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[Note]

A Basinwide Perspective on Entrainment of Fish in Irrigation Canals

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Abstract.—Entrainment in irrigation canals has been considered a major source of mortality for some fish populations. However, the magnitude of fish loss from entrainment is usually not evaluated from a basinwide perspective, thus precluding an assessment of population-level consequences. We incorporated such a perspective in evaluating entrainment losses of Bonneville cutthroat trout *Oncorhynchus clarkii utah* and brown trout *Salmo trutta* in a southwestern Wyoming river basin that is used for irrigating agricultural crops. We estimated the number of Bonneville cutthroat trout and brown trout (>150 mm TL) entrained in irrigation canals and then compared these numbers to population estimates within the river main stem and across the entire basin. We also examined previous studies to determine annual mortality rates for assessment of realized losses to irrigation canals. Small percentages of the Bonneville cutthroat trout (1.2–3.3%) and brown trout (0.4–1.2%) populations within the basin were entrained in 2004 and 2005. These values were much lower than the total annual mortality rates for inland riverine cutthroat trout *O. clarkii* (57.4%) and brown trout (56.4%) in the mountain west region of the United States. Examining the number of entrained fish in context with the basinwide population and total annual mortality allows evaluation of the significance of fish entrainment losses to irrigation canals.

Irrigation in the mountain west region of the United States accelerated in the mid- to late 1800s after development of agricultural systems in the arid climate (Smythe 1969). Irrigation often entailed building extensive canal systems, and it was soon recognized that fish would readily enter these canals and subsequently die when flows were terminated. As early as 1893, screening programs were implemented to protect fishery resources (Clothier 1953). In the absence of such preventative measures, large numbers of fish may be lost to irrigation canals (Gardner 1941; Clothier 1953; Gebhards 1959; Hallock and Van Woert 1959).

Early work on reducing fish mortality in irrigation canals focused on anadromous salmonids because of their economic value and migratory patterns (Hallock and Van Woert 1959; Fleming et al. 1987). However, recent work has emphasized that inland stream fishes often move among complementary habitats during their life cycle (Schlosser 1995; Fausch et al. 2002) and thus may be susceptible to entrainment in canals (Clothier 1953; Spindler 1955; Reiland 1997; Roberts 2004; Gale 2005). For example, Schrank and Rahel (2004) found that 23% of 40 cutthroat trout *Oncorhynchus clarkii* implanted with radio transmitters became entrained and subsequently died in an irrigation canal during a postspawning migration in a Wyoming stream.

Currently, there is little information about population-level effects of fish entrainment in irrigation canals (Moyle and Israel 2005). Several recent studies on inland fish species have estimated the numbers of fish entrained in canal systems (Reiland 1997; Roberts 2004; Gale 2005). An important next step is to evaluate the magnitude of these losses at the population level. Basinwide consequences of mortality may not be evident from studies that consider only local mortality levels (Schill and Beland 1995; McMichael et al. 1998).

Bonneville cutthroat trout *O. clarkii utah* undergo extensive seasonal migrations throughout the Bear River system, Wyoming, and its tributaries (Hilderbrand and Kershner 2000; Schrank and Rahel 2004; Colyer et al. 2005). Brown trout *Salmo trutta* have established a naturalized population that probably also migrates throughout the Bear River system. Consequently, river connectedness and anthropogenic disturbances that disrupt natural streamflows may affect fish populations throughout the system. On one of these tributaries, the Smiths Fork drainage in western Wyoming, we estimated the number of Bonneville cutthroat trout and brown trout entrained in several irrigation canals and we examined this source of mortality within a larger, basinwide population context. Our objectives were to (1) estimate the number of fish larger than 150 mm total length (TL) that were entrained in the major canals of the Smiths Fork drainage, (2) compare the estimated numbers of entrained fish with the total population sizes of each species within the Smiths Fork main stem and the

