Passage Behavior and Survival of Radio-Tagged Yearling and Subyearling Chinook Salmon and Juvenile Steelhead at Ice Harbor Dam, 2009

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EXECUTIVE SUMMARY

In 2009, we evaluated passage behavior, distribution, and survival of yearling Chinook salmon, steelhead, and subyearling Chinook salmon at Ice Harbor Dam. A central objective of these evaluations was to evaluate the effects of a removable spillway weir (RSW) used during two different spill operations. Study fish consisted of those collected and surgically tagged with both a radio transmitter and PIT tag for similar evaluations at Lower Monumental Dam. For the Ice Harbor evaluation, treatment groups consisted of fish released either 7 km above Lower Monumental Dam or into the tailrace of Lower Monumental Dam. These fish were regrouped by day of detection on the Ice Harbor forebay entry line, 600 m upstream from the dam. A total of 1,887 radio-tagged yearling Chinook salmon, 1,952 juvenile steelhead, and 2,592 subyearling Chinook salmon from these releases were utilized as treatment fish from the upstream releases for survival estimates based on the single-release model .

All yearling Chinook salmon and steelhead replicate groups were released during both day and night hours over 28 d from 28 April to 25 May. Subyearling Chinook salmon were released during day and night hours over 25 d from 10 June to 4 July. During the study we planned to alternate project operation treatments in 2-d random blocks between BiOp spill (45 kcfs during the day and spill to the dissolved gas limit at night) and 30% spill (30-40% of total flow volume). However, due to increased river flows, involuntary spill precluded use of either spill treatment during the last 10 d of the spring portion of the study, resulting in a loss of viable replicate treatments for comparison. While some data with which to compare behavior and passage was obtained during the first 20 d of the study, results during the latter portion of the study were obscured by project operations that averaged 50% spill. Therefore, analyses to compare the two project operation treatments had less statistical power because fewer fish passed under each operational treatment. We obtained data for a third "treatment" (50% spill), and present these results here. However, river flows were considerably higher during these 50% spill operations, and results were not comparable to the other two treatments. During the summer period of the study, spill treatments were held consistent throughout the season. All statistical analyses reported are comparisons between 30% and BiOp spill treatments.

Estimates of "dam survival" reported below include the entire "effect zone," that is, the immediate forebay, approximately 600 m upstream, the concrete, and the tailrace to the nearest survival transect located 5 km or further downstream (Peven et al. 2005). Over the years, Ice Harbor Dam has had some of the highest forebay mortality among dams due to its proximity to avian predator colonies. As a result, while concrete

survival is high across all routes, dam survival is continually lower at Ice Harbor than at most other dams because of high levels of forebay predation.

Yearling Chinook salmon**—**Median forebay delay for yearling Chinook salmon passing Ice Harbor Dam was significantly longer for fish that approached during 30% spill (3.1 h; 95% CI, 2.5-3.8 h) than for those that approached during BiOp spill (1.3 h; 1.3-1.5 h). During BiOp spill (n = 778), passage distribution was 93.2% through the spillway (31.2% of which passed over the RSW), 5.8% through the juvenile bypass, and 1.0% through the turbines (Table 1). During 30% spill (n = 582), 76.6% of yearling Chinook salmon passed via the spillway (56.9% of which passed over the RSW), 21.3% through the juvenile bypass, and 2.1% through the turbines.

During respective BiOp and 30% spill operations, fish passage efficiency (FPE) was 99.0% (95% CI, 98.2-99.7%) and 97.9% (96.8-99.1%), fish guidance efficiency (FGE) was 84.9% (75.1-94.7%) and 91.2% (86.3-96.0)%, and spillway passage efficiency (SPE) was 93.2% (91.4-95.0%) and 76.6% (73.1-80.1%; Table 1). Surface outlet efficiency for the RSW during BiOp spill was 31.2% (27.9-34.6), while during 30% spill it was 56.9% (52.8-61.0). Mean spillway passage effectiveness during BiOp and 30% spill treatments were 1.5:1 and 2.5:1, respectively. Mean surface outlet effectiveness was 4.0:1 under BiOp spill and 6.4:1 under 30% spill. Training spill effectiveness was near 1:1 for both treatments.

All comparisons of single-release survival estimates for the two prescribed treatments revealed no significant differences. Spillway survival was estimated at 0.925 during BiOp spill and 0.939 during 30% spill, and was not significantly different between operational treatments ($P = 0.520$). Survival through the RSW was 0.930 during BiOp spill and 0.939 during 30% spill, and was not significantly different between treatments ($P = 0.786$). Dam survival was estimated at 0.897 during BiOp spill and 0.922 during 30% spill ($P = 0.228$). The estimate for bypass survival was 0.854 (SE = 0.054) under BiOp conditions and 0.941 (SE = 0.035) during 30% spill ($P = 0.213$). Concrete survival, or the survival estimate for all fish that passed the project, was 0.931 during BiOp spill and 0.941 during 30% spill ($P = 0.613$).

Table 1. Dam operations, passage behavior, and survival for radio-tagged yearling Chinook salmon by spill treatment at Ice Harbor Dam, 2009.

			Spill Treatment		
			BiOp Spill	**30% Spill**	**50% Spill**
Operating conditions (average)	Discharge				
	Project (kcfs)		99.7	87.8	154.5
	Spill kcfs (%)		63.3 (64)	26.5 (30)	76.3 (49)
	RSW kcfs (%)		7.9 (8)	7.8 (9)	7.8 (5)
	Training flow kcfs (%)		55.5 (56)	18.7 (21)	68.5 (44)
	Tailwater elevation (ft msl)		345.5	344.9	349.5
	Water temperature (°C)		11.0	10.5	12.6
	Secchi depth (m)		4.0	4.1	3.3
Passage-route distribution and percentile	Total Number of fish passing		778	582	427
	Juvenile bypass		45 (5.8)	124 (21.3)	69 (16.2)
	Turbines	Unit 1	1 (0.1)	1 (0.2)	5 (1.2)
		Unit 2	1 (0.1)	1 (0.2)	4 (0.9)
		Unit 3	2 (0.3)	2 (0.3)	2 (0.5)
		Unit 4	2 (0.3)	2 (0.3)	1 (0.2)
		Unit 5	2 (0.3)	2 (0.3)	1 (0.2)
		Unit 6	0 (0.0)	4 (0.7)	0 (0.0)
		Turbines combined	8 (1.0)	12 (2.1)	13 (3.0)
	Spillways	Spill bay 1	0 (0.0)	0 (0.0)	0 (0.0)
		RSW	243 (31.2)	331 (56.9)	147 (34.4)
		Spill bay 3	30 (3.9)	55 (9.5)	20 (4.7)
		Spill bay 4	118 (15.2)	0 (0.0)	48 (11.2)
		Spill bay 5	36 (4.6)	47 (8.1)	22 (5.2)
		Spill bay 6	68 (8.7)	3 (0.5)	30 (7.0)
		Spill bay 7	85 (10.9)	0 (0.0)	27 (6.3)
		Spill bay 8	72 (9.3)	4 (0.7)	26 (6.1)
		Spill bay 9	35 (4.5)	1 (0.2)	14 (3.3)
		Spill bay 10	38 (4.9)	5 (0.9)	11 (2.6)
		Spillways combined	725 (93.2)	446 (76.6)	345 (80.8)
		Training spill	482 (62.0)	115 (19.8)	198 (46.4)
Passage metrics (95% CI)	Median forebay delay (h)		1.3 (1.3-1.5)	3.1 (2.5-3.8)	1.0 (0.9-1.1)
	Fish passage efficiency FPE (%)		99.0 (98.2-99.7)	97.9 (96.8-99.1)	97.0 (95.3-98.6)
	Spillway passage efficiency SPE (%)		93.2 (91.4-95.0)	76.6 (73.1-80.1)	80.8 (77.0-84.6)
	Spillway passage effectiveness SPS (%)		1.5 (1.4-1.5)	2.5 (2.4-2.7)	1.6 (1.6-1.7)
	Surface outlet efficiency SOE (%)		31.2 (27.9-34.6)	56.9 (52.8-61.0)	34.4 (29.8-39.0)
	Surface outlet effectiveness SOS (%)		4.0 (3.5-4.4)	6.4 (6.0-6.9)	6.8 (5.9-7.7)
	Fish guidance efficiency FGE (%)		84.9 (75.1-94.7)	91.2 (86.3-96.0)	84.1 (76.1-92.2)
	Median tailrace egress (min)		9.8 (8.6-11.6)	9.2 (8.4-9.6)	6.8 (6.0-7.8)
Survival estimates (SE)	Dam (forebay BRZ to tailrace)		0.897 (0.015)	0.922 (0.012)	0.895 (0.016)
	Concrete (all fish passing the dam)		0.931 (0.007)	0.941 (0.018)	0.914 (0.016)
	Juvenile bypass system (JBS)		0.854 (0.054)	0.941 (0.035)	0.861 (0.047)
	Spillway (through spillway)		0.925 (0.017)	0.939 (0.012)	0.921 (0.016)
	Removable spillway weir (RSW)		0.930 (0.025)	0.939 (0.016)	0.911 (0.027)

***Juvenile Steelhead*—**Median forebay delay for juvenile steelhead passing Ice Harbor Dam was significantly longer for fish that approached during 30% spill (4.0 h; 95% CI, 3.5-4.7) than for those that approached during BiOp spill (2.7 h; 2.2-3.1). During BiOp spill (n = 844), passage distribution was 88.0% through the spillway (26.9% of which passed over the RSW), 10.9% through the juvenile bypass, and 1.1% through the turbines (Table 2). During 30% spill (n = 575), 69.9% of juvenile steelhead passed via the spillway (47.1% of which passed over the RSW), 29.6% through the juvenile bypass, and 0.5% through the turbines.

During respective BiOp and 30% spill operations, fish passage efficiency was 98.9% (95% CI, 98.2-99.6%) and 99.5% (98.9-100.1%), fish guidance efficiency was 91.1% (85.4-96.8%) and 98.3% (96.3-100.3%), and spillway passage efficiency was 88.0% (85.8-90.3%) and 69.9% (66.1-73.7%; Table 2), respectively. Surface outlet efficiency for the RSW during BiOp spill was 26.9% (23.8-30.0%), while during 30% spill it was 47.1% (42.9-51.3%). Mean spillway passage effectiveness during BiOp and 30% spill treatments were 1.4:1 and 2.3:1, respectively. Mean surface outlet effectiveness was 3.4:1 under BiOp spill and 5.3:1 under 30% spill. Training spill effectiveness was near 1:1 for both treatments.

All comparisons of survival estimates between the two treatments revealed no significant differences. Spillway survival was estimated at 0.958 during BiOp spill and 0.940 during 30% spill, and was not significantly different (P = 0.200). Survival through the RSW was 0.927 during BiOp spill and 0.923 during 30% spill, and was not significantly different between operational treatments (P = 0.906). Dam survival was estimated at 0.911 during BiOp spill and 0.904 during 30% spill (P = 0.760). The estimate for bypass survival was 0.935 (SE = 0.069) under BiOp conditions and 0.944 (SE = 0.021) during 30% spill (P = 0.902). Concrete survival, or the survival estimate for all fish that passed the project, was 0.950 during BiOp spill and 0.943 during 30% spill (P = 0.592).

Table 2. Dam operations, passage behavior, and survival for radio-tagged juvenile steelhead by spill treatment at Ice Harbor Dam, 2009.

			Spill Treatment		
			BiOp Spill	30% Spill	50% Spill
Operating conditions (average)	Discharge				
	Project (kcfs)		99.7	87.8	154.5
	Spill kcfs (%)		63.3 (64%)	26.5 (30%)	76.3 (49%)
	RSW kcfs (%)		7.9 (8%)	7.8 (9%)	7.8 (5%)
	Training flow kcfs (%)		55.5 (56%)	18.7 (21%)	68.5 (44%)
	Tailwater elevation (ft msl)		345.5	344.9	349.5
	Water temperature (°C)		11.0	10.5	12.6
	Secchi depth (m)		4.0	4.1	3.3
Passage-route distribution and percentile	Total Number of fish passing		844	575	436
	Juvenile bypass		92 (10.9)	170 (29.6)	117 (26.8)
	Turbines	Unit 1	1 (0.1)	1 (0.2)	1 (0.2)
		Unit 2	0 (0.0)	0 (0.0)	2 (0.5)
		Unit 3	4 (0.5)	1 (0.2)	1 (0.2)
		Unit 4	2 (0.2)	0 (0.0)	0 (0.0)
		Unit 5	2 (0.2)	1 (0.2)	0 (0.0)
		Unit 6	0 (0.0)	0 (0.0)	0 (0.0)
		Turbines combined	9 (1.1)	3 (0.5)	4 (0.9)
	Spillways	Spill bay 1	0 (0.0)	0 (0.0)	0 (0.0)
		RSW	227 (26.9)	271 (47.1)	129 (29.6)
		Spill bay 3	72 (8.5)	67 (11.7)	19 (4.4)
		Spill bay 4	71 (8.5)	--	39 (8.9)
		Spill bay 5	28 (8.4)	40 (7.0)	21 (4.8)
		Spill bay 6	128 (3.3)	2 (0.3)	36 (8.3)
		Spill bay 7	68 (15.2)	2 (0.3)	26 (6.0)
		Spill bay 8	63 (8.1)	6 (1.0)	22 (5.0)
		Spill bay 9	46 (7.5)	2 (0.3)	12 (2.8)
		Spill bay 10	40 (5.5)	12 (2.1)	11 (2.5)
		Spillways combined	743 (88.0)	402 (69.9)	315 (72.2)
		Training spill	516 (61.1)	131 (22.8)	186 (42.7)
Passage metrics (95% CI)	Median forebay delay (h)		2.7 (2.2-3.1)	4.0 (3.5-4.7)	1.4 (1.2-1.7)
	Fish passage efficiency FPE (%)		98.9 (98.2-99.6)	99.5 (98.9-100.1)	99.1 (98.2-100.0)
	Spillway passage efficiency SPE (%)		88.0 (85.8-90.3)	69.9 (66.1-73.7)	72.2 (68.0-76.5)
	Spillway passage effectiveness SPS (%)		1.4 (1.4-1.4)	2.3 (2.2-2.4)	1.4 (1.4-1.5)
	Surface outlet efficiency SOE (%)		26.9 (23.8-30.0)	47.1 (42.9-51.3)	29.6 (25.2-34.0)
	Surface outlet effectiveness SOS (%)		3.4 (3.0-3.8)	5.3 (4.8-5.8)	5.9 (5.0-6.7)
	Fish guidance efficiency FGE (%)		91.1 (85.4-96.8)	98.3 (96.3-100.3)	96.7 (93.4-99.9)
	Median tailrace egress (min)		9.6 (8.6-10.8)	9.3 (8.3-9.8)	7.6 (6.2-8.5)
Survival estimates (SE)	Dam (forebay BRZ to tailrace)		0.911 (0.016)	0.904 (0.015)	0.881 (0.018)
	Concrete (all fish passing the dam)		0.950 (0.010)	0.943 (0.010)	0.901 (0.017)
	Juvenile bypass system (JBS)		0.935 (0.069)	0.944 (0.021)	0.875 (0.040)
	Spillway (through spillway)		0.958 (0.006)	0.940 (0.012)	0.913 (0.018)
	Removable spillway weir (RSW)		0.927 (0.022)	0.923 (0.023)	0.885 (0.034)

Subyearling Chinook salmon**—**Median forebay delay for subyearling Chinook salmon passing Ice Harbor Dam was significantly longer for fish that approached during 30% spill (2.3 h; 95% CI, 2.2-2.6 h) than for those that approached during BiOp spill (1.7 h; 1.6-1.8 h). During BiOp spill (n = 1,097), passage distribution was 92.8% through the spillway (23.6% of which passed over the RSW), 6.5% through the juvenile bypass, and 0.7% through the turbines (Table 3). During 30% spill (n = 1,160), 62.0% passed via the spillway (39.4% of which passed over the RSW), 34.6% through the juvenile bypass, and 3.4% through the turbines.

During respective BiOp and 30% spill operations, fish passage efficiency was 99.3% (95% CI, 98.8-99.8%) and 96.6% (95.5-97.6%), fish guidance efficiency was 89.9% (83.1-96.7%) and 90.9% (88.2-93.7%), and spillway passage efficiency was 92.8% (91.2-94.4%) and 62.0% (59.1-64.8%; Table 3). Surface outlet efficiency for the RSW during BiOp spill was 23.6% (21.0-26.2%), while during 30% spill it was 39.4% (36.5-42.3%). Mean spillway passage effectiveness during BiOp and 30% spill treatments were 1.3:1 and 2.0:1, respectively. Mean surface outlet effectiveness was 2.5:1 under BiOp spill and 4.1:1 under 30% spill. Training spill effectiveness was near 1:1 for both treatments.

All comparisons of survival estimates between the two operational treatments revealed no significant differences. Spillway survival was estimated at 0.886 during BiOp spill vs. 0.885 during 30% spill (P = 0.976), and RSW survival was estimated at 0.877 during BiOp spill vs. 0.919 during 30% spill (P = 0.081). Dam survival was estimated at 0.843 during BiOp spill and 0.842 during 30% spill (P = 0.971). The estimate for bypass survival was 0.961 under BiOp conditions and 0.958 during 30% spill (P = 0.913). Concrete survival, or the survival estimate for all fish that passed the project, was 0.896 during BiOp spill and 0.913 during 30% spill (P = 0.378).

Table 3. Dam operations, passage behavior, and survival for radio-tagged subyearling Chinook salmon by spill treatment at Ice Harbor Dam, 2009.

			Spill Treatment	
			BiOp Spill	**30% Spill**
Operating conditions (average)	Discharge			
	Project (kcfs)		83.2	80.6
	Spill kcfs (%)		57.8 (69%)	24.9 (31%)
	RSW kcfs (%)		7.7 (9%)	7.7 (10%)
	Training flow kcfs (%)		50.0 (60%)	17.1 (21%)
	Tailwater elevation (ft msl)		344.2	344.4
	Water temperature (°C)		16.4	16.7
	Secchi depth (m)		4.1	4.3
Passage-route distribution and percentile	Total Number of fish passing		1,097	1,160
	Juvenile bypass		71 (6.5)	401 (34.6)
	Turbines	Unit 1	2 (0.2)	9 (0.8)
		Unit 2	0 (0.0)	4 (0.3)
		Unit 3	4 (0.4)	10 (0.9)
		Unit 4	1 (0.1)	10 (0.9)
		Unit 5	1 (0.1)	5 (0.4)
		Unit 6	0 (0.0)	2 (0.2)
		Turbines combined	8 (0.7)	40 (3.4)
	Spillways	Spill bay 1	0 (0.0)	0 (0.0)
		RSW	259 (23.6)	457 (39.4)
		Spill bay 3	31 (2.8)	128 (11.0)
		Spill bay 4	139 (12.7)	--
		Spill bay 5	70 (6.4)	91 (7.8)
		Spill bay 6	144 (13.1)	--
		Spill bay 7	125 (11.4)	7 (0.6)
		Spill bay 8	111 (10.1)	12 (1.0)
		Spill bay 9	70 (6.4)	8 (0.7)
		Spill bay 10	69 (6.3)	16 (1.4)
		Spillways combined	1,018 (92.8)	719 (62.0)
		Training spill	759 (69.2)	262 (22.6)
Passage metrics (95% CI)	Median forebay delay (h)		1.7 (1.6-1.8)	2.3 (2.2-2.6)
	Fish passage efficiency FPE (%)		99.3 (98.8-99.8)	96.6 (95.5-97.6)
	Spillway passage efficiency SPE (%)		92.8 (91.2-94.4)	62.0 (59.1-64.8)
	Spillway passage effectiveness SPS (%)		1.3 (1.3-1.4)	2.0 (1.9-2.1)
	Surface outlet efficiency SOE (%)		23.6 (21.0-26.2)	39.4 (36.5-42.3)
	Surface outlet effectiveness SOS (%)		2.5 (2. 3-2.8)	4.1 (3.8-4.4)
	Fish guidance efficiency FGE (%)		89.9 (83.1-96.7)	90.9 (88.2-93.7)
	Median tailrace egress (min)		9.1 (7.9-9.8)	9.6 (8.9-10.4)
Survival estimates (SE)	Dam (forebay BRZ to tailrace)		.843 (0.019)	.842 (0.018)
	Concrete (all fish passing the dam)		.896 (0.015)	.913 (0.011)
	Juvenile bypass system (JBS)		.961 (0.023)	.958 (0.015)
	Spillway (through spillway)		.886 (0.013)	.885 (0.015)
	Removable spillway weir (RSW)		.877 (0.016)	.919 (0.014)

CONTENTS

INTRODUCTION

A primary focus of recovery efforts for depressed stocks of Pacific salmon *Oncorhynchus* spp. and steelhead *O. mykiss* has been assessing and improving fish passage conditions at dams. Spillway passage has long been considered the safest passage route for migrating juvenile salmonids at Columbia and Snake River dams. Holmes (1952) reported survival estimates of 96 (weighted average) to 97% (pooled) for fish passing Bonneville Dam spillway during the 1940s. A review of 13 estimates of spillway mortality concluded that the most likely mortality rate for fish passing standard spill bays ranges from 0 to 2% (Whitney et al. 1997).

More recent survival studies on juvenile salmonid passage through various routes at dams on the lower Snake River have indicated that survival was highest through spillways, followed by bypass systems, then turbines (Muir et al. 2001). Project operations at Lower Granite, Little Goose, and Lower Monumental Dams utilize a combination of voluntary spill and collection of fish for transport to improve passage survival of juvenile salmonids. These mitigation efforts were employed pursuant to Biological Opinions issued by the National Marine Fisheries Service in 2000 (NMFS 2000) and in subsequent years. Since Ice Harbor Dam is not equipped with transport facilities, passage survival improvement relies on increasing the proportion of fish that pass via spillways.

