Electrofishing and the Effects of Depletion Sampling on Fish Health: A Review And Recommendations For Additional Study

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Abstract

Depletion sampling in combination with multiple-pass electrofishing is an important fisheries management tool for wadeable streams. This combination of techniques has been used routinely by federal and state fishery management agencies for several decades as a reliable means to obtain quantitative data on trout populations or to describe fish community structure. In this paper we review the effects of electrofishing on fish and discuss this within the context of depletion sampling and multiple exposures of fishes to electric fields. The multiple wave forms most commonly used in sampling (alternating current, direct current, and pulsed direct current) are discussed as well as electrofishing induced response, injury and physiological stress. Fish that survive electrofishing injuries are more likely to suffer short and long-term adverse effects to their behavior, health, growth, or reproduction. Of greatest concern are the native, non-target species that may be subjected to multiple electrical shocks during the course of a 3-pass depletion survey. These exposures and their effects on the non-target species warrant further study as do the overall effects of electrofishing on populations and community structure.

Key words: Electrofishing, depletion sampling, native species, trauma, stress.

Introduction

Rigorous, scientifically valid and economically feasible techniques for sampling fishes in streams are important in all aspects of fishery management (Mace 1994). In addition to an assortment of active and passive capture gear, electrofishing has been used by fishery biologists since the 1950's (Reynolds 1996). Since then, there have been significant improvements and innovations in the design of electrofishing equipment and its reliability and effectiveness for capturing fish. Many studies have examined the effectiveness and utility of electrofishing, including the use of alternating current (AC), direct current (DC) and pulsed direct current (PDC) waveforms and on the effects of voltage, frequency, and other electric field characteristics on the capture of fish (Snyder 2003). As will be discussed in this review, others have focused on physiological and behavioral responses including stress and trauma, and injury to fish exposed to various electrofishing fields. Among all of the tools available to biologists to sample fish, electrofishing is most often used alone or in combination with other sampling gears.

Population depletion sampling methods are powerful techniques for assessing the abundance of fish (Hilborn and Walters 1992). These methods, in combination with electrofishing, are common tools for quantitative trout population assessments in wadeable streams (Van Deventer and Platts 1983). As such, multi-

ple or three-pass depletion sampling has been used by federal and state fishery management agencies for several decades to obtain quantitative data on trout populations.

In this paper, we review the benefits and liabilities of using electrofishing in depletion sampling for assessing trout populations in wadeable Appalachian streams. Of particular interest are the potential effects of various electrofishing fields on the principal target species for fisheries management in wadeable cold-water streams (e.g. - brook trout *Salvelinus fontinalis*, brown trout *Salmo trutta* and rainbow trout *Oncorhynchus mykiss*). We review what is known regarding the response of salmonid species in electrofishing fields and the incidence and severity of hemorrhagic and spinal trauma. We discuss the potential effects of electrofishing on non-target fishes that may be exposed to repeated electric shock during three-pass depletion sampling.

Electrofishing in Wadeable Streams

The first application of an "electric fishing" device was patented by Isham Baggs in 1863 in Great Britain (Hartley 1990). Since then, there have been significant improvements and innovations in the design of electrofishing equipment. The type of electrofishing gear used and the characteristics of the fields generated vary with the physical and chemical conditions found and the objectives of the study. Electrofishing gear can include: small battery powered DC backpack units; gasoline powered AC/DC backpack units; electrofishing boats, barges or rafts; streamside or shore-based systems; and electric seines. Regardless of the system used, the capture efficiency of the gear depends not only on the physical and chemical characteristics of the stream but also on the species and sizes of fish collected and the habitat complexity (Peterson et al. 2004).

Typically, DC, PDC, and/or AC backpack electrofishers have been used to sample small wadeable streams. Direct current and PDC electrofishing fields are most often used in streams with conductivities >100 µS/cm. However, in many southern Appalachian streams with low conductivities (<30µS/cm) biologists typically fish with AC backpack electrofishers due to the power limitations of DC and PDC electrofishing equipment (Habera et al. 1999). Poos et al. (2007) evaluated electrofishing and seining as tools n assessments of species at risk in wadeable Becausethe selection of gear types may influence estimates of distribution and abundance, they concluded that the trade-off for the need for rigorous quantitative data outweighs the potential injuries to fish from electrofishing. Similarly, in southeastern Queensland, Australia, Kennard et al. (2006) found that multiple pass electrofishing in combination with seine netting provided the most reliable and accurate estimates of fish communities.

