakima River, Prosser, Washington, fish passage, electrical screens, inclined screen trap, gear efficiency.

This study was performed in 1962 in a diversion of the Yakima River near Prosser, Washington. Massive structures for regulating the water velocity, producing the desired electrical field, and collecting the guided fish were installed. The fish tested were wild downstream migrating fingerlings of chinook salmon, coho salmon, and rainbow trout.

Fish guiding efficiency tended to decrease with increasing water velocity. The guiding efficiencies of the electrical system at water velocities of 0.2, 0.5, and 0.8 m/s were, respectively, 84.2, 54.2 and 50.2% for chinook; 82.4, 47.8, and 42.8% for coho; and 69.9, 40.2, and 44.8% for rainbow. The use of electricity to guide juvenile migrating salmon may be feasible in certain environments where water velocity does not exceed 0.3 m/s.

If future squawfish removal efforts were to include electric traps, weirs, or nets, the effects of water velocity on the efficiency need to be addressed.

Randall, R.G. 1990. Effect of water temperature, depth, conductivity and survey area on the catchability of juvenile Atlantic salmon by fishing in New Brunswick streams. Pages 79-80 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Atlantic salmon (*Salmo salar*), small streams, New Brunswick, Canada, modeling, environmental factors, gear efficiency, electric fishing.

During the electric fishing surveys in the Miramichi and Restigouche rivers, New Brunswick, probabilities of capture of juvenile Atlantic salmon varied significantly, both spatially and temporally. Average capture probabilities were significantly greater for parr (0.5) than fry (0.4). The hypothesis that environmental factors at the time of sampling (water temperature, conductivity, depth, discharge, and survey area) significantly affected capture probabilities could not be rejected. However, correlations between environmental factors and catchability were poor and inconsistent. Environmental conditions that would maximize capture probabilities could not be identified. Therefore, at least four electric fishing sweeps are necessary to estimate in-stream juvenile salmon populations.

Although the habitat and objectives detailed here are unique, the basic principles of factors affecting electrofishing success are applicable to squawfish removal.

Reynolds, J.B., S.M. Roach, and T.T. Taube. 1992. Injury and survival of northern pike and rainbow trout captured by electrofishing [Abstract] Page 15 in Western Division of the American Fisheries Society, Program Abstracts [Annual Meeting]. Am. Fish. Soc., July 1-16 1992 Western Division, Bethesda, Maryland.

Northern pike (*Esox lucius*), rainbow trout (*Oncorhynchus mykiss*), PDC, Coffelt Pulsed System (CPS), injury, mortality, Alaska.

The 1990 and 1991 studies were conducted to determine the effects of various electrical wave forms on large northern pike and rainbow trout. The results were quite different for the two species. PDC (30-60 Hz, 100-400V) produced spinal injury rates among northern pike of only 5-12%, with an increase to 29% when a 120Hz wave form was applied at 300-600V. Survival and growth of injured and control groups of pike held for nearly one year were not significantly different. All types of conventional PDC (20-60Hz) produced spinal injury rates of 40-60% in hatchery rainbow trout. Only continuous DC and CPS™ produced injury rate under 18% in the hatchery. In the field, CPS™ produced the lowest injury rates. It was concluded that 60Hz PDC could be used to capture northern pike with minimal injury problems and the DC and CPS™ should be further evaluated for electrofishing rainbow trout. Electrofishing-induced injuries vary among species and studies. More species need to be studied.

Saltveit, S.J. 1990. Studies on juvenile fish in large rivers. Pages 109-114 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Atlantic salmon (*Salmo salar*), brown trout (*Salmo trutta*), Norwegian rivers, population parameters, hydroelectric power, habitat surveys, electric fishing.

Norway is the largest user of hydroelectric power per capita in the world. In order to evaluate the effect of regulating large rivers and to identify the necessary mitigation measures (in-stream flows, stocking, fish passage), power companies have organized studies both before and after regulation. Electric fishing is a commonly used tool in these studies. Electric fishing has been used together with other sampling techniques to study the habitat preference of juvenile Atlantic salmon and brown trout in some Norwegian rivers.

This paper details alternative uses and parameters of electric fishing.

Schreck, C.B., R.A. Whaley, M.L. Bass, O.E. Maughan and M. Solazzi. 1976. Physiological responses of rainbow trout (*Salmo gairdneri*) to electroshock. J. Fish. Res. Board Can. :76-84.