Surface collection and bypass systems have been identified as a viable alternative for increasing survival and fish passage efficiency (FPE) for migrating juvenile salmonids at hydroelectric dams on the Snake and Columbia Rivers. At Wells Dam on the Columbia River, the spillway (located over the turbine units) passes 90% of the juvenile fish while spilling just 7% of the total discharge (Whitney et al. 1997). Studies evaluating a removable spillway weir (RSW) installed at Lower Granite Dam in 2001 have shown the RSW to be an effective and safe means of passing migrating juvenile salmonids (Anglea et al. 2003; Plumb et al. 2003, 2004). In 2002, the RSW at Lower Granite Dam passed 56–62% of radio-tagged fish while spilling only 8.5% of total discharge. In 2003, passage effectiveness ratios were 8.3-9.9:1 through the Lower Granite Dam RSW, with survival estimated at 98% (±2.3%).

Juvenile anadromous salmonids in the Columbia River Basin generally migrate in the upper 3 to 6 m of the water column (Johnson et al. 2000; Beeman and Maule 2006). However, fish must sound (dive) to depths of 15-18 m to enter existing juvenile fish passage routes at lower Columbia and Snake River dams. Engineers and biologists from the USACE and other fisheries agencies developed the RSW to provide a surface-oriented spillway passage route.

The RSW and temporary spillway weir (TSW) use traditional spillways and are either attached to the upstream face or lowered into a gate slot in front of spill bays. They allow juvenile salmon and steelhead to pass the dam near the water surface under lower accelerations and pressures, providing more efficient and less stressful passage conditions. In contrast, traditional spill bay gates, which open 15.2 m below the water surface at the face of the dam, create high water pressure and high velocity. An RSW was installed at Lower Granite Dam in 2001, at Ice Harbor Dam in 2005, and at Lower Monumental Dam prior to the 2008 spring juvenile migration. Prior to the 2009 migration, a TSW was installed at Little Goose Dam. Thus, surface passage routes are presently available at all lower Snake River dams.

Previous studies at Ice Harbor Dam have shown the majority of spring migrants pass through the spillway (Eppard et al. 2000, 2005a, b; Axel et al. 2006). In 2004 and 2005, we evaluated passage behavior, distribution, and survival of yearling Chinook salmon *O. tshawytscha* and juvenile steelhead associated with two dam operational conditions; bulk spill and flat spill. Bulk spill is obtained by using wide gate openings at fewer spill bays, with spill volume limited only by restrictions on dissolved gas levels in the tailrace (the gas cap). Flat spill uses narrow gate openings at more spill bays. Results from these studies indicated improved passage metrics and survival estimates for fish passing during bulk spill treatments (Axel et al. 2006; Eppard et al. 2005c).

In 2005, the first year of RSW evaluation at Ice Harbor Dam, estimates of fish passage survival through the RSW were high. However, an avoidance problem was also observed, where a higher proportion of yearling Chinook salmon passed through spill bay 1 than through the RSW spill bay (spill bay 2).

In 2006, we again utilized radiotelemetry to determine variations in behavior, passage distribution, and survival of yearling Chinook salmon and juvenile steelhead during two different operational conditions: BiOp spill, meaning spill levels of 45 kcfs during the day and spill to the gas cap at night; and 30% spill, with 30-40% of total flow volume spilled. Both were evaluated with the RSW operating continuously. Also during 2006, regional managers agreed to close spill bay 1, given the RSW avoidance behavior observed in 2005. This was intended to draw juvenile migrants away from the powerhouse and pass them through the RSW or safer spill bays, where survival estimates were higher.

Results indicated that with spill bay 1 closed, fish were successfully shifted toward the RSW and spillway, with fewer fish utilizing the powerhouse. During 2006, flows were high, with Snake River flow volume measuring higher than the 10-year average throughout the study period (Axel et al. 2007). In contrast, 2007 was a low flow year, with flow volume below the 10-year average nearly every day of the study. However, the lower flows during spring 2007 resulted in a 4% increase over spring 2006 in the percentage of total flow through the RSW, which in effect collected and passed more fish (Axel et al. 2008). Likewise, in summer 2007, the percentage of total flow through the RSW increased 7% over that during summer 2006. In summer 2007, approximately 21% of total river flow was available to attract subyearling Chinook salmon to approach and utilize the surface passage route (Ogden et al. 2008). This resulted in nearly 74% of tagged subyearlings using the RSW to pass the project during 30% spill treatments. Overall, there has been no significant difference in survival between species, project operation treatments, or flow years at Ice Harbor Dam. Results in 2008 were pooled across treatments because of high river flows and the inability to hold 30% spill treatments for 48-h blocks.

METHODS

Study Area

The study area encompassed a 119-km reach of river, from Lower Monumental Dam (rkm 589) on the lower Snake River to McNary Dam (rkm 470) on the lower Columbia River (Figure 1). The focal point of the study was Ice Harbor Dam (rkm 538) in southeast Washington State, the first dam on the lower Snake River, located 16 km upstream from its confluence with the Columbia River.

Ice Harbor Dam has three major juvenile passage routes; the spillway (including the RSW), turbines, and a juvenile bypass system (JBS). The spillway is 179.8 m long and consists of 10 spill bays numbered 1 to 10 from south to north. Spill bay flow is metered by operation of tainter gates, with the exception of the RSW bay (spill bay 2), where flow is regulated exclusively by forebay pool elevation. The spillway crest for conventional spill bays is located at an elevation of 119.2 m, while the RSW spills water at an elevation of 129.5 m. The powerhouse measures 204.5 m long, and each of its six turbine unit intakes is outfitted with standard length submerged traveling screens (STS), which divert downstream-migrating salmonids into the juvenile bypass system (JBS). The STSs are deployed at an elevation of 106.7 m, with all fish not diverted by the screens passing through a turbine. Turbine units are numbered 1 to 6 from south to north, where the junction between the powerhouse and the spillway is located.

Fish Collection, Tagging, and Release

River-run yearling Chinook salmon and juvenile steelhead were collected at the Lower Monumental Dam smolt collection facility from 25 April to 20 May. We chose only fish that did not have any gross injury or deformity, were not previously PIT tagged, and were at least 110 mm in length and 12 g in weight. River-run subyearling Chinook salmon were collected from 6 June to 1 July and were at least 100 mm in length and 10 g in weight. Fish were anesthetized with tricaine methanesulfate (MS-222) and sorted in a recirculating anesthetic system. Fish for treatment and reference release groups were transferred through a water-filled 10.2-cm hose to a 935-L holding tank. After collection and sorting, fish were maintained via flow-through river water and held for 20 h prior to radio transmitter implantation.

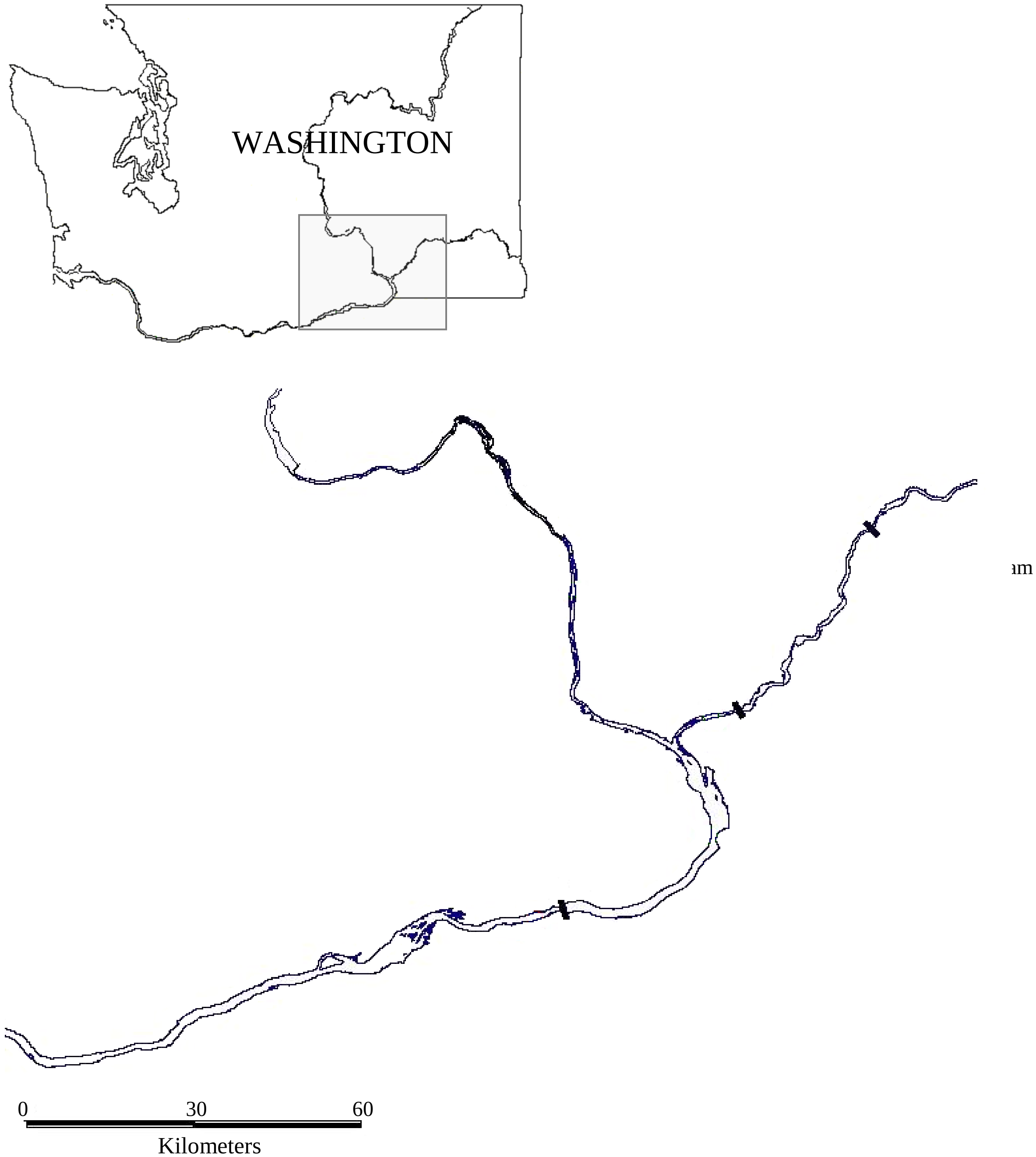

Figure 1. Study area showing location of radiotelemetry transects used for partitioning reach and project survival for radio-tagged yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon between Lower Monumental and McNary Dams, 2009. (Note: 1 = Ice Harbor Dam forebay; 2 = Goose Island transect; 3 = Snake River Bridge transect; 4 = Tank Farm transect; 5 = Sacajawea State Park transect.)

Radio tags were purchased from Advanced Telemetry Systems Inc.,[1] had a user-defined tag life of 10 d, and were pulse-coded at 30 MHz for unique identification of individual fish. Each radio tag measured 13.4 mm in length by 5.5 mm in diameter and had an average height of 3.6 mm and weight of 0.7 g in air. Average total volume for the tag was 265 mm^3.

Fish were surgically tagged with radio transmitters using techniques described by Adams et al. (1998a, b). Each fish also received a passive integrated transponder (PIT) tag before the incision was closed in order to monitor radio-tag performance. Detections from the PIT tag also ensured that study fish that passed through the Lower Monumental Dam juvenile fish bypass system were returned to the river so they could be used in estimates of JBS passage survival.

Immediately following tagging, fish were placed into a 19-L bucket (2 fish per bucket) with aeration until recovery from the anesthesia. Buckets were then closed and placed into a large holding tank (1.49-m wide, 2.48-m long, 0.46-m deep) that could accommodate up to 28 buckets and into which flow-through water was circulated during tagging and holding. Fish holding buckets were perforated with 1.3-cm holes in the top 30.5 cm of the container to allow exchange of water during holding. After tagging, fish were held a minimum of 24 h with flow-through water for recovery and determination of post-tagging mortality. Pre- and post-tagging temperatures at Lower Monumental Dam ranged between 9.1 and 12.0°C during the spring study and between 11.0 and 15.8°C during the summer study.

After the post-tagging recovery period, holding tanks with buckets containing radio-tagged fish were moved to the tailrace release areas at Little Goose and Lower Monumental Dam. All holding tanks were aerated with oxygen during transport to release locations. Little Goose tailrace release groups were transferred from holding tanks to a release tank mounted on an 8.5- by 2.4-m barge, transported to the release location, and released mid-channel water-to-water. Lower Monumental Dam tailrace release groups were transferred to holding tanks mounted on a truck, transported to the release location, and released a minimum of 7.6 m from the bank into the river through a release flume.

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[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Yearling Chinook salmon**—**Yearling Chinook salmon released for evaluations of survival at Lower Monumental Dam were utilized for evaluations of survival at Ice Harbor Dam, as their tags had adequate battery life to remain active while passing through our study area. At Lower Monumental Dam, fish were released into the tailrace about 1 km below the dam. Daytime releases to the tailrace were made between 0900 and 1500 PDT and nighttime releases between 2100 and 0300. Both day and night releases were made in 26 groups of approximately 20 fish. In conjunction with tailrace releases, treatment fish for Lower Monumental Dam were released 7 km upstream from the dam. These daytime treatment releases were made from 0900 to 1000 and from 1400 to 1500 PDT; both treatment releases were made in 26 groups of about 22 fish.

Juvenile steelhead**—**As described above for yearling Chinook salmon, juvenile steelhead tagged for evaluations of survival at Lower Monumental Dam were also used for evaluations at Ice Harbor Dam. Releases to the tailrace of Lower Monumental Dam were made in 26 groups of approximately 20 fish during both daytime (0900-1500 PDT) and nighttime (2100-0300) periods. Juvenile steelhead were released 7 km upstream from Lower Monumental Dam in 26 groups of approximately 22 fish during both daytime (0900-1000 and 1400-1500) release periods.

Subyearling Chinook salmon**—**As described above for yearling Chinook salmon and steelhead, subyearling Chinook salmon tagged for evaluations of survival at Lower Monumental Dam were also used for evaluations at Ice Harbor Dam. Releases to the tailrace of Lower Monumental Dam were made in 23 groups of approximately 45 fish during both daytime (0900-1500 PDT) and nighttime (2100-0300) periods. Fish were released 7 km upstream from Lower Monumental Dam in 23 groups of approximately 49 fish during both daytime (0900-1000 and 1400-1500) release periods.

Passage Behavior and Timing

Travel, Arrival, and Passage Timing

Travel time was measured as the time from release at Lower Monumental Dam to first detection at the forebay entrance transect at Ice Harbor Dam (the next dam downstream). First detection at the entrance transect at Ice Harbor Dam was also used to determine arrival time at the project. Passage timing was determined by using the last detection in a passage route, and was evaluated only for fish with a subsequent detection in the stilling basin or immediate tailrace.

Forebay Delay

Forebay delay was evaluated only for fish with at least one detection at each of the following locations: the forebay entrance transect, a passage route (spillway, turbine, or JBS), and the immediate tailrace (stilling basin, turbine draft tube, or tailrace exit transect). Arrival into the forebay was based on the first time a fish was detected on the forebay entry transect, located at the upstream end of the BRZ at Ice Harbor Dam (approximately 600 m upstream from the dam). Delay was measured as time from first detection on the forebay entrance transect to either last detection during spillway passage, or first detection on a fish guidance screen in a turbine unit or gatewell.

We estimated delay by species, treatment, and treatment block. Fish that entered under one treatment block and passed under the subsequent block produced "right censored" data (Hosmer et al. 2008) because on any given time scale, the point of interest being measured (passage) would be to the right of our actual data point (the end of the treatment block). For right censored data, delay time was estimated using time from forebay entry until the end of the treatment block, while the time spent in the subsequent treatment block was ignored. This was avoided potential bias in forebay delay estimates due to possible "edge effects" from the change between treatment operations.

To analyze forebay delay patterns, we used survival analysis, or "time-to-event" data (Lawless 1992; Tableman and Kim 2004). Time-to-event data track the time it takes for individuals to attain a particular event, which in this case was passage of Ice Harbor Dam. A benefit of this method is that is can accommodate right censored data. Survival analysis was based on the survival function, $S(t)$, which describes the proportion of the cohort remaining through time t. In other words, if we define a random variable T that represents the distribution of forebay passage times (t) of individuals in a population, then $S(t) = P(T > t)$. Note that $S(t)$ equals 1.0 at $t = 0.0$, and decreases to 0.0 through time.

For assessments of empirical passage distribution by species and treatment, we modeled the data with the non-parametric product-limit, or Kaplan-Meier method (K-M) (Lawless 1982, Hosmer et al. 2008). This method estimated the decrease in survival at each successive discrete point, i, where passage (one or more) occurred, while adjusting for censored data. The K-M survival estimate at time t was:

$$\hat{S}(t) = \prod_{i=1}^{k} \frac{n_i - d_i}{n_i}$$

where n_i was the number of individuals remaining in the forebay at the beginning of interval i, d_i was the number of fish passing at the end of interval i, and t was measured sometime between intervals k and k+1. Thus, the estimated proportion remaining was produced by multiplying together the probability of surviving through each time increment. The summary statistic we used to describe the "location" parameter of the K-M curve was the time at which 50% (median) of the fish had passed. Significant differences between K-M survival curves by treatment (spill operation) were determined using a log-rank chi-square test (Tableman and Kim 2004), which compared the actual and expected number of passage events at each time interval.

Passage Route Distribution

Passage distributions were based on detections either on the spillway or on the STS. Route of passage was based on the last time a fish was detected on a passage-route antenna (Figure 2) and was assigned only to fish subsequently detected in the tailrace on the stilling basin, turbine draft tube, or tailrace exit transect. For analysis of passage route distributions, we included only study fish detected in the forebay, detected again in a passage route, and detected a third time in the immediate tailrace either on the stilling basin, turbine draft tube, or a tailrace exit receiver.

Each spillway was monitored by four underwater dipole antennas (Beeman et al. 2004). Two antennas were installed along each of the two pier noses of each spill bay at depths of 6.1 and 12.2 m. Pre-season range testing showed this configuration effectively monitored the entire spill bay with no gaps. In addition, we mounted aerial loop antennas to the handrail of the RSW in order to ensure we detected all fish that passed over the RSW. We used armored co-axial cable, stripped at the end, to detect radio-tagged fish passing through the turbine unit and JBS (Knight et al. 1977). These antennas were attached on both ends of the downstream side of the STS support frame located within each turbine intake slot.

We also placed two loop antennas on the handrail at the collection channel exit located upstream from the JBS pipe. Fish detected on the STS telemetry antennas were designated as turbine-passed fish if they were not subsequently detected on either the PIT detection system in the JBS or by the telemetry monitor in the collection channel.

Fish Passage Metrics

Standard fish-passage metrics of spill efficiency, spill effectiveness, fish passage efficiency (FPE), and fish guidance efficiency (FGE) were also evaluated at Ice Harbor Dam using radiotelemetry detections in the same locations used for passage route evaluation described above. However, the method of calculating these metrics using radiotelemetry differed from those used in previous evaluations (e.g., FGE was formerly calculated based on the percentage of fish caught in gatewells and fyke nets). Fish passage metrics used for this evaluation were defined as follows:

Spillway passage efficiency (SPE): Total number of fish passing the spillway divided by total number passing the dam.

Spillway passage effectiveness (SPS): Proportion of fish passing the spillway divided by proportion of water spilled.

Fish passage efficiency (FPE): Number of fish passing the dam via non-turbine routes divided by total number passing the dam.

Fish guidance efficiency (FGE): Number of fish guided into the bypass system divided by total number passing via the powerhouse (i.e., the combined total for bypass system and turbine passage).

Surface outlet efficiency (SOE): Number of fish passing through a surface flow route (RSW) divided by the total number of fish passing the dam.

Surface outlet effectiveness (SOS): Proportion of fish passing through a surface flow route (RSW) divided by the proportion of water passing through the same route.

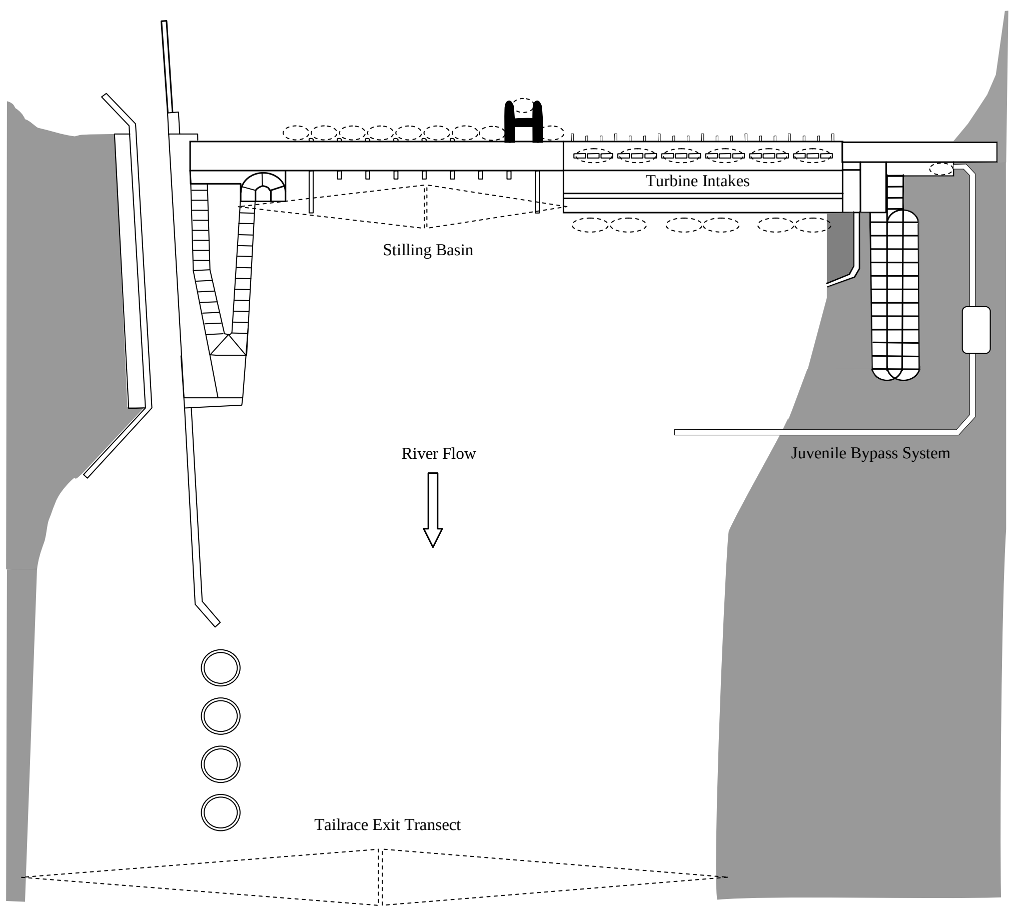

Figure 2. Plan view of Ice Harbor Dam showing approximate radiotelemetry detection zones for evaluation of passage behavior and survival at Ice Harbor Dam in 2009. Note: Dashed ovals represent underwater antennas. Dashed triangles represent aerial antennas.

