Negative Impacts to Fish Associated with Electrofishing
Introduction:

Electrofishing is a common sampling technique used by fisheries biologists to sample fish populations. In the simplest sense, electrofishing is the technology of capturing fish, by producing an electric field in water of sufficient intensity to cause strong neurological responses (Vibert 1967a). The use of electrofishing as a sampling technique became widespread because it was easy, efficient, and thought to be a relatively harmless fish-sampling method when used appropriately (Bohlin et al. 1989; Dalbey et al. 1996). However, recent studies have shown that typical electrofishing procedures with standard equipment and settings can result in several negative effects, including increased injury to fish (Thompson 1995; Thompson et al. 1997a), reduced growth (McMichael 1993; Hollender and Carline 1994; Dwyer and White 1995; Dalbey et al. 1996; Thompson et al. 1997b), and mortality (Hauck 1949; Schreck et al. 1976; Lamarque 1990; Ainslie et al. 1998). Thus, biologists may now question their previous assumptions that the effects of electrofishing on fish health are minimal. Since the fate of injured fish over the long term and the potential population effects of electrofishing remain largely unknown (Snyder 1992), this sampling technique should be used with caution.

Waveforms:

The waveform in which electrical power is presented (i.e., AC, continuous DC, or various forms of pulsed DC) not only affects how a fish’s nervous system is stimulated (Lamarque 1990; Sharber and Black 1999), but it has also been known to influence the incidence and severity of injury and mortality (Sharber and Carothers 1988; McMichael
Alternating current (AC) is considered the most injurious waveform to fish, direct current (DC) the least injurious and pulsed direct current (PDC) is intermediate to AC and DC (Hauck 1949; Lamarque 1990; Reynolds 1996). Initially AC current was widely used for electrofishing (Everhart and Youngs 1953), but a study by Sharber (1986) revealed the concerns of electrofishing with the AC waveform, and later biologists were advised against using AC (Reynolds and Kolz 1988). The AC waveform has limited use today. This is largely because AC has been shown to be highly injurious to fish (Hauck 1949), and because AC also fails to elicit the appropriate electrotaxis needed for efficient electrofishing (Vibert 1963). Direct current is also preferred over AC due to the fact that fish responses to DC are more predictable than those of AC (Reynolds 1996). Immediate fish mortality rarely occurs because of DC electroshock (Miranda and Dolan 2004), but physical injuries and physiological trauma have been noted, although these are often undetectable by external observations (Sharber et al. 1994). Pulsing the delivery of DC helps increase field strength by producing large bursts of peak power that are of short duration, which are followed by recovery periods that store energy for the following burst (Novotny 1990). By releasing the stored energy in short bursts, PDC is capable of delivering a higher instantaneous power level (Miranda and Dolan 2004). Because of this increased field strength, PDC can cause injuries that are more severe than continuous DC (Reynolds 1996). In most electrofishing practice today, PDC is used because it requires less power than unmodulated DC (Sharber et al. 1994). Both continuous DC and low-frequency 30-Hz PDC have been recommended for electrofishing (Fredenberg 1992; Snyder 1995; Sharber et al. 1994; Dalbey et al. 1996;
Ainslie et al. 1998), largely due to the lower injury rates that occur with these waveforms (Fredenberg 1992; Taube 1992; McMichael 1993; Sharber et al. 1994; Dalbey et al. 1996). However, depending on the species sought, environmental characteristics, and the type of habitat, all three waveforms are still used to some degree for sampling fish (Schneider 1992; Habera et al. 1996).

