Incidence of Spinal Injuries in Migratory Yellowstone Cutthroat Trout Captured at Electric and Waterfall-Velocity Weirs

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Abstract—The South Fork Snake River in Idaho supports a native Yellowstone Cutthroat Trout population YCT *Oncorhynchus clarkii bouvieri* jeopardized by nonnative Rainbow Trout *O. mykiss*. Electric weirs prevent Rainbow Trout passage into YCT spawning tributaries, but may cause spinal injuries. Yellowstone Cutthroat Trout YCT captured at electric weirs on Palisades and Pine creeks and a control waterfall-velocity weir on Burns Creek were x-rayed in 2012 and 2013 to estimate spinal injury rates. Electrical pulse frequency increased from 2012 to 2013 at the Palisades (from 11.5 to 20 Hz) and Pine weirs (13 to 20 Hz), with spinal injury rates increasing from 11.3% to 21.3% at Palisades Creek and from 6.5% to 14.7% at Pine Creek, while Burns Creek injury rates remained relatively unchanged (4.5% in 2012 and 6.0% in 2013), suggesting the electric weirs caused spinal injuries in YCT. Lower pulse frequencies may minimize YCT spinal injury while preventing Rainbow Trout from accessing YCT spawning tributaries.

Introduction

The South Fork Snake River in eastern Idaho, United States, supports an abundant population of Yellowstone Cutthroat Trout *Oncorhynchus clarkii bouvieri* (Meyer et al. 2006). This population is considered important because it is one of the few robust fluvial populations of Yellowstone Cutthroat Trout (YCT) remaining in Idaho (Thurow et al. 1988; Meyer et al. 2006; Gresswell 2011). However, the long-term persistence of YCT in the South Fork Snake River drainage is jeopardized by the increasing abundance of nonnative Rainbow Trout *O. mykiss* (High 2010). Rainbow Trout and YCT have similar life histories in the South Fork Snake River, including the fluvial nature of their spawning behavior (Henderson et al. 2000). While Rainbow Trout in the South Fork Snake River drainage tend to spawn slightly earlier (mid- to late May) than YCT (mid- to late June) and are more likely to spawn in the main-stem river (Henderson et al. 2000), both species also ascend the four main tributaries below Palisades Dam (Burns, Pine, Rainey, and Palisades creeks) to spawn (Fig. 1). Rainbow Trout and Cutthroat Trout have no reproductive isolation mechanisms and readily hybridize throughout the native range of Cutthroat Trout (Young 1995; Behnke 2002). Rainbow Trout and hybrids may also outcompete Yellowstone Cutthroat Trout in juvenile life history stages, causing a growth disadvantage for YCT in the presence of Rainbow Trout and hybrids (Seiler and Keeley 2009). While Rainbow Trout and hybrids will likely never be eliminated from the entire South Fork Snake River drainage, protection of pure YCT within the main stem and in the four main spawning tributaries in Idaho has become a high priority for the Idaho Department of Fish and Game (IDFG: LaBar 2007; High 2010).

Since 2001, IDFG has operated migration traps on these four tributaries of the South Fork Snake River to prevent upstream access by Rainbow Trout and hybrids during the spawning period. Rainbow Trout and hybrids are removed from the system at the migration traps, while Yellowstone Cutthroat Trout are released upstream to spawn. Various types of weirs have been used over time, including picket, Mitsubishi, and floating panel, but most were inefficient or could not be operated in high flows during the critical period of the spring spawning migration run (High 2010). More recently, a permanent combination waterfall-velocity weir was installed on Burns Creek in 2009, which has been efficient at capturing upstream-migrating salmonids. The remaining tributaries lacked sufficient channel gradient to install velocity barriers, so permanent electric weirs were installed in Palisades Creek in 2009, Pine Creek in 2010, and in Rainey Creek in 2011. Efficiencies for the electric weirs in these tributaries have ranged from 49 to 86% during the first few years while trying to match electrical settings to varying flow levels (B. High, unpublished data).