Tailrace Egress

For analysis of tailrace egress, we included only fish that had been released upstream from Ice Harbor Dam, detected in the forebay, detected again in a passage route, and detected a third time in the immediate tailrace either on the stilling basin, turbine draft tube, or tailrace exit transect. Tailrace egress was measured from the last known detection through the project (spillway, turbine, or JBS) to the last known detection at the telemetry transect located approximately 1 km downstream from Ice Harbor Dam. Operational treatment was assigned based on the block being conducted at the time of last detection at the project, regardless of the treatment at time of detection 1 km downstream. Analysis was conducted using K-M as described above for forebay delay, except that no adjustment was needed for right censored data, since these measurements produced no censored data.

Survival Estimates

Estimates of survival for Ice Harbor Dam were made based on detection histories using the single-release (SR) model (Cormack 1964; Jolly 1965; Seber 1965). The SR model uses recapture records (in this case, detections) from a single release group to estimate survival, considering the probability that a tagged fish may pass the downstream boundary of the area in question without being recaptured (detected). In order to separate the probability of detection from that of survival, the model requires detections of at least some fish downstream from the area of interest. To evaluate detection probabilities, we used detections at the tailrace exit, located 1 km below Ice Harbor Dam.

Previous studies indicated that dead, radio-tagged fish released at Ice Harbor Dam were not detected at downstream survival transects (Axel et al. 2003); therefore, we assumed that fish detected at each transect were alive after passage at Ice Harbor Dam. Survival was estimated for this evaluation through additional areas as follows:

Dam Survival: Survival through the entire "effect zone," meaning from approximately 600 m upstream from the dam to approximately 5 km downstream from the dam.

Spillway Survival: Survival of fish that passed through the spillway.

RSW Survival: Survival of fish that passed via the RSW.

*Bypass Survival: Survi*val of fish that passed via the juvenile bypass system.

Concrete Survival: Ratio of the survival estimate for fish that passed via all passage routes combined (forebay loss was not included in the estimate).

To create replicate groups from fish released at Lower Monumental Dam, we grouped fish according to time of arrival at the telemetry transect on the upstream edge of the boat restricted zone (BRZ) of Ice Harbor Dam. These groups were used for estimates of dam survival, with replicates composed of fish detected on the same date.

For estimates of spillway survival, we used only fish that were detected on a spillway receiver and subsequently detected on a stilling basin or tailrace receiver. This verified that fish last detected on a spillway receiver had actually passed the dam via the spillway. Turbine passage was verified by detections on the turbine draft tube antennas. Verification of bypassed fish was determined by PIT detections, as each fish also carried a PIT tag. Spillway, turbine, and bypass fish were grouped by treatment block for comparative analysis. Subsequent downstream telemetry detections at Goose Island and below were used for survival estimation (Figure 1).

Key assumptions of the SR model must be valid if the model is to produce unbiased estimates of survival through specific reaches or areas. One such assumption was that radiotelemetry detection at a given site did not affect subsequent detection probabilities downstream from that site. Tests of model assumptions are presented in Appendix A. For more detailed discussion of the SR model and its associated tests of assumption, see Iwamoto et al. (1994), Zabel et al. (2002), and Smith et al. (2003).

Avian Predation

Predation by Caspian terns *Hydoprogne caspia*, Double-crested cormorants *Phalacrocorax auritus*, and California gulls *Larus californicus* from the colonies on Crescent and Foundation Islands , located downstream from the Snake River mouth (Figure 1), was measured by physical recovery of radio transmitters and detection of PIT tags deposited on the island during August 2009 (after the birds had left the island). We used radio transmitter serial numbers to identify individual tagged fish. PIT-tag detections and recovery of radio transmitters at Crescent Island were provided by other NMFS researchers (S. Sebring, NMFS, personal communication; also see Ryan et al. 2001) and Real Time Research, Inc. (A. Evans, Real Time Research, Inc., personal communication).

RESULTS

Fish Collection and Tagging Data

Yearling Chinook Salmon and Juvenile Steelhead

Unmarked yearling Chinook salmon and juvenile steelhead were collected, radio tagged, and PIT tagged at Lower Monumental for 27 d from 27 April to 23 May. Collection and tagging began after approximately 2.1% of the yearling Chinook salmon and 1.0% of the juvenile steelhead had passed Lower Monumental Dam and was completed when more than 82% of these fish had passed (Figure 3). Overall mean fork length for 2,202 yearling Chinook salmon that were tagged and released was 141.2 mm (SD = 11.7) and overall mean weight was 26.5 g (SD = 7.0, Table 4). Overall mean fork length for 2,200 steelhead was 210.9 mm (SD = 17.8) and overall mean weight was 83.9 g (SD = 23.0, Table 5).

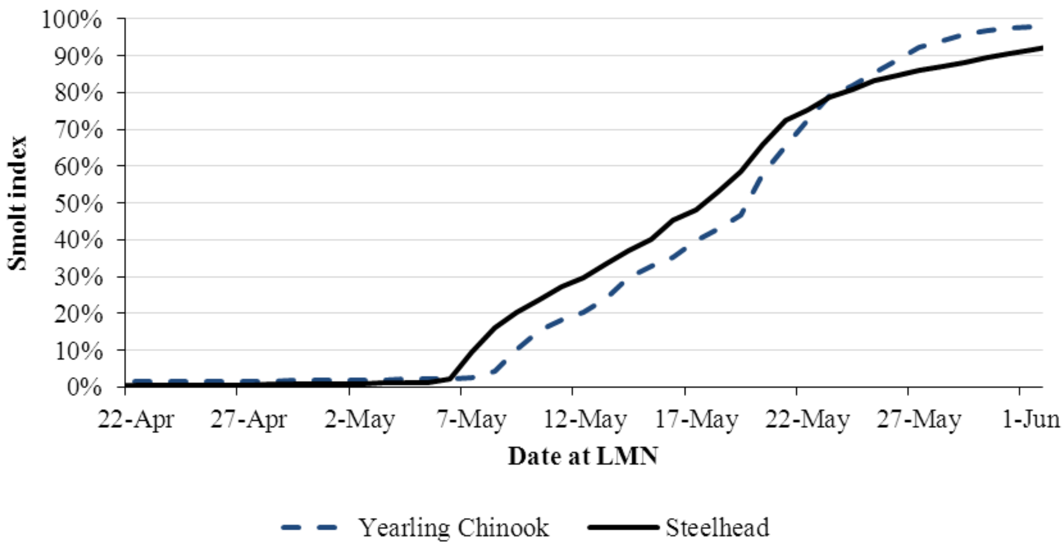

Figure 3. Percentage of yearling Chinook salmon and juvenile steelhead index estimated at Lower Monumental Dam during 2009.

Table 4. Sample size, range, mean, and standard deviation (SD) of fork lengths (mm) for radio-tagged yearling Chinook salmon released above Ice Harbor Dam to evaluate passage behavior and survival, 2009.

		Yearling Chinook salmon length (FL mm)				Yearling Chinook salmon weight (g)			
Tag date	n	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
27 April	34	118.0	183.0	144.5	16.1	17.0	54.0	31.1	10.3
28 April	71	121.0	179.0	147.6	13.1	17.0	52.0	31.0	8.0
29 April	73	119.0	185.0	147.6	14.9	14.0	61.0	31.9	9.8
30 April	85	111.0	180.0	140.6	15.1	14.0	56.0	28.3	9.1
01 May	88	115.0	178.0	143.2	13.5	14.0	53.0	28.4	8.1
02 May	90	117.0	172.0	141.5	12.8	17.0	56.0	29.6	8.5
03 May	86	108.0	177.0	140.0	16.0	13.0	54.0	27.8	9.4
04 May	88	122.0	184.0	143.0	13.3	15.0	61.0	27.5	8.6
05 May	87	116.0	169.0	139.8	11.7	15.0	49.0	25.8	7.4
06 May	86	115.0	186.0	140.7	13.0	13.0	57.0	26.3	8.0
07 May	89	116.0	165.0	137.4	11.9	15.0	46.0	26.6	7.4
08 May	86	116.0	168.0	139.1	10.4	15.0	40.0	24.2	5.6
09 May	88	113.0	183.0	141.6	11.6	14.0	56.0	26.0	6.9
10 May	88	118.0	180.0	142.0	13.9	14.0	53.0	26.0	8.3
11 May	86	113.0	167.0	137.4	12.1	15.0	52.0	26.2	7.4
12 May	87	123.0	177.0	140.6	10.5	15.0	53.0	25.1	6.5
13 May	88	122.0	190.0	142.0	12.5	16.0	64.0	26.0	7.8
14 May	88	114.0	176.0	138.3	11.1	15.0	49.0	24.0	6.2
15 May	83	120.0	157.0	140.1	8.7	17.0	36.0	24.5	4.6
16 May	87	119.0	160.0	137.1	8.4	16.0	40.0	25.3	4.6
17 May	88	121.0	164.0	138.9	9.3	14.0	42.0	23.1	4.8
18 May	84	112.0	174.0	140.0	10.4	14.0	47.0	23.4	5.7
19 May	85	116.0	160.0	140.6	8.7	15.0	38.0	24.7	5.0
20 May	89	122.0	169.0	143.3	8.9	13.0	43.0	24.6	5.3
21 May	85	117.0	160.0	140.5	8.7	15.0	36.0	24.4	4.1
22 May	78	120.0	158.0	139.0	7.8	17.0	46.0	26.3	5.3
23 May	35	126.0	175.0	145.4	10.4	18.0	48.0	26.7	6.8
Overall	2,202	117.4	173.2	141.2	11.7	15.1	49.7	26.5	7.0

Table 5. Sample size, range, mean, and standard deviation (SD) of fork lengths (mm) and weight (g) of radio-tagged juvenile steelhead released above Ice Harbor Dam to evaluate passage behavior and survival, 2009.

		Juvenile steelhead length (FL mm)				Juvenile steelhead weight (g)			
Tag date	n	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
27 April	36	177.0	252.0	211.4	19.6	48.0	145.0	89.0	26.8
28 April	70	161.0	263.0	208.9	20.4	34.0	163.0	83.8	24.2
29 April	73	151.0	258.0	199.3	19.4	27.0	151.0	71.3	23.3
30 April	83	158.0	244.0	203.7	19.1	34.0	147.0	76.7	23.7
1 May	87	141.0	243.0	195.3	17.7	28.0	138.0	68.3	21.3
2 May	88	152.0	246.0	199.3	18.0	29.0	138.0	71.6	22.3
3 May	87	150.0	250.0	193.5	20.4	28.0	137.0	64.4	20.8
4 May	85	153.0	241.0	200.0	19.3	33.0	120.0	70.5	20.7
5 May	88	159.0	234.0	191.6	14.3	38.0	119.0	60.8	16.3
6 May	89	154.0	238.0	197.7	17.5	31.0	121.0	66.6	19.4
7 May	88	166.0	254.0	202.5	17.1	43.0	158.0	79.2	22.4
8 May	90	170.0	264.0	209.3	17.7	37.0	164.0	77.4	21.8
9 May	86	156.0	249.0	210.4	20.0	32.0	142.0	81.4	24.0
10 May	89	163.0	253.0	213.8	16.5	37.0	141.0	88.7	20.6
11 May	87	173.0	249.0	213.7	16.6	46.0	149.0	93.1	23.7
12 May	88	179.0	262.0	222.1	18.0	50.0	169.0	96.8	24.7
13 May	87	178.0	265.0	222.7	19.7	49.0	172.0	98.1	28.5
14 May	88	188.0	283.0	224.2	19.4	52.0	192.0	99.3	29.2
15 May	86	184.0	265.0	218.2	17.4	49.0	168.0	87.8	25.5
16 May	88	181.0	260.0	217.7	14.6	52.0	161.0	98.2	20.6
17 May	87	176.0	261.0	218.5	16.8	46.0	157.0	91.0	23.2
18 May	84	177.0	261.0	217.7	18.0	43.0	141.0	87.4	21.7
19 May	86	180.0	265.0	220.4	17.0	42.0	166.0	91.8	23.9
20 May	84	190.0	274.0	223.2	16.2	56.0	160.0	93.5	23.1
21 May	82	196.0	259.0	220.4	16.2	58.0	150.0	89.5	20.8
22 May	79	180.0	262.0	220.9	18.0	50.0	172.0	100.7	26.4
23 May	35	181.0	247.0	218.0	16.6	52.0	133.0	87.7	22.0
Overall	2,200	169.4	255.6	210.9	17.8	41.6	150.9	83.9	23.0

Subyearling Chinook Salmon

Unmarked subyearling Chinook salmon were collected, radio tagged, and PIT tagged at Lower Monumental for 24 d from 9 June to 2 July. Collection and tagging began after approximately 47% of the subyearling Chinook salmon had passed Lower Monumental Dam and was completed when more than 89% of these fish had passed (Figure 4). Overall mean fork length for 4,363 subyearling Chinook salmon was 113.1 mm (SD = 5.2) and overall mean weight was 12.6 g (SD = 2.0, Table 6).

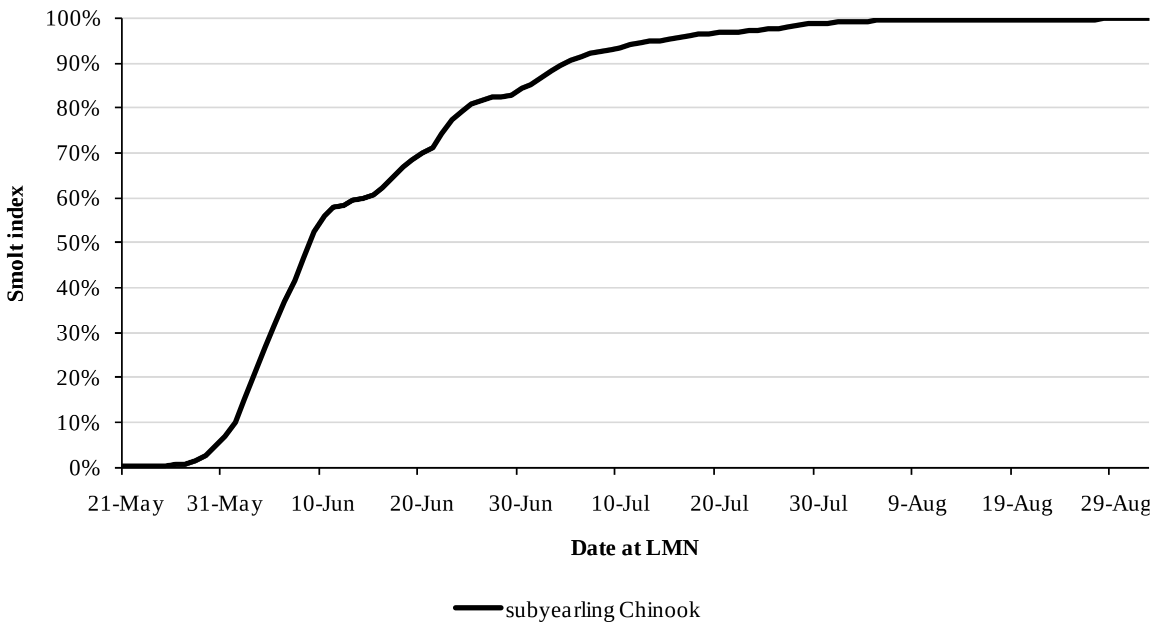

Figure 4. Percentage of subyearling Chinook salmon index estimated at Lower Monumental Dam during 2009.

Table 6. Sample size, range, mean, and standard deviation (SD) of fork lengths (mm) and weight (g) for radio-tagged, subyearling Chinook salmon released above Ice Harbor Dam to evaluate passage behavior and survival, 2009.

		Subyearling Chinook salmon length (FL mm)				Subyearling Chinook salmon weight (g)			
Tag date	n	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
9 June	57	101.0	121.0	111.2	4.3	11.0	17.0	13.1	1.3
10 June	103	105.0	125.0	112.5	3.8	10.0	9.0	12.1	1.4
11 June	106	103.0	127.0	110.4	4.5	10.0	20.0	12.0	1.7
12 June	122	104.0	125.0	111.8	4.7	10.0	18.0	11.8	1.8
13 June	101	104.0	125.0	111.7	4.7	10.0	17.0	11.8	1.5
14 June	126	105.0	128.0	113.4	4.7	10.0	20.0	12.4	1.7
15 June	197	103.0	128.0	113.1	4.3	10.0	20.0	12.4	1.5
16 June	210	104.0	133.0	114.0	4.9	10.0	22.0	12.5	1.9
17 June	294	105.0	138.0	114.4	5.4	10.0	22.0	12.7	2.0
18 June	211	105.0	127.0	114.2	4.8	10.0	18.0	12.6	1.7
19 June	203	105.0	131.0	114.7	4.7	10.0	20.0	12.6	1.7
20 June	211	105.0	133.0	114.8	5.0	10.0	19.0	12.6	1.8
21 June	209	104.0	130.0	113.2	4.6	10.0	20.0	12.6	1.7
22 June	208	104.0	136.0	113.3	4.9	10.0	27.0	12.8	2.0
23 June	203	103.0	133.0	113.2	4.9	10.0	21.0	12.5	1.8
24 June	288	103.0	136.0	113.2	5.0	10.0	25.0	12.7	2.0
25 June	209	104.0	130.0	113.5	5.3	10.0	20.0	12.6	1.9
26 June	207	104.0	126.0	111.8	3.9	10.0	18.0	12.0	1.5
27 June	212	104.0	136.0	112.4	5.9	10.0	24.0	12.6	2.5
28 June	190	102.0	137.0	111.9	5.7	10.0	24.0	12.4	2.3
29 June	206	102.0	153.0	112.6	7.1	10.0	36.0	13.3	3.2
30 June	204	103.0	157.0	113.3	7.7	10.0	43.0	13.4	3.9
1 July	187	103.0	148.0	114.2	7.7	10.0	37.0	13.7	3.5
2 July	99	104.0	137.0	115.6	6.5	10.0	24.0	14.3	2.7
Overall	4,363	103.7	133.3	113.1	5.2	10.0	22.5	12.6	2.0

Dam Operations

The 2009 voluntary spill program attempted to follow a 2-d random block design with two spill treatments; a high spill discharge in a BiOp spill operation (45 kcfs during the day and spill to the gas cap at night), and a 30% spill volume (30% of total flow volume), with both treatments utilizing the RSW. The spill program pattern also attempted to utilize spillway gates for each bay that were open at least two stops where feasible in order to allow for larger gate openings, leading to potentially higher survival. However, due to high river flows during the spring portion of the study, involuntary spill precluded the last ten days of the prescribed spill treatments schedule.

While there was some ability to compare behavior and passage during the first 20 d of the study period, the latter portion of the study was obscured by project operations that averaged 50% spill. Therefore, the operational treatments had less power in comparing the two because of fewer fish passing under each. We present results comparing the 30% and BiOp treatments. Results for the 50% spill treatment are reported, but are not compared to the other two treatments since this treatment was not alternated between the other two, and also took place during much higher flows. During the summer study spill treatments were held consistently.

During our spring study period, mean spill volume during BiOp spill treatments was 63.3 thousand cubic feet per second (kcfs) (64% of the total river flow) and 26.5 kcfs (30%) during 30% spill. During the summer, mean spill volume was 57.8 kcfs (69%) for BiOp treatments and 24.9 kcfs (31%) during 30% spill. Mean flow through turbines and spill bays for both treatments during the spring and summer evaluations are shown in Figures 5 and 6, respectively.

Mean daily total discharge was 113.6 kcfs (range 60.7-198.2 kcfs; Figure 7) during the spring study and 110.4 kcfs during the summer study (range 62.9-142.5 kcfs; Figure 8). Mean percentages of spill during spring and summer evaluations are shown in Figures 9 and 10, respectively. Mean daily flows (kcfs) for each turbine unit and spill bay are shown for the respective spring and summer study periods in Appendix D. Mean daily gate openings (stops) by spill bay are shown in Appendix D tables as well.

