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MANAGEMENT BRIEFS

Efficacy of Three Denil Fish Ladders for Low-Flow Fish Passage in Two Tributaries to the Blackfoot River, Montana

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Abstract.—We evaluated the efficacy of three Denil fish ladders retrofitted to three irrigation diversions in two tributaries to the Blackfoot River, Montana. Fish ladders were 2.4–6.1 m long, with slopes of 9.6–15.8% and mean velocities of 18–140 cm/s. We captured westslope cutthroat trout *Oncorhynchus clarki lewisi*, brown trout *Salmo trutta*, bull trout *Salvelinus confluentus*, and slimy sculpins *Cottus cognatus* upstream of the fish ladders (treatment groups), and in three nearby stream reaches without a ladder (control groups). Fish were marked and then released downstream of the fish ladders (treatment) or immediately downstream of their capture reaches (control). Fish lengths were similar between treatment and control sites (*t*-tests; $P > 0.05$). We resampled the reaches 5–7 d after marking and recaptured similar numbers of marked westslope cutthroat trout and brown trout in both treatment and control sections ($\chi^2 = 0.13$; df = 2; $P = 0.94$). No slimy sculpins were recaptured in treatment or control sections. Lengths of recaptured westslope cutthroat trout ranged from 92 to 305 mm after the trout ascended the ladders and were similar to lengths of marked fish in those sections (*t*-tests; $P > 0.05$). Although it was the longest, the fish ladder with the lowest slope and velocities appeared to limit small (<300 mm) brown trout movement. Recaptured brown trout in the treatment reach were significantly larger ($P = 0.05$; range = 215–352 mm) than marked brown trout. Fish ladders on irrigation diversions require frequent maintenance. When we evaluated the three structures, only one was operating correctly. Nevertheless, the ladders demonstrate promise for passing small stream-resident or juvenile fishes over irrigation diversions.

Many native fishes in the western United States are imperiled as a result of fish passage barriers (Minckley et al. 1991; Behnke 1992). Irrigation diversions that span stream channels are common throughout agricultural regions of the western United States and have restricted or eliminated passage through many Blackfoot River, Montana, tributaries. Irrigation diversion structures (or dams) use horizontal planks (flashboards) supported by vertical stanchions (pins) to impound water for diversion to an irrigation ditch. The removal of fish passage barriers in the Blackfoot River drainage has increased migratory fish usage of previously disjunct areas (Pierce and Schmetterling 1999). To accommodate upstream fish passage, some irrigation diversions have been retrofitted with Denil fish ladders (see Odeh [1999] for descriptions and diagrams of Denil ladders).

The effectiveness of Denil fishways appears to be related to fish species and size. Prior evaluations of the fish ladders have often demonstrated that the target species used the ladders, whereas other species were excluded (Schwalme et al. 1985; Monk et al. 1989; Lucas and Frear 1997). Therefore, a combination of several different fishways may be required for the most efficient passage of a wide variety of species and sizes (Schwalme et al. 1985; Monk et al. 1989). The ability of many anadromous fishes to use fishways has been tested because large mitigation projects use fishways to compensate for dams (Monk et al. 1989; Cada and Sale 1993; Bunt et al. 1999; Odeh 1999). However, the efficacy of Denil fishways for passing inland fishes in small (<1.0 m^3/s) streams is largely unknown.

Although swimming performance, jumping abilities (Powers and Orsborn 1985; Reiser and Peacock 1985; Belford and Gould 1989), and use of fish ladders by adult salmonids have been documented (Collins et al. 1962; Bryant et al. 1999), there is little information about swimming characteristics of juvenile salmonids or their behavior around fishways. Swimming performance of resident fishes is one factor to consider when evaluating structures. However, even if water velocities are suitable, avoidance of and lack of attraction to fish ladders may also hinder passage (Bunt et al. 1999).

