The influence of stream crossing structures on the distribution of rearing juvenile Pacific salmon

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Abstract

Roads and railroads often cause barriers to fish migration at stream crossing locations by modifying channel geometry causing rapid vertical drops or increased water velocities. Vertical drops or increased water velocities often exceed the leaping ability or the sustained or burst swimming speeds of juvenile anadromous salmon and resident fish. Adult salmon migration barriers can result in the absence of anadromous fish from stream systems and reduce the availability of marine-derived nutrients; however, the effects of juvenile salmon migration barriers on fish distribution and stream ecosystems is unclear. We tested for differences in juvenile Pacific salmon relative abundance upstream and downstream of crossing structures in five moderate sloped and five low-sloped streams. Stream channel width, bed slope, and substrate were measured within the natural channel and compared to the physical characteristics within the crossing structures. We measured water velocity at the inlet, outlet, and middle of culverts using velocity meters and obtained maximum and minimum velocities using the flow time of dissolved solutes. Water velocities were compared to the sustained and burst swimming speed of rearing juvenile salmon to evaluate fish passage. In the moderate-sloped streams that contained spawning adults, relative abundance of juvenile coho salmon was often 2 to 3 times greater upstream of the crossing. Within these stream reaches, downstream emigration of salmon fry from spawning locations likely was limited by avoidance of water velocities that exceeded the burst swimming speeds of juvenile coho salmon. Replacement of two of the crossing structure reduced water velocities and eliminated differences in coho salmon catch rates. In the low sloped wetland streams with spawning reduced or absent above the crossing, catch rates of coho salmon juveniles averaged 1 fish per trap above, and 50 fish per trap below the crossing. Therefore, high water velocities at crossing locations can affect both upstream and downstream fish movement and alter the distribution of rearing fish within stream systems. These changes in the relative abundance of juvenile salmon could influence rearing salmon fitness and survival, and other components of the stream ecosystem and could be used to evaluate the influence of rearing juvenile salmon on invertebrate community composition and abundance.

Introduction

Anthropogenic changes to the physical or chemical characteristics of streams can result in complete or partial barriers to fish migration. Physical changes often occur at sites where transportation corridors intersect streams and include channel straightening, narrowing, or substrate modification. Roads, railroads, and other transportation structures often cause barriers to fish migration at stream crossing locations. Stream crossing structures affect the movement of fish and other aquatic life by altering the stream physical characteristics. These types of physical changes influence water velocities and may result in increases above fish swimming ability. Migration barriers can have significant effects to fish production as access to large areas of spawning or rearing habitat can be eliminated or reduced (Sheer and Steel 2006). For this reason, considerable work has been done to assess fish passage and eliminate migration barriers.

The effect of dams and other cross channel structures on the migration and production of adult salmon is well known; however, the influence of migration barriers on the distribution of rearing juvenile salmon and resident fish is not understood. Resident and anadromous fish migrate from rearing to spawning areas and among fresh-water locations in search of food resources and physical habitat characteristics necessary for their survival and propagation. Juvenile salmon require access to rearing or overwintering habitats that are often located considerable distances from spawning areas. Several studies demonstrate the wide range of movement of juvenile anadromous salmon from spawning to rearing areas (Carlson 1992, Carlson and Hasbrouck 1993, Murphy et al. 1997). Blocking or limiting access to these areas also may affect fish distribution and the fitness or survival of rearing salmon. However, only a portion of the juvenile salmon population migrates, in response to antagonistic behavior, to access food or other resources, or to avoid extreme environmental conditions (Quinn 2005). In addition, due to the variability in water velocities with flow and fish swimming speeds, only a portion of those fish migrating may be affected by the crossing structure. Because only a portion of the rearing juvenile fish population migrate, and only a portion of those may be affected by a crossing structure, the effects of potential migration barriers on rearing juvenile salmon distribution are not clear.

Considerable work is being conducted in Alaska to restore fish passage by reconstructing crossing structures to mimic natural stream physical characteristics. However, the number of structures that are potential migration barriers exceeds the amount of funding and time available to devote to these efforts. In order for these efforts to be most efficient, stream crossing reconstruction projects should be directed to those sites that have the greatest influence on fish movement and production. Reconstruction also should effectively restore fish passage. To accomplish these objectives, we must increase our understanding of how crossing structures affect fish passage and the influence of these barriers on fish distribution and productivity.

The primary objective of this study was to determine whether crossing structures classified as migration barriers caused differences in juvenile salmon and resident fish distribution. The second objective was to use sites with differences in juvenile salmon catch rates to identify physical characteristics at the crossing locations that inhibited fish movement. Combined, these two objectives will help to more accurately identify those sites that are barriers to fish migration and those sites that modify juvenile salmon distribution. This information can be used to efficiently prioritize potential fish passage restoration projects.

Methods

Sampling Sites

The study was conducted in southcentral Alaska, on streams within the Susitna and Little Susitna River drainages (Table 1). Replicate sampling sites (n = 5) were selected at crossing locations on two stream types. These stream types were moderate-sloped (>1%) upland streams draining a mixed birch spruce forest, and low-sloped wetland streams draining closed black spruce forests and *Calamagrostis* meadows. The moderate-sloped, or upland sites, were cataloged by the Alaska Department of Fish and Game (ADFG) as spawning and rearing habitat for coho salmon (*Oncorhynchus kisutch*) (ADFG Anadromous Fish Stream Viewer) or where spawning coho salmon had been observed. The low-sloped, or wetland sites, were located on streams that had been identified as important for the rearing of coho salmon and where salmon spawning had not been observed and spawning habitat was limited by fine sediments. Stream crossings were selected as those that have been classified by the ADFG as barriers (red culverts) or potential barriers (grey culverts) to juvenile salmon migration based upon the modification of natural channel physical characteristics (Rich 2003, ADFG Fish Passage Inventory). Sampling was conducted in the spring (late May and Early June) and fall (late September) of 2008. Crossing structures were replaced at two locations between spring and fall sampling (Colter Creek and Coles Road) and sampling was extended into the summer of 2009 at these two locations.