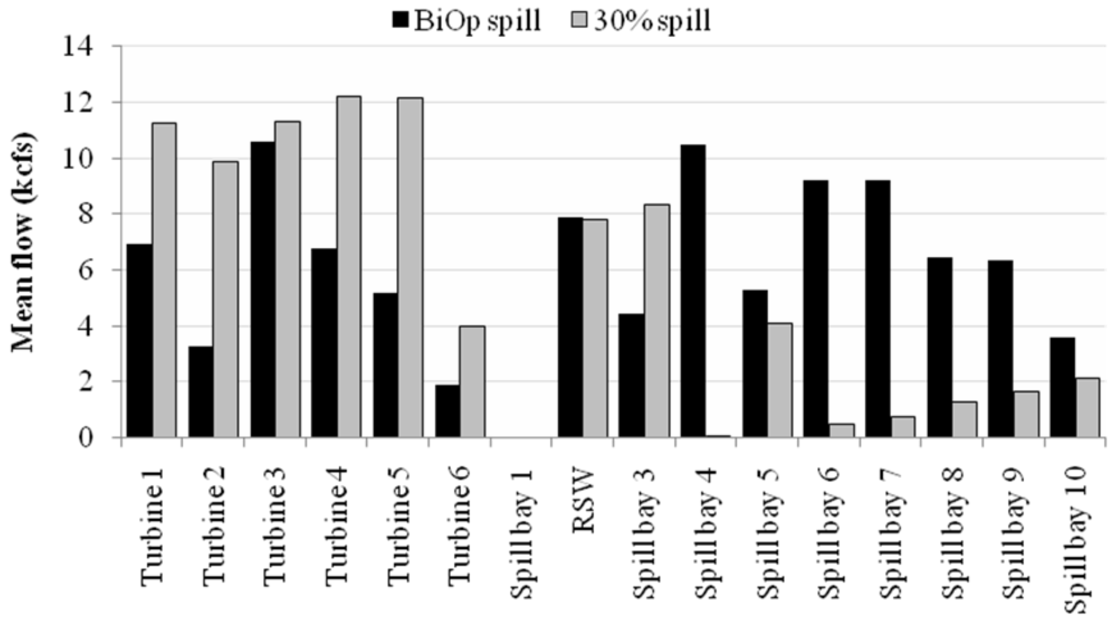

Figure 5. Mean flow (kcfs) during the spring spill treatments for the powerhouse and spillway for radio-tagged yearling Chinook salmon and juvenile steelhead arriving at Ice Harbor Dam, 2009.

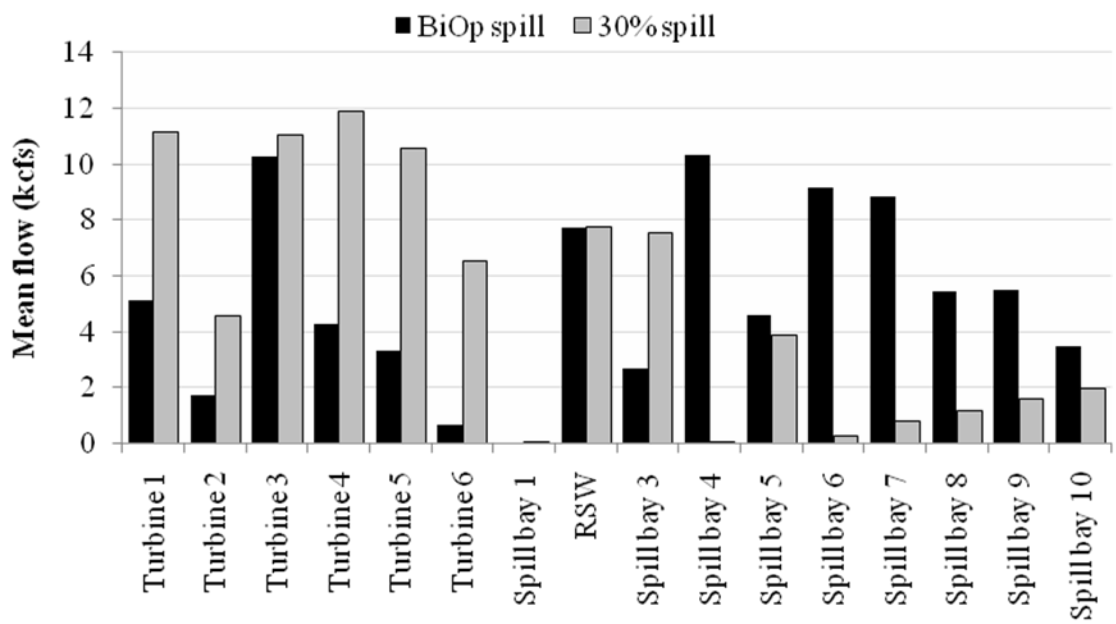

Figure 6. Mean flow (kcfs) during the summer spill treatments for the powerhouse and spillway for radio-tagged subyearling Chinook salmon arriving at Ice Harbor Dam, 2009.

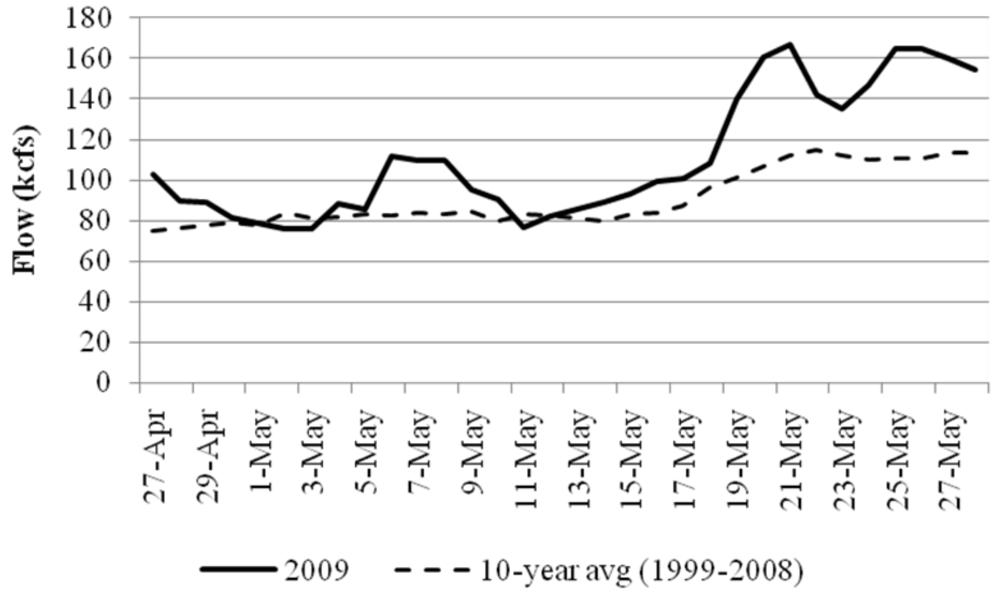

Figure 7. Mean daily and 10-year average (1999-2008) project discharge during passage of radio-tagged yearling Chinook salmon and steelhead for evaluating passage and survival at Ice Harbor Dam, 2009.

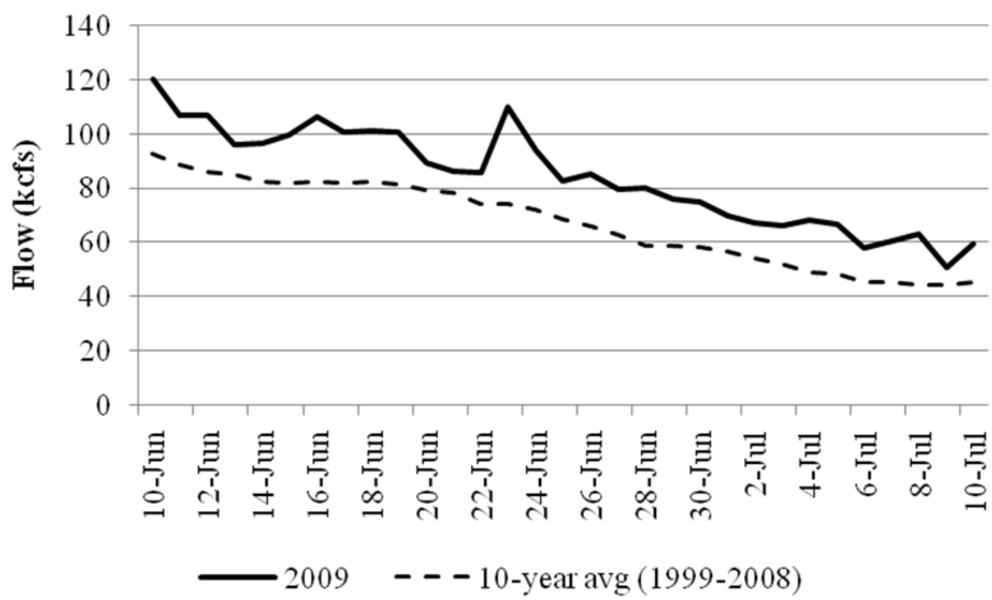

Figure 8. Mean daily and 10-year average (1999-2008) project discharge during passage of radio-tagged subyearling Chinook salmon for evaluating passage and survival at Ice Harbor Dam, 2009.

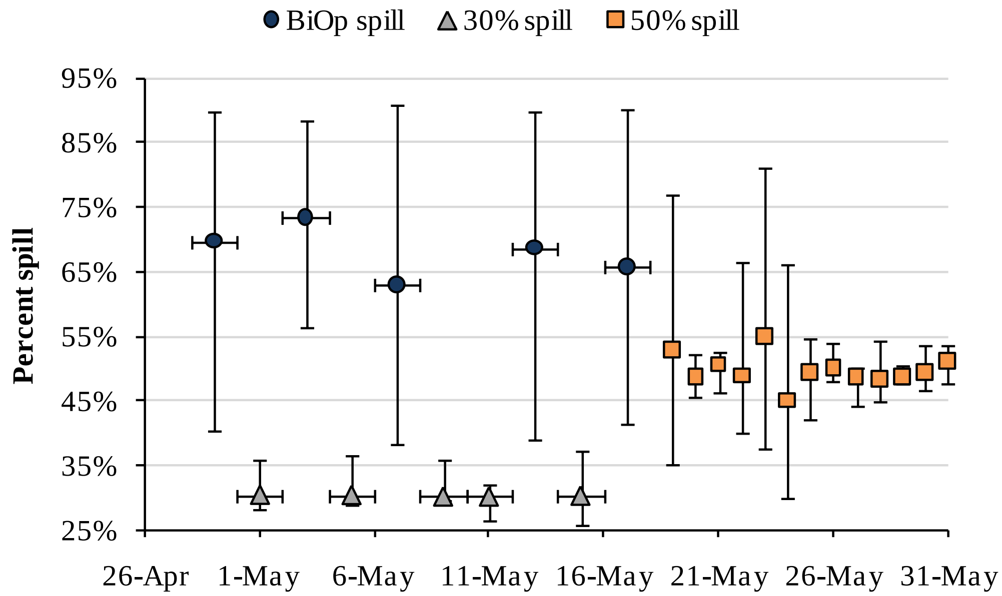

Figure 9. Mean daily spill percentage and range for radio-tagged yearling Chinook salmon and juvenile steelhead arriving during spring operations at Ice Harbor Dam, 2009.

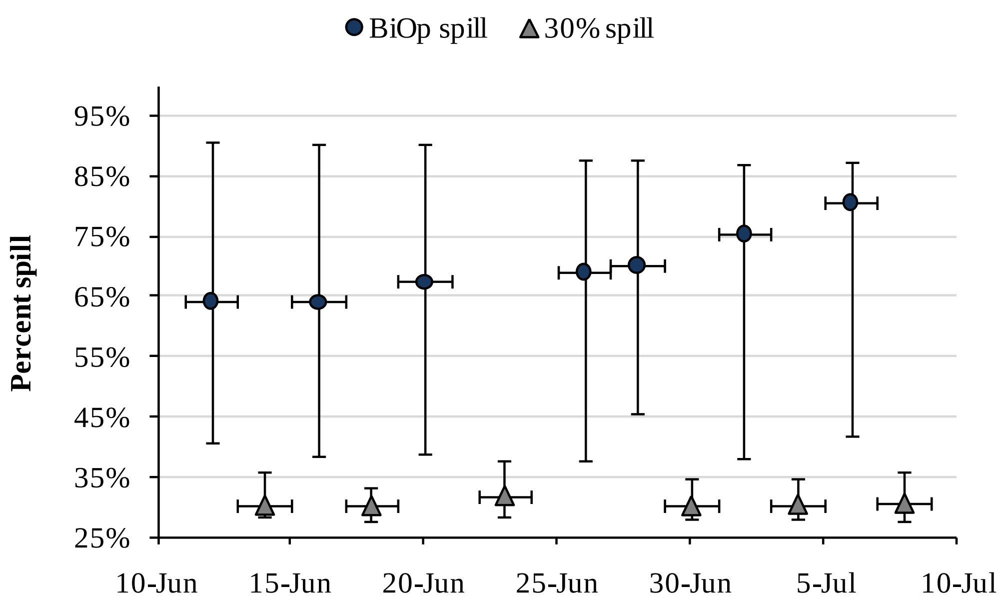

Figure 10. Mean daily spill percentage and range for radio-tagged subyearling Chinook salmon arriving during summer operations at Ice Harbor Dam, 2009.

Passage Behavior and Timing

Travel, Arrival, and Passage Timing

At the forebay entrance telemetry transect at Ice Harbor Dam, we detected 1,887 radio-tagged yearling Chinook salmon, 1,952 juvenile steelhead, and 2,592 subyearling Chinook salmon released for evaluations at Lower Monumental Dam. Travel time was calculated for each species from their respective release sites in the forebay or tailrace of Lower Monumental Dam, 58 and 50 km upstream from Ice Harbor Dam, respectively (Table 7).

Table 7. Travel time (days) from release into the forebay (58 km upstream) or tailrace (50 km upstream) of Lower Monumental Dam to detection at the forebay entry transect at Ice Harbor Dam for radio-tagged yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon, 2009.

	Travel time (d)					
	Yearling Chinook		Steelhead		Subyearling Chinook	
	Release location at Lower Monumental Dam					
	Forebay	Tailrace	Forebay	Tailrace	Forebay	Tailrace
N	944	943	1,007	945	1,162	1,430
Min	0.8	0.5	0.7	0.2	1.2	0.8
Percentile						
10th	1.5	0.9	1.3	0.9	2.2	1.5
20th	1.7	1.1	1.6	1.0	2.5	1.7
30th	1.9	1.2	1.8	1.2	2.7	1.9
40th	2.0	1.4	1.9	1.3	3.0	2.1
50th	2.2	1.5	2.1	1.4	3.2	2.3
60th	2.4	1.6	2.2	1.5	3.5	2.5
70th	2.6	1.8	2.4	1.7	3.8	2.8
80th	2.9	2.0	2.8	1.9	4.2	3.1
90th	3.5	2.4	3.4	2.2	4.9	3.7
Max	7.2	6.2	8.0	6.9	7.8	8.2
Travel time > 8 d	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.1%)

Arrival timing of yearling Chinook salmon at the forebay entrance line of Ice Harbor Dam and subsequent passage during 30% spill treatments averaged about 4.5% across all hours of the day (Figure 11). During BiOp spill treatments, yearlings displayed a similar trend for entry with a larger proportion of fish passing when project operations changed to gas cap spill from 1800-0500 hours. Yearlings entered during 50% spill treatments most predominantly between 0500 and 1300 hours with passage occurring sporadically throughout the day. The 50% treatments took place over the last week of the study with no alternation between the other treatments. Therefore, the results may not be a good comparison with the other two treatments (i.e. higher flows, higher temperatures, later segment of the fish run, etc.).

Juvenile steelhead arrival distribution was more heavily weighted during daytime hours with passage timing distribution offset due to some forebay delay (Figure 12). During 30% spill, steelhead passage declined consistently between 0400 and 0900 hours and then displayed a pulsating pattern as night approached. Steelhead passage during BiOp spill declined abruptly as spill was 30% to 45 kcfs and then increased throughout the day with higher proportions beginning to pass again when spill to the gas cap was continued. Steelhead passing during 50% spill tended to remain much more consistent in entry and passage distributions, though this treatment was not a good comparison with the other two treatments.

Subyearling Chinook salmon passing during the summer demonstrated somewhat similar trends for arrival during 30% spill as were observed for yearling Chinook salmon (Figure 13). Passage tended to peak with nighttime hours and 30% slightly during the daytime. BiOp operations tended to pass more subyearlings during the gas cap spill, as was observed with the other two species during spring operations.

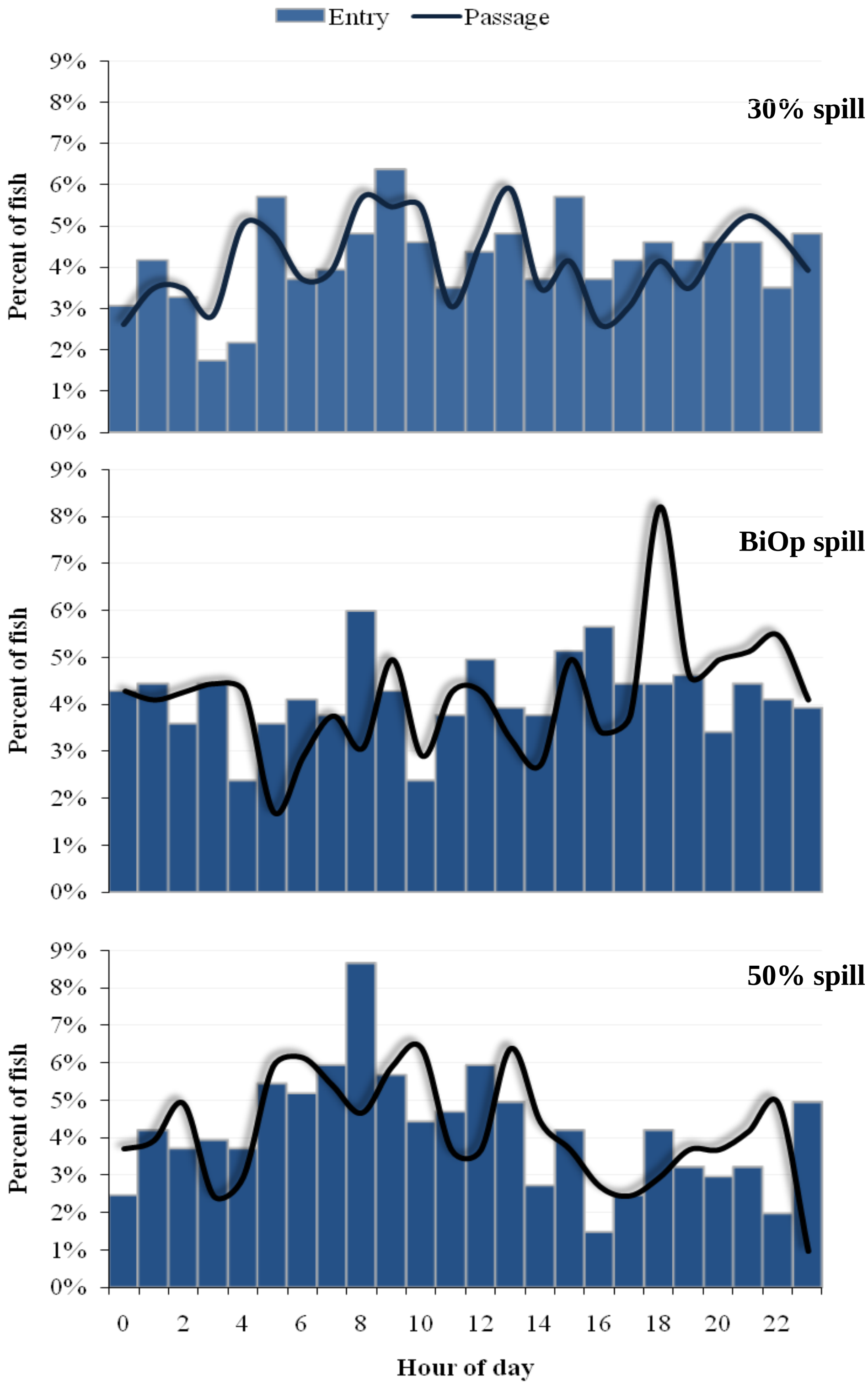

Figure 11. Percent of radio-tagged yearling Chinook salmon arriving and passing Ice Harbor Dam by hour of day during spring spill treatments, 2009.

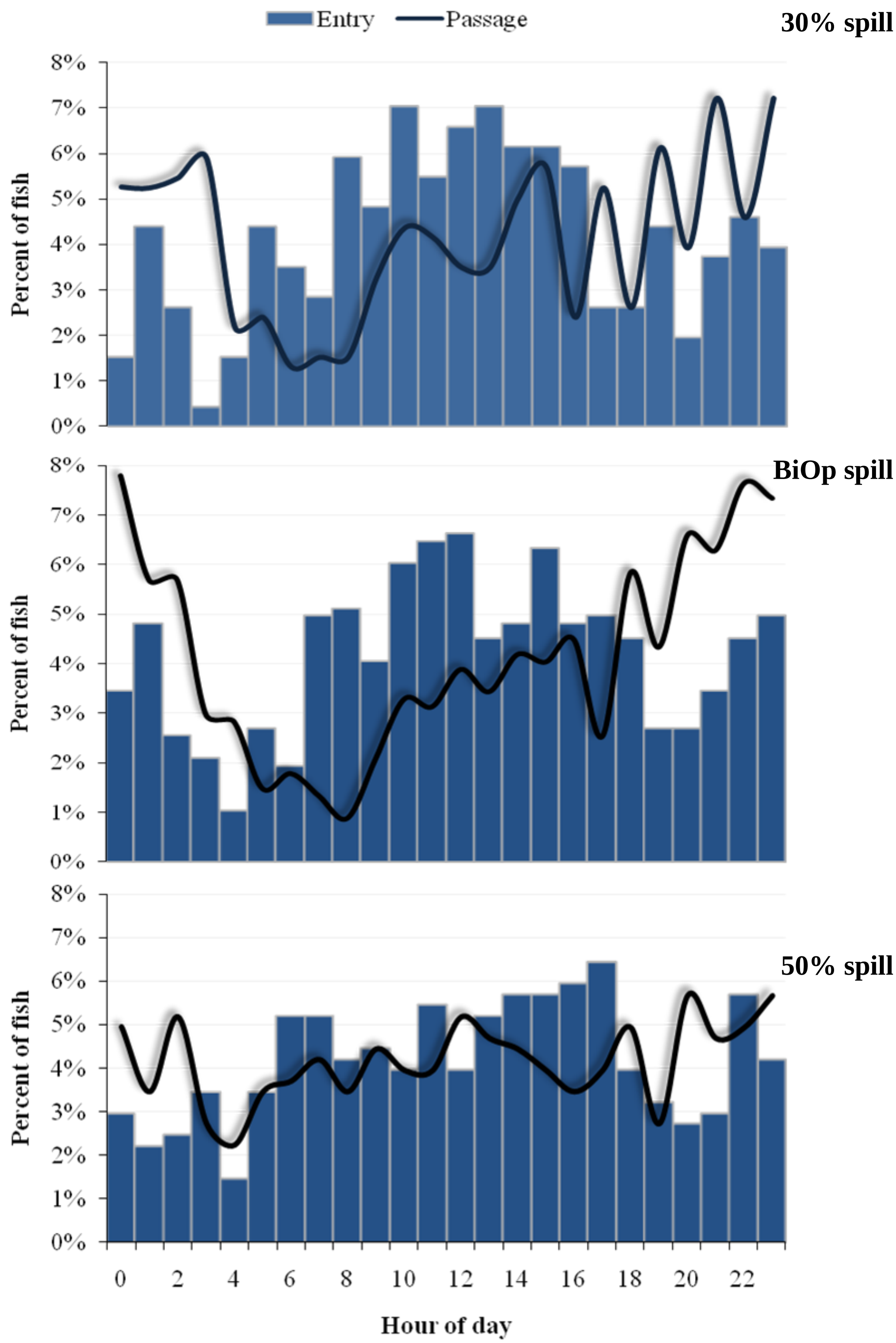

Figure 12. Percent of radio-tagged juvenile steelhead arriving and passing Ice Harbor Dam by hour of day during spring spill treatments, 2009.