While fish injuries at waterfall-velocity weirs are likely negligible, electric weirs have the potential to be more injurious to upstream or downstream migrating fish. However, no empirical data exist on the incidence of spinal injuries at electric or waterfall-velocity weirs. Electrical current in the water, such as occurs during electrofishing surveys, has repeatedly been shown to cause spinal and hemorrhage injuries in fish (reviewed in Reynolds and Kolz 2012). Trout species are especially vulnerable to injury from electric fields (Snyder 2003). Larger fish are more vulnerable to injury because their length results in a greater electric potential (Reynolds et al. 1988), and injuries generally increase with increasing electrical intensity, especially pulse frequency settings when using pulsed DC (McMichael 1993; Sharber et al. 1994; Reynolds and Kolz 2012). While both spinal injuries and hemorrhages are considered important when evaluating fish injuries from electricity (Reynolds and Kolz 2012), spinal injuries are much more critical because hemorrhages typically persist for a relatively short time and therefore do not normally represent a long-term mortality or health risk to the fish (Schill and Elle 2000).

The objective of this study was to evaluate spinal injuries in YCT presumably exposed to electricity at electric weirs by using a portable x-ray machine. It was expected that (1) spinal injury rates would be higher at the electric weirs than the waterfall-velocity weir, and (2) if the electric weirs were causing spinal injuries, then injury rates would increase at the electric weirs with an increase in pulse frequency, whereas injury rate would not change at the waterfall-velocity weir.

Methods

The study of YCT spinal injuries was conducted in three tributaries of the South Fork Snake River (Figure 1). Palisades Creek and Pine Creek have electric weirs that prevent upstream passage of Rainbow Trout and hybrids, whereas Burns Creek has a waterfall-velocity weir, which served as a control site for assessing spinal injuries at the electric weirs (Figure 2). Rainey Creek, another tributary of the South Fork Snake River, also has an electric weir, but its spawning migration run of YCT was too small to include fish from this stream in our analyses.

The weirs were operated each year from mid-March to mid-July, covering the entire spawning runs of Rainbow Trout, hybrids, and YCT. Fish were x-rayed from the three study streams on June 12-14 and June 25-26 in 2012, and again on June 10-12 in 2013. Ambient conductivity averaged 185, 298, and 359 µS/cm at Burns, Palisades, and Pine creeks, respectively (See Table 1 for additional stream characteristics).

Both electric weirs in this study have six parallel electrodes made of metal railing embedded in a concrete apron along the stream bottom, with the upper surfaces of the railings exposed to the water. The railings span the entire stream channel and continue up the concrete walls enclosing the entire stream except for the fish trap. Fish traps at both weirs are located on the right bank looking upstream, outside the electric field. The most downstream and upstream- electrodes are parasitic, meaning that electrical current does not diffuse upstream or downstream of these electrodes. Consequently, fish that approach the electric field from

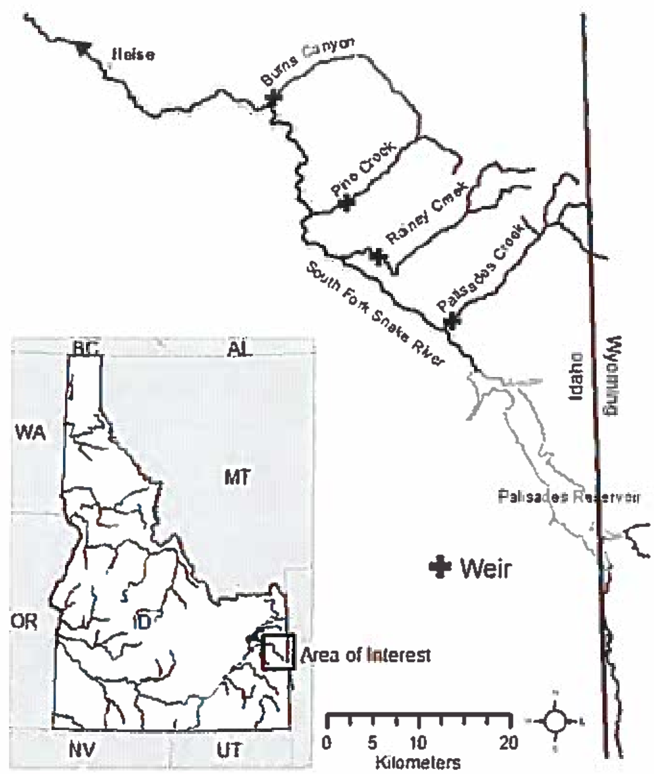

Figure 1. Location of South Fork Snake River tributaries and the electric and waterfall-velocity weirs where x-ray images were captured in Yellowstone cutthroat trout.

a downstream location can enter the fish trap without experiencing any electrical current.