Westslope cutthroat trout *Oncorhynchus clarki lewisi* migrate and spawn during high flows in Blackfoot River tributaries in the spring, often spawning in areas upstream of Denil fish ladders (Schmetterling 2000, 2001). However, during

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spring runoff, the flashboards on irrigation diversions are removed (no water is being diverted), so fish do not have to use the ladders. However, the efficacy of fishways equipped with flashboards at base or low flows is unclear. The objective of this study was to determine what species and sizes of fish could ascend past the irrigation structures during low flows, when fish must use these ladders to access upstream areas.

Methods

Chamberlain Creek and Cottonwood Creek are perennial tributaries to the Blackfoot River in western Montana, with average base flows ranging from 0.10 to 0.25 m^3/s (Pierce and Schmetterling 1999; Schmetterling 2000, 2001). Chamberlain Creek is a principal spawning tributary for fluvial westslope cutthroat trout in the Blackfoot River drainage (Schmetterling 2001), and westslope cutthroat trout is the most abundant fish species in the stream. The Chamberlain Creek fish ladder is located 1.5 km upstream from the mouth. The lower Cottonwood Creek fish ladder is located 6.4 km upstream from the mouth, and the reach is dominated by brown trout *Salmo trutta*. The upper Cottonwood Creek fish ladder is 19.5 km upstream from the mouth, and the reach contains primarily westslope cutthroat trout and bull trout *Salvelinus confluentus*. Slimy sculpins *Cottus cognatus* are present in both streams, but at higher densities in Chamberlain Creek.

To evaluate fish passage at three ladders, in July 2000 we captured fish upstream of each ladder (treatment group) in a 100-m reach, then marked and released them downstream of the ladder. We repeated this procedure for fish in three nearby stream reaches without a ladder (control group). In both streams, control reaches were located between 0.7 and 2.0 km from the treatment sections. Fish were collected with a backpack electrofishing unit (Coffelt Mark X) and then anesthetized with tricaine methanesulfonate or clove bud oil, measured (total length, mm), and marked. All salmonids had their adipose fins clipped and were marked with visible implant elastomer (VIE) tags (Northwest Marine Technology, Inc.) in the postocular tissue. We marked slimy sculpins with a VIE tag on the ventral side of the mandible, a minimally pigmented area (right side for treatment fish, left side for control fish).

After handling, fish were placed in a live car approximately 2 m downstream of the shocking reach for controls or downstream of irrigation diversions for treatment groups, and were released after they regained equilibrium. During low flows (e.g., summer), the only way for fish to surmount an irrigation diversion is via a fish ladder. We resampled the sections 5–7 d after marking to recapture fish that had returned to the reach where they were captured.

Water depths and velocities in the fish ladder were measured with a wading rod and a Marsh-McBirney current meter (model 201M). We measured water depth and velocity at each baffle (single vertical plane) in the fish ladder, and averaged the values to obtain a grand mean for each fish ladder. Velocity was measured at 0.6 times the water column depth, where velocity approximates a mean vertical water column velocity (McMahon et al. 1996). Fish ladder slope was measured from the height of each baffle with a laser level.

Although salmonids retain VIE tags well (Hale and Gray 1998; Close 2000), there is no information on VIE tag retention in sculpins. To determine whether the VIE tags were retained by slimy sculpins, we captured 50 similarly sized slimy sculpins (mean length = 69 mm; SD = 13.5 mm; range = 47–100 mm), marked them with VIE tags on the ventral surface of the mandible, and held them in a holding pen in a stream, where water temperatures ranged from 9°C to 14°C. After 6 d, we checked the slimy sculpins for VIE tag retention and readability.

We used a chi-square analysis to test whether the number of recaptured fish varied between treatment and control groups. We used recaptures from the control reaches as expected values to compare with treatment reach recaptures. To determine whether the fish ladders in the treatment reaches limited movement of certain sizes of fish returning to the capture areas, we used *t*-tests to compare the initial lengths of captured fish to lengths of recaptured fish in each group. Differences were considered significant at *P* values less than or equal to 0.05.