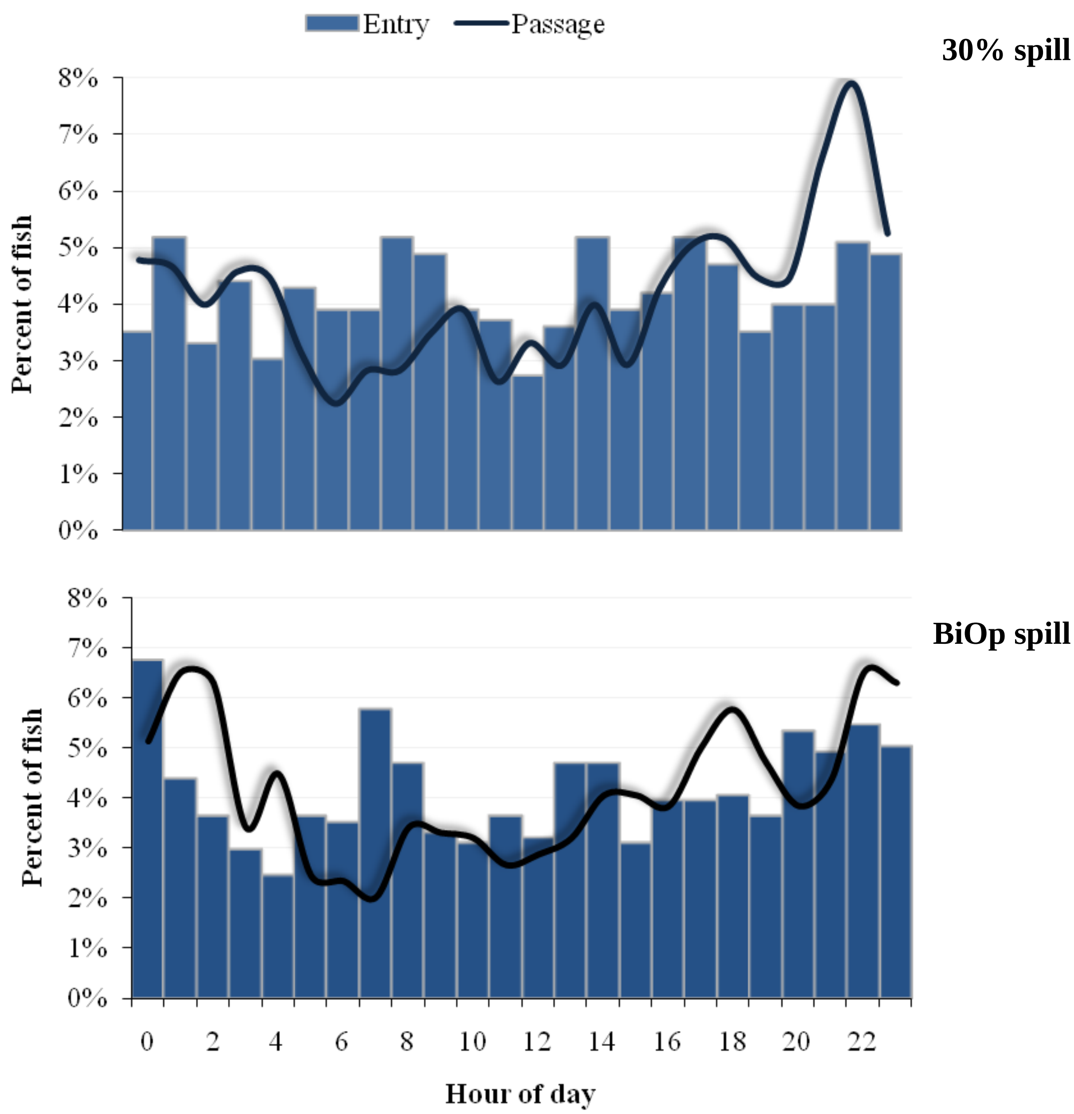

Figure 13. Percent of radio-tagged subyearling Chinook salmon arriving and passing Ice Harbor Dam by hour of day during summer spill treatments, 2009.

Forebay Delay

Forebay delay was measured for 1,565 yearling Chinook salmon, 1,671 steelhead, and 2,138 subyearling Chinook salmon based on two criteria; fish were detected at the entry line in the forebay, and subsequently determined to have a valid passage time. We estimated delay by species, treatment, and treatment block. Fish that entered under one treatment block and passed under the subsequent one were "right-censored." For censored fish, the time from entry until the end of the treatment block was recorded and used in estimation, while the time spent in the subsequent treatment block was ignored. This was done to avoid bias in forebay delay estimation due to possible "edge effects" from the change between treatment operations.

For yearling Chinook salmon, median forebay delay of fish that entered and passed during 30% spill treatments (3.1 h; 95% CI 2.5-3.8; Table 8) was significantly longer ($P < 0.001$) than those that passed during BiOp spill (1.3 h; 95% CI 1.3-1.5). Median forebay delay for steelhead during 30% spill (4.0 h; 95% CI 3.5-4.7; Table 8) was also significantly longer ($P < 0.001$) than for those passing during BiOp spill (2.7 h; 95% CI 2.2-3.1). Subyearling Chinook salmon exhibited a lower median forebay delay than that of yearling Chinook salmon and steelhead during both 30% spill (2.3 h; 95% CI 2.2-2.6; Table 9) and BiOp spill treatments (1.7 h; 95% CI 1.6-1.7), despite declining flows. Comparisons between both treatments yielded a significant difference as well ($P < 0.001$).

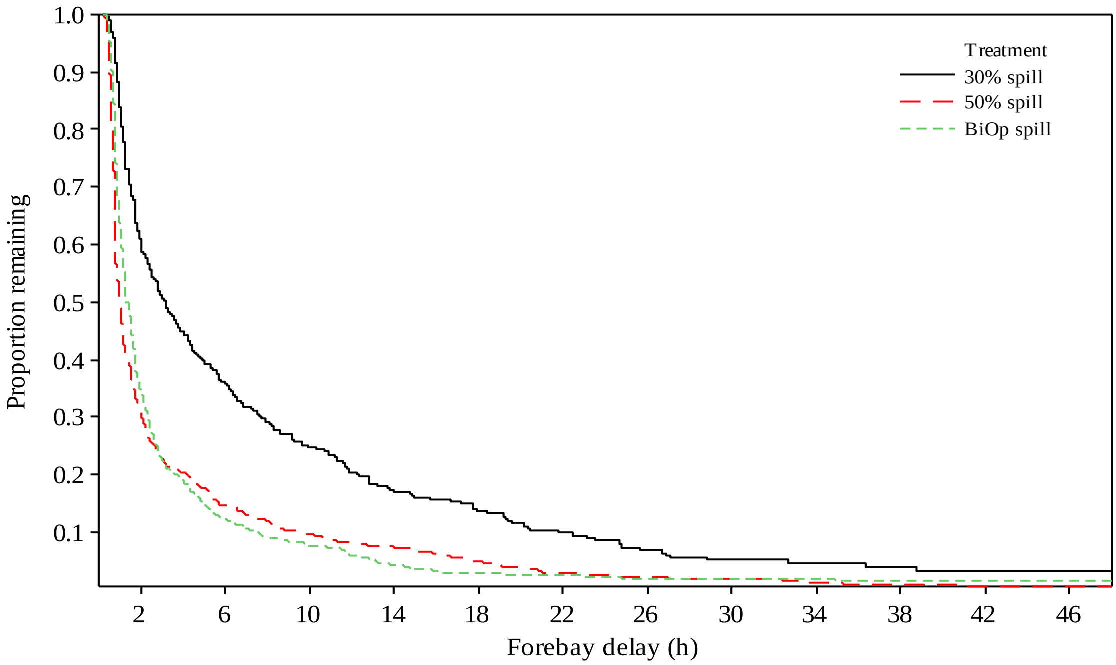

Figure 14. Forebay delay distribution of radio-tagged yearling Chinook salmon during spring spill treatments at Ice Harbor Dam, 2009.

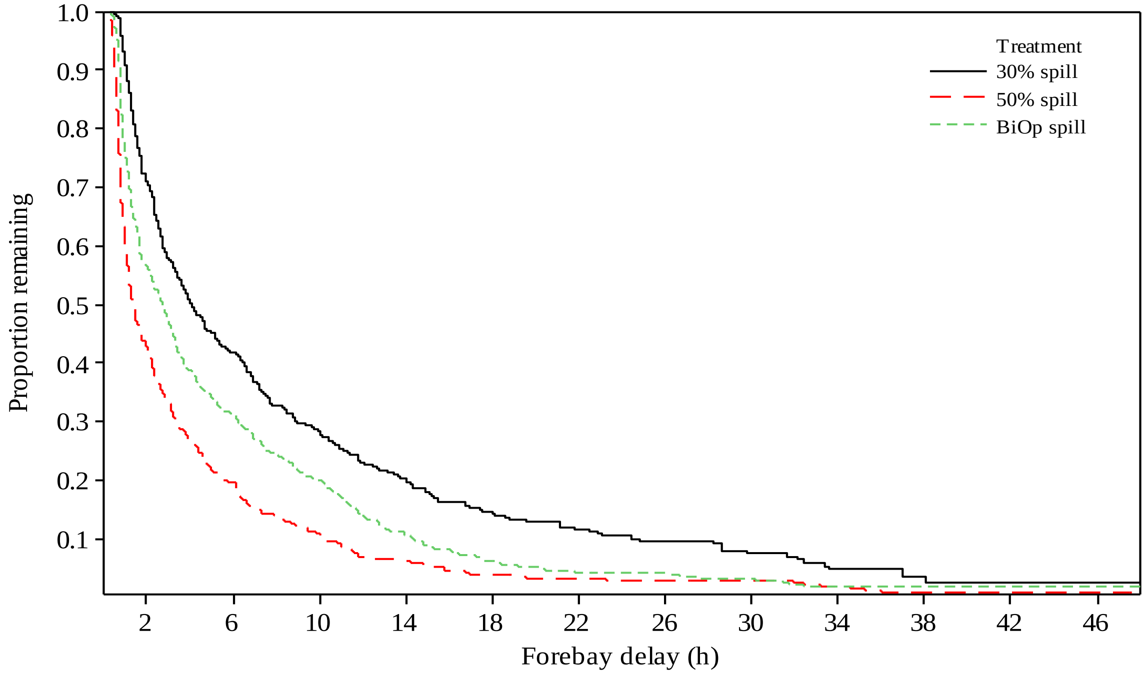

Figure 15. Forebay delay distribution of radio-tagged juvenile steelhead during spring spill treatments at Ice Harbor Dam, 2009.

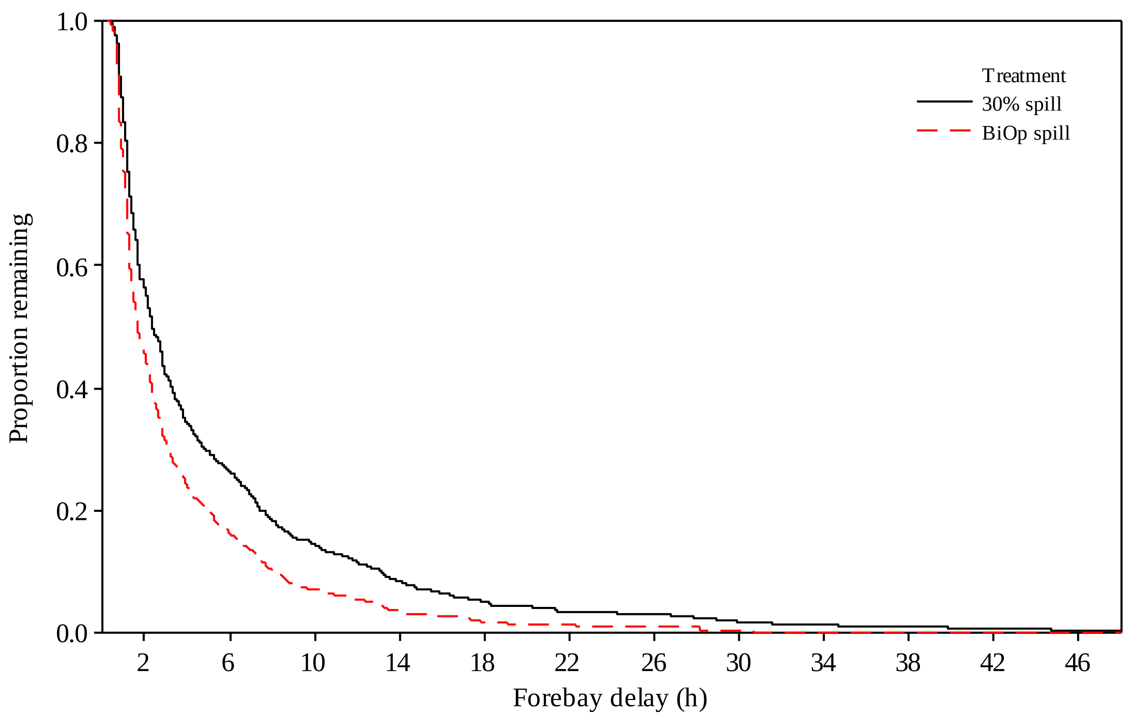

Figure 16. Forebay delay distribution of radio-tagged subyearling Chinook salmon during summer spill treatments at Ice Harbor Dam, 2009.

Table 8. Forebay delay (h) by spill treatment (percentile) between forebay entry and passage at Ice Harbor Dam for radio-tagged yearling Chinook salmon and steelhead, 2009.

Passage percentile	30% Spill	BiOp Spill	50% Spill
	Yearling Chinook salmon		
N	543	616	406
10th	0.9	0.6	0.5
20th	1.1	0.7	0.6
30th	1.4	0.9	0.7
40th	2.0	1.1	0.8
50th	3.1	1.3	1.0
60th	4.8	1.7	1.3
70th	7.6	2.3	2.0
80th	12.2	3.6	4.1
90th	21.8	7.5	9.2
95th	28.8	12.9	17.6
minimum	0.3	0.0	0.2
mean	7.6	3.3	3.5
median	3.1	1.3	1.0
mode	0.9	0.8	0.8
maximum	46.3	44.6	48.0
SD	7.6	5.1	6.7
	Juvenile steelhead		
N	549	717	405
10th	1.0	0.7	0.5
20th	1.4	0.9	0.6
30th	2.1	1.2	0.8
40th	2.7	1.7	1.0
50th	4.0	2.7	1.4
60th	6.4	3.7	2.2
70th	9.0	6.2	3.4
80th	13.7	9.8	5.5
90th	24.4	14.3	10.0
95th	33.4	19.2	15.1
minimum	0.0	0.0	0.3
mean	8.6	5.7	4.2
median	4.0	2.7	1.4
mode	0.9	0.8	0.6
maximum	42.1	44.1	48.0
SD	7.6	6.6	7.1

Table 9. Forebay delay (h) by spill treatment (percentile) between forebay entry and passage at Ice Harbor Dam for radio-tagged subyearling Chinook salmon, 2009.

	Subyearling Chinook salmon	
Passage percentile	30% Spill	BiOp Spill
N	1,131	1,007
10th	0.8	0.7
20th	1.1	0.9
30th	1.4	1.1
40th	1.7	1.3
50th	2.3	1.7
60th	3.2	2.2
70th	4.8	3.1
80th	7.4	4.9
90th	13.0	8.1
95th	17.8	12.6
minimum	0.0	0.0
mean	5.1	3.4
median	2.3	1.7
mode	1.2	0.8
maximum	45.0	30.7
SD	5.8	3.8

Passage Route Distribution

For radio-tagged yearling Chinook salmon passing Ice Harbor Dam during BiOp spill (n = 778), passage distribution was 93.2% through the spillway (31.2% of which passed over the RSW), 5.8% through the juvenile bypass, and 1.0% through the turbines (Table 1, Figure 17). During 30% spill (n = 582), 76.6% passed via the spillway (56.9% of which passed over the RSW), 21.3% through the juvenile bypass, and 2.1% through the turbines.

Juvenile steelhead passage distribution during BiOp spill (n = 844) was 88.0% through the spillway (26.9% of which passed over the RSW), 10.9% through the juvenile bypass, and 1.1% through the turbines (Table 2, Figure 18). During 30% spill (n = 575), 69.9% passed via the spillway (47.1% of which passed over the RSW), 29.6% through the juvenile bypass, and 0.5% through the turbines.

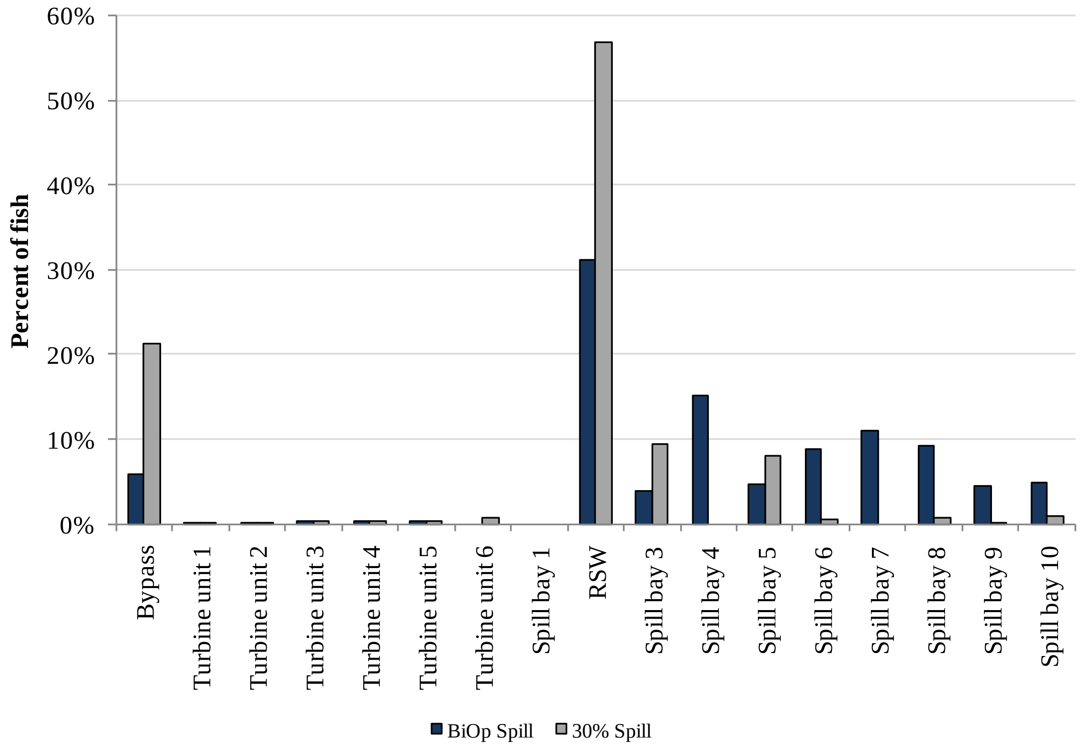

Figure 17. Horizontal passage distribution of radio-tagged yearling Chinook salmon during spring spill treatments at Ice Harbor Dam, 2009.

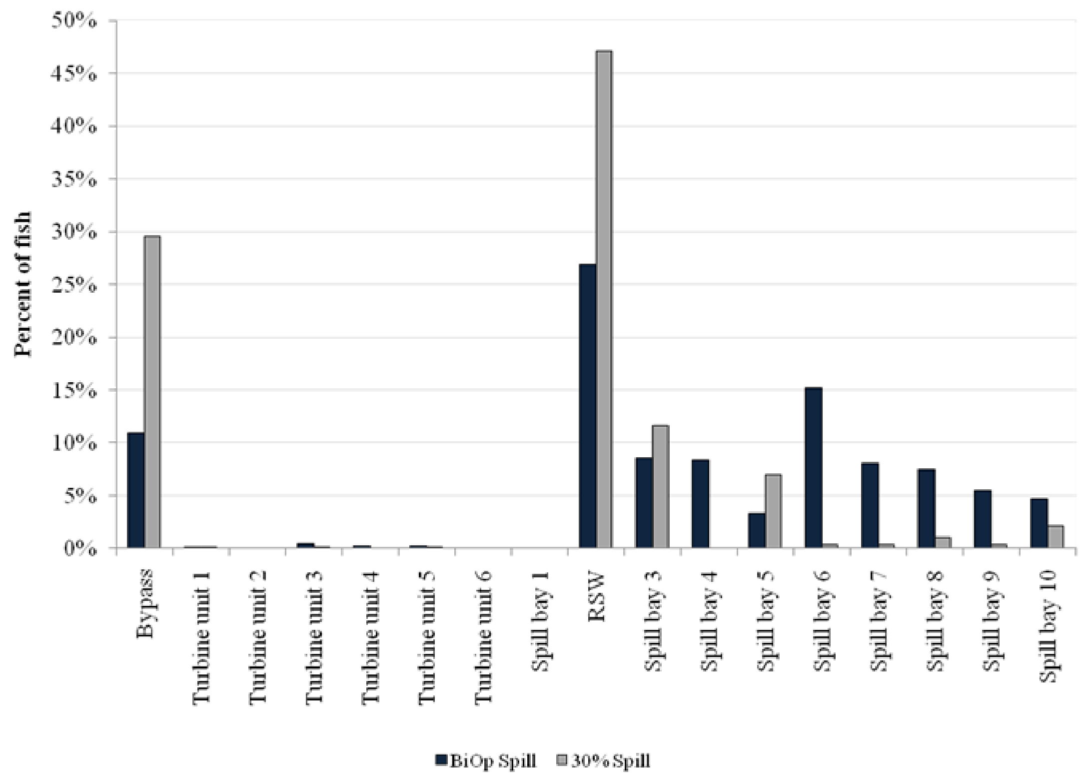

Figure 18. Horizontal passage distribution of radio-tagged juvenile steelhead during spring spill treatments at Ice Harbor Dam, 2009.