Stream physical characteristics were measured above and below the crossing structures. Physical measures included channel width, slope, substrate particle size, culvert width, culvert slope, culvert substrate, and culvert perch height. Channel width was measured at five locations upstream and downstream of the crossing locations, beyond any obvious area of culvert influence. Widths were measured on straight channel sections, at ordinary high water (vegetation line), and separated longitudinally by approximately 3 channel widths. Water surface slope, bed slope, and culvert slope was measured using a laser level and leveling rod. We measured bed and water surface heights between two riffles and the distance between riffles. Culvert slope was determined from the length of the pipe and the height at the inlet and outlet inverts. Substrate particle size was determined qualitatively. Maximum culvert width and culvert width at the rust line were measured. .Culvert perch height was determined as the distance from the height of the water surface at the culvert outlet and outlet pool.

Stream discharge was measured on each sampling date as the sum of individual component flows. Water velocity at three locations across the culvert inlet and outlet were measured using a Price AA pygmy or Swoffer meter. Water velocity was measured within the culvert using the Price or Swoffer meter if the pipe was large enough, or using a General Oceanics flow meter suspended from the end of a leveling rod extended into the culvert 3 to 4 meters. The lowest of the three velocity measurements taken at each location is reported and used for fish passage assessment.

Table 1. Stream sampling locations, stream type, and ADFG classification. Red is classified as a blockage, grey is classified as a potential blockage. Unclassified sites have not been surveyed.

Stream	Road Crossing	Drainage	Wetland/ Upland	Latitude	Longitude	ADFG Ranking
Answer Creek	Talkeetna Spur Road	Sunshine Creek/Susitna River	Upland	62.2025	150.0601	Grey
Sunrise Creek (AKA Poodle Creek)	Sunrise Road	Little Susitna River	Upland	62.6507	149.5654	Red
Unnamed Stream	Coles Road	Little Susitna River	Upland	61.6652	149.3799	Red
Colter Creek	Softwind Road	Little Susitna River	Upland	62.6558	149.4988	Red
Russet Creek	Edgerton Park	Little Susitna River	Upland	61.6905	149.2939	Red
Greys Creek (North Fork)	Parks Highway	Susitna River	Wetland	61.8974	150.0782	Red
Unnamed Stream	Mile 107.6 Parks Highway	Rabideux/Susitna River	Wetland	61.2161	150.2252	Red
Rabideux Creek	Parks Highway North Crossing	Susitna River	Wetland	62.2859	150.2507	Grey
Sawmill Creek	Parks Highway	Rabideux/Susitna River	Wetland	62.2432	150.2507	Grey
Unnamed Stream	Mile 118.7 Parks Highway	Susitna River	Wetland	62.3563	150.2567	Unclassified

We also measured water velocity using the flow time of dissolved solutes. A bolus of concentrated MgCl solution was added to the upstream end of the culvert and conductivity measured at 5 second intervals at the outlet to measure flow times. Maximum velocity was the time at which specific conductivity began to increase at the culvert outlet, mean velocity was the peak in specific conductivity, and minimum velocity was the time when conductivity returned to pre-injection concentrations. Restoration was evaluated by comparing how closely physical characteristics at the crossing mimicked those of the natural stream channel.

Water velocities at the crossing location were compared to the burst and sustained swimming speeds of juvenile coho salmon. Swimming speeds were taken from equations used in the Fish Xing program V3

(2006). Sustained swimming speed for 50 to 70 mm long coho salmon ranges from 0.98 to 1.2 ft/s. Maximum burst swimming speed is 2.5 ft/s.

Biotic evaluation of fish passage was determined through samples of the fish community in stream reaches above and below crossing locations prior to and following site restoration. The fish community was sampled using 10 or 20 baited (salmon roe) minnow traps fished for 20 to 24 hours. Fish traps were placed at 10 to 20 meter intervals extending approximately 200 meters above and below the crossings. Traps were placed in pools or low velocity areas with cover provided by deep water, woody debris or undercut banks. All captured fish were identified to species and fork length measured. Each trap was assessed individually to give 10 to 20 replicate catch per trap values for each sampling location.

Paired, one-tailed T-tests (alpha = 0.05) were used to test for differences in average catch per trap for upstream and downstream of wetland and upland stream crossings, independently. T-tests also were used to test for significant differences in coho salmon, coho salmon less than or equal to 55 mm in fork length, coho salmon greater than 55 mm fork length, Chinook salmon (*Oncorhynchus tshawytscha*), and Dolly Varden (*Salvalinus malma*) catch per trap for each site independently. Individual sites with significant differences in catch rates were used to estimate the changes in physical characteristics at the crossing location that resulted in migration barriers.

Results

Juvenile coho salmon were the dominant salmonid species captured through minnow trapping at stream crossing locations. Trapping efforts also yielded juvenile Chinook salmon and resident Dolly Varden and rainbow trout (*Oncorhynchus mykiss*). We captured both Dolly Varden and rainbow trout in the upland streams, but Dolly Varden were not captured in the wetland streams. Chinook salmon were captured within both stream types; however, average catch rates in wetland streams were less than 1 fish per trap and from 2 to 3 fish per trap in the upland streams (Table 2 and Table 3). Catch rates of juvenile salmon generally were greater in late September than May or early June, particularly for smaller (< 55 mm) fish.

