Guidelines for Assessment and Reduction of Electrofishing-Induced Injuries in Trout and Salmon

J.B. Reynolds and F.M. Holliman
School of Fisheries and Ocean Sciences
University of Alaska Fairbanks
P.O. Box 757220
Fairbanks, AK 99775

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Abstract

Over a decade has past since the revelation that large (>30 cm) rainbow trout *Oncorhynchus mykiss* caught by pulsed DC electrofishing are frequently (~50%) injured. Since then, substantial effort has been expended to understand and reduce electrofishing injuries, especially in salmonids. Injury data on adult fish cannot be extrapolated to juveniles; the latter experience much less risk for injury than the former. Biologists must document electrical waveforms they use with an oscilloscope; this provides "ground truth" relative to injury. Pulsed DC frequency (pulses per second) is the most critical waveform factor relative to injury and should be reduced to 15-30 pps if injury is to be significantly reduced. Pulse duration (i.e., pulse width) and voltage should also

be reduced to threshold levels that maintain acceptable catch rates while minimizing fish injury and stress. Although experimental research can provide guidelines, biologists should conduct assessments of their own situations. Injury can be assessed by filleting fish and looking for hemorrhages. A sample of 20 similar-size fish is sufficient to assess injury, including an estimate of proportion injured (p) with adequate confidence limits. Evaluation of sample p must include a perspective of effects at the population level. Effects will be more important on small, threatened stocks than on large, healthy stock.

Introduction

During the 1950s-1980s, success with electrofishing centered on catch rate and efficiency with little concern for fish injury. Alternating current (AC) was generally regarded as more damaging to fish than continuous direct current (DC), due to the early work on rainbow trout *Oncorhynchus mykiss* by Hauck (1949). As pulsed DC became popular in the 1950s and 1960s, the possibility that it affected fish more like AC than DC was largely ignored by our profession, despite early warnings (McLain and Nielsen 1953). Not until the late 1980s, when Sharber and Carothers (1988) reported that about one of every two large (>30 cm) rainbow trout caught by pulsed DC electrofishing in the Colorado River had internal injuries caused by capture, did we realize that fish captured by electrofishing may be injured even though they appear and act normal when released. Studies during the late 1980s and early 1990s in Alaska (Holmes et al. 1990), Wyoming (Meyer and Miller 1990) and Montana (Fredenberg 1992) generally confirmed the findings in Arizona: large trout are at high risk of internal injury (spinal damage and dorsal muscle hemorrhage) when captured by pulsed DC electrofishing, operating at 50-60 pulses per second (pps or Hz), the most commonly-used waveform of pulsed DC in North America.

Soon after this realization, some western states and federal agencies placed self-imposed restrictions on the use of electrofishing (Schill and Beland 1995), most of which remain in effect today. During the 1990s a growing concern about the electrofishing-injury issue resulted an urgent calls for research (e.g., Snyder 1992) and wider bans on electrofishing in waters containing threatened or endangered stocks of salmonids (Nielsen 1998). Electrofishing turned from a catch-oriented activity to a manager’s balancing act: take the chance and use the tool to get the data, or lose the tool by avoiding risk with bans or restrictions; both approaches have been used while all await more information.

In this paper, we highlight research findings during the 1990s, what they mean and how they can be used in the management setting. Although we have extensively reviewed the literature, we have relied on pre-1980 literature only where necessary for the purpose of this paper. Our report focuses on pulsed DC because it remains the most common waveform for electrofishing and is at the center of this issue, and on salmonids because of the trout-oriented theme of this conference.

Injury and its Risk Factors

Trauma is a general term (Reynolds 1996) that includes stress (physiological and behavioral changes) and injury (mechanical damage to soft and hard tissues). In restricting this report to injury we do not imply that stress is unimportant. It is well known that electroshocked fish requires hours, even days, to regain normal physiological status (e.g., Mesa and Schreck 1989). We contend that injury occurs during the first 1-2 seconds of exposure to high-intensity electrical fields and that continued exposure primarily serves to increase stress. Stress is probably a larger threat to juvenile salmonids than is injury, at least when electrofishing is the capture method.

