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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 (Idaho, USA) supports a native Yellowstone cutthroat trout (YCT) population *Oncorhynchus clarkii bouvieri* (Richardson) threatened by non-native rainbow trout *O. mykiss* (Walbaum). Electric weirs prevent rainbow trout passage into YCT spawning tributaries but may cause spinal injuries. 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 was increased from 2012 to 2013 at the Palisades (from 11.5 to 20 Hz) and Pine weirs (13–20 Hz), and spinal injury rates were found to increase from 11.3 to 21.3% at Palisades and from 6.5 to 14.7% at Pine, while Burns injury rates remained constant (4.5% in 2012 and 6.0% in 2013), suggesting the electric weirs caused spinal injuries in YCT. Lower pulse frequencies may minimise YCT spinal injury but still prevent rainbow trout from accessing YCT spawning tributaries.

KEYWORDS: electric fishing, fluvial spawning, hybridisation, non-native species, pulse frequency, salmonids.

Introduction

The South Fork Snake River in eastern Idaho (USA) supports an abundant population of Yellowstone cutthroat trout (YCT), *Oncorhynchus clarkii bouvieri* (Richardson) (Meyer *et al.* 2006). This population is considered important because it is one of the few robust fluvial populations of 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 threatened by the increasing abundance of non-native rainbow trout, *Onchorhynchus mykiss* (Walbaum) (High 2010). Rainbow trout and YCT have similar life histories in the South Fork Snake River, including the fluvial nature of their spawning behaviour, and both species ascend the four main tributaries below Palisades Dam (Burns, Pine, Rainey, and Palisades Creeks) to spawn (Fig. 1) (Henderson *et al.* 2000). Rainbow trout and YCT have no reproductive isolation mechanisms and readily hybridise throughout the YCT's native range. Introduced rainbow trout and its hybrids with YCT (henceforth, referred to simply as hybrids) may out-compete pure YCT during the juvenile period, causing a growth disadvantage for YCT in the presence of rainbow trout and hybrids (Young 1995; Behnke 2002; Seiler & Keeley 2009). 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), and the present study may have implications for the management of other native/non-native species conflicts (IDFG 2007; High 2010).

The IDFG operates migration traps on these four tributaries of the South Fork Snake River to prevent upstream access by rainbow trout and hybrids during the YCT's spawning period. Rainbow trout and hybrids are removed from the system at the migration traps, whereas YCT 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 during high discharges in the critical period of the spring spawning migration run (High 2010). More recently, a permanent waterfall and velocity combination 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

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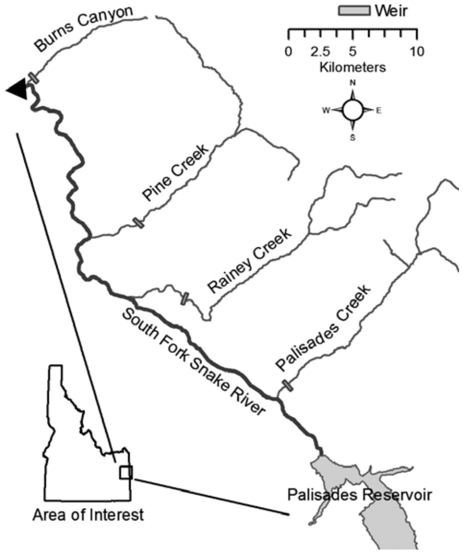

Figure 1. Location of South Fork Snake River tributaries and the electric and waterfall-velocity weirs where x-ray images were captured in Yellowstone cutthroat trout. Main-stem electric fishing surveys occurred in the shaded section of river designated in the map.

and Pine Creek in 2010. Fish capture 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). Fish capture efficiencies at these weirs are measured by marking all YCT caught in the trap and released upstream, and then sampling upstream of the trap and determining the ratio of marked to unmarked fluvial-sized (>350 mm) YCT (High 2010).

Electric current in the water, such as occurs during electrofishing surveys, has repeatedly been shown to cause spinal and haemorrhage injuries in fishes (reviewed in Reynolds & Kolz 2012). Trout species are especially vulnerable to injury from electric fields (Snyder 2003), and larger fish are more vulnerable to injury because their length results in a greater electric potential (Reynolds *et al.* 1988). Studies have also shown that increasing electric field strengths, water conductivity, pulse frequency and current duration can lead to an increase in spinal and haemorrhagic injuries in salmonids (McMichael 1993; Sharber *et al.* 1994; Robb *et al.* 2002; Roth *et al.* 2003, 2004; Lines & Kestin 2004; Reynolds & Kolz 2012). Both spinal injuries and haemorrhages are considered important when evaluating fish injuries from electricity (Reynolds & Kolz 2012), but spinal injuries are much more critical than haemorrhages, which typically persist for a relatively short time and therefore do not normally represent a long-term mortality or health risk to the fish (Schill & Elle 2000).