Methods for Depletion Sampling

Multiple-pass electrofishing and the use of maximum-likelihood functions for estimating population sizes are widely accepted in the fisheries profession (Zippin 1956, Hilborn and Walters 1992). This technique estimates population size by extrapolating the rate of decline in catch per unit effort (C/f) over multiple sampling units of effort. The

assumptions for applying the technique are that the population is closed, fishing effort is constant, and fish are equally vulnerable to capture by the electrofishing gear throughout the sampling period (Bacon and Youngson 2007). However, these assumptions are almost always violated to some degree (Riley and Fausch 1992) and there are alternative statistical approaches that deal with these limitations (Carle and Strub 1978). In general, studies have shown a tendency to overestimate capture efficiency and underestimate fish abundance or population size (Peterson et al. 2004).

In addition to its usefulness as a tool for estimating population size, multiple-pass electrofishing coupled with seining in wadeable streams can provide accurate and precise estimates of species composition, richness, and relative abundance (Kennard et al. 2006). For these reasons, U.S. Geological Survey's National Water Quality Assessment Program initially relied on multi-pass electrofishing as a primary assessment tool for fish communities (Meader et al. 1993). In another investigation, Meader et al. (2003) found that combinations of multi-pass and single-pass sampling could reduce overall sampling efforts over large geographic regions and provide precise characterizations of fish community structure. However, single-pass back-pack electrofishing is usually inadequate for determining population size (Bertrand, et al. 2006), which is most often the required metric for trout surveys in small streams. For this reason, multiple pass or three-pass electrofishing has remained the standard by which most resource management agencies determine population size for trout in wadeable streams. This technique exposes fishes, both the target and the non-target species, to multiple electrical shocks.

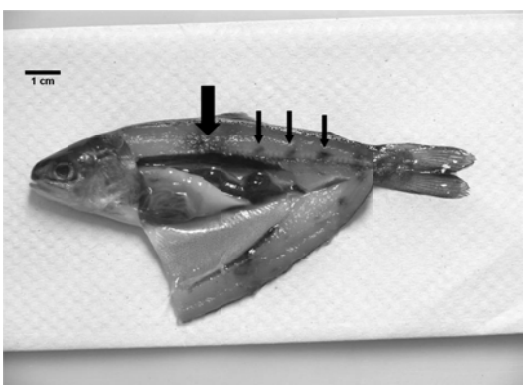
Electrofishing Induced Response and Injury of Target Species

There are many factors that influence the frequency and degree of injury of fish in electric fields. Not only are there environmental factors to consider (e.g. - water conductivity, temperature, physical habitat complexity), but factors such as the species sampled, unique species behavior, the type of electrofishing equipment used, and wave form produced all have direct influences on potential injury rates. The four basic responses of fish to electric fields are: 1) *Avoidance*, in which fish detect the electrical field and swim away from the anode; 2) *Taxis*, in which fish experience electrotaxis and swim to the anode; 3) *Narcosis*, in which fish are immobilized but muscles are relaxed and respirations are normal; and 4) *Tetany*, in which fish are immobilized but muscles are rigid and gills are most often flared without exhibiting respirations. It is in this later response of tetany where the most debilitating injuries occur and most practitioners attempt to regulate their equipment to obtain narcosis without tetany.

The response of fish in electric fields depends upon the field intensity which can be measured by the voltage gradient, current density or power density (Snyder 2003). Current density and power density cannot be directly measured and must be calculated. As such, they have limited practical applications for field studies. Voltage gradient is the average voltage differential per unit distance along lines of current or flux between two