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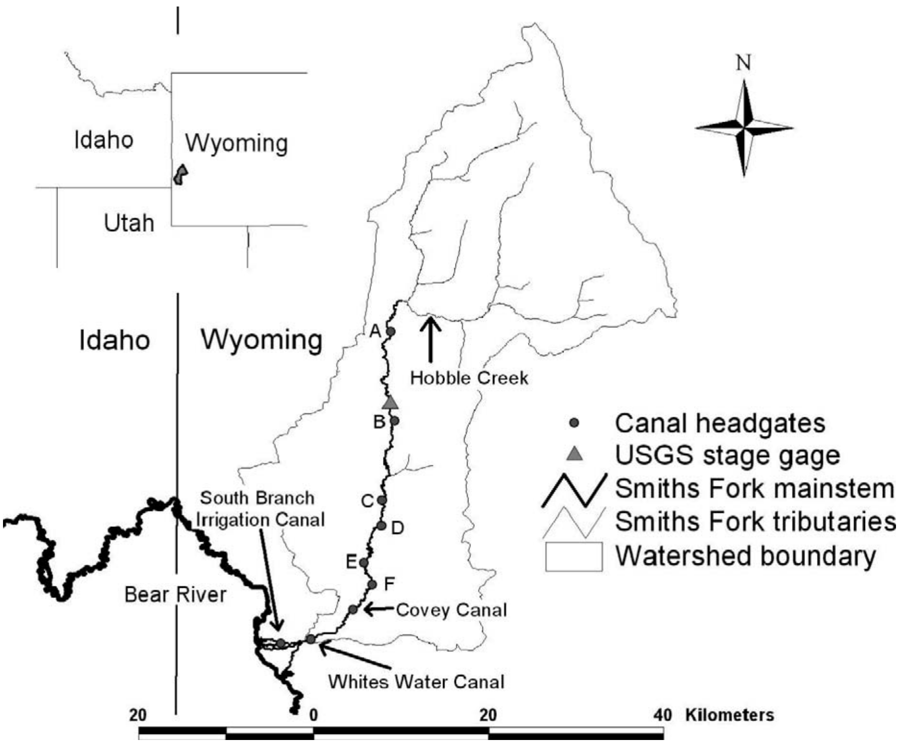

FIGURE 1.—Map of Smiths Fork drainage in western Wyoming: Smiths Fork main stem, major tributaries, and locations of headgates for irrigation canals (A = Quinnborne, B = Buttonflat, C = Progress, D = Emelle, E = Cooper, and F = Wheelock) throughout the watershed.

entire basin, and (3) compare entrainment mortality with total annual mortality to assess the relative population loss due to irrigation canals.

Study Site

Smiths Fork (Lincoln County) is a fourth-order stream that originates in the Bridger National Forest (basin area = 708 km^2) and flows south, entering the Bear River near Cokeville, Wyoming (approximately 240 river kilometers [rkm] upstream from the Great Salt Lake; Figure 1). The Bear River at Cokeville is 1,850 m above sea level, and the headwaters reach elevations above 3,000 m. Smiths Fork has an average annual discharge rate of 5.39 m^3/s (U.S. Geological Survey gage 10032000; 1943–2005). The climate consists of hot, dry summers; cold, windy winters; and large accumulations of snow at higher elevations (Curtis and Grimes 2004). Discharge throughout the drainage varies with the time of the year. Streamflow increases markedly with snowmelt beginning between late March and mid-April, and base flows return in mid-July. During the irrigation season (1 May to 30 September), a series of canals removes an average of 32.0% of the water from the lower 54.4 rkm of Smiths Fork. The majority of removed water enters the Covey Canal system (50.5 rkm; includes the Mau Canal), Whites Water Canal (5.2 rkm), and South Branch Irrigation Canal (3.4 rkm; Figure 1). All canals in the Smiths Fork basin originate in the lower 54.4 rkm of the river. Native Bonneville cutthroat trout and naturalized brown trout are found throughout the Smiths Fork basin.