Using all sites and all sampling dates, catch rates of juvenile coho salmon were greater upstream of crossing structures in upland streams and downstream of crossings in wetland streams. Using paired t-tests, these differences were significant for upland streams ($p = 0.01$) but not for wetland streams ($p = 0.09$). Within upland streams, juvenile coho salmon catch rates for fish greater than 55 mm in fork length were significantly higher upstream of crossing ($p = 0.01$), but for juveniles less than 56 mm in fork length, average catch rates were greater upstream, but differences were not significant ($p = 0.06$). Differences in juvenile coho salmon were on average 3.5 fish per trap higher above crossings in upland streams with a maximum difference of 8.7 fish per trap. In wetland streams, juvenile coho salmon averaged 6.5 fish per trap greater downstream of crossings with a maximum difference of 49 fish per trap.

Table 2. Average catch per trap (n=10) above (UP) and below (DN) wetland stream crossings. Asterisks denote significant differences. CO = coho salmon, 55 and 56 is fork length in mm, DV = Dolly Varden, RB = rainbow trout, and TOT = total salmonids.

LOC	DATE	UPCO	DNCO	UPCO<56	DNCO<56	UPCO>55	DNCO>55	UPDV	DNDV	UPRB	DNRB	UPTOT	DNTOT
Sawmill Creek at Parks Hwy	5/23/2008	2.8	3.4	0.5	0.4	2.3	3.0	0.0	0.0	0.0	0.7*	2.9	4.1
Sawmill Creek at Parks Hwy	9/10/2008	15.2	12.6	3.9	4.2	11.3	8.4	0.0	0.0	0.1	0.7*	15.3	14.0
Upper Rabideux Parks Hwy	5/24/2008	2.1	2.5	0.0	0.0	2.1	2.5	0.0	0.0	0.0	0.1	2.1	2.6
Upper Rabideux Parks Hwy	9/10/2008	9.4	14.0	1.6	6.4*	7.8	7.6	0.0	0.0	0.0	0.2	9.4	14.2
Greys Creek (N) Parks Hwy	5/29/2008	0.4	4.9*	0.0	0.0	0.4	4.9*	0.0	0.0	0.0	0.0	0.4	4.9*
Greys Creek (N) Parks Hwy	9/11/2008	2.0	8.0*	0.0	1.0*	2.0	7.0*	0.0	0.0	0.1	0.0	2.2	8.0*
Mile 107.6 Parks Hwy	5/14/2008	0.3	8.8*	0.0	0.8*	0.3	8.0*	0.0	0.0	0.00	0.2	0.7	17.8*
Mile 107.6 Parks Hwy	9/10/2008	0.0	49.9*	0.0	21.0*	0.0	29.0*	0.0	0.0	0.0	0.0	0.0	50.3*
Mile 118.7 Parks Hwy	5/21/2008	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Mile 118.7 Parks Hwy	9/11/2008	2.7	1.3	0.0	0.0	2.7	1.3	0.0	0.0	0.0	0.0	2.7	1.3

Table 3. Average catch per trap (n=10) for upland stream crossings. Asterisks denote significant differences. CO = coho salmon, 55 and 56 is fork length in mm, DV = Dolly Varden, RB = rainbow trout, TOT = total salmonids, and NS = not sampled (fish traps stolen).

LOC	DATE	UPCO	DNCO	UPCO<56	DNCO<56	UPCO>55	DNCO>55	UPDV	DNDV	UPRB	DNRB	UPTOT	DNTOT
Colter at Softwind	6/3/08	9.9*	3.4	3.9	1.5	6.0*	1.9	2.3	1.8	0.0	0.0	12.2	5.2
Colter at Softwind	9/25/08	11.9*	3.2	7.8*	2.1	4.1*	1.1	1.8	1.1	0.0	0.0	15.7	6.8
Coles Road	6/4/08	3.6*	0.7	2.2*	0.6	1.4*	0.1	3.0	1.9	0.0	0.0	6.6*	2.6
Russet Creek	6/4/08	0.9	2.8	0.5	1.1	0.4	1.7*	0.3	0.8	0.0	0.0	1.2	3.6*
Russet Creek	9/27/2008	7.5	3.6	3.8*	1.6	3.7	2.0	0.1	8.0*	0.0	0.0	7.6	11.6*
Answer Creek	5/20/08	3.3*	0.8	0.2	0.2	3.1*	0.6	0.0	0.0	1.9	3.7*	5.2	4.5
Answer Creek	9/11/08	11.7*	6.0	1.4	1.8	10.2*	4.2	0.0	0.0	3.7	6.1*	15.4	12.1
Sunrise Road	6/2/08	6.9	6.7	4.4	4.7	2.5	2.0	3.2	5.6*	0.0	0.0	10.1	12.3
Sunrise Road	9/24/08	NS	16.5	NS	8.7	NS	7.8	NS	5.5	NS	0.0	NS	23.6