**Pulse Shape, Frequency, and Duty Cycle:**

The pulse shape and frequency of the electricity have been known to influence the incidence and severity of injury to fish (Sharber and Carothers 1988; McMichael 1993; Sharber et al. 1994). Three pulse shapes are available for DC electrofishing devices: exponential, square wave, and one-quarter-sine wave (Haskell 1954; Halsband 1967; Hartley 1967). The exponential pulse has been found to be the most effective and least traumatic (Halsband 1967; Hartley 1967; Sternin el al. 1972; Novotny and Priegel 1974). Pulsed DC waveforms are composed of a pulse frequency (pulses per second; Hz). When other factors are held constant, incidence of hemorrhage and spinal damage tend to increase with pulse frequency (Sharber and Carothers 1988; Fredenberg 1992; Taube 1992; McMichael 1993; Sharber et al. 1994; Dalbey et al. 1996; Dolan et al. 2002). However, Lamarque (1990) suggested that narrow, high-frequency pulses minimize injury rates; and a study by Dolan et al. (2002) revealed that low frequencies can produce the greatest levels of mortality in black crappies *Pomoxis nigromaculatus*. Sharber et al. (1994) hypothesized that most fish injuries occur at high pulse frequencies because injuries are caused by the myoclonic jerks associated with shocking induced seizures, and such seizures developed more rapidly at higher than at lower frequencies.
Pulsed DC waveforms are not only composed of a pulse frequency, but also pulse duration (time on for 1 pulse; ms). Together these are often described in terms of duty cycle (a pulsed DC 110 Hz, 6 ms waveform has a 66% duty cycle; Reynolds 1996). Thus duty cycle is essentially the percentage of time the electrofishing field is energized. Duty cycle can be controlled by manipulating pulse frequency and pulse duration using the instrumentation provided by most commercial electrofishing equipment (Dolan and Miranda 2004). As duty cycle is decreased, increasingly higher power densities are required to immobilize fish (Miranda and Dolan 2004), which in itself may be sufficient to cause injury. Therefore, electrofishing with intermediate to high duty cycles (between 10% and 50%) can potentially reduce harm to fish, by providing improved ability to avoid tetany (Miranda and Dolan 2004). Such a strategy would allow an increase in the radius of immobilization action, allowing higher peak power to be transmitted further away from the electrodes and requiring less peak power to immobilize fish, which in turn maximizes the effectiveness of the operation (Miranda and Dolan 2004).

**Variables:**

Many factors can influence the rate and severity of electrofishing-induced injuries. Environmental conditions, such as the conductivity and depth of water, as well as the substrate type affect electrofishing efficacy. The type of electrical hardware and amount of electrical current used has also been known to produce pronounced differences (Sternin et al. 1972). Therefore the relative rates of injuries are likely to vary, due to the amount of electricity needed to immobilize fish in relation to various characteristics.

**Species Differences:**
Electrofishing has been known to cause mortality or physical injury to a variety of fish species (Hauck 1949; Horak and Klein 1967; Lamarque 1967; Spencer 1967; Schreck et al. 1976; Whaley et al. 1978), but it has been established that the rate and seriousness of injury varies markedly within and among species (Hauck 1949; Pratt 1954; Horak and Klein 1967; Spencer 1967; Vibert 1967a; Maxfield et al. 1971; Hudy 1985). Rainbow trout *Oncorhynchus mykiss*, along with other salmonids appear particularly susceptible to injury during shocking (Hudy 1985; Reynolds and Kolz 1988; Snyder 1992). Differences in the susceptibilities to injury among species likely derive from anatomical and morphological attributes linked to species adaptations (Dolan and Miranda 2004).

**Fish size:**

The immobilization thresholds of electrofishing have often been linked to fish size (Zalewski and Cowx 1990; Reynolds 1996). In theory large fish are easier to immobilize than small ones because they require less peak power (Reynolds and Simpson 1978; Zalewski 1985; Buettiker 1992; Anderson 1995), since larger fish intercept a greater head-to-tail voltage gradient than smaller fish. Therefore, a positive relationship exists between fish size and the frequency of electrofishing injury (Ellis 1975; Regis et al. 1981; Jesien and Hocutt 1990; Lamarque 1990; Hollender and Carline 1994; Dalbey et al. 1996; Thompson et al. 1997a). However, Fredenberg (1992) observed no such relationship and suggested that injuries in smaller fish are more difficult to detect than similar injuries in larger fish.