Methods

In selecting our study canals, we consulted with regional fisheries biologists and canal managers, who suggested that the three largest canals in the system (Covey, Whites Water, and South Branch Irrigation) were the most likely to entrain fish. We did a synoptic survey of the nine largest canals in the Smiths Fork basin in 2003, which verified that the three largest canals were, in fact, entraining most of the fish. This survey involved estimating the abundance of Bonneville cutthroat trout and brown trout in the first 50 m downstream of the headgate of each canal within several days after water inflow was terminated but while water remained within the canal. The rationale for this sampling protocol was that fishes entrained in irrigation canals have been reported to congregate immediately downstream from headgates when flows are reduced (Clothier 1953). In the 50 m downstream of the headgate, two or three passes were made with a backpack electrofishing unit (Smith-Root, Vancouver, Washington; Model LR-24) by use of standard techniques (Van Den Avyle and Hayward 1999). Program CAPTURE was used to estimate the abundance and variance of fish larger than 150 mm TL based on a removal estimator (model M_{bh}; White et al. 1982).

For the three largest canals, we estimated abundance of Bonneville cutthroat trout and brown trout from late July to early August in 2004 and 2005. Once fish were entrained in canals, they were assumed to be lost from the population (Roberts 2004; Schrank and Rahel 2004). Reaches (length = 100–200 m) sampled within the canals belonged to one of two strata: congregated or random. Congregated reaches were previously identified as having features where fish were concentrated and were of various lengths depending on the feature (e.g., areas near the headgate, siphons, or natural stream crossings; Roberts 2004). All of the congregated reaches present in each canal were censused. In addition, one to four random reaches (length = 100 m) were selected from each of three to five designated segments in each canal. The segments were defined based on structures that would inhibit upstream movement of fish, such as headgates or siphons. Random reaches were obtained by randomly selecting a river (canal) kilometer in a geographic information system (ArcView 3.3; ESRI, Redlands, California). The number of random reaches sampled per segment depended on segment length, but in all cases we sampled at least 2.5% of the total canal length. Random reaches were used to extrapolate the abundance of Bonneville cutthroat trout and brown trout within the respective canal segment.

In the three canals, 8.1% of the combined length was sampled: 3.3% in 12 congregated reaches and 4.8% in 25 random reaches. In each reach, three or four passes with a backpack electrofishing unit (Smith-Root; LR-24) were made by use of standard techniques (Van Den Avyle and Hayward 1999). Program CAPTURE was used to estimate the abundance of fish larger than 150 mm TL in the canals based on model M_{bh} (White et al. 1982; fish $\leq$150 mm TL were not effectively sampled by the electrofishing unit [described below] used in the Smiths Fork main stem and were therefore excluded from analysis). The abundance estimates and sampling variances from the congregated reaches were added to the extrapolated abundance and variance estimates from the random strata following Roberts' (2004) methods.

For Smiths Fork, we estimated fish abundance at two spatial scales: (1) main stem and (2) basinwide, including the main stem plus all first- through third-order tributaries known to harbor Bonneville cutthroat or brown trout. The main stem consisted of the lower 54.4 rkm of Smiths Fork from Hobble Creek (near where Smiths Fork becomes a fourth-order stream) to the confluence with the Bear River (Figure 1). The main-stem site was divided into five 5–13-km-long reaches delineated by access points and major diversion locations. Three reaches were sampled in 2004 and three were sampled in 2005; one reach was sampled in both years to evaluate annual variability in fish abundance. All sampling was done during base flow conditions (mid-July to mid-August). Across the 2 years, we sampled 85.8% of the length of the Smiths Fork main stem. In main stem reaches, fish were sampled using a raft-mounted, fixed-boom electrofishing unit (Coffelt, Flagstaff, Arizona; Model VVP 15). A multiple-census mark–recapture sample was conducted in each reach over a 3-d period (marking on day 1, capture and marking on day 2, and capture on day 3); at least 1 d of nonsampling elapsed between reach censuses. Abundance estimates and associated variances for Bonneville cutthroat trout and brown trout ($>$150 mm TL) in each reach were calculated via a multiple-recapture census estimator (program CAPTURE, model M_t in White et al. 1982).