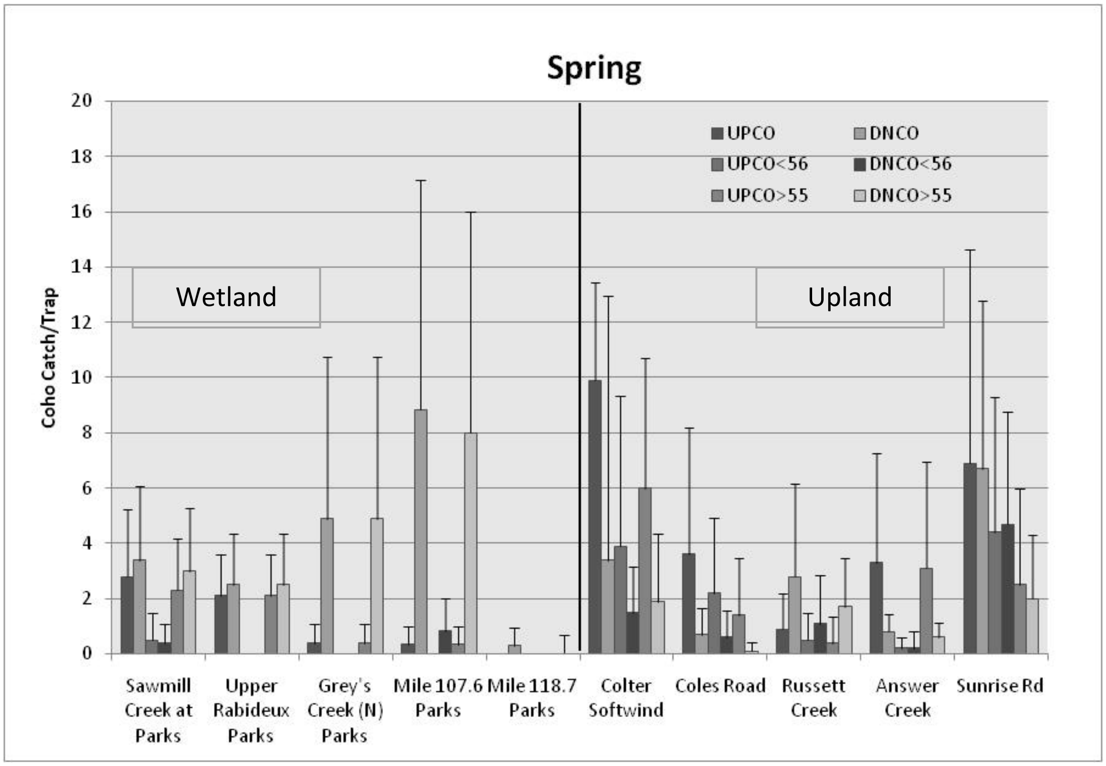

Figure 1. Average spring (late May or early June) coho salmon catch per trap for wetland (left panel) and upland stream crossings. Error bars represent one standard deviation.

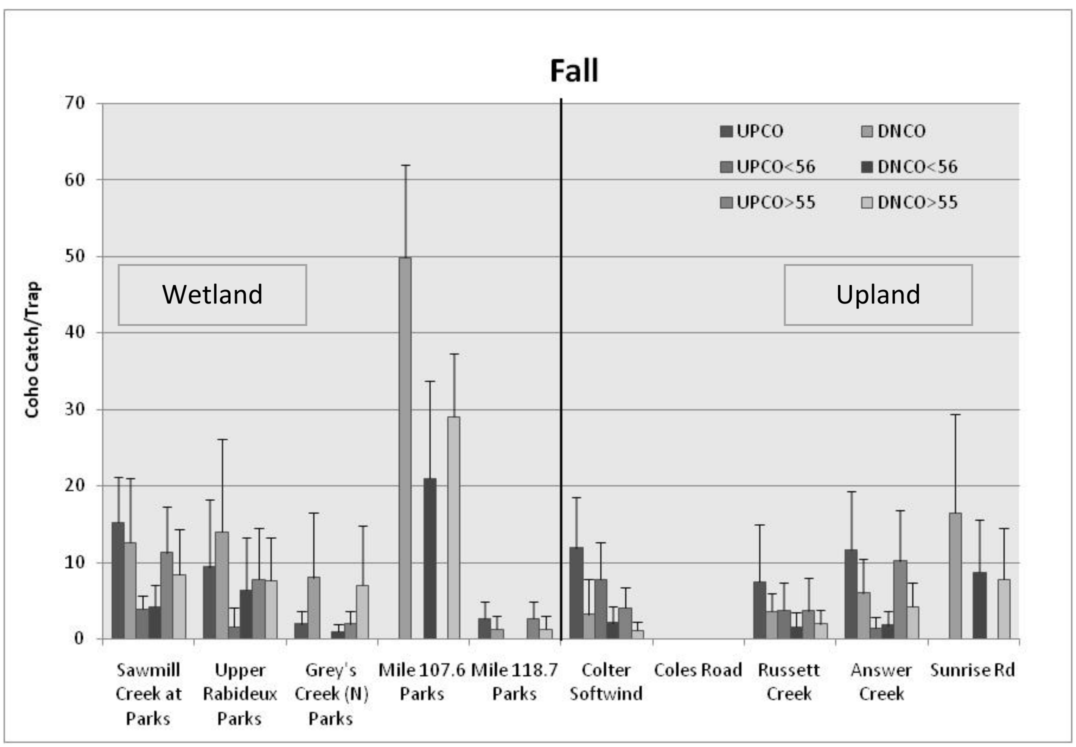

Figure 2. Average fall (late September and early October) coho salmon catch per trap for wetland (left panel) and upland stream crossings. Error bars represent one standard deviation.

Average catch rates of juvenile salmon in both size classes were greater downstream at wetland stream crossings but differences were not significant ($p = 0.11$ and 0.09 for those < 56 and >55, respectively).