The waterfall-velocity weir consists of a 0.6-m drop that falls on a 3.7-m concrete apron with high water velocity. Typical flows during spring runoff result in water depths of less than 10 cm on the concrete apron of the velocity barrier. The combination of fast water on the apron and the lack of water depth below the waterfall from which to jump from effectively blocks upstream fish passage. Adjacent to the barrier, the fish trap is located on the left bank when looking upstream, at the top of a fish ladder which guides upstream migrants into the trap.

In 2012, the Palisades Creek electric weir output was set at 11.5 Hz, 2.5 milliseconds (ms) pulse width, and 265 volts, and the Pine Creek weir output was set at 13 Hz, 2 ms pulse width, and 270 volts. These electrical settings produced similar horizontal voltage gradients at each weir, ranging from -11 to +12 V/cm but with most values falling within the range of -5 to +5 V/cm. In 2013, pulse frequency settings were increased to 20 Hz at both weirs to evaluate whether higher electrical settings would improve fish capture efficiency; voltage and pulse width were held constant. The change in pulse frequency also provided a means of comparing injury rates between different pulse frequency settings at the weirs.

Yellowstone Cutthroat Trout were netted from the trap box at each weir, anesthetized using MS-222, and measured for total length (TL). A MinXRay HF

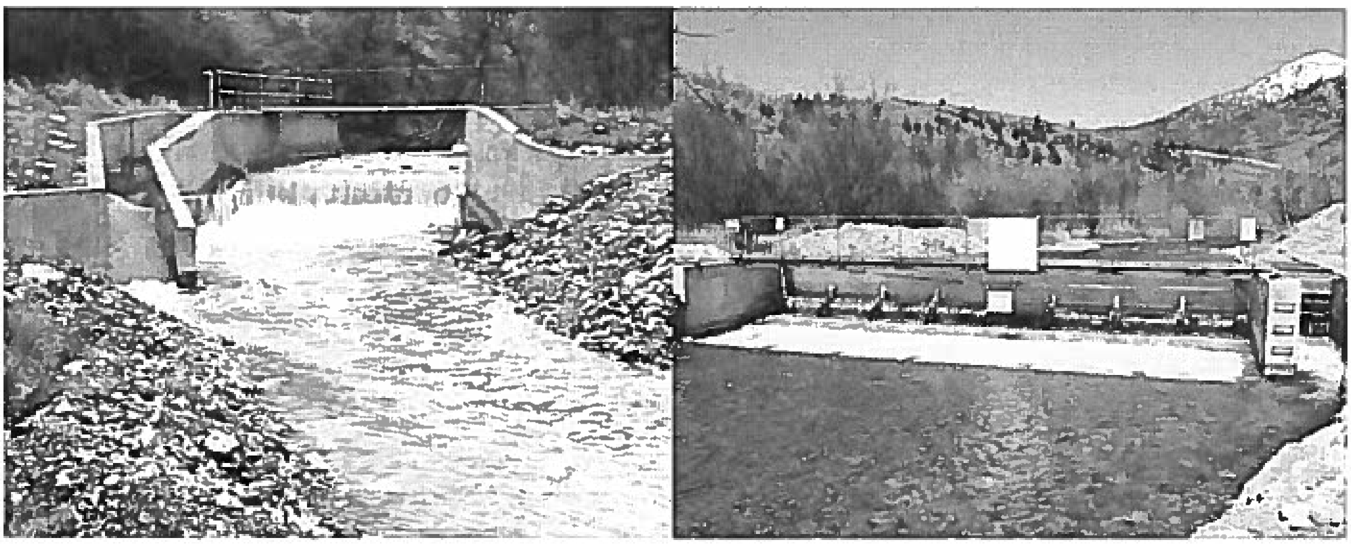

Figure 2. View looking upstream of waterfall-velocity (left) and electric weirs (right) on Burns Creek and Palisades Creek, respectively. The fish trap is located on the left bank at the waterfall-velocity weir and on the right bank at the electric weir.

Table 1. Characteristics of three tributaries of the South Fork Snake River that served as study streams in our analyses.