Differences due to size may also be linked to disparities in muscle mass and muscle composition. Larger fish often have more well-developed muscles than smaller
fish; these muscles are able to contract more forcefully, and may severely alter the vertebrae to cause spinal injury and associated hemorrhage (Lamarque 1990). Larger fish also tend to have a higher proportion of white muscle fibers that are larger than red muscle fibers and also contract more powerfully (Helfman et al. 1997). The condition of the fish may also be a determinate in the rate of injury. A study by Thompson et al. (1997a) hypothesized that fish in better condition may actually be more susceptible to be injured because of more powerful muscle contractions than those of poorer condition. In contrast, Stewart (1962) claimed that the decalcification produced by spawning, and the lack of magnesium and calcium resulting from a poor diet can lead to an increased likelihood of electrofishing-induced injuries.

**Exposure:**

Since electrofishing fields are created by the dispersion of energy between electrodes, heterogeneous fields result, where strength of the field is greatest next to the electrodes and rapidly dissipates as horizontal and vertical distance from the electrodes increases (Reynolds 1996). The size of the electric field and the fish’s position within the field determines the actual field strength encountered by the fish (Miranda and Dolan 2004). Size and strength of an electrofishing field depends on the amount of electrical power that can be transmitted between electrodes, which in turn, hinges on water conductivity, electrode size and shape, electrode positioning, electrode separation, and the voltage and current capabilities of the power source (Novotny 1990; Kolz 1993; Reynolds 1996). The density of the electric current near the electrodes is directly related to the electrode's size, shape, and electrical resistivity (Novotny and Priegel 1974).
Greater levels of injury and mortality have been reported for fish that are tetanized by electrofishing (Lamarque 1990; Reynolds 1996; Dolan and Miranda 2004). Since tetany is associated with shock near the electrode in the strongest part of the electric field, the hypothesis assumes that the principal cause of morphological damage is the high voltage gradient around the fish (Sharber et al. 1994). Reynolds and Kolz (1988) suggested that rainbow trout are severely injured when fish are shocked within the area of high voltage that occurs near the anode at all waveforms. Alternatively, Sharber et al. (1994) postulated that the cumulative time of exposure to electricity could be a factor in electrofishing injuries. They theorized that the severe muscular contractions thought to produce spinal injuries, may occur at any time after the onset of electrotaxis; and that they are not a result of field intensity or the proximity of the fish to the anode, but are more a function of duration of exposure.

Repeated exposures to electrofishing fields have resulted in negative impacts in many studies (Gatz et al. 1986; Gatz and Adams 1987; Mesa and Schreck 1989; Schneider 1992). The rate and severity of injuries, as well as the magnitude of growth alterations typically increase with the number of passes, or the frequency of exposures to electroshocks (Ainslie et al. 1998).

**Injuries:**

Injuries typically resulting from electrofishing occur as spinal damage (e.g., vertebral compressions, separation, and fractures), hemorrhages in the blood vessels and soft tissues, and immediate or delayed mortality in worse case scenarios (Reynolds 1996). It’s important to be aware that injuries from electrical shock in fish can occur with no
visible external signs (Reynolds 1996). These injuries include muscle, nerve, and tissue damage (Hauck 1949; McMichael 1993; Hollender and Carline 1994; Thompson et al. 1992a), alterations in blood constituents (Schreck et al. 1976; Gatz et al. 1986, Mesa & Schreck, 1989; Maule & Mesa, 1994; Mitton & McDonald 1994a; Barton & Grosh 1996), change of fish behavior (Mesa & Schreck 1989), reduced growth rate (Gatz et al. 1986; Gatz & Adams 1987; Dwyer & White 1995, 1997; Thompson et al. 1997a), increased metabolic and coughing rates (Vosilene 1991), reduced swimming performance and stamina (Horak and Klein 1967; Mitton and McDonald 1994a, 1994b), and reduced fertility (Marriott 1973; Muth and Ruppert 1996). Electroshock treatment has also been shown to have detrimental effects on embryos as well (Dwyer et al. 1993; Dwyer & Erdahl 1995; Muth & Ruppert 1996, 1997).