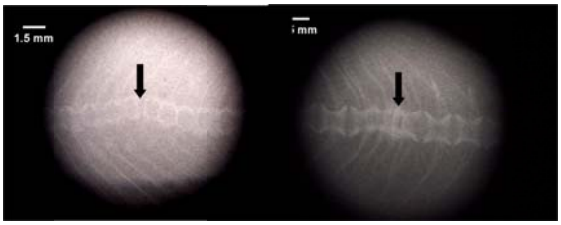
isopotential surfaces and is usually expressed as volts/centimeter (V/cm). Voltage gradient can be physically measured in the water with a voltage gradient probe connected to an oscilloscope or voltage multimeter. According to Kolz (1989), the effectiveness of electrofishing power transfer is maximized when the resistivity of the water equals that of the fish. This rarely occurs and knowledge of peak voltage gradient (V/cm) typically varies by species, age and size, water conductivity and type of electrofishing current (Snyder 2003). By understanding the voltage gradient biologists can better predict the potential injury of fish in an electric field.

Figure 1: Class-2 (small arrows) and class-3 (large arrow) hemorrhages in juvenile rain-bow trout exposed to a 100V PDC 60 Hz electrofishing field.



There have been many studies on the potentially harmful effects of AC, DC, and PDC electrofishing on salmonids (Snyder 2003). In general, AC fields are most injurious to fishes and continuous DC is least injurious (Reynolds 1996). Hauck (1949) provided one of the earliest and perhaps the most comprehensive descriptions of electrofishing injuries in fish. These potential effects include cardiac or respiratory

Figure 2: Compression fractures in juvenile rainbow trout exposed to a 100V PDC 60 Hz electrofishing field. (Photos by authors)



failure, spinal or other related internal injuries, stress and fatigue (Reynolds 1996). Habera et al. (1996) found spinal and hemorrhagic injury rates of about 3% in AC-shocked rainbow trout within southern Appalachian streams. However, in other investigations the injury rates were much higher. For instance, in low conductivity Appalachian streams sampled with AC electrofishing, Habera et al. (1999) found large (>264 mm) brown trout with hemorrhagic and spinal injury rates of 60% and 35%, respectively. Some authors (Dalby et al. 1996) found greater incidences of spinal injury among rainbow trout captured with PDC over DC electrofishing. Reynolds (1996) devised a classification system for assessing hemorrhagic and spinal column damage in comparative studies (Table 1). An example of a Reynold's class-2 and 3 hemorrhage is shown in Figure 1 and compression fractures in Figure 2 for juvenile rainbow trout exposed to a 100V PDC 60Hz electrofishing field in experimental tanks at the National Fish Health Research Laboratory.

Shaber and Carothers (1988) found spinal and soft injuries of 44% to 67% in rainbow trout collected by PDC in the Colorado River at Glen Canyon National Recreation Area. These findings raised concern among managers within the

National Park Service and the U.S. Bureau of Reclamation regarding use of electrofishing to monitor endangered humpback chub (*Gila cypha*) populations in Grand Canyon National Park (Snyder 2003). These findings also opened a much larger professional debate regarding the efficacy of electrofishing as a sampling tool for some species and resulted in some state and federal agencies imposing operational restrictions on the use of electrofishing (Schill and Beland 1995).

Table 1: Criteria for assigning trauma scores for hemorrhages and spinal damage in fish exposed to electrofishing fields (reproduced after Reynolds 1996)

Type of Injury	Score	Criteria
Internal Hemorrhage	0	No hemorrhage present
	1	Mild hemorrhage with one or more wounds in muscle, separate from spinal column
	2	Moderate hemorrhage with one or more wounds located on the spinal column and $\leq$ 2 vertebrae
	3	Severe hemorrhage with one or more large wounds on spinal column > 2 vertebrae
Spinal Damage	0	No spinal damage present
	1	Vertebral compression
	2	Vertebral compression and misalignment
	3	Vertebral fracture of $\leq$ 1 vertebrae or complete separation of $\leq$ 2 vertebrae