Tributaries	Weir type	Drainage area (km^2)	Stream width at weir (m)	Spawning run size 2012 YCT	Spawning run size 2012 RBT/HYB	Spawning run size 2013 YCT	Spawning run size 2013 RBT/HYB	Weir capture efficiency (%) 2012	Weir capture efficiency (%) 2013
Palisades	Electric	166	13	232	20	619	23	88	96
Pine	Electric	188	7.4	1,427	3	1,908	1	-	89
Burns	Waterfall-velocity	55	6.6	496	0	898	6	90	98

100+ portable digital x-ray generator and a TruDR lx system plate and computer program were used to generate x-ray images. Images were taken with a peak kilovoltage of 100 and an exposure of ~1.3 milliampere seconds, but settings were adjusted slightly as needed to obtain clear x-ray images for each fish. After recovering from anesthesia, YCT were released upstream of the weir and fish trap to continue their spawning migration.

The x-ray images were analyzed for presence of spinal injuries. Injuries were classified using the injury criteria in Reynolds (1996) of 0 for no spinal damage, 1 for vertebral compressions only, 2 for misalignments and compressions, and 3 for fracture of one or more vertebrae or complete separation of two or more vertebrae along with misalignments or compressions. Both vertical and horizontal x-rays were taken for nearly all injured fish and a subsample of uninjured fish to confirm that spinal injuries could be detected using horizontal x-rays only. Compressions were always visible using either vertical or horizontal x-rays, and we never detected misalignments or fractures with one view that was not also visible in the other view. Hairline fractures, which would be classified as a class 3 injury, were likely not visible in our x-ray images (Dalbey et al. 1996).

Data were analyzed in SAS (SAS Institute 2009) using a generalized linear model (at $\alpha = 0.10$) with a dummy response variable of 0 for uninjured fish and 1 for fish with a spinal injury. The primary explanatory variable of interest was a combination variable of stream and year, with each of the six stream × year combinations considered as a separate treatment. Total length was also included in the model because of the aforementioned greater electrical potential in larger fish that makes them more vulnerable to spinal injury when exposed to electric currents (Reynolds et al. 1988).

Results

In 2012, a total of 349 YCT were x-rayed, including 134 fish at Burns Creek, 106 at Palisades Creek, and 109 at Pine Creek. A total of 25 spinal injuries were detected in 2012. In 2013, a total of 251 fish were x-rayed, including 67 fish at Burns Creek, 80 at Palisades Creek and 104 at Pine Creek. A total of 36 spinal injuries were detected in 2013. A small number of fish with spinal malformations, always in the caudal peduncle, were determined to have congenital defects ($n = 2$ in 2012 and $n = 1$ in 2013) and were not categorized as injured for our analyses. The average length of fish at each site (± 1 standard error) was 385 ± 3 mm at Burns Creek, 389 ± 3 mm at Palisades Creek, and 374 ± 3 mm at Pine Creek.

The full general linear model explained only 4% of the variation in spinal injuries, but the model was statistically significant ($F = 4.52$, $P = 0.0002$). Spinal injury rates differed among stream × year treatments ($F = 4.64$, $P = 0.0004$), and Duncan's multiple range test indicated that injury rates at both electric weirs were higher in year two than in year one, but did not differ between years at the waterfall-velocity weir (Figure 3). In 2012, at the lower electrical settings, injury rates did not differ significantly among the two electric weirs and the waterfall-velocity weir, but in 2013, at the higher electrical settings, injury rates were significantly higher at the two electric weirs than the waterfall-velocity weir. Individual estimates of spinal injury rate (± 90% confidence intervals) in 2012 and 2013 were 6.5 ± 3.9% and 14.7 ± 5.9%, respectively, at Pine Creek, 11.3 ± 5.1% and 21.2 ± 7.7% at Palisades Creek, and 4.5 ± 3.0% and 6.0 ± 4.9% at Burns Creek.