**Spinal Injuries:**

Spinal damage may consist of fracture, misalignment, or compression of the vertebral column (Dolan et al. 2002). A study by Stewart (1974) claimed that spinal malformations caused by DC are usually of the compacted type (compression of several vertebrae), whereas the oblique type (misalignment of successive vertebrae) is more common with the AC waveform. Lamarque (1990) hypothesized that spinal injuries likely result from severe muscle contractions that occur when the fish experience tetany. Tetany is the last stage in a series of three general behavioral responses recognized in fish exposed to electroshock. In tetany, fish are immobilized, and their muscles are rigid, and no breathing motions occur. Tetany is preceded by narcosis, where fish are immobilized with muscles relaxed, but still breathing. And fright, which occurs as sporadic swimming (Miranda and Dolan 2004). This hypothesis has led to the widely held opinion that
vertebral fracturing can be avoided if electrofishing equipment is operated at voltage levels sufficiently strong to induce narcosis but weak enough to avoid tetany (Vibert 1967b; Sternin et al. 1972; Novotny and Priegel 1974). However, a study conducted by Sharber et al. (1994) suggested that electrofishing-induced seizures capable of causing spinal compression fractures can happen any time after electrotaxis begins, and the state of tetany does not need to be reached.

Electrofishing-induced spinal injuries likely result from myoclonic jerks, which are the simultaneous contraction of the white muscle tissue on either side of the spine, which frequently accompany the onset of epileptic events (Sharber et al. 1994). These seizures may also cause less detectable injuries such as organ, tissue, and cell damage that may eventually lead to delayed mortality (Dolan and Miranda 2004). The normal swimming mechanism of a fish is a sinusoidal curvature of the body with the muscles of one side of the body contracting while those on the other side are relaxed (Nursall 1956). When the fish are stimulated by such pulsed currents the muscles on both sides of the body are excited at the same time, submitting the vertebral column to opposing constraints, the spinal column compensates for this stress by compressing, fracturing or misaligning (Lamarque 1990). A single pulse, sometimes at low voltage, can be sufficient enough to provoke this effect (Lamarque 1990). Spinal injury and hemorrhage typically occur most often on or near the vertebral column in dorsal–anterior regions of the trunk (Sharber and Carothers 1988; Fredenberg 1992; Ainslie et al. 1998, Dolan and Miranda 2004). This is expected, since this region of the body contains more muscle mass than the far anterior or posterior spine regions, making it more susceptible to damage (Lamarque 1990).
Branding:

Bruising often referred to as “branding,” is thought to be caused by the erratic stimulation of chromatophores when nerve fibers are damaged by vertebral dislocation (Lamarque 1990; Fredenberg 1992) or by hemorrhaging of damaged capillaries near the skin (Reynolds 1996). With branding, a dark spot that is often chevron shaped, corresponding to the underlying myomeres, may be externally noticeable (Reynolds 1996). Bruising can be long lasting and may offer sites for bacterial or fungal infections (Reynolds 1996). Based on a review of several studies (Holmes et al. 1990; Fredenberg 1992; McMichael 1993; Hollender and Carline 1994), it appears that hemorrhages constitute about half of the total injuries reported. The presence of brands can be related to the occurrence and severity of spinal damage, but lack of branding may not indicate a lack of spinal injury (Fredenberg 1992; Ainslie et al. 1998). Fredenberg (1992) observed brands on 26% of a sample of adult rainbow trout, and noted that these fish had a much higher spinal injury rate (97%) than those without such marks (50%). However, Fredenberg (1992) also concluded that since brands may remain visible for a very short period, often less than one week post electroshock, they are not reliable indicators of past electroshocking injury. Through observations and knowledge by field personnel that most fish bearing these marks are being injured, changes can be made in the field to refine electrofishing gear settings.
**Mortality:**