The aim of this study was to evaluate spinal injuries in YCT presumably exposed to electricity at electric weirs using a portable X-ray machine. It was assumed 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.

Materials and methods

The study was conducted in three tributary creeks of the South Fork Snake River (Fig. 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. The weirs were operated each year from mid-March to mid-July, covering the entire spawning runs of rainbow trout, YCT and their hybrids. Fish were X-rayed from the three study streams on 12–14 and 25–26 June 2012 and again on 10–12 June 2013. Mean ambient conductivity was 185, 298 and 359 μS cm^{-1} 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 along the stream bottom in a concrete apron, with the upper surfaces of the railings exposed to the water (Fig. 2). The railings span the entire stream channel and continue up the concrete walls, enclosing the entire stream except for the fish trap that is situated outside the electrical field. The lowermost and uppermost electrodes are parasitic, so electrical current does not bleed upstream or downstream of these electrodes. Consequently, fish that approach the electric field from a downstream location can enter the fish trap without experiencing any electrical current, but may experience electric shock if they enter the electric field of the weir. During the months when fluvial YCT and rainbow trout are not spawning and thus are not migrating from the main stem into tributaries, the electric weirs are turned off, and the fish traps are closed to prevent trout from experiencing unnecessary exposure to electricity.

The waterfall-velocity weir (Fig. 2) 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, while an adjacent fish ladder guides upstream migrants into the trap.

In 2012, the Palisades Creek electric weir output was set at 11.5 Hz, 2.5 ms pulse width and 265 V, and the

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

				Spawning run size				Weir capture efficiency (%)	
				2012		2013			
Tributaries	Weir type	Drainage area (km^2)	Stream width at weir (m)	YCT	RBT/HYB	YCT	RBT/HYB	2012	2013
Palisades	Electric	166	13	232	20	619	23	88	96
Pine	Electric	188	7.4	1427	3	1908	1	–	89
Burns	Waterfall-velocity	55	6.6	496	0	898	6	90	98

YCT, Yellowstone cutthroat trout; RBT, Rainbow trout; HYB, hybrid.

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.

Pine Creek weir output was set at 13 Hz, 2 ms pulse width and 270 V. These electrical settings produced similar horizontal voltage gradients at each weir, ranging from -11 to $+12$ V cm^{-1} but with most values falling within the range of -5 to $+5$ V cm^{-1}. In 2013, pulse frequency settings were increased to 20 Hz at both weirs to evaluate whether higher electrical settings would improve fish capture efficiency at the weir fish traps; 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, anesthetised using MS-222 and measured for total length (TL). A MinXRay (Northbrook, IL, USA) HF 100+ portable digital X-ray generator and a TruDR 1× system plate and computer program were used to generate X-ray images. Images were taken with a peak kilo-voltage of 100 and an exposure of ≈1.3 mA seconds, but settings were adjusted slightly as needed to obtain clear X-ray images for each fish. After recovering from anaesthesia, YCT were released upstream of the weir and fish trap to continue their spawning migration, and hybrids and rainbow trout were euthanised.

The X-ray images were analysed for the presence of spinal injuries. Injuries were classified using the injury criteria in Reynolds (1996) of 0 = no spinal damage, 1 = vertebral compressions only, 2 = misalignments and compressions and 3 = fracture of one or more vertebrae or complete separation of two or more vertebrae along with misalignments or compressions. X-rays were taken of both dorsoventral and lateral aspects for nearly all injured fish and a subsample of uninjured fish to determine whether spinal injuries could be detected using horizontal X-rays only. Compressions were always visible using either vertical or horizontal X-rays, and no misalignments or fractures were detected 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 the X-ray images (Dalbey *et al.* 1996).