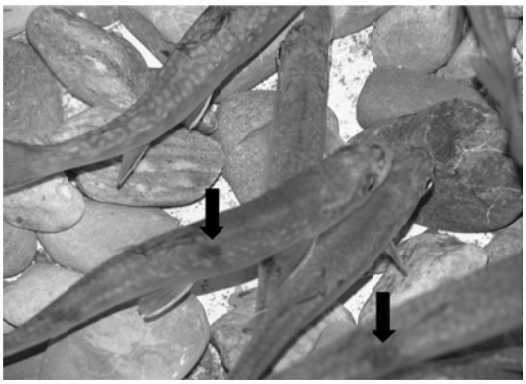
Most internal injuries resulting from electrofishing do not have external signs (Reynolds 1996). However, several investigators have noted the presence of vertical dark "brands" or banding on trout that have been electrofished (Fredenberg 1992). These brands or bands generally occur in the area of the dorsal fin where the muscle mass is the greatest (Figure 3). Ainslie et al. (1998) found these brands in juvenile rainbow trout to be associated with internal injuries. In electrofishing experiments conducted at the National Fish Health Research Laboratory we documented banding in brook trout, green sunfish (*Lepomis cyanellus*) and largemouth bass (*Micropterus salmoides*).

In addition to injury due to hemorrhage and fracture, electrofishing can result in physiological and behavioral changes. Gatz et al. (1986) hypothesized that multiple pass or repeated electrofishing exposures might result in measurable effects on growth. To test this hypothesis, he electrofished with 600V 120 HZ PDC twice within a 1-3 day period for up to 7 months and monitored changes in growth rate of trout. He found the percentage of fish with instantaneous growth rates less than average was significantly greater for fish that were electrofished four or more times during the year and warned that growth studies in populations repeatedly electroshocked are likely to underestimate growth. Similar observations have been made in field studies involving multiple-pass depletion sampling on cutthroat trout (Mesa and Schreck 1989). However, in his review of the literature, Synder (2003) concluded that electrofishing caused no overall long-term effects on growth.

Physiological Responses

In addition to physical injuries caused by hemorrhagic trauma and spinal compressions, misalignments and fractures, fishes also may undergo a variety of stress related effects resulting from electrofishing that could have short-term or long-term implications for their health.

Figure 3: Banding or branding evident on juvenile rainbow trout exposed to a 100V PDC 60 Hz electrofishing field (Photo by authors).



Neuroendocrine changes resulting from exposure to electric fields are known to induce changes in blood chemistry and hematology (Bracewell et al. 2004). These changes can include hyperglycemia (Specter and Schreck 1980) and hyperlactemia (Driedzic and Kiceniuk 1976) and changes in plasma cortisol levels (Barton et al. 1986). Other stress related parameters include plasma osmolality, plasma chloride, plasma protein, hematocrit, leucocrit and hemoglobin (Barton and Grosh 1996).

Bracewell et al. (2004) exposed chub (*Leuciscus cephalus*) to simulated PDC electrofishing and found plasma glucose and blood lactate to be significantly higher than that of the controls within 0.5-hrs of treatment. These levels peaked within 2-hrs and returned to baseline levels within 8-hrs. Mesa and Schreck (1989) examined physiological changes in cutthroat trout resulting from multipass depletion sampling and fish marking with monochord attached fingerling tags. In their combination of field and laboratory studies they found plasma cortisol and blood lactate to increase significantly in cut-throat trout. Multiple shock electrofishing coupled with marking elicited the most severe stress response. Vanderkooi et al. (2001) found suppressed genera-tion of antibody-producing cells (APC) by anterior kidney leukocytes in Chi-nook salmon (*Oncorhynchus tshawytscha*) exposed to a 300V 50Hz PDC electric field. The authors concluded that electrofishing may have aided the progression of disease in *Renibacterium salmoninarum* infected salmon resulting in the accelerated death of infected fish. It did not, however, make the fish more susceptible to infection or disease. The authors found plasma cortisol and blood glucose levels significantly elevated by 3-hrs post shocking and which typically returned to control levels after 24-hrs. In some instances, control levels were not obtained until 7-days post shock (Vanderkooi et al. 2001). Some authors have suggested that full physiological recovery of electroshocked fishes takes up to 24-hrs (Barton and Dwyer 1997).