Respiratory failure, hemorrhaging, internal injuries, and trauma have been considered the primary factors in causing electrofishing mortalities (Hauck 1949; Schreck et al. 1976; Lamarque 1990; Ainslie et al. 1998). Hemorrhaging, bruising, and spinal injury may not always be immediately lethal, however these injuries can cause delayed mortality (Bardygula-Nonn et al. 1995; Habera et al. 1996); since the fish may be more vulnerable to predation, less competitive, or unable to feed (Horak and Klein 1967; Mesa and Schreck 1989). While physical damage from electrofishing may appear obvious, acute physiological disturbances in fish are not as easily detected and could have detrimental effects on other performance attributes and subsequent survival, possibly long after fish are released (Barton and Dwyer 1997). Similarly, Barton and Grosh (1996) and Barton and Dwyer (1997) determined that electric current can alter blood constituents, and suggested that the stress associated with these changes may reduce survival.

Immediate mortality resulting from electrofishing may be due to the persistence of tetany after the interruption of current (post-tetanic potentiation), which prevents the resumption of respiration, leading to suffocation (Dolan and Miranda 2004). This process is the result of synaptic fatigue, which occurs when the fish has been overexposed to a tetanizing current (Lamarque 1990). Mortality related to respiratory failure usually occurs within minutes or a few hours after a fish is shocked (Reynolds 1996). Research has shown that the mechanisms causing physical injuries, such as hemorrhage and spinal injury, may not be the same as those that cause immediate mortality (Taylor et al. 1957; Spencer 1967; Hudy 1985; Dolan and Miranda 2004).
Taylor et al. (1957) found that mortalities of rainbow trout induced by electrofishing were almost never associated with ruptured blood vessels, injury to bones or organs, or other trauma, but instead, hypothesized that mortality of trout appeared to result from factors that were not visible either grossly or microscopically. Future research to pinpoint an exact cause of immediate mortality for fish exposed to electric current may need to focus on exploring injury at smaller scales, through examination of vital organs such as the respiratory and circulatory systems (Dolan and Miranda 2004). Although electroshocking produces various short-term physiological effects, modern gear typically causes minimal mortality (Hudy 1985).

**Growth:**

Electrofishing may reduce the condition and growth rates in fish. Single exposures to electroshocking may not have significant effects on growth (Halsband 1967; Maxfield et al. 1971; Ellis 1974; Kynard and Lonsdale 1975; Schneider 1992), but exposure to frequently repeated electroshocking can slow the rate of growth in fish (Gatz et al. 1986; Gatz and Adams 1987; Schneider 1992; Dalbey et al. 1996; Thompson et al. 1997b; Ainslie et al. 1998).

Gatz et al. (1986) found that repeated electrofishing reduced growth rates in some salmonids, and claimed that instantaneous growth rates of wild brown trout *Salmo trutta* and rainbow trout were reduced when fish were electrofished at intervals of 2.5 months or less, but saw few or no differences if fish had 3 months or more to recover between samplings. Therefore it is recommended that trout not be exposed to electrofishing more often than every 3 months (Gatz et al. 1986). Similarly Gatz and Adams (1987) reported
that growth of hybrid sunfish *Lepomis cyanellus* x *L. macrochirus* electroshocked every week was reduced compared with fish stunned at 2, 4, or 12 week intervals. Annual electrofishing for population monitoring is capable of reducing growth and condition of individual fish, but not consistently (Thompson et al. 1997b). A study by Schneider et al. (1992) determined that growth of largemouth bass *Micropterus salmoides* and walleyes *Sander vitreus* exposed to electrofishing once a year was not reduced compared with largemouth bass and walleyes caught with other gear types. Determining what interval of exposure is "too" frequent will likely vary with environmental conditions, the availability of food, and may also vary with the species of fish targeted. Protocols for age and growth studies should be designed with these considerations in mind.