Average catch rates of resident fish were greater downstream of both wetland and upland stream crossings. Differences were not significant in upland streams where catch rates differed by 1.06 Dolly Varden per trap ($p = 0.17$), 0.53 rainbow trout per trap ($p = 0.09$), or 1.58 total resident fish per trap ($p = 0.08$). Average catch rate of resident rainbow trout among wetland streams was 0.16 fish per trap greater downstream, and this difference was statistically significant ($p = 0.04$).

Differences in the catch rates of juvenile coho salmon and resident trout were observed at some but not all of the upland or wetland stream crossings. Among the wetland streams, significant differences in juvenile coho salmon catch rates (catch rates higher downstream of the crossings) were measured at the Mile 107.6 and the north Greys Creek crossings. These differences were significant for spring and fall samples of total juvenile coho salmon and for the two size classes (Table 2 and Figures 1 and 2). In addition, we found significant differences in fall catch rates of juvenile salmon less than 56 mm in fork length at the Upper Rabideux Creek crossing of the Parks Highway and rainbow trout at Sawmill Creek. Among the upland streams, significant differences in total coho salmon catch rates were found at Colter Creek, Coles Road, and Answer Creek. At all of these sites, catch rates of coho juveniles of both size categories were greater upstream of the crossing in either spring or fall samples. At Russett Creek, differences in catch rates of total coho salmon were not significant, but catch rates of coho greater than 56 mm were higher downstream in spring samples and fish less than 55 mm were more abundant upstream in the fall. We did not measure differences in coho salmon at Sunrise Road, but resident Dolly Varden were significantly more abundant downstream of the crossing. Similarly, rainbow trout were more abundant downstream of the Answer Creek crossing.

Perched culverts were the only physical characteristic that explained differences in juvenile salmon catch rates among the stream crossings. Stream channel and culvert physical characteristics are shown in Table 4. Culverts within the upland streams constricted channel widths from 0.3 to 0.76 times average channel widths. Culverts in the upland streams increased channel slopes at all locations when compared to slopes measured upstream of the crossings but only at three of the five sites when compared to downstream channel slopes. Channel slopes in upland streams were significantly steeper downstream from crossings (paired t-test $p < 0.05$), but there was no significant differences in channel widths. Crossing structures in wetland streams similarly constricted channel widths from 0.3 to 0.7 times, with the exception of upper Rabideux Creek where the combined width of the two culverts approximated stream channel widths.

Culvert slopes at the wetland crossings were 2 to 10 times steeper than natural channel slopes with the exception of the crossing structures at Mile 107.6 and Mile 118.7 where culvert slopes were less than upstream channel slopes but greater than downstream channel slopes. Differences between upstream and downstream channel slopes and widths were not consistent or statistically significant. Culverts at three of the wetland crossings were perched. We found significant differences in fish catch rates at two of the three sites with perched culverts, including Mile 107.6 (perch height of 1.3 m), and Greys Creek (perch height of 0.20 m).

Differences in catch rates were observed at crossings where maximum water velocities in the culvert exceeded burst swimming speeds or minimum flow time velocities exceeded the sustained swimming speeds of juvenile coho salmon. Culvert water velocities obtained through point measures at the culvert inlet, outlet, and middle or by the flow time of dissolved solutes are shown in Tables 5 and 6. Using a burst swimming speed of 2.3 ft/s and a sustained swimming speed of 1.0 ft/s, all of the sites except for Sawmill, Upper Rabideux, and Mile 118.7 Creeks would be barriers to fish migration during low flow conditions in the spring. Similarly during higher fall flows, water velocities exceeded juvenile salmon swimming speeds within the crossing structures at all of the sites measured except for Sawmill and Upper Rabideux Creeks. We found no difference in juvenile salmon catch rates above and below the Sawmill Creek and Rabideux Creek crossings. Based on measured water velocities, the stream crossing at Mile 118.7 should be a barrier to fish migration; however, we did not measure significant differences in juvenile salmon catch rates. Juvenile salmon catch rates were extremely low in the spring with 3 fish captured downstream of the crossing and none upstream. Catch rates were slightly higher in the fall with 13 coho salmon captured downstream and 27 upstream. All of these fish were greater than 56 mm in fork length. We did not capture any resident Dolly Varden or rainbow trout during either sampling event. These low numbers limit the ability to evaluate the crossing based on measures of relative fish catch rates and suggest the presence of additional barriers downstream. The Sunrise Road crossing also should be a barrier based upon water velocities measured during high flows. Evaluation of this site, however, is limited due to the unavailability of water velocities in the spring due to equipment problems, and during the fall due to vandalism to our downstream fish traps.

Replacement of the Colter Creek and Coles Road crossings in 2008 restored natural channel widths, slopes, and substrate; reduced water velocities; and eliminated differences in juvenile coho salmon catch rates. Water velocities and fish catch rates prior to and following reconstruction of the Colter Creek crossing are shown in Tables 7 and 8. During high fall flows (14 cfs) following reconstruction, maximum velocities still exceeded burst swimming speeds, and minimum velocities as measured by flow time through the culvert exceeded the sustained swimming speeds of juvenile coho salmon. During mid-July, however, stream flows decreased to 1.6 cfs and maximum and minimum water velocities within the crossing were well below the burst and sustained swimming speeds of juvenile coho salmon. Significantly more junvenile coho salmon were captured upstream of the crossing immediately following reconstruction in September, 2008, but we found no difference in catch rates in samples collected the following spring and summer.

Table 4. Stream channel and culvert physical characteristics and ratios of stream to culvert characteristics for upland (above) and wetland (below) stream crossings. For sites with multiple culverts, only one value for channel characteristics are provided.