Although injuries to gills and internal organs do occur, the incidence of these injuries due to electroschock seems to be infrequent and less explicable; an exception is gill hemorrhaging in coregonids, an event seen by many cold-water biologists. We focus on those injuries more likely to occur in salmonids: external hemorrhages (often called "branding" but actually bruising) and internal spinal damage and muscle hemorrhage that may be present even in the absence of external bruising. Bruises occur when the epithelial capillaries rupture, spreading small quantities of blood into the surrounding surface tissue; they are often well defined because they tend to conform to the shape of the underlying, chevron-shaped myomeres. Dark blotches on the back of a fish may be stress-induced aggregations of chromatophores that will disappear as the fish recovers. Bruises are likely indicators that a fish also has spinal or muscular injuries (e.g., Fredenberg 1992) but their absence does not mean a fish is uninjured internally. Bruises can become sites for bacterial infection after the fish is released.

From the short-term perspective, fish have an amazing capacity to survive severe internal injuries (e.g., ruptured dorsal aorta, separated spine) that would usually prove lethal to birds and mammals. Nevertheless, fish that are released with such injuries logically have a much-reduced prospect of returning to full health and normal function. When induced by electroshock, muscle hemorrhage and spinal damage are caused by severe contractions, simultaneously on both sides of the fish, primarily in the dorsal musculature (Lamarque 1990). Sharber and Black (1999) proposed epilepsy as the underlying cause for all electrofishing-induced injuries in fish, but they offered no proof for their theory. In salmonids, damage to spinal and muscular structures tends to be centered midway between the head and tail (Fredenberg 1992, Ainslie et al. 1998). Spinal damage and muscular hemorrhage are assessed by x-rays and filleting, respectively, and have been classified according to apparent severity for consistency in reporting (Reynolds 1996), but this system has not been well-related to fish well-being (e.g., survival, growth, reproduction). Even though the classification system uses numbers (0, 1, 2, 3) to rank the apparent severity of both types of injuries, these numbers are not ordinal (quantitative) and should only be used as categories. The categorical data for spinal damage and muscle hemorrhage should not be combined.

There are many possible causes related to risk of electrofishing injury for a fish but we suggest that most can be categorized into one of three major risk factors: fish size, electrical waveform and electrical field intensity. All three factors can be considered in the process to assess and, if necessary, reduce electrofishing injury.

Fish Size as a Risk Factor

That electrofishing tends to be size selective, larger fish being more vulnerable to capture, has long been established (Reynolds 1996). Larger fish are also more likely to be injured by electrofishing than smaller ones of the same species (Taylor et al. 1957, McMichael 1993, Hollender and Carline 1994, Dalbey et al. 1996, Thompson et al. 1997, Ainslie et al. 1998). Our unpublished findings from a nation-wide study of electrofishing injury in various cold- and warm-water species (www.shockingnews.org) are in agreement with this size-injury relationship. In general, salmonids less than 15 cm long are much less at risk than those longer than 15 cm, and especially those longer than 30 cm. Data on injury rates (injury incidence) for adult salmonids should not be assumed to apply to juveniles.

Electrical Waveform as a Risk Factor

Pulsed DC waveforms have three characteristics that are related, to varying degrees, to the risk of fish injury: pulse shape, pulse frequency and pulse duration. Manipulation of these characteristics ranges from highly flexible on some electrofishing units to completely fixed on others. Operators can learn about these features by asking the manufacturer for equipment specifications or by using an oscilloscope to view the output at different settings.

pulse shape

Although one tends to envision a classical square wave when thinking about pulsed DC, more often than not the actual waveform is something else. Sharber and Carothers (1988) compared the effects of three pulsed DC (60 Hz) waveforms—square, quarter-sine and exponential decay—on injury in large rainbow trout in the Colorado River. They found that the quarter-sine wave was significantly more injurious than the other two types (although the main impact of their paper was the message that *any* 60-Hz pulsed DC waveform can cause high injury rates). Generally, pulse shape is a fixed feature of most equipment and cannot be changed by the operator. In some units, the pulse shape changes with amplitude (voltage), either by design to compensate for increasing power demands, or, more commonly, by consequence of component limitations (e.g., square wave changes to sawtooth shape at higher voltages because the capacitors cannot sustain the peak voltage during each pulse).