A reduction in growth and condition by rainbow trout having injuries induced by electrofishing has been observed in studies by (Dalbey et al. 1996; Thompson et al. 1997b; Ainslie et al. 1998). Dalbey et al. (1996), compared spinal-injured with uninjured electrofished rainbow trout, using X-ray evaluation of live fish. Their results found that uninjured fish gained significantly more length and weight and were in better condition at both 100 and 335 d post electrofishing than did fish that incurred spinal dislocations or fractures of any severity; however the effects were especially pronounced for the most severely injured fish, which lost weight and condition during their study. Similarly, Ainslie et al. (1998) also found that fish with a large number of damaged vertebrae gained less length than did less severely injured fish. Reduced growth experienced by fish suffering from electrofishing-induced injuries likely results from the energy requirements to repair damaged tissues and bones (Ainslie et al. 1998) and decreased feeding behavior (Bouck and Ball 1966; Mesa and Schreck 1989). It’s also postulated...
that the calcification and fusion of injured vertebrae during healing, may cause abnormal swimming behavior, which could interfere with foraging effectiveness and predator avoidance (Sharber and Carothers 1988; Fredenberg 1992).

**Recovery:**

Electrofishing-induced injuries such as spinal deformity and hemorrhaging are not necessarily lethal or debilitating, and they often heal, so injured fish do not always suffer long-term physical constraints or mortality (Horak and Klein 1967; Hudy 1985; Schill and Elle 2000). Fish typically exhibit rapid recovery, measured in hours or days, from the physiological and behavioral effects of electroshock (Horak and Klein 1967; Mesa and Schreck 1989; Mitton and McDonald 1994). A study by Schill and Elle (2000) suggested that the healing of hemorrhages begins soon after injury, as the majority of injuries in their study healed 22 d post shocking, but hypothesized that the complete healing of all injuries were likely in the time frame of 9–12 weeks. Even though these injuries may quickly heal, certain effects may be long lasting. Miranda and Dolan (2004) showed that the healing of spinal injury was readily apparent in radiographs of injured fish 1 year after shocking, as injury sites showed significant calcification and apparent fusion of vertebrae.

Since the survival of fish may be indirectly influenced by the adverse effects of electric shock on behavior, health, growth, and reproduction (Gatz and Adams 1987; Mesa and Schreck 1989; Muth and Ruppert 1996), it remains uncertain if injuries that appear to be minor, have long-term deleterious effects on individual fish (Thompson et al. 1997a).
The quantification of electrofishing induced injuries through field observations is likely underestimated, since immediate mortality after electrofishing is usually low, and external signs of injury such as spinal damage and hemorrhaging are often absent or are undetected (Hudy 1985; McMichael 1993; Hollender and Carline 1994; Sharber et al. 1994). Therefore, normal-acting but severely injured fish might be overlooked. However, both spinal injuries and hemorrhaging are detectable using X-ray and necropsy methods (Sharber and Carothers 1998; Schill and Elle 2000). Due to the near absence of outward signs of spinal injury, X-ray or autopsy analyses are needed to properly assess spinal injuries from electrofishing (Sharber and Carothers 1998). Although X-raying fish is thought to be an effective method in testing for injuries, incidence and severity of spinal injury from electroshock may be underestimated with standard X-ray equipment. Since X-rays may fail to reveal all injuries to the spinal column, the initial estimates of severe injury should be considered conservative (Dalbey et al. 1996; Thompson et al. 1997a). Dalbey et al. (1996) discovered that rainbow trout X-rayed soon after capture may exhibit no detectable signs of spinal injury, but later show calcification indicative of old injuries if X-rayed again after 335 d in a pond. Injuries may also appear to be more severe in the later set of X-ray exposures than in the earlier set (Dalbey et al. 1996). It should also be noted that radiographs do not detect soft tissue damage, which may be more prevalent than damage to the spinal column (Fredenberg 1992; McMichael 1993); however, Schneider and Carothers (1988) indicated that injuries evident on the X-ray

**Testing for Injuries:**

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photographs were highly correlated with extensive internal bleeding or splintering of bone in autopsied fish.