To estimate fish abundance in first- through third-order tributaries of the Smiths Fork basin, we first calculated, by stream order, the lengths of tributaries known to contain Bonneville cutthroat or brown trout. Based on data from removal surveys conducted by the Wyoming Game and Fish Department (30 backpack electrofishing surveys during 1987–1997; unpublished data) and Trout Unlimited (18 backpack electrofishing surveys in 2003; Colyer and Harig 2004), we calculated the number of fish per meter and variance for each survey using model M_{bh} (White et al. 1982). Surveys were combined by stream order, and estimates and variances were extrapolated to estimate the number of fish in the headwaters of Smiths Fork (Carlson 2006). This tributary estimate was then added to the main-stem estimate to calculate the number of Bonneville cutthroat trout and brown trout in the basin.

We calculated percent entrainment at the same two spatial scales. At the main-stem scale, we divided the estimated number of Bonneville cutthroat or brown trout entrained in the three largest canals by the combined estimates for the Smiths Fork main stem and the three canals. At the basin scale, we divided the estimated number entrained in the three largest canals by the combined estimates for the Smiths Fork basin and the three canals. Two-sided 95% confidence intervals were calculated for each percentage (Zar 1999).

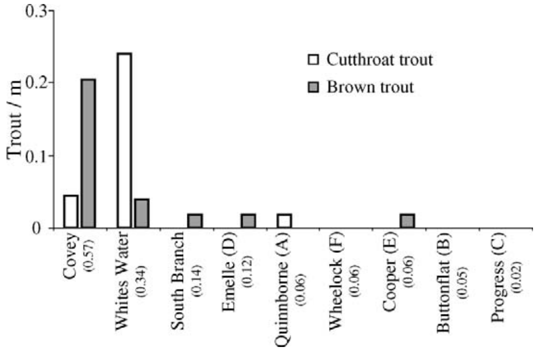

FIGURE 2.—Bonneville cutthroat trout and brown trout abundance (fish/m) within the first 50 m of nine canals in the Smiths Fork drainage, western Wyoming, sampled by electrofishing in 2003. The average amount of water diverted into each canal (m^3/s) in 2003 is presented in parentheses.

The above analyses provided estimated percentages of the Bonneville cutthroat trout and brown trout populations that were entrained (100% postentrainment mortality is assumed) in Smiths Fork canals. To put entrainment mortality estimates into a broader perspective, we compared them with total annual mortality rates of Bonneville cutthroat trout and brown trout. We estimated the total annual mortality rates using two approaches. First, we used age-frequency data from surveys on Bonneville cutthroat trout in the Smiths Fork–Bear River basin to construct a catch curve (Van Den Avyle and Hayward 1999) for estimating the total annual mortality in the study area (Binns 1981). Second, we reviewed the literature for estimates of total annual mortality of cutthroat trout and brown trout in streams of the mountain west region (Colorado, Idaho, Montana, Utah, and Wyoming). When the total annual mortality or survival rates were presented, we used those values. In studies that only presented the numbers of fish in each cohort, we identified the point at which the sampling gear fully recruited the population (usually age 2 or above) and used successive ages or a catch curve to calculate total instantaneous mortality and from total annual mortality (Van Den Avyle and Hayward 1999).