Rainbow trout (*Oncorhynchus mykiss*), physiology, lactate, pulsed direct current, controlled environment, electric fishing.

This paper investigated the physiological consequences of electroshock-induced paralysis in rainbow trout as part of an investigation into the efficiency of electroshocking as a tool for population estimation. The assumption tested was that once a fish is shocked and swims away, it rapidly returns to a normal physiological condition, or whether there are lasting residual effects (stress, avoidance or mortality) that would reduce an individual's chance for recapture. A total of 48 15-month-old hatchery-reared rainbow trout (average weight, 169 +/- 5.4 g) was held outside in concrete raceways. A Coffelt backpack shocker (230 V, 2.3 A DC) was used to simulate electrofishing in a stream.

The results showed that electroshocking elicited an immediate increase in plasma corticoid and lactate concentrations. Plasma lactic acid levels doubled immediately after shocking and remained high for one hour and returned to near normal within three hours. Plasma protein, calcium, magnesium, and androgen levels were not measurably affected. A violent 'coughing' response was noted. Normal breathing resumed after 60 seconds. The circulatory efficiency of these fish was impaired by raised blood lactate levels.

Schreck postulates that electrofishing elicits a general stress response lasting several hours. This stress closely parallels that induced by hypoxia (oxygen debt) or severe muscular activity, the degree of stress being directly related to the severity and duration of applied electric field.

Death of fish collected by electrofishing may be the result of both acute and chronic factors. Immediate death is due to direct trauma, i.e., respiratory failure, hemorrhaging, or fractured vertebrae. Delayed mortality results from the combined effects of trauma, factors associated with the repayment of oxygen debt, and stress-induced exhaustion.

If electrofishing is to be used as the capture technique in a mark-recapture population study for squawfish in the Columbia River, the sampling bias of the electrofishing unit used in such a regime should be carefully assessed.

Sharber, N.G. and S.W. Carothers. 1987. Submerged, electrically shielded live tank for electrofishing boats. N. Am. J. Fish. Manage. 7:453-455.

Humpback chub (*Gila cypha*), Colorado River, physiology, electric gear, Faraday's law, electric fishing.

Fish caught by electrofishing are usually held in live tanks until data are recorded. If water in these holding tanks is not circulated, changes in temperature and oxygen concentration may be harmful to the fish.

This paper details the design specifications for a successfully used live tank which is submerged through the hull of a catamaran type white water raft. The tank is placed in the water being electrofished so that power free, continuous water circulation is maintained. Fish in the tank are protected from the electrofishing field by the design of the tank, which uses to advantage a phenomenon known as Faraday shielding (an electrostatic shield created with conductor, ground, and a series of parallel wires). This tank is easy and inexpensive to construct and safe to use on many styles of boat.

Sharber, N.G. and S.W. Carothers. 1990. Influence of electric fishing pulse shape on spinal injuries in adult rainbow trout. Pages 19-26 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Rainbow trout (*Oncorhynchus mykiss*), Colorado River, morphology, x-ray, autopsy, electric parameters, electric fishing.

Adult rainbow trout captured from the Colorado River by electric fishing were analyzed for spinal injury by x-ray and autopsy techniques. During electric fishing, three pulse shapes were used and compared. The analysis of 209 x-rays showed that 50.2% of the fish suffered spinal injuries involving an average of eight vertebrae (dislocated and/or splintered vertebrae). The number of fish injured was significantly different between the exponential pulse (44.4%) and the 1/4 sine wave pulse (67.3%) and between the square wave (43.6%) and the 1/4 sine wave (67.3%). The severity of the injuries in the spinal column changed as a function of pulse shape. The average number of vertebrae displaced or broken was significantly greater with the 1/4 sine wave (9.5) than for the exponential pulse (6.6). Of the three commonly used pulsed wave shapes, the exponential pulse is the most effective and least traumatic.

In this study, electric fishing was performed at night using a boat-mounted Honda 6.5 KVA, gas-powered single-phase (60 Hz), 240 volt generator. Electrodes were two stainless steel balls 30 cm in diameter. Captured fish were placed in a Faraday shielded live well (Sharber and Carothers 1987). A Coffelt VVP-15 (variable volt pulsator) generated the square wave and 1/4 sine waves. The exponential pulse was generated through a pulsator of the authors' design (Vector Max 101). Water temperature ranged from 9 to 11 degrees Celsius, conductivity ranged from 600 to 800 µS/cm, and water depth ranged from 1 to 3 meters. The trout had a mean total length of 360 mm.