Subyearling Chinook salmon passage distribution during BiOp spill (n = 1,097) was 92.8% through the spillway (23.7% of which passed over the RSW), 6.5% through the juvenile bypass, and 0.7% through the turbines (Table 3, Figure 19). During 30% spill (n = 1,160), 62.0% passed via the spillway (39.4% of which passed over the RSW), 34.6% through the juvenile bypass, and 3.4% through the turbines.

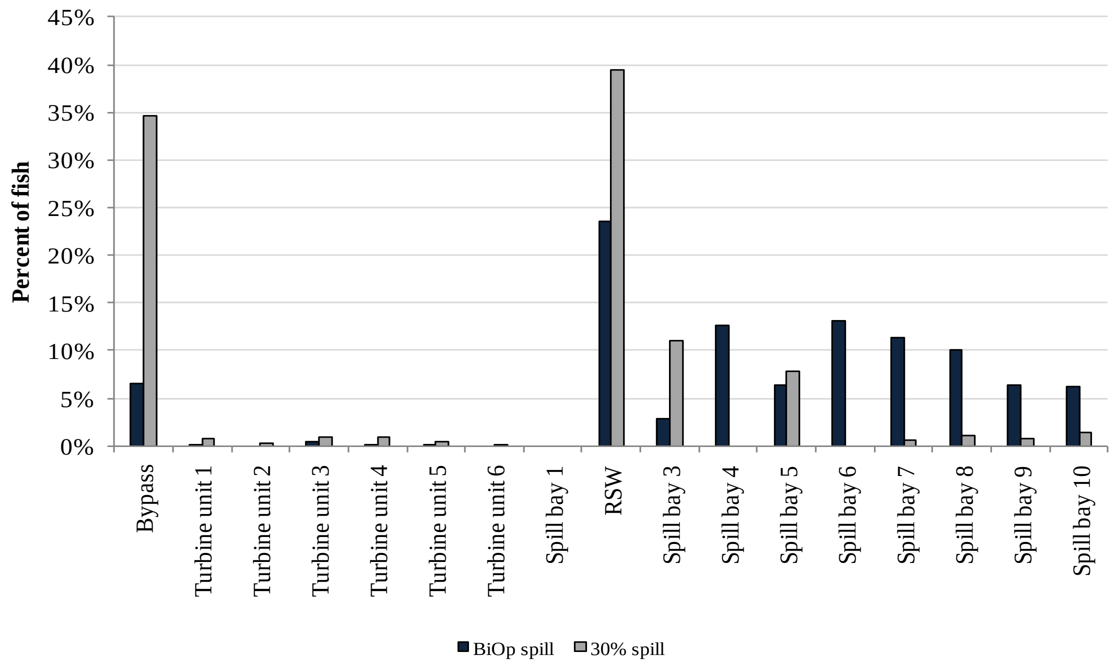

Figure 19. Horizontal passage distribution of radio-tagged subyearling Chinook salmon during summer spill treatments at Ice Harbor Dam, 2009.

Fish Passage Metrics

Yearling Chinook Salmon—For radio-tagged yearling Chinook salmon passing Ice Harbor Dam during BiOp spill treatments, fish passage efficiency was 99.0% (95% CI, 98.2-99.7%) fish guidance efficiency was 84.9% (75.1-94.7%) and spillway passage efficiency was 93.2% (91.4-95.0%; Tables 1 and 10). During 30% spill treatments, FPE was 97.9% (96.8-99.1%), FGE was 91.2% (86.3-96.0%), and SPE was 76.6% (73.1-80.1) for these fish.

Surface outlet efficiency for the RSW during BiOp spill was 31.2% (27.9-34.6), while during 30% spill it was 56.9% (52.8-61.0). Mean spillway passage effectiveness during BiOp and 30% spill treatments were 1.5:1 and 2.5:1, respectively. Mean surface outlet effectiveness was 4.0:1 under BiOp spill and 6.4:1 under 30% spill. Training spill effectiveness was near 1:1 for both operational treatments.

Juvenile Steelhead—For juvenile steelhead passing Ice Harbor Dam during BiOp spill treatments, FPE was 98.9% (95% CI, 98.2-99.6%), FGE was 91.1% (85.4-96.8%), and SPE was 88.0% (85.8-90.3%; Tables 2 and 11). During 30% spill treatments, FPE was 99.5% (98.9-100.1%), FGE was 98.3% (96.3-100.3%), and SPE was 69.9% (66.1-73.7%).

Surface outlet efficiency for the RSW during BiOp spill was 26.9% (23.8-30.0), while during 30% spill it was 47.1% (42.9-51.3). Mean spillway passage effectiveness during BiOp and 30% spill treatments were 1.4:1 and 2.3:1, respectively. Mean surface outlet effectiveness was 3.4:1 under BiOp spill and 5.3:1 under 30% spill. Training spill effectiveness was near 1:1 for both treatments.

Subyearling Chinook Salmon—For subyearling Chinook salmon passing during BiOp spill treatments, FPE was 99.3% (98.8-99.8), FGE was 89.9% (83.1-96.7), and SPE was 92.8% (91.2-94.4; Tables 3 and 12). During 30% spill treatments, FPE was 96.6% (95.5-97.6), FGE was 90.9% (88.2-93.7), and SPE was 62.0% (59.1-64.8).

Surface outlet efficiency for the RSW during BiOp spill was 23.6% (21.0-26.2), while during 30% spill it was 39.4% (36.5-42.3). Mean spillway passage effectiveness during BiOp and 30% spill treatments were 1.3:1 and 2.0:1, respectively. Mean surface outlet effectiveness was 2.5:1 under BiOp spill and 4.1:1 under 30% spill. Training spill effectiveness was near 1:1 for both treatments.

Table 10. Passage distribution and fish passage metrics for radio-tagged yearling Chinook salmon passing Ice Harbor Dam during spring spill treatments, 2009.

		Yearling Chinook salmon											
		Mean spill	Passage route					Fish passage metrics (95% CI)					
Date	Block	(kcfs)	Spillway	RSW	Bypass	Turbine	Total	SPE	FPE	FGE	SOE	SOS	SPS
								30% Spill					
Apr 30-May 2	1	23.5	4	38	8	0	50	0.840	1.000	1.000	0.760	7.600	2.766
May 4-6	2	26.9	34	72	42	1	149	0.711	0.993	0.977	0.483	5.428	2.345
May 8-10	3	29.4	35	67	25	3	130	0.785	0.977	0.893	0.515	6.526	2.608
May 10-12	4	24.8	25	80	25	1	131	0.802	0.992	0.962	0.611	6.427	2.661
May 14-16	5	29.5	17	74	24	7	122	0.746	0.943	0.774	0.607	7.230	2.468
Total		**27.2**	**115**	**331**	**124**	**12**	**582**	0.766	0.979	0.912	0.569	6.413	2.536
								(0.731-0.801)	(0.968-0.991)	(0.863-0.960)	(0.528-0.610)	(6.408-6.417)	(2.534-2.537)
								BiOp Spill					
May 2-4	2	60.1	79	35	1	0	115	0.991	1.000	1.000	0.304	2.938	1.339
May 6-8	3	74.5	137	44	19	4	204	0.887	0.980	0.826	0.216	3.078	1.421
May 12-14	4	57.8	111	46	8	1	166	0.946	0.994	0.889	0.277	3.056	1.382
May 16-18	5	60.4	68	60	8	2	138	0.928	0.986	0.800	0.435	5.250	1.425
May 18-20	6	72.6	87	58	9	1	155	0.935	0.994	0.900	0.374	6.090	1.754
Total		**65.9**	**482**	**243**	**45**	**8**	**778**	0.932	0.990	0.849	0.312	3.953	1.467
								(0.914-0.950)	(0.982-0.997)	(0.751-0.947)	(0.279-0.346)	(3.949-3.958)	(1.467-1.467)
								50% Spill					
May 20-27		76.1	198	147	69	13	427	0.808	0.970	0.841	0.344	6.799	1.637
								(0.770-0.846)	(0.953-0.986)	(0.761-0.922)	(0.298-0.390)	(6.790-6.808)	(1.636-1.637)

Table 11. Passage distribution and fish passage metrics for radio-tagged juvenile steelhead passing Ice Harbor Dam during spring spill treatments, 2009.

	Juvenile steelhead													
		Mean	Passage route					Fish passage metrics (95% CI)					
Date	Block	spill (kcfs)	Spillway	RSW	Bypass	Turbine	Total	SPE	FPE	FGE	SOE	SOS	SPS
								30% Spill					
Apr 30-May 2	1	23.5	5	34	10	1	50	0.780	0.980	0.909	0.680	6.800	2.568
May 4-6	2	26.9	50	80	40	1	171	0.760	0.994	0.976	0.468	5.255	2.506
May 8-10	3	29.4	23	56	37		116	0.681	1.000	1.000	0.483	6.113	2.264
May 10-12	4	24.8	23	51	35	1	110	0.673	0.991	0.972	0.464	4.879	2.234
May 14-16	5	29.5	30	50	48		128	0.625	1.000	1.000	0.391	4.656	2.068
Total		**27.2**	**131**	**271**	**170**	**3**	**575**	0.699 (0.661-0.737)	0.995 (0.989-1.001)	0.983 (0.963-1.003)	0.471 (0.429-0.513)	5.314 (5.309-5.319)	2.313 (2.312-2.315)
								BiOp Spill					
May 2-4	2	60.1	90	38	6	2	136	0.941	0.985	0.750	0.279	2.698	1.272
May 6-8	3	74.5	129	33	18	1	181	0.895	0.994	0.947	0.182	2.602	1.433
May 12-14	4	57.8	96	44	16	1	157	0.892	0.994	0.941	0.280	3.090	1.303
May 16-18	5	60.4	105	56	17	1	179	0.899	0.994	0.944	0.313	3.778	1.382
May 18-20	6	72.6	96	56	35	4	191	0.796	0.979	0.897	0.293	4.772	1.492
Total		**65.9**	**516**	**227**	**92**	**9**	**844**	0.880 (0.858-0.903)	0.989 (0.982-0.996)	0.911 (0.854-0.968)	0.269 (0.238-0.300)	3.404 (3.400-3.408)	1.386 (1.385-1.386)
								50% Spill					
May 20-27	50% spill	76.1	186	129	117	4	436	0.722 (0.680-0.765)	0.991 (0.982-1.000)	0.967 (0.934-0.999)	0.296 (0.252-0.340)	5.851 (5.842-5.859)	1.438 (1.438-1.439)

Table 12. Passage distribution and fish passage metrics for radio-tagged subyearling Chinook salmon passing Ice Harbor Dam during summer spill treatments, 2009.

	Yearling Chinook salmon												
		Mean spill	Passage route					Fish passage metrics (95% CI)					
Date	Block	(kcfs)	Spillway	RSW	Bypass	Turbine	Total	SPE	FPE	FGE	SOE	SOS	SPS
								30% Spill					
June 13-15	1	28.2	19	25	22	1	67	0.657	0.985	0.957	0.373	4.540	2.171
June 17-19	2	30.3	53	53	41	7	154	0.688	0.955	0.854	0.344	4.413	2.281
June 21-25	3	32.1	118	209	203	19	549	0.596	0.965	0.914	0.381	4.607	1.855
June 29-July 1	4	22.4	36	100	69	6	211	0.645	0.972	0.920	0.474	4.431	2.137
July 3-5	5	20.1	34	70	64	7	175	0.594	0.960	0.901	0.400	3.407	1.955
July 7-9	6	18.2	2		2		4	0.500	1.000	1.000			1.640
Total		**28.0**	**262**	**457**	**401**	**40**	**1160**	0.620	0.966	0.909	0.394	4.105	2.009
								(0.591-0.648)	(0.955-0.976)	(0.882-0.937)	(0.365-0.423)	(4.102-4.108)	(2.008-2.010)
								BiOp Spill					
June 12-13	1	84.0	13	1			14	1.000	1.000		0.071	0.976	1.564
June 15-17	2	74.9	107	26	10	2	145	0.917	0.986	0.833	0.179	2.420	1.418
June 19-21	3	62.3	100	31	23	6	160	0.819	0.963	0.793	0.194	2.316	1.216
June 25-27	4	57.4	153	62	15		230	0.935	1.000	1.000	0.270	2.847	1.376
June 27-29	5	57.1	151	55	9		215	0.958	1.000	1.000	0.256	2.608	1.379
July 1-3	6	52.8	138	55	7		200	0.965	1.000	1.000	0.275	2.463	1.274
July 5-7	7	51.5	97	29	7		133	0.947	1.000	1.000	0.218	1.717	1.178
Total		**59.1**	**759**	**259**	**71**	**8**	**1097**	0.928	0.993	0.899	0.236	2.537	1.336
								(0.912-0.944)	(0.988-0.998)	(0.831-0.967)	(0.210-0.262)	(2.534-2.539)	(1.336-1.337)

We have been evaluating fish passage at Ice Harbor Dam with respect to operation of an RSW for 4 years. As a result, we have data from a large number of fish that have passed under variable levels of percent spill. Regressions were plotted for percentage of fish that passed vs. percentage of spill for yearling Chinook salmon (n = 6,663), juvenile steelhead (n = 6,325), and subyearling Chinook salmon (n = 6,360; Figure 20). Results identified various operating points, in terms of percent spill, where project operation might influence fish passage distribution. For yearling Chinook salmon, spill percentages greater than 37% appear to shift fish away from the powerhouse, but levels higher than 48% appeared to decrease the effectiveness of the RSW. Similar respective beneficial and detrimental operating points were identified at approximately 39 and 53% spill for steelhead, and 45 and 59% spill for subyearling Chinook.

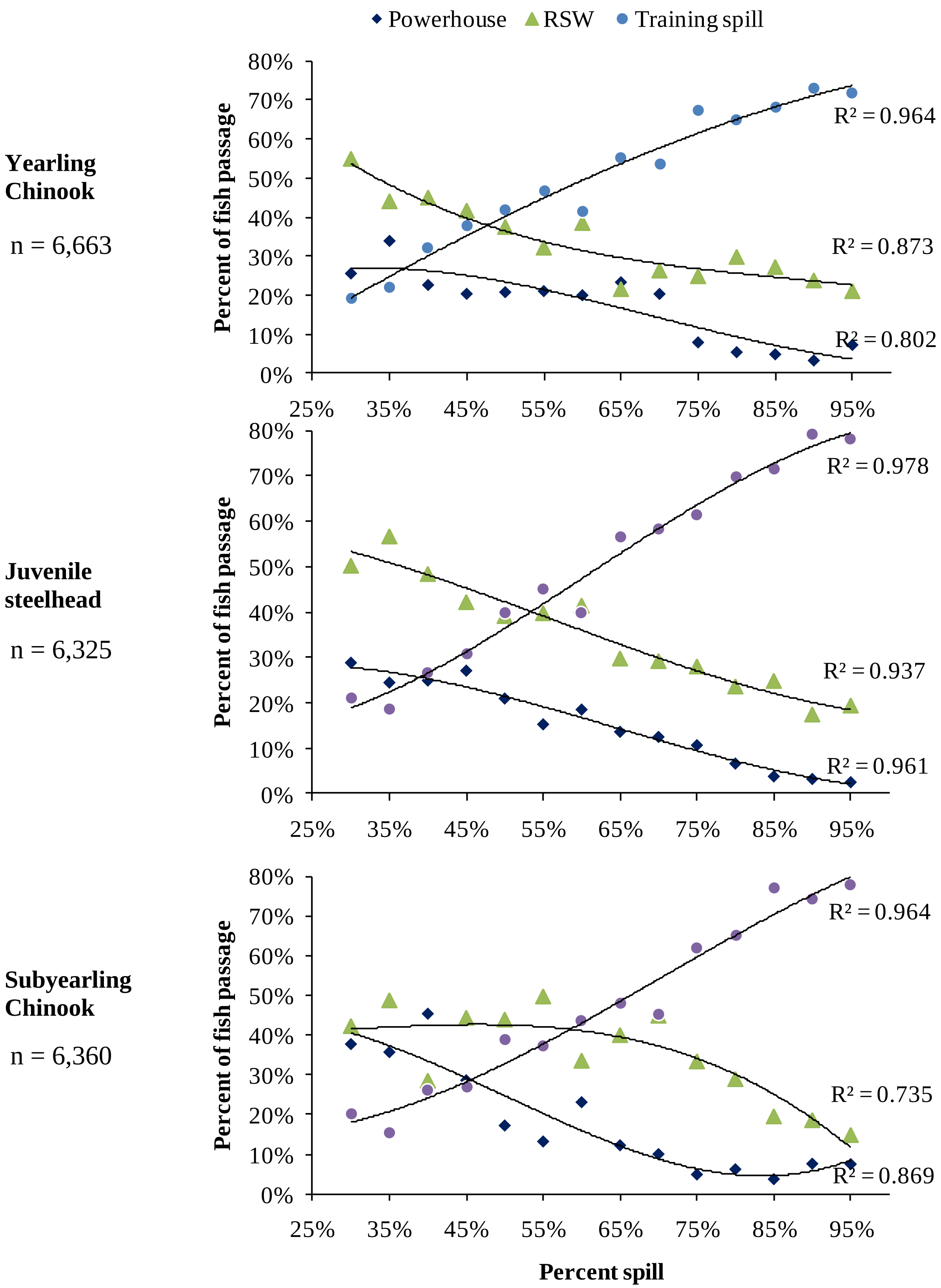

Figure 20. Percent of radio-tagged yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon passing via the powerhouse, RSW, and training spill during varying levels of percent spill at Ice Harbor Dam, 2006-2009.

Tailrace Egress

Tailrace egress was measured for 368 yearling Chinook salmon, 449 steelhead, and 491 subyearling Chinook salmon based on two inclusion criteria: fish were determined to have a valid passage time and had been detected subsequent to passage at the tailrace exit line. Kaplan-Meier analysis provided curves regarding the proportion remaining within the tailrace through time for each passage treatment (Figure 21-23). Median tailrace egress of yearling Chinook salmon during 30% and BiOp spill was 9.2 and 9.8 min, respectively (P = 0.034). Steelhead egress was similar, 9.3 minutes for 30% spill and 9.6 minutes for BiOp spill (P = 0.053). Subyearling Chinook salmon also displayed similar egress timing (9.6 and 9.1 min, respectively) during summer conditions (P = 0.983), which differed slightly from spring conditions. Percentile distribution by treatment for tailrace egress for radio-tagged yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon is shown in Tables 13, 14, and 15, respectively.

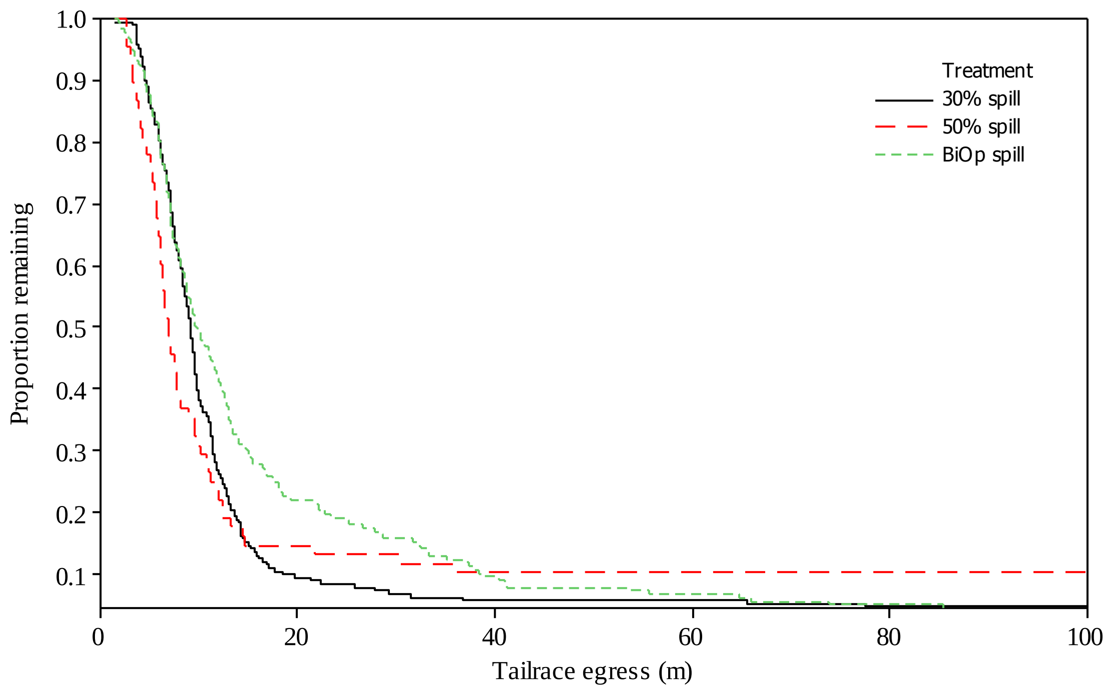

Figure 21. Tailrace egress distribution of radio-tagged yearling Chinook salmon during spring spill treatments at Ice Harbor Dam, 2009.