Results

The three largest canals collectively accounted for an average of 58.9% of the water removed by Smiths Fork basin canals during the 2003–2005 irrigation seasons. Entrainment of Bonneville cutthroat or brown trout was mainly associated with the three canals, which collectively contained 93.4% of the Bonneville cutthroat trout and 86.9% of the brown trout entrained during the 2003 synoptic survey (Figure 2).In the three largest canals, 136 Bonneville cutthroat trout and 209 brown trout were entrained during 2004 and 391 Bonneville cutthroat trout and 70 brown trout were entrained during 2005 (Table 1). The canals generally entrained large fish; only 24.3% of entrained Bonneville cutthroat trout and 21.9% of entrained brown trout were smaller than 150 mm TL.

In the Smiths Fork main stem, the abundances of Bonneville cutthroat trout and brown trout in the replicated sampling reach were statistically similar between 2004 and 2005, based on the 95% confidence intervals. Thus, we pooled the 2004 and 2005 estimates for all reaches in determining abundances. The total population sizes were estimated at 5,128 Bonneville cutthroat trout and 3,947 brown trout in the lower 54.4 rkm of Smiths Fork (Table 1). Relative to the combined population estimates for Smiths Fork and its canals, small percentages of these populations were entrained

TABLE 1.—Estimated numbers (with 95% confidence intervals) of Bonneville cutthroat trout and brown trout (>150 mm total length) in the Smiths Forks system, Wyoming, 2004–2005; three largest canals, river main stem, and entire basin. Entrainment is the number of fish living and subsequently entrained in the three canals divided by the total number of fish in the main stem or basin and canals; comparison for total annual mortality in the mountain west region averaged 57.4% for riverine cutthroat trout and 56.4% for riverine brown trout.

	Bonneville cutthroat trout		Brown trout	
Variable	2004	2005	2004	2005
		Canals[a]		
Population estimate	136 (106–165)	391 (327–454)	209 (194–223)	70 (66–74)
		Main stem		
Population estimate	5,128 (4,354–5,902)	5,128 (4,354–5,902)	3,947 (3,505–4,389)	3,947 (3,505–4,389)
Entrainment (%)	2.6 (2.2–3.1)	7.1 (6.4–7.8)	5.0 (4.4–5.7)	1.7 (1.4–2.2)
		Basin		
Population estimate	11,450 (10,523–12,377)	11,450 (10,523–12,377)	16,593 (13,883–19,302)	16,593 (13,883–19,302)
Entrainment (%)	1.2 (1.0–1.4)	3.3 (3.0–3.6)	1.2 (1.1–1.4)	0.4 (0.3–0.5)

[a] Covey Canal, Whites Water Canal, and South Branch Irrigation Canal.

in the canals (Figure 3): for Bonneville cutthroat trout, the percentage entrained was 2.6% in 2004 and 7.1% in 2005, and for brown trout the percentage was 5.0% in 2004 and 1.7% in 2005. The 95% confidence intervals around these percentages were small (Table 1).

For the entire Smiths Fork basin, we estimated populations of 11,450 Bonneville cutthroat trout and 16,593 brown trout exceeding 150 mm TL (Table 1). Thus, based on the combined population estimates for the Smiths Fork basin and canals, even smaller percentages were entrained in the canals (Figure 3). Bonneville cutthroat trout entrainment was 1.2% in 2004 and 3.3% in 2005; brown trout entrainment was 1.2% in 2004 and 0.4% in 2005. The 95% confidence intervals for these values were small (Table 1).

Using data from Binns (1981), we calculated total annual mortality rates of Bonneville cutthroat trout at two sites in the Smiths Fork–Bear River basin. Total annual mortality was 55.7% in Giraffe Creek and 48.5% in Contag Creek. From the literature, we obtained an additional 34 estimates of total annual mortality of Bonneville cutthroat trout (Table A.1). For brown trout, there were no age-frequency data from within the basin, so we used 17 estimates from the literature (Table A.1). We calculated mean annual total mortality rates of 57.4% (95% confidence interval = 52.0–62.3%) for cutthroat trout and 56.4% (95% confidence interval = 48.4–64.3%) for brown trout in riverine systems in the western USA.