	Culvert Slope	Upstream Channel Slope	Downstream Channel Slope	Upstream Culvert Width (m)	Upstream Channel Width (m)	Downstream Culvert Width (m)	Downstream Channel Width (m)	Culvert Width/ Upstream Width	Culvert Width/ Stream Width (DN)	Culvert Slope/Stream Slope (UP)	Culvert Slope/Stream Slope (DN)	Culvert Substrate	Perch Height (m)
Answer Creek	0.014	0.005	0.016	3.32	4.98	3.18	5.94	0.67	0.54	2.80	0.88	None	None
Sunrise Creek (Rt. Culvert)	0.028	0.017	0.035	1.33	3.50	1.38	4.00	0.76	0.69	1.65	0.80	None	0.04
Sunrise Creek (Lt. Culvert)	0.028			1.33		1.38				1.65	0.80	None	0.02
Coles Road	0.045	0.013	0.035	1.24	2.59	1.16	2.04	0.48	0.57	3.46	1.29	None	None
Colter Creek	0.050	0.009	0.043	1.50	3.48	1.50	4.08	0.43	0.37	5.56	1.16	None	None
Russett Creek at Edgerton Park	0.040	0.001	0.010	1.19	1.80	1.22	1.89	0.66	0.65	40.0	4.00	None	None
Mile 107.6	0.040	0.072	0.015	1.20	2.99	1.22	2.55	0.40	0.48	0.56	2.67	None	1.33
Mile 118.7	0.005	0.037	0.016	1.83	4.83	1.83	5.23	0.38	0.35	0.14	0.31	Cobble	0.20
Upper Rabideux (Rt. Culvert)	0.020	0.007	0.001	2.20	4.06	2.20	4.52	1.08	0.97	2.86	20.00	Gravel	None
Upper Rabideux (Lt. Culvert)	0.010			2.20	4.06	2.20	4.52			1.43	10.00	None	None
Sawmill Creek	0.039	0.004	0.031	2.32	7.02	2.35	5.64	0.33	0.42	10.0	1.26	Boulders	None
Greys Creek	0.008	0.002	0.003	2.90	4.26	2.90	4.16	0.68	0.70	4.00	2.67	Boulders	0.18

Table 5. Upland stream culvert velocities measured at the inlet, outlet, and middle of the crossing, and flow time velocities using dissolved solutes. Middle culvert velocities not reported due to inaccurate data from an inoperative velocity meter.

	Answer Creek		Sunrise Creek (Rt. Culvert)	Sunrise Creek (Lt. Culvert)	Coles Road	Colter Creek	Russett Creek	
Flow (cfs)	3.95	13.57	9.13	9.13	2.2	5.0	1.19	5.98
Culvert Inlet Velocity (ft/s)	1.5	2.0	1.5	2.23	1.8	5.8	2.82	2.68
Culvert Middle Velocity (ft/s)	1.8	2.4	NM	NM	NM	7.3	NM	NM
Culvert Outlet Velocity (ft/s)	1.3	2.5	5.2	3.72	3.5	4.7	1.87	2.50
Maximum Flow Time Velocity (ft/s)	2.76	3.69	3.6	5.18	4.7	6.69	3.05	4.07
Average Flow Time Velocity (ft/s)	1.84	3.16	2.17	2.59	3.2	6.69	1.74	2.44
Minimum Flow Time Velocity (ft/s)	0.69	1.70	1.08	0.94	1.6	6.69	0.76	0.81

Table 6. Wetland Stream culvert velocities measured at the inlet, outlet, and middle of the crossing, and flow time velocities measured using dissolved solutes. Stream flows are total flows and not for individual culverts when two are present.

	Mile 107.6	**Mile 118.7 (Right)***	**Mile 118.7 (Right)**	**Mile 118.7 (Left)**	**Upper Rabideux (Right)**	**Upper Rabideux (Left)**	**Upper Rabideux (Right)**	**Upper Rabideux (Left)**	**Sawmill Creek**		**Greys Creek**	
Stream Flow (cfs)	0.76	0.23	8.89	8.89	1.04	1.04	4.85	4.85	2.41	12.0	5.4	9.16
Culvert Inlet Velocity (ft/s)	0.69	0.338	1.86	1.27	1.42	1.76	1.75	1.45	0.77	0.82	1.51	1.99
Culvert Middle Velocity (ft/s)	1.5	0.504	NM	NM	0.88	1.32	NM	NM	0.45	0.49	2.21	NM
Culvert Outlet Velocity (ft/s)	2.1	2.11	3.96	3.44	0.97	1.93	1.47	1.31	0.42	0.55	2.37	5.17
Maximum Flow Time Velocity (ft/s)	1.96	0.82	3.03	2.65	0.92	0.97	2.30	2.30	0.68	0.84	2.13	2.48
Average Flow Time Velocity (ft/s)	1.4	0.54	2.12	1.77	0.61	0.66	1.54	1.42	0.47	0.66	1.35	1.66
Minimum Flow Time Velocity (ft/s)	0.93	0.31	1.18	0.96	0.23	0.28	0.53	0.53	0.25	0.41	0.68	1.10

Table 7. Colter Creek and Coles Road flows and water velocities (ft/s) at the road crossings prior to and following site restoration.