Implications for Non-target Species

Studies on the effects of electrofishing on non-salmonid fishes are very limited and fewer still have examined the effects of electrofishing on native, non-game fishes. Those studies that have been published (Dolan and Miranda 2004) focused mostly on non-salmonid species

that are of interest to fishery managers (e.g. - largemouth bass, *Micropetrus salmoides*, bluegill *Lepomis macrochirus*, and channel catfish *Ictalurus punctatus*). Henry et al. (2004) examined immediate mortality resulting from homogeneous electric fields of 60Hz PDC on several fishes and found a wide variation in susceptibility among species. The most susceptible species tested was the blackbanded darter (*Percina nigrofasciata*); a relatively large darter found in tributaries to many of the major rivers in the southeast. Recently, Holliman et al. (2003) examined electroshock induced mortality of the endangered Cape Fear shiner (*Notropis mekistocholas*). In their study they concluded that electrofishing may be safely used to sample small cyprinids when the appropriate waveform is used (PDC, 60 Hz or less). The authors found that mortality was dependent upon waveform, voltage gradient, exposure time and fish length. Kocovsky et al. (1997) investigated the long-term effects of annual electrofishing on stream fish and detected no adverse population effects for brook trout, brown trout, or rainbow but a notable effect on longnose suckers (*Catostomus catostomus catostomus*). In a study of the effects of both AC and PDC electrofishing on the spotfin chub (*Cyprinella monacha*), Holliman and Reynolds (2003) concluded that electrofishing should be limited to immobilization to prevent injury and mortality. In their study they found that PDC 60 Hz single-pass electrofishing at 5 V/cm caused 25% mortality in the spotfin chub. This would be unacceptable in any management program for a species-at-risk. In a study of the effects of PDC 3-Hz electrofishing on American eel (*Anguilla rostrata*) in the St. Lawrence River, 60% of the electrofished eels exhibited spinal injuries by radiograph and 30% exhibited hemorrhages (Reynolds and Holliman 2004). Other investigators have found physiological and behavioral changes resulting from exposure in electrofishing fields. Some species may display reduced swimming stamina (Mitton and McDonald 1994), lethargy and cryptic behavior (Sigismondi and Weber 1988), reduced fertility (Muth and Ruppert 1996) or impairment of cardiac function (Schreer et al. 2004).

Conclusions

Despite all of the available knowledge on the effects of electrofishing on fishes, we are aware of only a few studies that have examined injuries and health effects to native, stream dwelling fishes exposed to multiple electrical shocks resulting from standard three-pass electrofishing. The target species for these surveys are most often either a sport or game fish such as brook trout or an endangered or at risk species such as the Cape Fear shiner. The other native species subjected to electrofishing are generally ignored as the survey crew focuses their attention on the target species. As such, non-target species can receive multiple electrical shocks during each pass of a three-pass depletion survey. Fish that survive the exposures despite electrofishing injury or physiological stress likely suffer complications that affect their behavior, health, growth, or reproduction.

The literature clearly suggests that injuries and physiological stressors associated with electrofishing can have negative or debilitating effects on fish. The degree of these injuries depends in part upon the type of electrofishing field, voltage gradient, pulse width, frequency,

and the number of exposures. Ideally, the target species of depletion electrofishing are exposed to one electrofishing pass. However, experienced field biologists know that this does not necessarily occur as fish often escape capture. Once fish are netted they are removed from the population and processed. Those target fish that escape the initial electrofishing pass may be subject to additional electrofishing passes before they are removed from the population. There have been few studies that have looked at these effects critically and additional research is needed to evaluate multiple electrical shocks on fish physiology and survival.

The evidence suggests that fish subjected to electrofishing sustain some level of physiological stress, can become lethargic or cryptic, or exhibit other abnormal behaviors. These physiologically induced behavioral changes likely alter a fish's catchability, which can introduce bias in any maximum-likelihood estimate of population size. Estimating changes in catchability can be made by comparing the actual catch in the third electrofishing pass from that predicted from the first and second passes (Zippin 1956).

In addition to implications for bias in depletion estimates, multiple-pass electrofishing may have additional effects on non-target native species. These fishes typically receive multiple exposures to electrofishing fields during multiple-pass depletion sampling. For many of these species we know little if anything about their response and risk to electrofishing fields. As pointed out by Synder (2003) in his review of electrofishing, significant numbers of surviving but adversely affected fish may ultimately impact community structure, population size, quality of the fishery resource, and management strategies. The short-term and long-term effects of multiple-pass depletion sampling on health and survival of these non-target native species and their populations are largely unknown and warrant further investigation.

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