pulse frequency

Pulse frequency, also called pulse rate, is a key factor affecting risk for injury in salmonids. Sharber et al. (1994) demonstrated a curvilinear relationship between pulse frequency and injury rate in large rainbow trout; frequencies of 60 Hz and higher were more damaging than lower frequencies. This relationship has been confirmed repeatedly (McMichael 1993, Dalbey et al. 1996, Ainslie et al. 1998). The likelihood of tetany (forced muscle contraction) also increases with pulse frequency, lending credence to the idea that tetany tends to induce injury. Pulse frequency can often be manipulated on manufactured equipment, In general, operators should reduce pulse frequency to the range of 15-30 Hz, while trying to maintain acceptable catch rate, if injury rate is to be significantly reduced.

pulse duration

Pulse duration is also called pulse width and is measured in milliseconds; 4-8 ms is the typical range for pulsed DC. Pulse duation is related to duty cycle, the percentage of time that pulses are on, relative to total time on and off; for example, if pulse duration is increased while pulse frequency remains constant, duty cycle will also increase. The effect of pulse duration on injury is not clear. At a given peak voltage or amplitude, changing pulse duration will change the average voltage (area under the waveform curve), meaning that the fish is subjected to more electrical energy. It is possible that longer pulse duration (e.g., 6-8 ms) contributes more to added stress than injury, compared to shorter pulse duration (e.g., 2-4 ms).

Electrical Intensity as a Risk Factor

The intensity of an electrical field can be expressed in terms of voltage, current (amperes) or power (watts). The most common expression of intensity is voltage and this feature is almost always changeable on an electrofishing unit. In isolated fish muscle, no contraction occurs below some voltage threshold As voltage increases above the threshold, muscle contraction increases in a stepwise manner until complete contraction occurs; further increases in voltage have no effect (Haskell and Adelman 1955). Although the threshold function serves as a basis for a voltage-injury relationship, the effect of voltage on injury is subject to debate (Reynolds and Kolz 1995, Sharber et al. 1995). As basic as the question is, no studies have yet clearly demonstrated that risk for injury increases with voltage because alternative explanations for increased injury became apparent. Nevertheless, we suggest that the threshold principle of muscle contraction will eventually support the notion that injury can be decreased by reducing field intensity.

Assessment of Injury

Field Procedure

Biologists can inexpensively evaluate electrofishing injury in a target fish population. The target to be sampled is a cohort (or similar sizes) of fish in a population of interest during an electrofishing operation. A sample is defined as 20 fish of a cohort, or of similar size, in a population; generally these are the larger fish in a population because the liklihood of injury, if it occurs, increases with fish size. During a normal electrofishing operation, collect one or more samples; handle and euthanize the fish with care to avoid additional injury. If possible, collect a control sample by another method (e.g., seine, trap, angling). Record all settings used on the control unit and, if possible, the water temperature, depth and conductivity (as these factors could relate to injury rates). Record the length of each fish in the sample and keep a record of other fish caught during the operation. Estimate the proporton of each species that escaped while sampling, or make a judgement regarding the acceptability of catch effectiveness.

Necropsy Procedure

Keep all fish in each sample together on ice if they are to be transported; they can be frozen for later analysis if necessary. Each fish, fresh or thawed, should be filleted on both sides, cutting or scraping the flesh to the spine. Examine both sides of each fish for hemorrhages, bloody spots on or near the spine with corresponding spots on the fillet. Do not be fooled by blood that appears during filleting; this is easily wiped away, but hemorrhages are not. Find the worst hemorrhage and classify it according to a classifcation system (i.e., 0, 1, 2 or 3) described by Reynolds (1996).

Data Analysis

Calculate the proportion (p) of injured fish in each sample (those with one or more hemorrhages) and estimate the confidence limit of p by assuming that each fish has an equal and independent chance of being injured, using the normal approximation of the binomial distribution, p +/- z{[(p•q)/n]^0.5}, where z is the normal approximation statistic at a given confidence level, q equals 1 - p and n is sample size (e.g., 20). The usual confidence levels of 0.01 or 0.05 may be too high for a sample size of 20; lower confidence will likely be necessary. Also calculate the proportion of fish in each injury class to indicate the injury severity in the sample.

To X-Ray or Not?