Spinal injury rates for YCT also increased as fish size increased ($F = 5.64$, $P = 0.018$). Excluding fish captured at the waterfall-velocity weir to evaluate

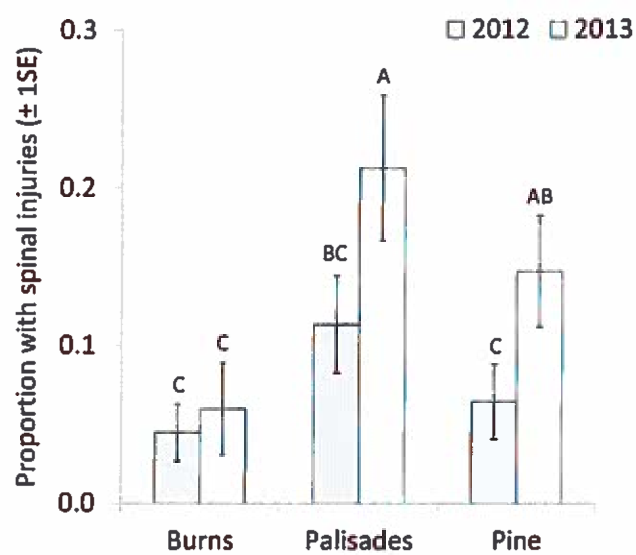

Figure 3. Spinal injury rates in Yellowstone cutthroat trout captured at a waterfall-velocity weir (Burns Creek) and two electric weirs (Palisades and Pine creeks). Estimates with different letters indicate statistical significance at α = 0.10.

the effect of fish size on spinal injuries at the electric weirs, estimates of injury rate (± 90% confidence intervals) for fish ≥ 375 mm TL (22.1 ± 4.6%) was nearly double that for fish < 375 mm (11.3 ± 4.3%).

The number of vertebrae involved in YCT spinal injuries in 2012 and 2013 ranged from 2 to 34, with an average of 16.6 vertebrae affected in each injured fish across all streams and years. Injuries of varying severity occurred across streams and years; however, 100% of all spinal injuries involved vertebral compressions, while spinal fractures and misalignments were encountered less frequently and were involved in 55% and 22% of all spinal injuries, respectively.

Discussion

The fact that spinal injury rates doubled in 2013 compared to 2012 at both electric weirs following a near doubling of pulse frequency, while the injury rates at the waterfall-velocity weir remained unchanged in 2013, suggests that the electric weirs caused injuries in YCT at the higher electrical settings. Injury rates at the lower electrical settings were also higher at the electric weirs (mean = 8.9%) compared to the waterfall-velocity weir (4.5%), but the lack of statistical significance leads to the conclusion that these lower settings were causing little if any injuries, although low overall sample size reduced the statistical power to detect a real difference.

The low level of spinal injuries at the Burns Creek waterfall-velocity weir likely represents a background level of injuries in the entire YCT population in the South Fork Snake River drainage. Indeed, it is unlikely that the spinal injuries we observed at the waterfall-velocity weir were caused by (1) fish jumping at the waterfall, since there is no pool from which to jump, or (2) fish handling. It is also unlikely that wild trout that have never been exposed to electricity have an elevated background level of spinal injuries (Kocovsky et al. 1997). A more likely source for these injuries is boat electrofishing surveys conducted each September and February in the main stem of the South Fork Snake River to monitor trout populations. These electrofishing surveys span 75 km, encompass the confluences of all three study streams (Figure 1), and occur at a time when most migratory YCT spawners are located in the mainstem and thus could potentially be exposed to boat electrofishing. Although spinal compressions can heal visibly within a year (Dalbey et al 1996; J. Reynolds, personal communication), these types of injuries were likely visible in x-ray images for several months after the February electrofishing surveys and perhaps the September surveys as well. If all or nearly all of the injuries at Burns Creek can be attributed to main-stem electrofishing surveys, then a similar level of injuries at the two electric weirs should also be attributed to these same electrofishing surveys. Thus, all of this study's estimates of spinal injury rates were likely overestimated to a similar degree (i.e., ~ 5%). Many salmonid populations that are monitored through time with electrofishing surveys have background levels of spinal injury in the survey reaches (e.g., Kocovsky et al. 1997; McMichael et al. 1998). Nevertheless, the difference in injury rates between 2012 and 2013 at the two electric weirs and the unchanged injury rate at the waterfall-velocity weir leads us to conclude that the electric weirs at the higher electrical settings caused some spinal injuries in upstream migrating YCT.