Data were analysed in SAS (SAS Institute Inc 2009) using a generalised 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, with a total of 25 spinal injuries detected. 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, with a total of 36 spinal injuries detected. A small number of fish with spinal malformations, always in the caudal peduncle, were assessed as having congenital defects ($n = 2$ in 2012 and $n = 1$ in 2013) and were not categorised as injured for the analyses. The mean TL of fish at each site (±1 SE) 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 between 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 2013 than in 2012, but did not differ between years at the waterfall-velocity weir (Fig. 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 the effect of fish size on spinal injuries at the electric weirs, estimates of injury rate (±90% confidence intervals) for fish $\geq$375 mm TL (22.1 ± 4.6%) were nearly double that for fish <375 mm TL (11.3 ± 4.3%).

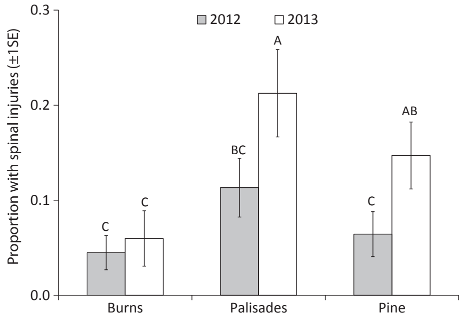

Figure 3. Spinal injury rates in Yellowstone cutthroat trout captured at a waterfall-velocity weir (Burns Creek) and two electric weirs (Palisades and Pine Creeks). Estimates with different letters indicate statistical significance at $\alpha = 0.10$.

The number of vertebrae involved in YCT spinal injuries in 2012 and 2013 ranged from 2 to 34, with a mean 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 (55% of all spinal injuries) and misalignments (22%) were encountered less frequently.

Discussion

After pulse frequency was increased at both electric weirs, spinal injury rates at both locations nearly doubled in 2013 compared with 2012, but injury rates at the waterfall-velocity weir remained unchanged in 2013. This 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%) than the waterfall-velocity weir (4.5%).

The low spinal injury rates at the Burns Creek waterfall-velocity weir probably represent 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 observed at the waterfall-velocity weir were caused by handling of the fish, or from fish jumping at the waterfall, as there is essentially no pool from which to jump. Equally unlikely would be a background spinal injury rate in wild trout that have never been exposed to electricity (Kocovsky *et al.* 1997). A more likely source for these injuries is boat electric fishing surveys of trout populations conducted each September and February in the main stem of the South Fork Snake River. These surveys span 75 km, encompass the confluences of all three study streams (Fig. 1), and occur at a time when most migratory YCT spawners occupy the main stem and therefore would be exposed to boat electric fishing. 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 electric fishing 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 electric fishing surveys, then a similar level of injuries at the two electric weirs should also be attributed to these same electric fishing surveys. Thus, all estimates of spinal injury rates in the present study were likely overestimated to a similar degree (i.e. ≈5%). Many salmonid populations that are monitored through time with electric fishing 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 suggests 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. These findings are consistent with reported spinal injury rates of 3% in wild rainbow trout exposed to pulsed DC current at 15 Hz and 24% at 30 Hz (Sharber *et al.* 1994), and a rate of 28% in electric-fished rainbow trout >256 mm TL exposed to 30 Hz pulsed DC (McMichael *et al.* 1998). There were no comparable estimates of fish injury rates at electric weirs or waterfall-velocity weirs. Additional studies of spinal injuries at both types of weirs would help substantiate or refute these results.

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 may occur in fish overexposed to electricity that float dead 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 60–63 vertebrae, the mean number of vertebrae (17) associated with injured YCT in the present study constitutes a considerable level of injury. Other studies have found a mean of six to eight vertebrae involved in salmonid spinal injuries due to electric fishing (Hollender & Carline 1994; Sharber & Carothers 1988), although those studies involved fish with lower TLs (136 and 360 mm, respectively) compared with 382 mm in the present study, and thus, the fish were likely not as affected by electricity as were the larger fish in the present study (Reynolds *et al.* 1988). Although most of the injuries observed in the present study were compressions, Dalbey *et al.* (1996) found that vertebrae with hair-line 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 the present study was able to detect.

Although the electric weirs appear to be causing a low level of spinal injuries in YCT migrating to spawning tributaries of the South Fork Snake River, the observed injury rates are not considered detrimental to the population for several reasons. First, spinal injury rates were much lower at the lower pulse frequency settings, so using pulse frequencies <15 Hz should help minimise or eliminate injuries. Second, fish 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, as 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 each year. Fourth, some YCT are captured via annual electric fishing 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 with the electric fishing surveys conducted bi-annually 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). This study suggests 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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