Results

The three fish ladders differed in length, number of baffles, height, slope, and velocity (Table 1). All of the recaptured westslope cutthroat trout and brown trout retained VIE tags, as confirmed by adipose fin clips. Similarly, after 6 d in a holding pen, all slimy sculpins retained the VIE tags, which were easily seen by the unaided eye (i.e., without a blue light).

In the treatment reach on Chamberlain Creek, we captured and marked 26 slimy sculpins (range = 56–123 mm), 27 westslope cutthroat trout

TABLE 1.—Attributes of three Denil fish ladders on two Blackfoot River tributaries, Montana.

Location	Length (m)	No. of baffles	Height (m)	Slope (%)	Mean velocity range[a] (cm/s)	Grand mean velocity (cm/s)
Chamberlain	2.4	6	0.38	15.8	18–82	53
Lower Cottonwood	6.1	14	0.59	9.6	12–72	23
Upper Cottonwood	3.6	13	0.59	16.4	28–140	57

[a] Measured at each baffle.

(range = 76–220 mm), and 1 brown trout (425 mm; Table 2). In the control reach, we captured 25 slimy sculpins (range = 57–113 mm), 34 westslope cutthroat trout (range = 71–240 mm), and 1 brown trout (185 mm). Means and standard deviations (SD) are given in Table 2. The lengths of westslope cutthroat trout and slimy sculpins were similar between treatment and control reaches (*t*-tests; $P = 0.74$).

We recaptured 10 westslope cutthroat trout in the Chamberlain Creek treatment reach (range = 93–172 mm) and 11 westslope cutthroat trout in the control reach (range = 70–165 mm; Table 2). The mean lengths of recaptured westslope cutthroat trout were similar to those of marked westslope cutthroat trout in the treatment (*t*-test; $P = 0.71$) and control reaches (*t*-test; $P = 0.65$). In both reaches, each brown trout was recaptured and no slimy sculpins were recaptured.

In lower Cottonwood Creek, we captured and marked 43 brown trout (range = 129–424 mm) in the treatment reach and 30 brown trout in the control reach (range = 108–405 mm; Table 2). The mean lengths of treatment and control fish were not significantly different (*t*-test; $P = 0.12$).

We recaptured six brown trout in the lower Cottonwood Creek treatment reach and eight in the control reach (Table 2). Recaptured brown trout in the treatment reach were significantly longer (*t*-test; $P = 0.05$) than those originally marked in that reach; however, the lengths of recaptured brown trout in the control reach were not different from those of marked fish in the control reach ($P = 0.74$).

In upper Cottonwood Creek, we captured 45 westslope cutthroat trout (range = 57–305 mm) and 8 bull trout (range = 90–152 mm) in the treatment reach and 38 westslope cutthroat trout (range = 65–246 mm) and 11 bull trout (range = 87–187 mm) in the control reach (Table 2). Westslope cutthroat and bull trout lengths were similar between treatment and control reaches (*t*-tests; $P > 0.27$).

TABLE 2.—Species, number, and mean length (mm; SD in parentheses) of fish marked and recaptured in treatment and control reaches in two tributaries to the Blackfoot River, Montana, following translocation. Asterisks indicate significant differences ($P \leq 0.05$).

		Capture			
		First		Second	
Species	Group	*n*	Mean length	*n*	Mean length
		Chamberlain Creek			
Westslope cutthroat trout	Treatment	27	106 (32)	10	108 (266)
	Control	34	107 (39)	11	112 (32)
Slimy sculpin	Treatment	26	80 (17)		
	Control	25	75 (16)		
Brown trout	Treatment	1	425	1	425
	Control	1	185	1	185
		Lower Cottonwood Creek			
Brown trout	Treatment	43	224 (91)*	6	275 (47)*
	Control	30	193 (80)	8	201 (67)
		Upper Cottonwood Creek			
Westslope cutthroat trout	Treatment	45	156 (64)	5	208 (59)
	Control	38	142 (52)	4	163 (26)
Bull trout	Treatment	8	126 (30)		
	Control	11	127 (28)		

We recaptured five westslope cutthroat trout in the upper Cottonwood Creek treatment reach and four in the control reach (Table 2). The lengths of recaptured westslope cutthroat trout did not differ between fish marked in the treatment ($P = 0.12$) and control ($P = 0.23$) reaches. No bull trout were recaptured in either the treatment or control sections.