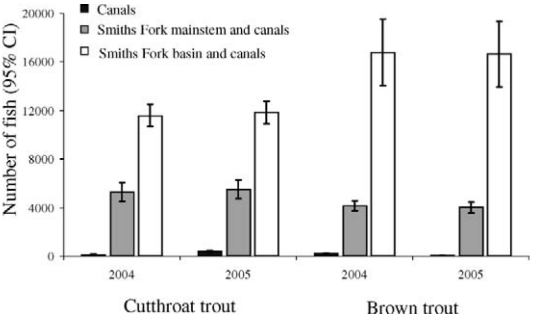

FIGURE 3.—Numbers (±95% confidence interval) of Bonneville cutthroat trout and brown trout in the Smiths Fork drainage, western Wyoming, 2004–2005: three major canals (i.e., entrainment; Covey Canal, Whites Water Canal, and South Branch Irrigation Canal); the main stem and canals; and the basin and canals.

Discussion

From a basinwide perspective, small percentages of Bonneville cutthroat trout and brown trout larger than 150 mm TL were entrained in Smiths Fork irrigation canals during our study. The canals appear to be entraining larger trout, as evidenced by the fact that 75.7% of the Bonneville cutthroat trout sampled in the canals exceeded 150 mm TL. Other studies have also found that canals entrain mainly large fish (Roy 1989; James 1990). This is contrary to reports that canals entrain high numbers or percentages of age-0 fish (Gebhards 1959; Hallock and Van Woert 1959; Fleming et al. 1987; Gale 2005). Selectivity of canals for certain size-classes reflects an interaction between the timing of water withdrawal and species life history patterns. Bonneville cutthroat trout in the Bear River drainage reside in headwater tributaries for at least 1 year after hatching, and downstream migration begins at age 1 (90–120 mm; Colyer and Harig 2004). By contrast, large (>290 mm) Bonneville cutthroat trout begin a postspawning downstream migration in late spring that coincides with maximum water withdrawal by irrigation canals (Schrank and Rahel 2004).

Our survey of the nine largest canals confirmed the experience of regional fisheries biologists and land owners that the three largest canals were the major sites of fish entrainment in the Smiths Fork basin. Although factors such as the type and location of headgates can influence fish entrainment rates, the number of fish entrained often increases with the amount of water diverted (Spindler 1955; Megargle 1999). By focusing on the three largest canals, we feel we were able to account for the vast majority of Bonneville cutthroat trout and brown trout entrained in the Smiths Fork system's irrigation canals.

We assumed that once fish were entrained in canals, they were lost to the population. Fish are often trapped after they pass through the headgate structure and into the canal. Water velocities and headgate structures generally prohibit fish from moving back through the headgate and returning to the main stem. However, canals occasionally have natural stream crossings in which a tributary stream bisects the canal and allows fish to return to the main stem. Provided there is ample water, canals can also flow back into the main stem after they have passed through the irrigational district, allowing another passageway back to the main stem for entrained fish. However, canals in Smiths Fork generally end in irrigated meadows and little flow returns to the main stem. In Montana, Megargle (1999) found 40% of entrained radio-tagged rainbow trout *O. mykiss* navigated back to the main stem through canal headgates, and Gale (2005) found that 11% of entrained radio-tagged westslope cutthroat trout *O. clarkii lewisi* returned to the main stem through canal headgates. In the Covey Canal system of Smiths Fork, Roberts (2004) found that 20% of radio-tagged Bonneville cutthroat trout were able to return to the main stem. The return of at least some entrained fish to Smiths Fork would further decrease the already minimal effect of canals on the fish population throughout the main stem and basin.