During x-ray analysis and autopsy, it was possible to distinguish between the abnormalities caused by electric fishing and those occurring naturally. Natural abnormalities were indicated by more dense and fused section of the vertebral column. Electric-induced injuries are usually separations of the vertebrae showing visible misalignment. All injuries noted were associated with internal bleeding and/or splintered bones due to compression fractures caused by tetanus in the muscle tissue along the spinal column. Fish that possessed natural abnormalities (compacted vertebrae) displayed no hematoma or splintered bone.

The incidence of injury (43.6% - 67.3%) reported here represents the highest level of electric fishing induced damage to fish vertebrae and nearby soft tissue yet reported. Hauck (1949) recorded 26% mortality with large rainbow trout, Pratt (1954) reported 6.4% mortality on rainbow, Hudy (1985) recorded >5% on brook and rainbow trout, McCrimmon and Bidgood (1965) reported 7.6% in rainbow trout, and Spencer (1967) had mortalities on bluegill which ranged from 1.5% to 12.2%.

It has been Sharber and Carothers' ground-breaking work on electrofishing-induced injuries that has established the need for extensive re-evaluation of accepted electrofishing principles and practices.

Simpson, D.E. and J.B. Reynolds. 1977. Use of boat-mounted electrofishing gear by fishery biologists in the United States. Prog. Fish Cult. 3(2):88-89.

Mail survey, United States, fishery biologists, electric gear, electric fishing.

A 1976 mail survey of fishery biologists in the continental United States indicated that boat-mounted electrofishing gear was used on lakes more often than streams (71%), and for management rather than research (54%, 231 respondents). Alternating current was used by 62%, and about two thirds had at least one device for modifying electrical current (e.g., variable voltage pulsator). PDC was used more often in research than in management, in steams than in lakes, and in the West than in other regions of the country.

A boat-mounted Smith-Root 7.5 GPP or Coffelt VVP-15 electrofishing system would prove effective at removing squawfish from the Columbia River.

Snyder, D.E. and S. A. Johnson 1991. Draft index bibliography of electrofishing literature. Prepared for USDI Bureau of Reclamation and Glen Canyon Environmental Studies Team. Larval Fish Laboratory, Colorado State Univ., Ft. Collins, CO 80521.

Electrofishing, indexed bibliography.

This topically indexed bibliography of 854 references was prepared for a review of fish injuries and mortality caused by electrofishing and the various factors associated with these impacts. This bibliography is extensive and should be considered a primary reference source for any electrofishing project. The topic headings covered are: effects of electric fields on fish, factors affecting fish response and electrofishing efficiency, comparisons of effects of factors with non-electric gear as technical gear design, construction and operation, application, sampling design and analysis, safety regulations and guidelines. The required research involved in establishing and maintaining an electrofishing operation would be greatly facilitated by use of this bibliography.

Spencer, S.L. 1967. Internal injuries of largemouth bass and bluegill caused by electricity. Prog. Fish Cult. 29:168-169.

Largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), controlled conditions, Alabama, harm caused by AC, DC electrofishing.

This paper reported on the incidence and severity of injury on three warm-water species of fish (bluegill, largemouth bass and channel catfish) after being exposed to several common types of AC and DC electrofishing current.

Fish were subjected to the selected voltage and exposure period, frozen, and then later dissected. In bluegill, dislocated vertebrae and ruptured dorsal arteries were easily seen with the unaided eye. Most ruptures were accompanied by a local blood clot. In every test with bluegill 230 volts AC gave the highest incidence (12.2 %) of injury, 115 volts AC gave 4.6% injury, and 115 volts DC gave 1.5% injury. Additional tests on bluegill showed that there is no apparent relationship between exposure time and incidence of injured vertebrae. Vertebral injury appears to occur immediately upon exposure to the electrical stimulus.

When electrofishing for squawfish, potentially harmful effects on incidentals such as bluegill may be abated by operating the electrofishing equipment at less harmful current and waveforms (i.e., pulsating 115 volt DC over AC).

Steinmets, B. 1990. Electric fishing: some remarks on its use. Pages 1-4 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Mail survey, European Inland Fisheries Advisory Commission (EIFAC), fishery biologists, electric gear, electric fishing.