	Colter Creek			Coles Road		
Date	6/13/07	9/25/08	7/27/09	7/20/08	9/26/08	7/28/09
Pre- Post Restoration	Pre	Post	Post	Pre	Post	Post
Discharge (cfs)	5.03	14.3	1.67	2.16	4.91	1.27
Culvert Inlet	5.80	2.14	0.88	1.80	2.70	0.38
Culvert Middle	7.83	NM	0.50	NM	NM	0.36
Culvert Outlet	4.57	2.88	0.52	3.50	1.18	0.65
Flow Time Maximum	6.69	2.88	1.44	4.70	2.85	1.78
Flow Time Minimum	6.69	1.31	0.69	1.60	0.95	0.75
Flow Time Average	6.69	2.40	1.03	3.19	2.03	1.29

Table 8. Fish catch per trap above and below crossing structures prior to and following site restoration at Colter Creek and Coles Road. CO is coho salmon, K is Chinook (King) salmon, DV is Dolly Varden char, < 56 or > 55 is fork length in mm, and TOT is total salmonids. Asterisks denote significant difference ($p < 0.05$).

	Colter Creek				Coles Road		
DATE	6/3/08	9/25/08	5/26/09	7/27/09	6/4/08	9/23/08	7/28/09
Pre- Post Restoration	Pre	Pre	Post	Post	Pre	Post	Post
UPCO	9.9*	11.9*	0.3	5.9	3.6*	4.2	1.5
DNCO	3.4	3.2	0.7	5.8	0.7	3.5	2.1
UPCO<56	3.9	7.8*	0.1	1.0	2.2*	3.6	0.5
DNCO<56	1.5	2.1	0.4	1.9	0.6	3.3	1.2
UPCO>55	6.0*	4.1*	0.2	4.9	1.4*	0.6	1.0
DNCO>55	1.9	1.1	0.3	3.9	0.1	0.2	0.9
UPK	0.0	2.0	0.0	1.2	0.0	0.0	0.0
DNK	0.0	2.6	0.0	2.3	0.0	0.0	0.0
UPDV	2.3	1.8	1.6	3.6	3.0*	1.9	3.9
DNDV	1.8	1.1	0.7	3.3	1.9	2.6	4.6
UPTOT	12.2*	15.7*	1.9	10.7	6.6	6.1	5.4
DNTOT	5.2	6.8	1.4	11.4	2.6	6.1	6.7

The Coles Road crossing was reconstructed in August, 2008. Water velocities and fish catch rates prior to and following reconstruction of the Coles Road crossing are shown in Tables 7 and 8. In September during high flows near 5 cfs, water velocities were reduced from pre-restoration values. Maximum velocities were below the burst swimming speeds and minimum velocities were below sustained swimming speeds. During July 2009, stream flows were near 1.3 cfs and maximum and minimum water velocities were below 1.8 and 0.75 ft/s, respectively. There were no differences in the catch rate of juvenile coho salmon above or below the crossing on either of the two sampling dates following reconstruction.

Discussion

Stream crossing structures can alter the distribution of rearing coho salmon by restricting upstream and downstream migration. This results in increased relative abundance either above or below a migration barrier. For these small upland and wetland streams, relative abundance of rearing coho salmon is likely related to the location of adult spawning habitat. Our results show that in addition to physical blockages (perched culverts), juvenile coho salmon are unable to migrate upstream through crossings where water velocities exceed the burst and sustained swimming speeds of juvenile coho salmon and avoid migrating downstream through similar areas of high velocity.

Upon emergence from spawning gravels, salmon fry migrate either upstream or downstream to rearing and overwintering locations (Kahler and Quinn 1998). Within the upland streams, the crossing structures evaluated were not barriers to adult salmon migration. Adult salmon and/or salmon carcasses were observed upstream of all of the crossing locations with the exception of Sunrise Creek. A portion of the emerging fry were expected to migrate downstream across the migration barrier, decreasing upstream abundance. Juvenile coho salmon have been documented to migrate out of tributary streams during fall storms (Quinn 2005) and we believed that age 0 fish emigrating from tributary streams to overwintering locations would not be able to return to small rearing streams for their second year of freshwater residency. This would result in decreased upstream abundance of rearing salmon. However, this study documented higher catch rates upstream of migration barriers, counter to our expectations. Previous studies have shown that migrating Chinook salmon smolts will avoid areas of high velocity (Kemp et al. 2005) and that culverts can limit downstream migration of juvenile salmon (King *In Review*). We hypothesize from this study that juvenile coho salmon are avoiding the high velocities encountered at culvert inlets resulting in increased upstream abundance. Streams isolated by crossing structures are analogous to small coastal streams with falls or other small barriers near salt water that do not limit adult salmon access to spawning habitat but are barriers to juvenile upstream migration. Salmon fry emigration from these streams upon emergence would likely result in decreased survival and adaptation, which could explain this behavioral response.

The presence of rearing fish in spring samples demonstrates that a portion of the population successfully overwintered in these small upland tributary streams. These first or second order tributary streams are usually ice covered in October and do not become ice free until May. The amount of flowing surface water is very limited and overwintering habitat may be restricted to interstitial or subsurface flows. Overwintering within the substrate has been shown as a survival mechanism for rearing juvenile trout (Smith and Griffith 1994). The structure at the Softwind Road crossing of Colter Creek, with water velocities over 6 ft/s, was a definite barrier to juvenile fish migration; however, spring catch rates of presumably age one fish were higher upstream of the crossing; therefore, winter survival in these small streams is clearly possible.

Higher catch rates of rearing juvenile salmon above upland streams crossings in this study cannot be extrapolated to all migration barriers. The inability to migrate upstream due to increasingly steep slopes could limit emigration and explain the high catch rates in these streams. A migration barrier located further downstream, without any additional upstream barriers, would allow for the population to distribute to upstream rearing and overwintering locations. We did not measure consistently higher catch rates of rearing coho salmon upstream of the Russett Creek crossing of Edgerton Park Road. There is only a small upstream reach (approximately 0.5 km) before the next juvenile migration barrier. The effect of these combined migration barriers on fish distribution is unclear, but may be related to differences in overwinter survival and migration based upon fish size.