Overall, between treatment and control reaches, the number of fish recaptured was similar ($\chi^2 = 0.13$; df = 2; $P = 0.94$). Only the upper Cottonwood Creek fish ladder was functioning properly during the evaluation of the ladders (we repaired all ladders prior to translocating fish). A fourth fish ladder was not evaluated in this study because all flows were diverted at the diversion structure, and water was neither flowing through the fish ladder nor flowing to downstream reaches.

Discussion

Assessment of passage requirements for juvenile or small stream-resident fishes is hindered by the lack of information on these fish. Comparisons are inevitably made to adults or large migratory species. Recaptures of individual fish that ascended fish ladders in this study provide useful information on fish swimming abilities and on design parameters for fish ladders on small inland streams.

Denil ladders are designed to mitigate for slope and velocity. Water velocity is a greater impediment to fish passage than slope is (Collins et al. 1962). However, fish will often pass upstream through Denil fishways when velocities in the ladder should theoretically preclude their passage (Schwalme et al. 1985) by swimming from baffle to baffle (Bunt et al. 1999) or by using areas near the bottom of baffles, where velocity is lower (Wada et al. 2000).

Among the Chamberlain Creek treatment group, a 93-mm westslope cutthroat trout ascended the fish ladder through a velocity of 82 cm/s. Based on the calculations of Beach (1984), Reiser and Peacock (1985), and Hawkins and Quinn (1996), a fish would need to travel 107 cm/s (water velocity × 30%), which is equivalent to 11.5 body lengths/s, to move through a water velocity of 82 cm/s. Similarly, a 165-mm westslope cutthroat trout must swim 186 cm/s to ascend a 140-cm/s fish ladder. Therefore, a 165-mm westslope cutthroat trout would have to swim at a rate of 11.2 body lengths/s. Since such small trout are unlikely to attain these speeds (Reiser and Peacock 1985), their passage can most likely be explained by Denil fish ladders providing a series of refugia.

We did not observe any movement back to capture locations for slimy sculpins or bull trout. However, upstream summer movement of slimy sculpins and juvenile bull trout has been documented in western Montana (S. Adams, U.S. Forest Service, personal communication) and specifically in Chamberlain Creek (D. A. Schmetterling, unpublished data). Since we did not recapture any slimy sculpins in the treatment or control reaches, the effect of the fish ladders on this species is unclear. The absence of slimy sculpin recaptures could result from the high density (approximately 700 fish/100 m) and low capture efficiency of sculpins in Chamberlain Creek (D. A. Schmetterling, unpublished data). Lack of bull trout recaptures in the upper Cottonwood Creek treatment or control reaches may reflect the small number of marked fish.

Although Denil ladders demonstrate promise for passing fishes of various sizes over irrigation diversions, they require maintenance (e.g., supplying adequate flow through the ladder or clearing debris). Even in the Blackfoot River watershed, where landowners support fisheries improvement projects on private land (Pierce and Schmetterling 1999), retrofitting of irrigation diversions with fish ladders is of limited use without enforceable commitment from landowners to maintain the fish ladders.

Individual fish recaptured after moving upstream over the fish ladders demonstrate that fish of a range of sizes can ascend Denil fish ladders. Although measuring fish ladder effectiveness can be difficult (Bunt et al. 1999), future studies should determine ladder efficiency and fish avoidance. Recapture of fish in similar proportions in both control (unobstructed) reaches and treatment reaches suggests that Denil fish ladders are effective in allowing fish passage, particularly that of juvenile or stream-resident westslope cutthroat trout.

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