A questionnaire to identify the present use of electric fishing was sent to 25 EIFAC national correspondents. Replies from 30 agencies in 10 European countries were received. Classical wading and classical boat fishing (two hand-held anodes) on large water bodies are the main electric fishing activities in Europe. In the United States, boat fishing with boom-mounted arrays is most common (Lazauski and Malvestuto 1984).

Sternin, V.G., I.V. Nikonorov and Y.K. Bumeister. 1972. Electric fishing, theory and practice. Translated from Russian by Israel Program for Scientific Translations. Jerusalem, 1976.

Electric parameters, behavior, physiology, morphology, fishing gear, electric gear, electric fishing.

This textbook presents detailed material on electric theory, electrical conductivities in water, electrode function and design, electrical fields in water, conductivities of fish, fish behavior in electric fields, the effects of electricity on fish, and electric fishing gear and its operation.

This book should be considered a complementary text to I.G. Cowx's Fishing with Electricity.

Stewart, P.A.M. 1990. Electrified barriers for marine fish. Pages 243-255 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Atlantic salmon (*Salmo salar*), marine aquaculture, Aberdeen, Scotland, controlled environment, behavior, physiology, electric parameters, electric barriers, behavior of fish to electric barriers.

This study was concerned with low-powered electrified fish barriers. Useful basic information on the form of electric stimulus needed to operate a barrier by defining the pulse shapes which induce significant muscular contractions in fish is detailed. These contractions are an irritant, which do not themselves produce a particular behavioral reaction, but can induce fish to leave an electrified zone.

It was found in both aquarium and sea-cage experiments that the electrified zone has to be clearly visible to the fish before it acts as a barrier. The electric field appears to reinforce the visual impact of a barrier. Observations on the effects of an electrified barrier in a sea cage found that flat fish, but not round fish, could be confined. A bubble curtain tested under the same conditions confined round fish, but not flat fish.

It is feasible that present Merwin Traps could be upgraded to include electric barriers.

Taylor, G.N., L.S. Cole and W.F. Sigler. 1957. Galvanotaxic response of fish to pulsating direct current. J. Wildl. Manage. 21(2):201-213.

Rainbow trout (*Oncorhynchus mykiss*), physiology, electrical parameters, continuous direct current, pulsating direct current, alternating current.

The galvanotaxic response of fish to PDC and DC was investigated. Both PDC (96 pulses per second) and DC using duty cycles of 0.33, 0.47, and 0.88 yielded good galvanotaxic responses in rainbow trout. Pulsed DC reduced the necessary power requirements by 45% as compared with continuous DC. Tests using 0.47 and 0.88 duty cycles indicate that they were less efficient at producing galvanotaxis than the 0.33 duty cycle.

There were no mortalities on the 91 fish treated with continuous DC, 0.3% mortality occurred in the 1,641 PDC-treated fish, and 42% mortality occurred in the 46 fish treated with alternating current. In general, this study suggests that PDC (triangular pulse shapes) run at lower duty cycles with a fast pulse rate (96 Hz) is an effective and efficient method of electrofishing. This information could be directly applied to the squawfish electrofishing removal effort.

Vibert, R. 1963. Neurophysiology of electric fishing. Trans. Am. Fish. Soc. 92(3):265-275.

European eel (*Anguilla anguilla*), brown trout, (*Salmo trutta fario*), rainbow trout (*Oncorhynchus mykiss*), neurophysiology, laboratory experiment, direct current, galvanotaxis, electric fishing.

The basis for contemporary understanding of the causative mechanisms involved with fish neurophysiology in electrofishing has been established primarily by the work of R. Vibert and fellow Frenchman P. Lamarque.

This paper summarized Vibert's 100-page study that comprehensively identified the main reactions fish demonstrate in a continuous direct current electric field. The mechanisms of the observed behavior were investigated and explained in terms of the fish nervous system.

Vibert described the following reactions of fish to a direct-current field of increasing strength: (1) primary reactions without galvanotaxis, fins and muscular twitching, (2) inhibition of normal swimming, (3) galvanotaxis, induced forced swimming (4) narcosis, relaxation of musculature, (5) pseudo-forced swimming, tetanus, second stage of forced swimming period, (6) tetanus hypertonic stiffness, seizure of musculature being induced at high voltages, often followed by death.