**Minimizing Negative Impacts:**

Minimizing the risk of harm to fish during population surveys is clearly an important goal of fish sampling. Fish captured via electrofishing are frequently released after sampling, so it is critical that fish survive and behave normally after release. The best course of action is to find and use electrofishing settings and waveforms that minimize all levels of injury without compromising efficiency too greatly. To avoid injuries, biologists should use continuous DC if possible, or pulsed DC at low frequencies (30 Hz or less) and intermediate to high duty cycles (between 10% and 50%; Dolan and Miranda 2004; Reynolds 1996). However, duty cycles should be lower (near 10%) if larger fish will be affected (Reynolds 1996). Personnel should also carefully observe the fish’s reaction to the electric field, and refine electrofishing gear settings if necessary. In certain circumstances, it may even be beneficial to use an alternative capture method, when electrofishing causes concern for conservation and animal welfare (Reynolds 1996).

**Voltage Output:**

Many researchers (Vibert 1967a; Lamarque 1990; Dolan et al. 2002) have suggested that injuries can be avoided if electrofishing equipment is operated at voltages strong enough to induce narcosis but not tetany. Therefore electrofishing crews using PDC should use the minimum effective voltage to achieve adequate sample sizes (Reynolds 1996; Reynolds and Kolz 1988; Muth and Rupert 1997); without creating
unequal size efficiencies, since electrofishing is more effective for immobilizing large fish. In contrast, Sharber et al. (1994) suggested that injury-causing seizures are relatively independent of the strength of the electrical stimulus, and that the strong automatism of electrotaxis does not determine the intensity of myoclonic jerks. Electrofishing may also be standardized, meaning that voltages be adjusted to homogenize power density over waters with diverse conductivities, thus maintaining relatively constant power, which reduces intersite variability in catch rates (Burkhardt and Gutreuter 1995 Dolan et al. 2002).

**Duty Cycle:**

Electrofishing with intermediate to high duty cycles (between 10% and 50%) maximizes the effectiveness of electrofishing, and can potentially minimize detrimental effects to fish by providing improved ability to avoid tetany (Dolan and Miranda 2004; Miranda and Dolan 2004). Tetany is avoided more easily with high duty cycles because of a wider margin of difference between the electrical power required to narcotize fish and that required to tetanize them (Miranda and Dolan 2004). High power density requirements and seizures, coupled with the need to tetanize fish to achieve immobilization, probably contribute to the harmful effects of low duty cycles (Dolan and Miranda 2004). Manipulation of maximum power output to target immobilization of large individuals would avoid the peak powers required to immobilize small individuals, therefore overall mortality rates would be reduced (Dolan and Miranda 2004).

**Frequency:**

Low pulse frequencies of 30 Hz or less, or complex pulse patterns are also thought to reduce the overall injury rate (Vibert 1967b; Snyder 1992; Sharber et al. 1994;
Dalbey et al. 1996; Muth and Rupert 1997; Siepker et al. 2006). Sharber et al. (1994) hypothesized that more fish injuries are seen at higher pulse frequencies rather than high voltage gradients, because the trauma of myoclonic jerks in white muscles does not develop to the point of an epileptic seizure as rapidly at low frequencies as at higher frequencies. In contrast, Lamarque (1990) indicated that electrical settings consisting of short-pulse durations were the most injurious to fish. Therefore field crews should adjust electrofishing settings to a low pulse rate, and possibly to a narrow pulse width to minimize the amount of electricity fish are exposed to (Thompson et al. 1997b).