At the basin scale, brown trout were entrained at a lower rate than Bonneville cutthroat trout. Two factors may explain this pattern. One factor involves differences in life history patterns. Species exhibiting resident versus migratory life history behaviors may differ in their vulnerability to entrainment (Northcote 1992). In the Bear River basin, adult Bonneville cutthroat trout undergo long-distance spawning migrations (Hilderbrand and Kershner 2000; Schrank and Rahel 2004; Colyer et al. 2005; Carlson 2006). The spring and early summer migration period coincides with an increase in water diversion into irrigation canals. This life history characteristic makes Bonneville cutthroat trout greater than 150 mm TL in the Bear River basin vulnerable to entrainment. Likewise, Clothier (1953) found that brook trout *Salvelinus fontinalis* were most susceptible to entrainment in canals when they migrated to spawn in the West Gallatin River, Montana. By contrast, brown trout spawn in fall and are generally sedentary in the late spring and summer (Young 1994; Burrell et al. 2000; Bettinger and Bettoli 2004). The difference in life histories may lead to an "ecological trap" (Schlaepfer et al. 2002) for spring-migrating Bonneville cutthroat trout that is not shared by brown trout.

A second factor that may explain interspecific differences in entrainment rates involves the relative spatial distributions of brown trout and Bonneville cutthroat trout throughout the basin. Approximately 50% of the Bonneville cutthroat trout in the basin were present in the main stem section and thus were in close proximity to the canals. By contrast, only 25% of the brown trout population occurred in the main stem, whereas the remaining fish were in upstream portions of the basin. Thus, at the basin scale, Bonneville cutthroat trout are more susceptible to entrainment in canals than brown trout. In Montana, Clothier (1953) found that canals at higher elevations entrained more brook trout and rainbow trout, whereas canals at lower elevations entrained more brown trout, reflecting elevation differences in species composition within the basin.

The scale at which entrainment is examined may influence conclusions about the population-level importance of fish losses. At a local scale (main stem), 454 Bonneville cutthroat trout and 233 brown trout were entrained but these represented relatively small percentages of the overall main-stem populations (Bonneville cutthroat trout: 2.6–7.1%; brown trout: 1.7–5.0%). When the numbers of entrained fish are compared to the basin population, the effect of entrainment is even smaller (Bonneville cutthroat trout: 1.2–3.3%; brown trout: 0.4–1.2%). Similarly, although Post et al. (2006) estimated that 1,683 rainbow trout were entrained in an irrigation canal in Alberta, Canada, entrained fish constituted less than 1% of the population in the source river.

The overall effect of canal entrainment on the Bonneville cutthroat trout and brown trout populations in Smiths Fork also depends on whether entrainment mortality is additive or compensatory. To exert the largest effect on the population, entrainment mortality would have to be completely additive. If such is the case in Smiths Fork, we would expect that 0.4–3.3% of the total annual mortality at the basin scale would be due to canals. Canal screening could therefore reduce the total annual mortality by up to 5.7% (i.e., 3.3% divided by 57.4%, the average total annual mortality for western riverine cutthroat trout). In some cases, relatively small reductions in vital rates can mean the difference between population stability, growth, and decline (Hilderbrand 2003). However, it would seem likely that some of mortality due to canal entrainment is compensatory; thus, the overall effect on the population would be even less than the additional 0.4–3.3% mortality estimated for trout species in the Smiths Fork basin.

We estimated that 1.2–3.3% of Bonneville cutthroat trout and 0.4–1.2% of brown trout were entrained at the basin scale. At this scale, losses to canal entrainment appear to be small relative to the total annual mortality (around 57% per year) for trout in the western United States. Schill and Beland (1995) noted the importance of taking a large-scale perspective in their assessment of the effects of electrofishing mortality on fish populations. Likewise, McMichael et al. (1998) evaluated local-scale (reach) losses from electrofishing and contrasted these losses with basin abundance and natural mortality rates. Both studies concluded that what may appear to be significant population losses at a local scale become much less important when extrapolated to the regional scale.