The material presented by Vibert is one of the definitive works on fish neurophysiology in electric fields. This material is still directly applicable to today's electrofishing operations.

Weisser, J.W. and G.T. Klar. 1990. Electric fishing for sea lampreys (*Petromyzon marinus*) in the Great Lakes. Pages 59-64 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

Sea lamprey (*Petromyzon marinus*), Great Lakes, fishery management, fishing gear, traps, poison, electric weirs, electric fishing.

By the mid 1940s, it was apparent that the parasitic-phase sea lamprey were rapidly depleting valuable fish stocks in the Great Lakes (Smith et al. 1974). This paper summarizes electric fishing gear developed to collect adult and larval sea lampreys in the tributaries and offshore areas of the Great lakes.

Electric fishing for lampreys in the Great Lakes began with stream surveys in the 1940s. The first control effort began in 1952 with the development of in-stream electric weirs. More than 750,000 adult sea lampreys were trapped and destroyed from 1953 to 1969 (Smith 1971). Juvenile lampreys were collected with various backpack shocking units, the most modern and effective being the Abp-2 backpack electrofishing unit. Electric trawls were also used, but with limited success, being later replaced by an effective bottom toxicant.

Future agency-operated squawfish removal methods could include electric weirs or electrified Merwin Traps. The present longline commercial fishery could utilize the backpack units in the collection of juvenile lampreys for bait purposes.

Welton, J.S., W.R.C. Beaumont and R.H.K. Mann. 1990. The use of boom-mounted multi-anode electric fishing equipment for a survey of the fish stocks of the Hampshire Avon. Pages 236-242 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

River Avon, Hampshire, United Kingdom, collection methods, site selection, modeling, electric gear, electric fishing, comparison of capture techniques.

Two methods were compared: (1) three wooden punts deployed across a width of river, each containing a fishing team with a generator and two hand-held anodes, and (2) a boom-mounted, multi-anode electric fishing system on a single boat. After a series of trials, the boom-mounted multi -node system was chosen to be used in the main survey of the river.

The boom electric fishing boat was modeled after the system designed by the Severn-Trent Water Authority (Cowx et al. 1988). It was a 4.3 meter long cathedral hulled boat, propelled by a Honda 100 (9.9 HP) outboard, with a 10 m boom pivoted in the center and mounted on the bow. Ten 800 mm tubular copper anodes (30 mm diameter) were suspended at equally spaced intervals along the boom. Two inflatable rubber boats were rowed behind the main boat to act as additional catchers. Electrical power was from a 7.5 KVA Allan generator to a Millstream LR (FB8A) electric fishing box. This produced an output of 230 V, 18 A at 100 pulses per second.

Fishing down stream, four successive fishing runs were carried out at each site. The boom was kept at right angles to the bank. Speed was maintained at slightly faster than the current.

In this study, 14 species of fish were caught, totaling 2,807 individuals ranging in size from 3 to 1,100 mm. Catch efficiency ranged from 33% (grayling) to 52% (barbell). The efficiency per fishing run for all species combined at each site ranged from 33% to 50%, with an average of 42%.

In an attempt to increase catch efficiency, stop nets were set around electrofishing sites. Difficulties were encountered in setting stop nets in the river. If placed where water velocity was high, a large bag developed, making it impossible to extract weed or fish from the net. Accumulation of weed in the net disrupted sampling (lead line lifted). There was no evidence of fish being driven in front of the boat. If no stop nets were used, larger sections of the river could be fished in the time available. The net setting and retrieval took two to three hours per day.

The electric fishing gear detailed here represents a successful alternative to Novotny's Wisconsin ring. Regardless of which anode is used, the sampling procedure outlined, for the multi-anode boom boat, would be successful in the Columbia River.

Whaley, R.A., O.E. Maughan and P.H. Whiley. 1978. Lethality of electroshock to two freshwater fishes. Prog. Fish Cult. 40(4):161-163.

Fantail darter (*Etheostoma flabellare*), bluegill (*Lepomis macrochirus*), electrophysiology, electric fishing.

The lethality of electroshock to bluegill and fan-tailed darters subjected to commonly employed ranges of pulsating direct current was examined. The knowledge of lethality of electric shock to targeted fish is of primary concern to fisheries biologists in the field. If electroshock is employed as a capture tool of a catch-depletion-based population estimate, fish not captured during the first electrofishing attempt must remain available for capture during later attempts.