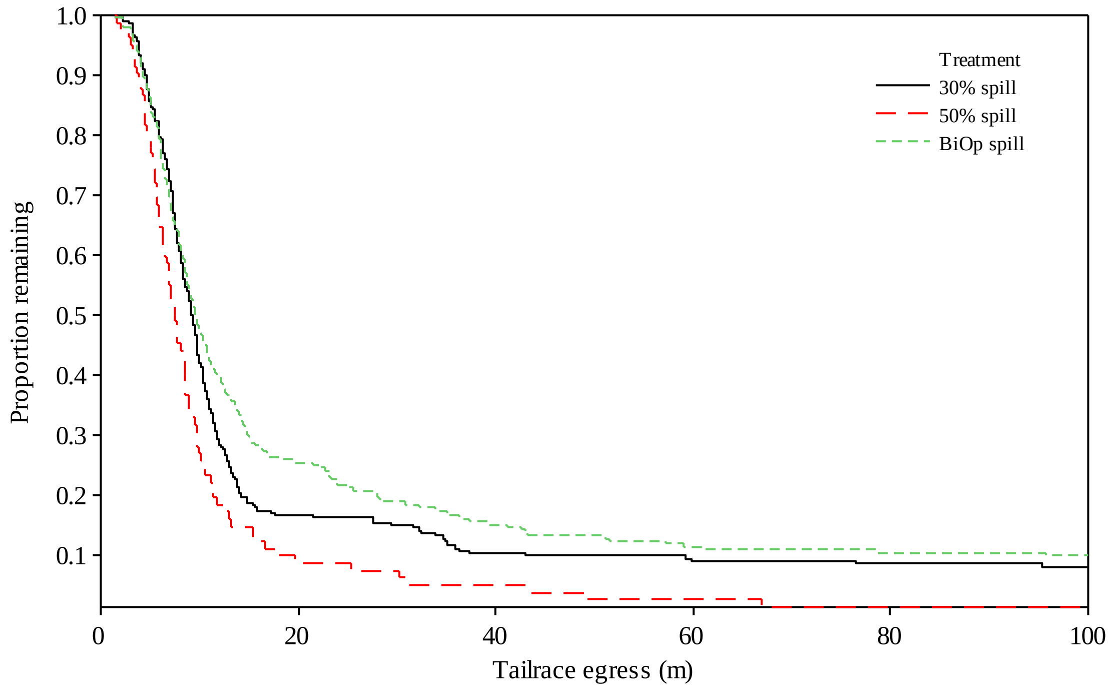

Figure 22. Tailrace egress distribution of radio-tagged juvenile steelhead during spring spill treatments at Ice Harbor Dam, 2009.

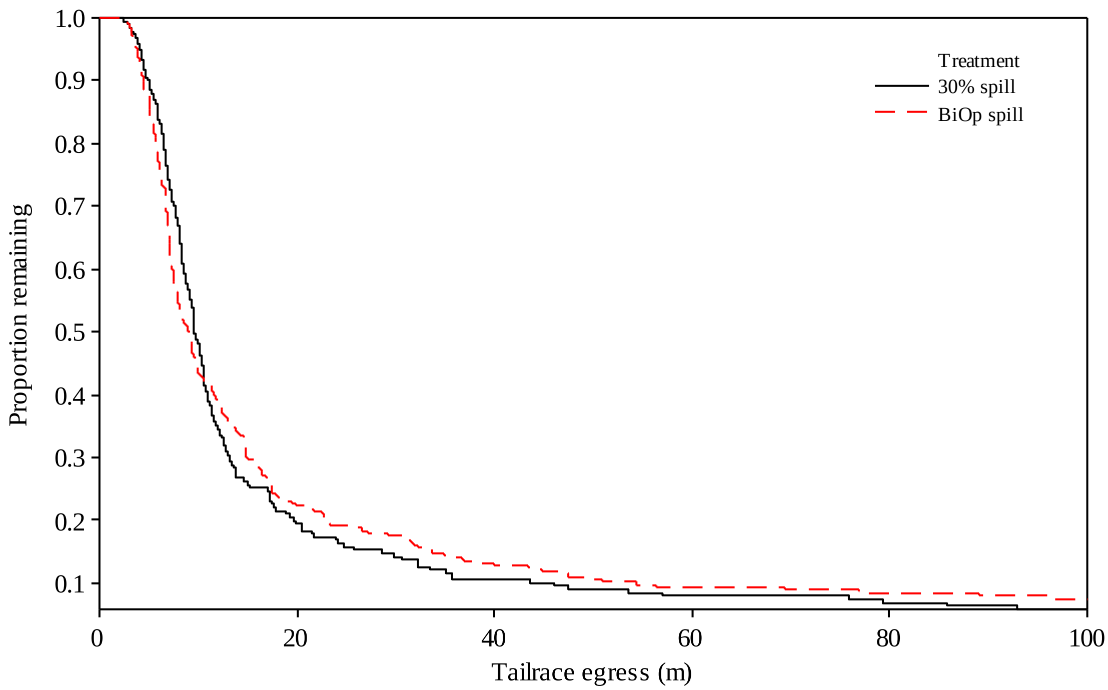

Figure 23. Tailrace egress distribution of radio-tagged subyearling Chinook salmon during summer spill treatments at Ice Harbor Dam, 2009.

Table 13. Distribution by passage percentile for tailrace egress (minutes) from passage time at Ice Harbor Dam to the tailrace exit for radio-tagged yearling Chinook salmon, 2009.

	Yearling Chinook salmon Tailrace egress (min)	
Passage percentile	30% Spill	BiOp Spill
N	191	177
10th	4.7	4.5
20th	6.0	6.0
30th	7.2	7.0
40th	8.2	8.2
50th	9.2	9.8
60th	9.8	12.3
70th	11.4	14.8
80th	13.5	22.7
90th	18.4	38.4
95th	71.5	76.2
minimum	1.4	1.8
mean	65.8	78.7
median	9.2	9.8
mode	7.2	6.0
maximum	7209.2	5258.2
SD	534.8	482.8

Table 14. Sample size, percentile distribution, minimum, mean, median, mode, and maximum tailrace egress (minutes) from passage time at Ice Harbor Dam to the tailrace exit for radio-tagged juvenile steelhead, 2009.

	Juvenile steelhead tailrace egress (min)	
Passage percentile	30% Spill	BiOp Spill
N	236	213
10th	4.5	4.3
20th	5.9	5.9
30th	7.3	6.8
40th	8.1	8.2
50th	9.3	9.6
60th	10.3	11.9
70th	11.7	14.9
80th	14.1	28.0
90th	40.3	92.2
95th	182.3	801.5
minimum	1.5	1.5
mean	103.0	249.2
median	9.3	9.6
mode	7.3	7.9
maximum	6004.6	8354.3
SD	605.0	1134.6

Table 15. Sample size, percentile distribution, minimum, mean, median, mode, and maximum tailrace egress (minutes) from passage time at Ice Harbor Dam to the tailrace exit for radio-tagged subyearling Chinook salmon, 2009.

	Subyearling Chinook salmon tailrace egress (min)	
Passage percentile	30% Spill	BiOp Spill
N	191	300
10th	5.0	4.4
20th	6.4	5.8
30th	7.7	6.7
40th	8.6	7.4
50th	9.6	9.1
60th	10.9	11.5
70th	13.1	14.9
80th	19.6	22.8
90th	43.7	54.4
95th	139.0	266.8
minimum	2.5	2.3
mean	124.3	110.1
median	9.6	9.1
mode	9.5	6.7
maximum	5900.9	7482.5
SD	703.5	650.9

Survival Estimates

Yearling Chinook salmon

Survival estimates for yearling Chinook salmon from each operational treatment replicate are reported in Table 16. All comparisons of survival estimates between the two operational treatments revealed no significant difference (Table 17). During BiOp and 30% spill operations, respectively, survival was estimated at 0.925 and 0.939 (P = 0.520) through the spillway, and 0.930 and 0.939 (P = 0.786) through the RSW. Dam survival was estimated at 0.897 during BiOp spill and 0.922 during 30% spill (P = 0.228). Estimated survival through the juvenile bypass system was 0.854 (SE = 0.054) under BiOp conditions and 0.941 (SE = 0.035) during 30% spill (P = 0.213). Concrete survival, or the survival estimate for all fish that passed the project, was 0.931 during BiOp spill and 0.941 during 30% spill (P = 0.613).

Juvenile Steelhead

All comparisons of survival estimates between the two operational treatments revealed no significant difference (Table 18). During BiOp and 30% spill operations, respectively, survival was estimated at 0.958 and 0.940 (P = 0.200) through the spillway, and 0.927 and 0.923 (P = 0.906) through the RSW. Dam survival was estimated at 0.911 during BiOp spill and 0.904 during 30% spill (P = 0.760). Estimated bypass survival was 0.935 (SE = 0.069) under BiOp conditions and 0.944 (SE = 0.021) during 30% spill (P = 0.902). Concrete survival, or the survival estimate for all fish that passed the project, was 0.950 during BiOp spill and 0.943 during 30% spill (P = 0.592).

Subyearling Chinook Salmon

All comparisons of survival estimates between the two operational spill treatments revealed no significant difference (Tables 19 and 20). During BiOp and 30% spill operations, respectively, survival was estimated at 0.886 and 0.885 (P = 0.976) through the spillway, and 0.877 and 0.919 (P = 0.081) through the RSW. Dam survival was estimated at 0.843 during BiOp spill and 0.842 during 30% spill (P = 0.971). Estimated bypass survival was 0.961 under BiOp conditions and 0.958 during 30% spill (P = 0.913). Concrete survival, or the survival estimate for all fish that passed the project, was 0.896 during BiOp spill and 0.913 during 30% spill (P = 0.378).

Table 16. Sample sizes and mean estimates of survival for radio-tagged hatchery yearling Chinook salmon and juvenile steelhead passing Ice Harbor Dam during 30%, BiOp, and 50% spill treatments, 2009. Standard errors are in parenthesis.

	Estimated Survival (SE)								
	Yearling Chinook salmon								
	30% spill			BiOp spill			50% spill		
	n	Survival	95% CI	n	Survival	95% CI	n	Survival	95% CI
Project survival									
Dam survival	585	0.922 (0.012)	0.887-0.956	660	0.897 (0.015)	0.856-0.938	432	0.895 (0.016)	
Concrete survival	571	0.941 (0.018)	0.891-0.992	770	0.931 (0.007)	0.913-0.950	417	0.914 (0.016)	
Route-specific survival									
Spillway survival	446	0.939 (0.012)	0.906-0.972	725	0.925 (0.017)	0.879-0.972	345	0.921 (0.016)	
JBS survival	124	0.941 (0.035)	0.844-1.038	45	0.854 (0.054)	0.706-1.003	69	0.861 (0.047)	
RSW survival	331	0.939 (0.016)	0.893-0.985	243	0.930 (0.025)	0.860-1.001	147	0.911 (0.027)	
Turbine survival*	1	N/A		0	N/A		5	N/A	
	Juvenile steelhead								
	30% spill			BiOp spill			50% spill		
	n	Survival	95% CI	n	Survival	95% CI	n	Survival	95% CI
Project survival									
Dam survival	591	0.904 (0.015)	0.862-0.946	767	0.911 (0.016)	0.865-0.957	413	0.881 (0.018)	
Concrete survival	572	0.943 (0.010)	0.916-0.969	839	0.950 (0.010)	0.923-0.978	429	0.901 (0.017)	
Route-specific survival									
Spillway survival	402	0.940 (0.012)	0.908-0.972	742	0.958 (0.006)	0.941-0.976	311	0.913 (0.018)	
JBS survival	169	0.944 (0.021)	0.885-1.003	91	0.935 (0.069)	0.742-1.127	116	0.875 (0.040)	
RSW survival	271	0.923 (0.023)	0.858-0.988	227	0.927 (0.022)	0.866-0.988	126	0.885 (0.034)	
Turbine survival*	1	N/A		6	N/A		2	N/A	

*Not enough fish passed to estimate survival

Table 17. Differences and comparison of survival for radio-tagged yearling Chinook salmon passing Ice Harbor Dam during the 30% and BiOp spill treatments, 2009.

	30% spill		BiOp spill						
	Survival	95% CI	Survival	95% CI	Mean difference	se	*t*	df	*P*
Project survival									
Dam survival	0.922 (0.012)	0.887-0.956	0.897 (0.015)	0.856-0.938	2.5%	1.9%	1.31	8	0.228
Concrete survival	0.941 (0.018)	0.891-0.992	0.931 (0.007)	0.913-0.950	1.0%	1.9%	0.53	8	0.613
Route-specific survival									
Spillway survival	0.939 (0.012)	0.906-0.972	0.925 (0.017)	0.879-0.972	1.4%	2.0%	0.67	8	0.520
JBS survival	0.941 (0.035)	0.844-1.038	0.854 (0.054)	0.706-1.003	8.6%	6.4%	1.35	8	0.213
RSW survival	0.939 (0.016)	0.893-0.985	0.930 (0.025)	0.860-1.001	0.9%	3.0%	0.28	8	0.786

Table 18. Differences and comparison of survival for radio-tagged juvenile steelhead passing Ice Harbor Dam during the 30% and BiOp spill treatments, 2009.

	30% spill		BiOp spill						
	Survival	95% CI	Survival	95% CI	Mean difference	se	*t*	df	*P*
Project survival									
Dam survival	0.904 (0.015)	0.862-0.946	0.911 (0.016)	0.865-0.957	-0.7%	2.2%	0.32	8	0.760
Concrete survival	0.943 (0.010)	0.916-0.969	0.950 (0.010)	0.923-0.978	-0.8%	1.4%	0.56	8	0.592
Route-specific survival									
Spillway survival	0.940 (0.012)	0.908-0.972	0.958 (0.006)	0.941-0.976	-1.8%	1.3%	1.40	8	0.200
JBS survival	0.944 (0.021)	0.885-1.003	0.935 (0.069)	0.742-1.127	0.9%	7.2%	0.13	8	0.902
RSW survival	0.923 (0.023)	0.858-0.988	0.927 (0.022)	0.866-0.988	-0.4%	3.2%	0.12	8	0.906

Table 19. Sample sizes and mean estimates of survival for radio-tagged subyearling Chinook salmon passing Ice Harbor Dam during 30% and BiOp spill treatments, 2009. Standard errors are in parenthesis.

	30% spill			BiOp spill		
	n	Survival	95% CI	n	Survival	95% CI
Project survival						
Dam survival	1,245	0.842 (0.018)	0.792-0.893	1,216	0.843 (0.019)	0.794-0.893
Concrete survival	1,223	0.913 (0.011)	0.883-0.943	1,201	0.896 (0.015)	0.856-0.935
Route-specific survival						
Spillway survival	720	0.885 (0.015)	0.843-0.927	1,004	0.886 (0.013)	0.852-0.919
JBS survival	402	0.958 (0.015)	0.915-1.000	71	0.961 (0.023)	0.901-1.020
RSW survival	459	0.919 (0.014)	0.879-0.959	258	0.877 (0.016)	0.836-0.918
Turbine survival*	2	N/A		10	N/A	

* Not enough fish passed to estimate survival

Table 20. Differences and comparison of survival for radio-tagged subyearling Chinook salmon passing Ice Harbor Dam during the 30% and BiOp spill treatments, 2009.

	30% spill		BiOp spill						
	Survival	95% CI	Survival	95% CI	Mean difference	se	*t*	df	*P*
Project survival									
Dam survival	0.842 (0.018)	0.792-0.893	0.843 (0.019)	0.794-0.893	0.1%	2.6%	0.04	9	0.971
Concrete survival	0.913 (0.011)	0.883-0.943	0.896 (0.015)	0.856-0.935	-1.8%	1.9%	0.93	9	0.378
Route-specific survival									
Spillway survival	0.885 (0.015)	0.843-0.927	0.886 (0.013)	0.852-0.919	0.1%	2.0%	0.03	9	0.976
JBS survival	0.958 (0.015)	0.915-1.000	0.961 (0.023)	0.901-1.020	0.3%	2.8%	0.11	9	0.913
RSW survival	0.919 (0.014)	0.879-0.959	0.877 (0.016)	0.836-0.918	-4.2%	2.2%	1.97	9	0.081

Avian Predation

Tag recovery efforts at the Crescent Island Caspian tern and gull colonies produced 144 radio transmitters and 209 unique PIT tags from study fish released in 2009. The overall tag recovery represented 1.2% of the yearling Chinook salmon, 3.6% of the steelhead, and 5.7% of the subyearling Chinook salmon released for Ice Harbor and Lower Monumental Dam survival and passage studies (Table 21). We also obtained PIT detections from Foundation Island for 86 of our study fish representing 1.2% of the yearling Chinook, 2.4% of the steelhead, and 0.2% of the subyearling Chinook salmon released. Detection efficiencies for PIT tags within the Caspian tern and gull colonies on Crescent Island were 71% (SE 18.3%) and 72.5% (SE 12.5%), respectively (A. Evans, Real Time Research, Inc., personal communication). The detection efficiency at Foundation Island was 72.8T (SE 4.9%).

For fish with tags recovered on Crescent and Foundation Island (Figures 24 and 25), we plotted the last known detection transect on which they were detected in order to determine where "predation zones" might be located. During 2009, subyearling Chinook salmon were most vulnerable to Caspian terns within the Ice Harbor Dam pool. Subyearling Chinook salmon and juvenile steelhead were also more susceptible at the juvenile outfall locations and near the confluence of the Snake and Columbia Rivers. Yearling Chinook were taken at a much lower level than the other two species. Double-crested cormorants preyed more heavily on steelhead and to a lesser extent yearling and subyearling Chinook salmon.

Table 21. Number of fish released, number of radio transmitters recovered, number of unique PIT tags detected, total recovered, and the minimum percent predation for radio-tagged yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon, 2009.

Species	Number released	Number transmitters recovered	Number unique PITs	Total recovered	Percent predation
Crescent Island					
Yearling Chinook	2,202	4	23	27	1.2%
Steelhead	2,200	22	57	79	3.6%
Subyearling Chinook	4,352	118	128	246	5.7%
Foundation Island					
Yearling Chinook	2,202	0	26	26	1.2%
Steelhead	2,200	0	52	52	2.4%
Subyearling Chinook	4,352	0	9	9	0.2%

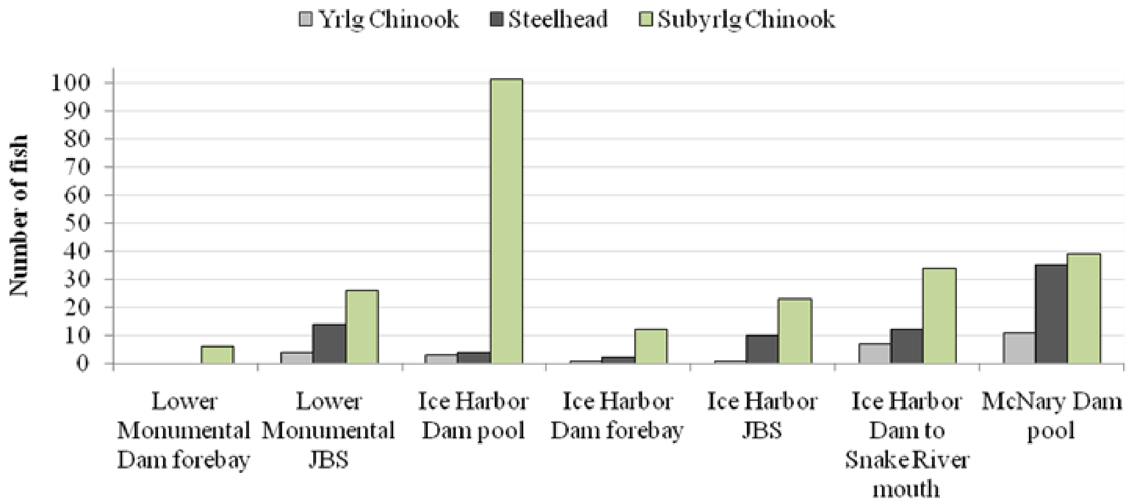

Figure 24. Percentage of radio-tagged juvenile steelhead, yearling Chinook, and subyearling Chinook salmon migrants with their last known telemetry detection site before Crescent Island predation event, 2009.

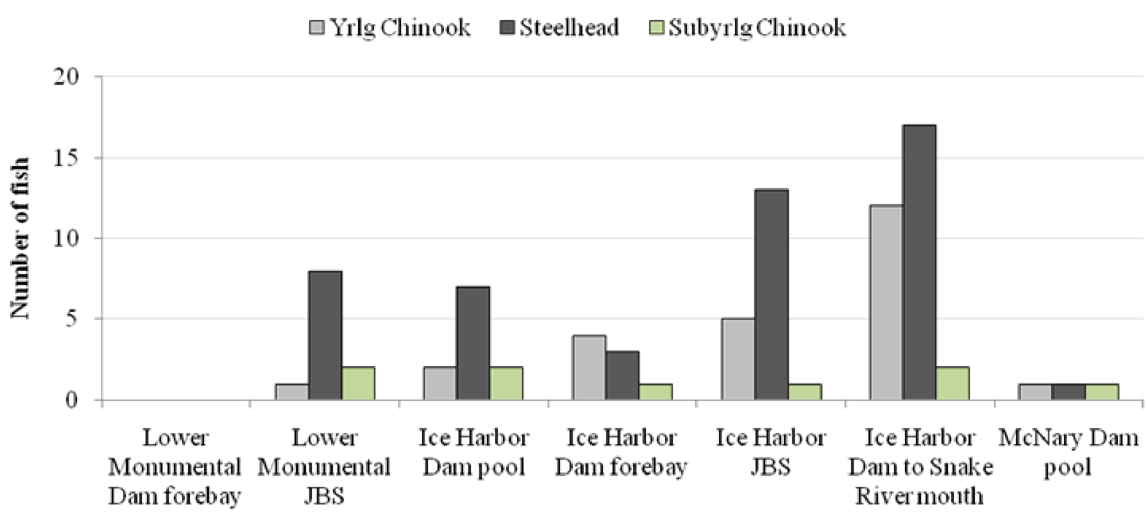

Figure 25. Percentage of radio-tagged juvenile steelhead, yearling Chinook, and subyearling Chinook salmon migrants with their last known telemetry detection site before Foundation Island predation event, 2009.