Similar catch rates of rearing juvenile salmon and resident fish following reconstruction further supports the influence of crossing structure on fish distribution and the benefits of site restoration. Site reconstruction resulted in channel physical characteristics at the crossing locations that were similar to the unmodified channel. Simulation of channel widths, slopes, and substrate size distribution resulted in reduced water velocities at the crossing locations. The differences in catch rates were eliminated following reconstruction clearly documenting the benefits of site restoration.

While the effect of increased abundance on the fitness and survival of rearing salmon in upland streams due to migration barriers is unknown, juvenile migration barriers in wetland streams can result in complete absence of salmon upstream of the crossing. Wetland streams provide important rearing and overwintering habitat. Juvenile salmon that occupy low velocity off-channel or estuarine habitats tend to grow faster than fish that rear or overwinter in other habitats. For example, Bennett (2006) found that coho salmon smolt emigrating from a low sloped, wetland stream were relatively larger than those from higher velocity and steeper reaches within the same stream system. Dolloff (1987) compared coho production among different stream types and found that streams through meadows tend to be more productive than forested streams or streams with an open canopy. Larger size leads to increased overwinter and marine survival of juvenile anadromous salmon. For example, juvenile salmon that were larger (based on fork length) or had a higher condition factor (length to weight relationship) in the fall had higher winter survival rates in an Oregon tributary stream (Ebersole et al. 2006). Similarly, Henning et al. (2006) found high growth and survival rates for juvenile coho salmon rearing in emergent floodplain wetlands.

Many low-sloped wetland streams contain sediment deposits of fine silts and sands. These substrates do not provide quality spawning habitat and salmon distribution is largely due to juvenile migration from spawning locations in nearby streams. The unnamed stream crossing the Parks Highway at mile 107.6, with a perch height of over 1 m, is a clear blockage to juvenile salmon migration. This stream is a tributary to Rabideux Creek that supports coho and Chinook spawning. Coho salmon capture rates were 10 to 40 fish per trap greater downstream of the barrier. This represents 100 to 400 more fish/100 m sampling reach or 5,000 to 20,000 fish for the 5 km of stream isolated by this crossing. As catch rates represent only a portion of the total population, this is an underestimate of the effects of this crossing on rearing salmon.

Juvenile Chinook salmon were absent from wetland streams and at low abundance in some of the upland streams; therefore, the influence of crossing structures on juvenile Chinook salmon is not addressed in this study. However, juvenile Chinook salmon were captured in Colter Crek following restoration, but not before. Catch rates of Chinook juveniles in Colter Creek also were much lower than catch rates in Swiftwater Creek (Davis and Davis 2009) with is a very similar, adjacent stream. Juvenile Chinook salmon more often are found rearing and overwintering in larger stream systems and distribution into smaller tributary streams may be easily limited by crossing structures due to behavioral response rather than physical limitations.

Catch rates of resident Dolly Varden and rainbow trout were greater downstream of crossing locations in both wetland and upland streams. These results suggest that the crossing structures affect resident fish distribution and that upstream migration is influenced more than downstream movement. Captured resident fish were larger than juvenile salmon and the high velocities at crossing structures may not have influenced downstream migration. Resident fish also spend their entire life rearing in freshwater, and downstream abundance could increase over time as fish were unable to migrate back upstream.

Results from this study support our previous findings (Davis and Davis 2008) that measures of channel modification at crossing locations alone are not adequate to determine migration barriers. A combination of measures of channel and culvert physical characteristics, point measures of water velocity, and flow time measures of water velocity were most effective at evaluating potential barriers. Point measures of water velocity at the culvert inlet and outlet are necessary to document high velocity areas that are likely to exceed the burst swimming speeds of migrating fish. The flow time of dissolved solutes takes into account transient storage areas (Webster and Valett 2006), which may be related to low velocity areas that can be accessed by 55 mm long juvenile salmon. Water velocities within or adjacent to the substrate are more descriptive of velocities experienced by juvenile salmon than average vertical velocities measured at 0.6 depths.

Increased water velocities at stream crossing locations can influence the distribution of rearing juvenile salmon. These effects can cause increased or decreased abundance depending on the location of the barrier relative to adult spawning locations. The effects of migration barriers likely will vary based on their location relative to other barriers and the distribution, abundance, and access to rearing and overwintering habitats. The increased abundance of juvenile salmon may influence fitness and survival and affect the trophic structure of the stream ecosystem.

Biotic evaluation of fish abundance at crossing locations should be an integral component of fish passage restoration projects. Continued biotic evaluation can provide additional information to help identify and prioritize migration barriers and evaluate the success of restoration projects. In addition, comparisons between streams and stream systems with and without barriers can provide additional information on the distribution of juvenile salmon and their influence on other stream ecosystem components. Further work should evaluate how increased concentrations of juvenile salmon either above or below migration barriers effects fish fitness and growth rates. Differences in the macroinvertebrate community with and without juvenile salmon could provide information on the influence of a top predator on the relative abundance of prey. Similarly, concentrations of Dolly Varden and rainbow trout below crossing structures may increase the loss of rearing juvenile salmon to predatory fish. Stream crossing structures also influence the transportation of sediment and woody debris, which could influence the quality of juvenile rearing habitat. Further work should be conducted on the potential influence of crossing structures on the distribution of juvenile Chinook salmon. If Chinook juvenile salmon migration is influenced by crossing structures due to a behavioral response, then physical characteristics at the crossing location affecting migration may be unrelated to fish swimming abilities.

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