**Proximity to Electrodes & Exposure:**

Although agreement has not been reached if the proximity of fish to the anode influences injury (Reynolds and Kolz 1995; Sharber et al. 1994), a conservative approach is to ensure that fish do not come near an electrode, and to minimize the time fish spend in the electrical field if possible. Therefore electrofishing crew members should attempt to remove fish from the field as quickly as possible to speed physiological recovery of individuals (Schreer et al. 2004; Thompson et al. 1997b). Even though the operator may have the ability to control the power transmitted between electrodes, they may not be able to control exposing fish to high power densities that are commonly encountered in the proximity of electrodes (Dolan and Miranda 2004). In certain instances, modifications to the electrode system may be necessary to avoid high power densities that commonly occur in the proximity of electrodes (Dolan and Miranda 2004).

**Tetany:**
Although Miranda and Dolan (2004) claim that injury and mortality may not be fully accounted for by tetany, but rather influenced by other unidentified factors; many researchers (Vibert 1967b; Lamarque 1990, Dolan et al. 2002; Dolan and Miranda 2004) have suggested that injuries can be avoided if electrofishing equipment is operated at voltages that induce narcosis but not tetany. Since tetany appears to be associated with higher injury rates. Such an operational approach simplifies electrofishing, by requiring adjustment of electrical output through observation of fish behavior in the electrical field rather than through in-water measurement of electrical variables (Dolan and Miranda 2004). Narcosis and tetany endpoints depend on the nature and intensity of the electrical field, which are managed by manipulating power density through reductions or increases in voltage or amperage (Reynolds 1996).

**Conclusion:**

Electrofishing is an effective sampling technique that should be used with great caution by fisheries professionals. With increasingly more information indicating that the effects of electrofishing may be damaging to individual fish, opportunities to minimize negative impacts must be identified and utilized to prevent future impacts to the resource. It is critical to minimize the negative impacts often associated with electrofishing, since many long-term intensive studies on fish populations require that large samples of fish be captured and released unharmed. After release, the sampled fish should be able to survive, grow, and behave normally. This consideration is especially crucial when conducting age and growth analyses and population studies using a mark and recapture method. For these studies, it is important to assess the effects of electrofishing on the targeted fish populations. Researchers making repeated samplings must avoid techniques
that result in fish mortality or reduced growth. Failing to reduce electrofishing-induced injury and mortality in fish collected for mark–recapture studies may lead to inflated population estimates or deflated exploitation estimates (Pratt 1954; Barrett and Grossman 1988; Dolan et al. 2002). In addition, electrofishing effects should be known by the biologists before this technique is used on endangered or threatened fish populations, since the detrimental effects of electrofishing may severely affect threatened or endangered fish populations (Barrett and Grossman 1988). In these situations electrofishing should be employed with great caution or simply avoided. It is also important that biologists use caution when sampling large fish, spawning fish, and nesting areas.

Population-level impacts resulting from sampling mortality are ultimately important to fishery managers. The population-level effect of electrofishing depends on the type of abundance estimate, the number of sampling passes, and the proportion of the population sampled (Ainslie et al. 1998). Even though some studies have shown no or limited population-level effects (Schill and Beland 1995; Kocovsky et al. 1997; Carline 2001), concern and awareness should be applied by biologists.

Although electrofishing is widely used for the research and management of freshwater fish, it is sometimes used without the essential knowledge of the potential negative impacts that may result. Crew experience is an intangible that likely affects the frequency and severity of injuries to fish. Field personnel should be thoroughly briefed on the principles of electrofishing before they take to the field. This briefing should include the concepts of field strength, the various physical responses of fish, and the
importance of preventing fish from entering the zone of tetany or remaining within the electrical field for an extended period of time (Thompson et al. 1997b).

Additional research is needed to characterize the causes of severe injury during electroshocking, and develop ways to reduce it. It would also be beneficial to gain a better understanding of the long-term consequences, mortalities, and possible population-level impacts associated with contemporary electrofishing equipment and practices. Despite the risks and negative impacts to fish associated with this sampling technique, electrofishing remains a valuable tool for inland fisheries management when applied judiciously.
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