Whaley et al. showed that even electrotaxic currents (pulsed DC) produce some amount of mortality. Duration of exposure time appeared to be the factor most responsible for the death of fish. Mortalities were low when exposure time was kept under fifteen seconds. With experience and by understanding the electro-physiological responses in fish, researchers can adjust electrofishing units to operate efficiently with minimal harm to fish.

Willemstad, J. 1990. The electrified trawl as an alternative type of fishing gear to eel traps. Pages 70-78 *in* I.G. Cowx, ed., Developments in Electric Fishing. Oxford: Fishing News Books, Blackwell Scientific Publications, Ltd.

European eel (*Anguilla anguilla*), perch (*Perca fluviatilis*), Lake Ijssel, Netherlands, commercial fishing, fishing gear, beam trawl, electric beam trawl, electric fishing.

This study investigates whether an electrified beam trawl would be a good alternative to the commercial eel trap, a gear which causes high incidental mortality among the young of other commercially important species. The electrified trawl proved to be effective for catching eel. Catch rates were 7 to 20 times greater in nets with electric current than without. Incidental catches of perch, bream, and roach were reduced by a factor of two to three.

Future squawfish removal efforts may want to upgrade existing trap or purse seine equipment by adding electricity to their design.

Willis, C.F. et al. 1985. Abundance and distribution of northern squawfish and walleye in the John Day Reservoir and Tailrace, 1982. Annual Progress Report, 1982. Oregon Dept. Fish Wildl.. 33 p.

Squawfish (*Ptychocheilus oregonensis*), walleye (*Stizostedion vitreum*), Columbia River, drift and stationary gillnets, trap nets, boat electrofishing, hook and line, radio tag, abundance and distribution of salmon predator populations.

A variety of gear types were used to assess the abundance and distribution of squawfish and walleye in the John Day Reservoir. Squawfish abundance in the boat restricted zones of John Day and McNary Dams was approximately 4,600 and 8,500 fish, respectively. Walleye abundance could not be estimated because they were not recaptured.

Angling appeared to be the most effective method in capturing squawfish near the dams (2,100 fish, 4 fish per hour), compared with other gear types (670 fish, <1 fish per hour). Beach seines (20 sets) were ineffective at catching either species. Electrofishing tended to capture smaller fish, whereas angling captured squawfish >300 mm. Squawfish moved into the tailrace area after spilling stopped.

Witt, A.J. and R.S. Cambell. 1959. Refinements of equipment and procedures in electrofishing. Trans. Am. Fish. Soc. 88:33-35.

Centrarchids, Missouri, seine nets, electric fishing gear, electric fishing, efficiency comparison.

A boat-mounted electric seine is described. This boom seine was three times more efficient at night than during the day. The catch of the boom seine in a Missouri impoundment is compared with the catch from nets. This gear was found to be selective for centrarchids (except white crappie) in waters where nets were selective toward white crappie, gizzard shad, white bass and freshwater drum. Selectivity was related to the behavior of fishes and the habitat where fishing was done. Average catch for diurnal electrofishing in June was 98 fish per hour and for nocturnal electrofishing on the same day was 346 per hour.

The results of electrofishing for any one species is dependent on its diel movements. Having an understanding of squawfish behavior will greatly increase capture rates.

Yundt, S. 1983. Changes in catchability related to multiple electroshock. Proceedings of thc Annual Conference, Western Association of Fish and Wildlife Agencies 63: 116-123.

Rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta fario*), Bighorn River, Wyoming, population estimates, electrofishing, throwing electrode.

The purpose of this study was to determine whether the length of time between electrofishing mark-and-recapture runs affected population estimates, and if so, to determine which population model assumptions had been violated.

Electrofishing mark/recapture population estimates were shown to be affected by the length of time between fishing runs. The assumption that all fish have the same probability of being recaptured is violated if subsequent electrofishing runs occur too close together. Electroshocked fish develop avoidance behavior and experience spatial drift, making them less available to subsequent sampling efforts.

Squawfish population indexing efforts in the Columbia River have accounted for the potential sampling bias of electrofishing by allowing for sufficient recovery time between re-sampling of designated areas. Our efforts in the Columbia will concentrate on simple squawfish removal, not population estimates. Therefore, the induced bias of unequal catchability will have only a limited effect on our efforts.