The results of our study should be interpreted with caution because we estimated the effect of entrainment only for a 2-year period when the system was recovering from a 6-year drought. Entrainment rates can vary from year to year (Clothier 1953; Post et al. 2006). In some cases, a coincidence of events could conspire to greatly increase the impact of entrainment mortality. In particular, entrainment could be especially high if the peak in downstream migration of post-spawning Bonneville cutthroat trout coincided with withdrawal of a high proportion of the streamflow, such as during a drought year. Under these circumstances, the basinwide impact of entrainment mortality on Bonneville cutthroat trout could be much higher than our estimates. Furthermore, we found relatively few young trout entrained in the irrigation canals, which reflects the spatial location of the canals (low in the drainage basin) relative to where spawning habitat is located (in headwater tributaries). In situations where water is withdrawn from spawning areas or juvenile migration corridors, significant entrainment of young fish can occur (Gebhards 1959; Fleming et al. 1987; Gale 2005).

The most common approach to minimizing fish entrainment in canals is through screening (McMichael et al. 2004). Although screens can be effective, they are costly to install and require ongoing maintenance. Thus, the costs and benefits of screening must be considered in comparison with other management actions that could enhance fish populations, such as restrictive harvest, habitat improvement, and supplemental stocking. Analyses that examine entrainment mortality at various scales can aid managers in determining population-level effects of irrigation canals. Such information will be useful in deciding whether funding should be spent in installation and maintenance of irrigation canal screens or is better spent elsewhere to protect and manage fishery resources.

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Appendix: Mortality of Mountain West Trout Species

TABLE A.1.—Reported or calculated percent total annual mortality of inland riverine cutthroat trout and brown trout populations in the mountain west region of the United States.

Reference	State	Location	Percent mortality
Colorado River cutthroat trout *Oncorhynchus clarkii pleuriticus*			
Quinlan 1980	Wyoming	North Fork Little Snake	80
Peterson et al. 2004	Colorado	Willow Creek	43
		Little Muddy	63
Snake River cutthroat trout *O. clarkii behnkei*			
Hayden 1968	Wyoming	Snake River	50
			50
			50
Hagenbuck 1970			66
Kiefling 1972			61
Kiefling 1978		Bar BC Spring Creek	46
		Fish Creek	71
Westslope cutthroat trout *O. clarkii lewisi*			
Johnson 1963	Montana	Flathead drainage tributaries	59
		Flathead drainage rivers	65
Rankel 1971	Idaho	St. Joe River	16
			28
			36
			47
			56
Rieman and Apperson 1989		Coeur d'Alene River	58
		Middle Fork	68
		Coeur d'Alene River	70
		Upper St. Joe	72
		Kelly Creek	72
		Salmon River	78
		Lower St. Joe	78
Schill 1991		Upper St. Joe River	31
		South Fork Snake River	38
		Coeur d'Alene River	40
		Kelly Creek	47
Yellowstone cutthroat trout *O. clarkii bouvieri*			
Thurow et al. 1988	Wyoming	Teton River above dam	53
		Teton River below dam	69
		South Fork Snake River	73
	Idaho	Willow Creek	65
		Black Foot River	69
		South Fork Snake River	83
Brown trout *Salmo trutta*			
Sowards 1958	Wyoming	Tongue River	86
Rockett 1964		Middle Fork Powder River	73
		Sand Creek	28
Mueller and Rockett 1967		North Fork Powder River	55
Bowman 1978		North Platte	72
Snigg 1979		Lower Green River	47
			48
			68
WGFD[a] 1980		Laramie River	43
Rockett 1983		Sand Creek	28
			60
WGFD[a] 1987		North Platte River	41
WGFD[a] 1990			51
WGFD[a] 1995			62
WGFD[a] 1995			74
WGFD[a] 1998			58
WGFD[a] 2000			64

[a] Unpublished data from the Wyoming Game and Fish Department, Cheyenne.