The same analysis just described for hemorrhages can also be done for spinal injuries, but requires X-ray analysis. If hemorrhage incidence is low in samples, spinal injury is likely unimportant and X-rays are not needed. However, if hemorrhage injuries are significant, it may be worthwhile to get additional samples for X-ray analysis.Veterinary facilities will often agree to do these, but at a cost. Both dorsal and lateral perspectives are needed when doing this work because spinal injury is directional.

Interpretation

As an arbitrary guide, a sample with 10% or less of fish injured should be considered to mean that injury is not important unless, of course, the fish in question are threatened or endangered. Fish capture and handling by any method intended to release fish alive will cause injury rates in the 1-10% range. Samples injury rates higher than 10% will be regarded as significant or not, depending on the management situation. Schill and Beland (1995) called for research that would put sample-level injury rates into a population-level perspective and a number of researchers responded (Dalbey et al. 1996, Habera et al. 1996, Kocovsky et al. 1997, Thompson et al. 1997, McMichael et al. 1998 and Ainslie et al. 1998). The main outcome of these studies has shown that shocked salmonids tend to survive after release, but may experience reduced growth. However, when these sample-level effects were projected to the population level, the effects were negligible. Socio-political factors may over-ride the fact that population effects are nil: it did not matter to Kenai River fishing guides when Alaskan managers demonstrated no population effects from electrofishing injuries to trophy rainbow trout—any chance that a client would see such an injury was unacceptable (D. McBride, Alaska Department of Fish and Game, Anchorage, personal communication). Nevertheless, biologists must document population effects if at all possible so that the science is there for all to see. It is possible for reproductive success to be reduced in smaller stocks where pre-spawning females are shocked for egg takes; in these cases the eggs of gravid females have reduced viability, and "green" females returned without being stripped may be too stressed to recover in time to spawn. Thus, electrofishing effects should be carefully evaluated, both in terms of sample effects projected to the population (McMichael et al. 1998) and whole-population ecology.

Reduction of Injury

Measures to reduce injury need not lead to a significant drop in catch effectiveness. Many biologists fish with more electrical energy than needed. Several guidelines will help to balance catch and injury rates.

First, consider fish response (behavior) during capture and handling. Are they completely immobilized? Do they exhibit signs of tetany (flared opercles, stiff muscles)? Does recovery (regaining equilibrium) require lengthy periods (5-10 minutes or more)? If answers to these questions are yes, too much energy is being used. We recommend using a simple classification of fish response in the electrical field:

Escape—fish exhibit avoidance by rapidly swimming upright away from the field;

Taxis—fish swim upright, sometimes with jerking motions, toward the anode;

Loss of Equilibrium—fish swim, but without equilibrium, in a disoriented manner; and

Immobilzation—fish exhibit no movement; may be relaxed (narcosis) or stiff (tetany).

Taxis and loss of equilibrium are usually as favorable for fish capture as immobilization and are more likely to reduce stress, injury and death. Fish should be captured before touching energized electrodes and should not be held in the electrical field longer than necessary.

Second, consider the waveform and voltage being used. If pulse frequency can be controlled, try to elicit taxis or loss of equilibrium with frequencies lower than 30 Hz. When threshold frequency is reached, try further reducing energy level by decreasing voltage (and pulse duration if a control is available). In other words, seek the threshold waveform and intensity that gives the minimal capture-prone response.

Third, consider the size of electrodes being used. Commercial manufacturers typically provide cable-style anodes with a 3-6 mm diameter; these create small, intense electrical fields that produce an "all-or-none" effect—the fish feels little or no intensity until it gets close, then it gets all of it. Larger-diameter cables (12-18 mm) or a sphere will produce larger more effective fields with lower intensities near the anode. However, anodes that are too large may overload the power source, especially in more conductive waters, so one must test the limits of the battery or generator under actual conditions before selecting the largest electrodes possible.

Finally, document the effect of reduction measures taken. Was the incidence or severity of injuries reduced? Do the fish recover more quickly? Are catch rates still acceptable? This extra effort will instill confidence through knowledge in those doing the work, and provide guidance for those who will follow. Remember that when the situation changes (e.g., new species, different equipment), the electrofishing ground rules have also changed and a new evaluation will be necessary.

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