Mean spinal injury rate at the two electric weirs combined was 17.6% in 2013, when pulse frequency was 20 Hz at both weirs. With or without a slight downward adjustment to this estimate to account for main-stem electrofishing injuries, these findings concur with Sharber et al. (1994), who reported spinal injury rates of 3% for wild Rainbow Trout exposed to pulsed DC current at 15 Hz and 24% at 30 Hz. Similarly, McMichael et al. (1998) reported electrofishing-induced spinal injury rates of 27.7% at 30 Hz pulsed DC for Rainbow Trout > 250 mm (fork length). There were no estimates of fish injury rates at electric weirs or waterfall-velocity weirs to which these results could be compared directly. Additional studies of spinal injuries at both types of weirs would help substantiate or refute these results.

Not all detrimental effects to the YCT population at the electric weirs are the result of spinal injuries. For example, while x-raying fish at Pine Creek, two dead YCT were found caught in the electric field of the weir, circling in an eddy. The two dead fish were x-rayed but did not have any spinal injuries, suggesting they likely died from asphyxiation or some other severe physiological stress response to electricity (Snyder 2003). Although rare, fish are sometimes observed challenging the electric fields at the Pine and Palisades weirs, occasionally reaching the headboards before becoming immobilized and eventually washing downstream. While fish are recovering their equilibrium, they may asphyxiate or get caught in instream structures downstream such as root wads or woody debris. Mortalities observed at the electric weirs have generally been low, averaging only 0.8% of the entire spawning run (across both weirs and years) and are often due to handling stress rather than exposure to electricity (B. High, unpublished data). However, unobserved mortality resulting from overexposure may occur in fatally wounded fish that float downstream without being observed by the weir operators. Annual exposure to electricity for the migratory component of the YCT population may also lead to a long-term reduction in fish growth rates (Gatz et al. 1986), or may reduce egg survival for fish that are passed upstream of the electric weirs (Marriott 1973; Dwyer et al. 1993; Roach 1999).

Given that Cutthroat Trout have an average of 60-63 vertebrae, an average of 17 vertebrae involved in the injured YCT in this study constitutes a significant level of injury. Other studies have found an average of 6 to 8 vertebrae involved in salmonid spinal injuries due to electrofishing (Sharber and Carothers 1988; Hollender and Carline 1994), although these studies involved fish with lower mean lengths (136 mm and 360 mm, respectively, compared to 382 mm in this study) and thus the fish were likely not as affected by electricity as were the larger fish in this study (Reynolds et al. 1988). Although most of the injuries observed in this study were compressions, Dalbey et al. (1996) found that vertebrae with hairline fractures (class 3), were not always detected in initial x-rays and that the proportion of fish with class 3 injuries increased markedly from day 1 to day 335 of their study. Therefore, the proportion of class 3 injuries for fish captured at the electric weirs could be higher than this study was able to detect.

Although the electric weirs appear to be causing a low level of spinal injuries in Yellowstone Cutthroat Trout migrating to spawning tributaries of the South Fork Snake River, for several reasons we do not consider the observed injury rates to be detrimental to the population. First, spinal injury rates were much lower at the lower pulse frequency settings, so that using pulse frequencies <15 Hz should help minimize or eliminate injuries. Second, capture efficiencies at the electric weirs are reasonably high at the lower pulse frequency settings and were not dramatically improved at the higher settings (Table 1), so most of the Rainbow Trout and hybrids attempting to migrate into these tributaries should be excluded even at the lower frequency settings. Third, since the weirs are operated only from mid-March to mid-July, and outmigration of YCT usually occurs after mid-July, the majority of YCT only encounter the electric weirs once a year. Fourth, some YCT are captured via annual electrofishing surveys in the main stem of the South Fork Snake River, at pulse frequencies much higher than used at the electric weirs. Thus the additional exposure to low-level electricity at the migration weirs may be minor compared to the electrofishing surveys conducted biannually on the entire YCT population. Finally, YCT that spawn in consecutive years make up a substantial portion of each run, and the proportion of consecutive spawners does not differ significantly among the three tributaries (B. High, unpublished data). Thus, we believe that the benefits the electric weirs provide to the South Fork Snake River YCT population by preventing upstream passage of Rainbow Trout and hybrids far outweigh the harm caused by the low level of spinal injuries likely due to the electric weirs.

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