DISCUSSION

Overall, the RSW at Ice Harbor Dam continues to be extremely effective in passing more fish with less water. However, there remain concerns regarding which passage routes will provide juvenile salmonids with the highest potential for survival through the hydropower system in the Columbia River Basin. The RSW was developed to allow juvenile salmon and steelhead to pass the dam near the water surface under lower accelerations and pressures, providing a more efficient and less stressful dam passage route (http://www.nww.usace.army.mil/spillway_weir/Default.html). During drought conditions, the RSW would potentially maintain high fish passage efficiencies with its ability to draw and pass surface-oriented salmon and steelhead, while at the same time, improve the opportunity for power generation.

While survival estimates have been high through the surface passage route during both spill treatments, there still exists a high level of mortality in the forebay at Ice Harbor Dam. This forebay is associated with some of the highest measured levels of mortality within the Columbia River Basin. One reason for this high mortality is that predators, both avian and piscivorous, have long exploited the holding behavior in this area by migrating juvenile salmonids. Predator exploitation of this holding behavior has made Ice Harbor forebay one of the highest areas of smolt loss to predation (Poe et al. 1991; Beamesderfer and Rieman 1991; Antolos et al. 2005). The Caspian tern colonies on Crescent Island and double-crested cormorant colonies on Foundation Island have played a major role in this predation loss over the last decade, though to a lesser extent in 2008 and 2009. We have observed a recent shift toward more localized predation on subyearling Chinook by Caspian terns, primarily in the Ice Harbor pool. This predation occurs immediately prior to entrance into the forebay by subyearling Chinook.

Evaluations were conducted from 2006 to 2009 by NOAA Fisheries to examine fish passage behavior and survival with respect to 30% spill and BiOp spill in order to determine the best project operations for juvenile fish. During these evaluations, we were able to examine passage and survival over a differing flow years. We have found that in general, surface outlet efficiency is mostly a function of the percent of water spilled.

During reduced spill tests at 30% of the total river flow, yearling and subyearling Chinook salmon and juvenile steelhead primarily utilized the RSW, though fish also passed through the juvenile bypass system at higher proportions than those observed during BiOp spill tests. This was mostly a result of more flow being directed toward the powerhouse to maintain the reduced spill treatments. Increased flow toward the powerhouse has resulted in wandering behavior and increased forebay delay, probably caused by hesitation of fish while they decide which flow queue to follow. Forebay delay increases exposure to predators. BiOp spill calls for 45 kcfs spill during the day and increasing to the gas cap at night, which directs the majority of fish passage through the spill, reducing powerhouse passage for fish and forebay delay as well.

Forebay delay in 2009 was longer than that found in previous years for both species under similar spill treatments (Axel et al. 2007, 2008). Median forebay delay for yearling Chinook salmon during the high flows of 2006 was 1.8 h for 30% spill and 1.1 h for BiOp spill. During 2007, we observed median forebay delays of 2.0 h for 30% and 1.5 h for BiOp spill. Results in 2006 for steelhead were similar to those of yearling Chinook salmon, with delays of 1.8 h for 30% and 1.7 h for BiOp spill. While different methods of analysis were used for these data (time-to-event method; Lawless 1982; Tableman and Kim 2004), analysis of these data using the previous methodology resulted in similar findings, with longer delays in 2009.

Since flows were relatively high during 2009, one explanation for the longer delays in this year might be the new caution float line installed in the forebay. These were installed to prevent boaters from entering the potentially hazardous currents created by operation of the RSW. The caution float, composed of a boom created by floating barrels, may provide structure that is being utilized by juvenile salmonids as they approach an area of higher flows. Southard et. al (2006) demonstrated that the shading caused by over-water structures could deter or delay juvenile salmonid movement. They found that fish moved past structures quickly during late evening, when there was a less distinct shadow boundary than during full daylight. While there may be some evidence of this behavior with respect to juvenile steelhead and subyearling Chinook salmon entry and passage, evaluation of behavior with regard to this structure was not an objective of the study and was not formally monitored. Future evaluation of fish behavior near the float line may be needed to determine if this addition to the forebay causes delay for migrating smolts.

Comparisons of survival for fish passing under each spill treatment yield no significant statistical differences, but there still may be concerns related to passage at Ice Harbor Dam that are not manifesting themselves until further downstream. Normandeau Associates (2006) found that fish passing close to the crest of spillways and RSWs may have an increased chance of collision with flow deflectors, particularly high-angle deflectors like those utilized at Ice Harbor. Currently, there are plans to modify the shape of the ogee and flow deflector in the RSW bay (spill bay 2) to decrease the potential for injury.

Further examination of survival of radio-tagged fish over a longer distance (detection at McNary Dam transects) yielded no evidence of a passage effect. However, avian colonies in the study area may have influenced this assessment by picking off injured individuals between the mouth of the Snake River and McNary Dam. Regional coordination is currently underway to monitor and potentially mitigate this issue.

Passage efficiency for steelhead, yearling Chinook, and subyearling Chinook salmon passing through the powerhouse, RSW, and training spill were examined over the last four years as a function of the percent spill during the time of passage. Our results suggest that a correlation exists between the percentage of spill and the number of fish that utilize the powerhouse. There also exists a point of diminishing returns, where additional spill reduces the overall effectiveness of the RSW, as well as the spillway as a whole. For yearling Chinook salmon, spill percentages greater than 37% appear to shift fish away from the powerhouse, but levels higher than 48% appeared to decrease the effectiveness of the RSW. Similar respective beneficial and detrimental operating points were identified at approximately 39 and 53% spill for steelhead, and 45 and 59% spill for subyearling Chinook.

In summary, the RSW continues to provide higher passage effectiveness than all other routes due to its ability to pass more fish with less flow. The surface outlet has added some flexibility with respect to project operations particularly during low flow conditions. At higher flows, additional evaluation will be needed to determine which routes will provide the highest survival probability, since project operation will play a major role in determining passage distribution. While estimates of concrete survival did not meet the minimum levels mandated by the 2008 Biological Opinion (NOAA Fisheries 2008), these estimates were made using the single-release model. Paired-release studies in 2006 and 2007 have shown that survival levels were reasonably consistent with these standards at Ice Harbor Dam.

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APPENDIX A

Evaluation of Study Assumptions

We used a single-release model (Cormack 1964; Jolly 1965; Seber 1965) to estimate survival of radio-tagged yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon released above Ice Harbor Dam. Evaluation of critical model and biological assumptions of the study are detailed below.

A1. All tagged fish have similar probabilities of downstream detection.

Of the 1,901 radio-tagged yearling Chinook salmon detected at Ice Harbor Dam, 1,705 (89.7% of those observed) were detected either at or below the primary survival transect at Goose Island. Detection probability for fish used in survival analysis at Ice Harbor Dam was 0.970 overall (Appendix Table A1).

Of the 1,954 radio-tagged juvenile steelhead detected at Ice Harbor Dam, 1,763 (90.2% of those observed) were detected either at or below the primary survival transect. Detection probability for fish used in survival analysis at Ice Harbor Dam was 0.971 overall (Appendix Table A1).

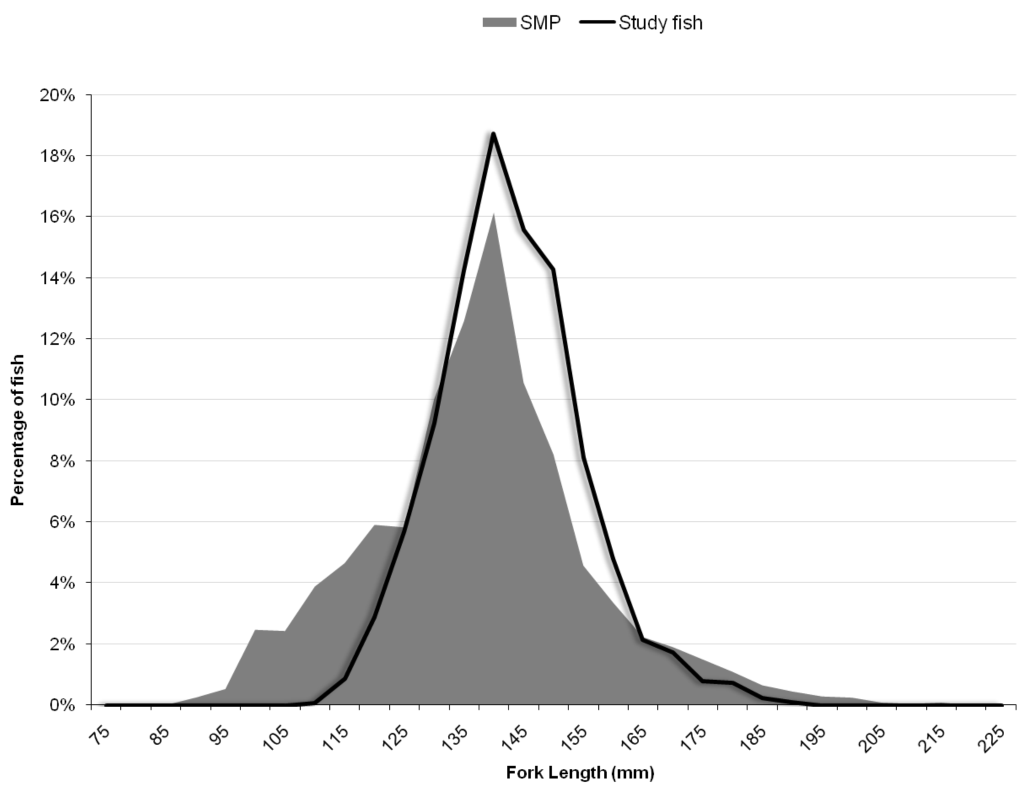
Of the 2,592 radio-tagged subyearling Chinook salmon detected at Ice Harbor Dam, 2,204 (85.0% of those observed) were detected either at or below the primary survival transect. Detection probability for fish used in survival analysis at Ice Harbor Dam was 0.981 overall (Appendix Table A1).

Appendix Table A1. Treatment fish released above Ice Harbor Dam and detected at or below the primary survival transect. These detections were used for evaluating survival of yearling and subyearling Chinook salmon and steelhead at Ice Harbor Dam, 2009.

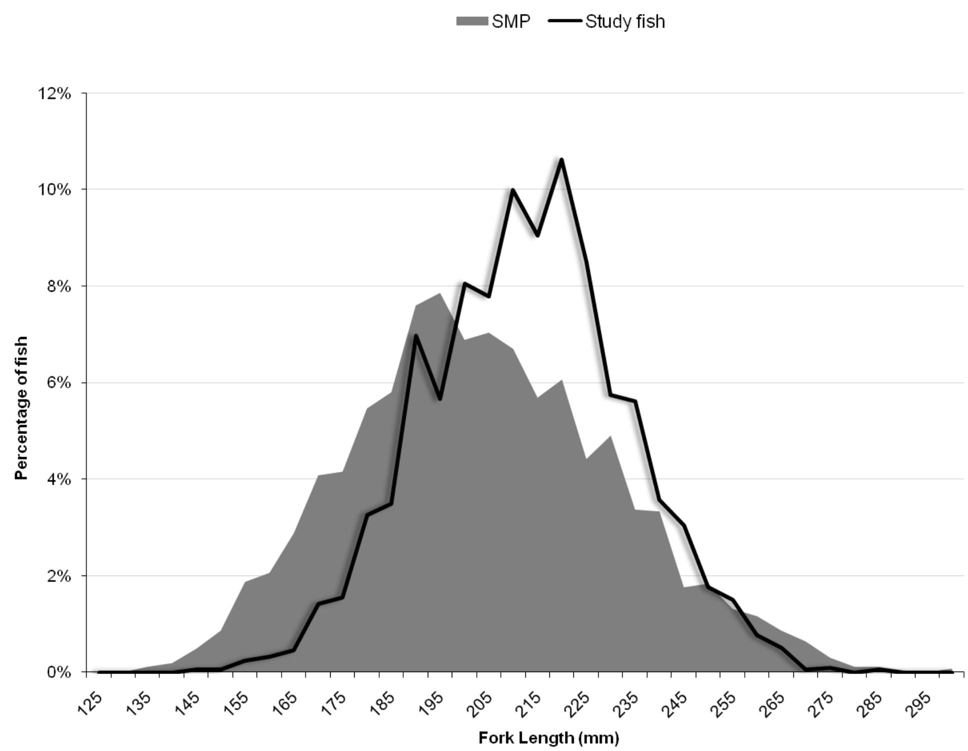
Species	Detected at Goose Island	Detected at or below Goose Island	Detection probability
Yearling Chinook salmon	1,654	1,705	0.970
Juvenile steelhead	1,712	1,763	0.971
Subyearling Chinook salmon	2,161	2,204	0.981

A2. Individuals tagged for the study are a representative sample of the population of interest.

Unmarked yearling Chinook salmon and juvenile steelhead were collected, radio tagged, and PIT tagged at Lower Monumental for 27 d from 27 April to 23 May. Collection and tagging began after approximately 2.1% of the yearling Chinook salmon and 1.0% of the juvenile steelhead had passed Lower Monumental Dam and was completed when more than 82% of these fish had passed (Figure 3). Overall mean fork length for 2,202 yearling Chinook salmon that were tagged and released was 141.2 mm (SD = 11.7, Table 4) and overall mean weight was 26.5 g (SD = 7.0, Table 5). Overall mean fork length for 2,200 steelhead was 210.9 mm (SD = 17.8, Table 6) and overall mean weight was 83.9 g (SD = 23.0, Table 7). Appendix Figures A2a and A2b display comparisons between smolt monitoring data (SMP) and fish used for this study. The difference in steelhead distribution is a result of the wild fish collected which were not tagged for this study.

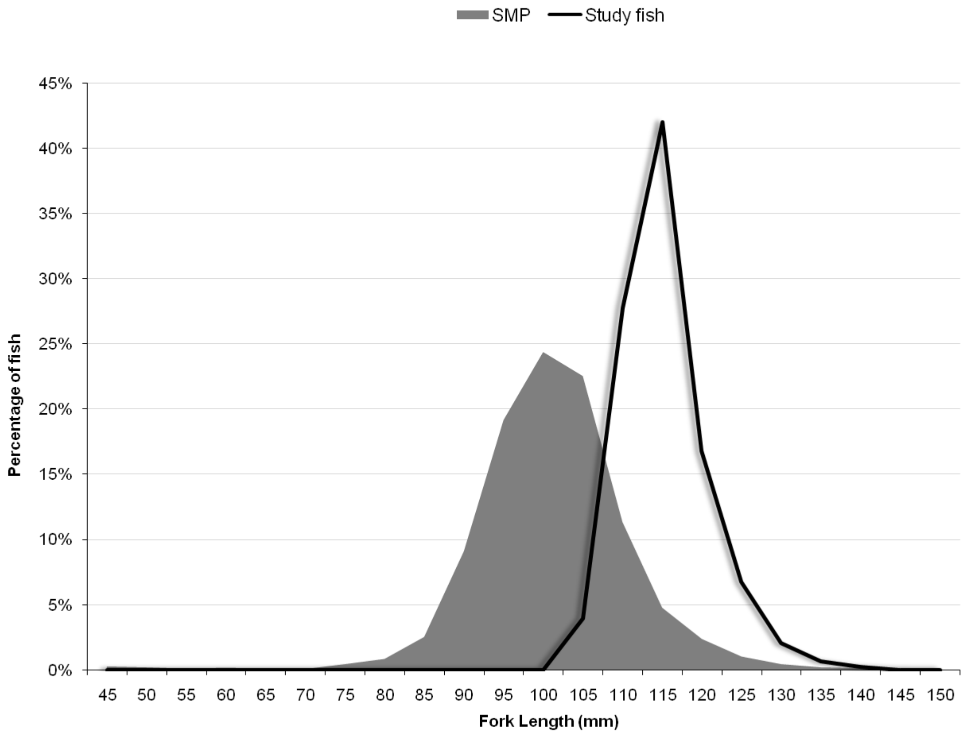


Appendix Figure A2a. Size distribution for SMP collection of yearling Chinook salmon and those tagged for evaluations at Ice Harbor Dam, 2009.



Appendix Figure A2b. Size distribution for SMP collection of juvenile steelhead and those tagged for evaluations at Ice Harbor Dam, 2009.

Unmarked subyearling Chinook salmon were collected, radio tagged, and PIT tagged at Lower Monumental for 24 d from 9 June to 2 July. Collection and tagging began after approximately 47% of the subyearling Chinook salmon had passed Lower Monumental Dam and was completed when more than 89% of these fish had passed (Figure 4). Overall mean fork length for 4,363 subyearling Chinook salmon was 113.1 mm (SD = 5.2, Table 8) and overall mean weight was 12.6 g (SD = 2.0, Table 9). Appendix Figure A2c displays comparisons between smolt monitoring data (SMP) and fish used for this study.



Appendix Figure A2c. Size distribution for SMP collection of subyearling Chinook salmon and those tagged for evaluations at Ice Harbor Dam, 2009.

A3. The tag and/or tagging method does not significantly affect the subsequent behavior or survival of the marked individual.

Assumption A3 was not tested for validation in this study. However, the effects of radio tagging on survival, predation, growth, and swimming performance of juvenile salmonids have previously been evaluated by Adams et al. (1998a,b) and Hockersmith et al. (2003). From their conclusions, we assumed that behavior and survival were not significantly affected over the length of our study area.

A4. Radio transmitters functioned properly and for the predetermined study period.

All transmitters were checked upon receipt from the manufacturer, prior to implantation into a fish and prior to release, to ensure that the transmitter was functioning properly. A total of 4,436 tags were implanted in yearling Chinook salmon and steelhead, of which 24 (0.5%) were not working 24 hours after tagging. A total of 4,429 tags were implanted in subyearling Chinook salmon, of which 11 (0.2%) were not working 24 h after tagging. All fish with tags that were not functioning properly were excluded from the study.

In addition, a total of 143 radio transmitters throughout the spring study were tested for tag life by allowing them to run in river water and checking them daily to determine if they functioned for the predetermined period of time (Appendix Table A2). Maximum median travel time from release to Ice Harbor Dam was 3.2 days overall with less than 0.1% of the fish overall taking 8 days or more (max = 8.2 d) to reach Ice Harbor Dam (Table 17).

Appendix Table A2. Frequency of days tags lasted in tag life testing, 2009.

Tag life (d)	Number of tags	Percent of tags (%)
1	0	0
2	0	0
3	0	0
4	0	0
5	1	0.7
6	2	1.4
7	3	2.1
8	2	1.4
9+	135	94.4

APPENDIX B

Telemetry Data processing and Reduction Flowchart

Overview

Data collected for the Juvenile Salmon Radio Telemetry project is stored by personnel at the Fish Ecology Division of the NMFS Northwest Fisheries Science Center. This project tracks migration and passage routes of juvenile salmon and steelhead at dams on the Columbia and Snake Rivers. Data is collected using a network of radio receivers that record signals emitted from radio transmitters ("tags") implanted in fish. Special emphasis is placed on route of passage and survival through individual routes at the various hydroelectric dams. Data stored in the database include observations of tagged fish and the locations and configurations of radio receivers and antennas.

Database Inputs

The majority of data supplied to the database are observations of tagged fish recorded at the various radio receivers, which the receivers store in hexadecimal-formal files ("hex" files). The files are saved to a central computer four times daily, and placed on an FTP server automatically once per day for downloading into the database.

In addition data in the form of a daily updated tag files, which contains the attributes of each fish tagged, along with the channel and code of the transmitter used and the date, time, and location of release after tagging.

Database Outputs

Data are consolidated into a summary form that lists each fish and receiver on which it was detected, and includes the specifics of the first and last hits and the total number of detections for each series where there was no more than a 5-minute gap between detections. This summarized data is used for data analyses.

Processes

The processes in this database fall into three main categories or stages in the flow of data from input to output: loading, validation, and summarization.

A. **Data Loading.** The loading process consists of copying data files from their initial locations to the database server, converting the files from their original format into a format readable by SQL, and having SQL read the files and store the data in preliminary tables.

B. **Data Validation.** During the validation process, the records stored in the preliminary tables are analyzed. We determine which study year, site identifier, ant identifier, and tag identifier they belong to, flagging them as invalid if one or more of these relationships cannot be determined. Records are flagged by storing brief comments in the edit notes field. Values of edit notes associated with each record are as follows:

***Null*:** denotes a valid observation of a tag.

Not Tagged: Denotes an observation of a channel-code combination that was not in use at the time. Such values are likely due to radio-frequency noise being picked up at an antenna.

***Noise Record**:* Denotes an observation where the code is equal to 995, 997, or 999. These are not valid records, and relate to radio-frequency noise being picked up at the antenna.

Beacon Record: Hits recorded on channel = 5, code = 575, which is being used to ensure proper functioning of the receivers. This combination does not indicate the presence of a tagged fish.

Invalid Record Date: Denotes an observation whose date/time is invalid (occurring before we started the database; prior to Jan. 1, 2004, or some time in the future). Due to improvements in the data loading process, such records are unlikely to arise.

Invalid Site: Denotes an observation attributed to an invalid (non-existent) site. These are typically caused by typographical errors in naming hex files at the receiver end. They should not be present in the database, since they should be filtered out during the data loading process.

Invalid Antenna: Denotes an observation attributed to an invalid (non-existent) antenna. These are most likely due to electronic noise within the receiver.

Lt start time: Assigned to records occurring prior to the time a tag was activated (its start time).

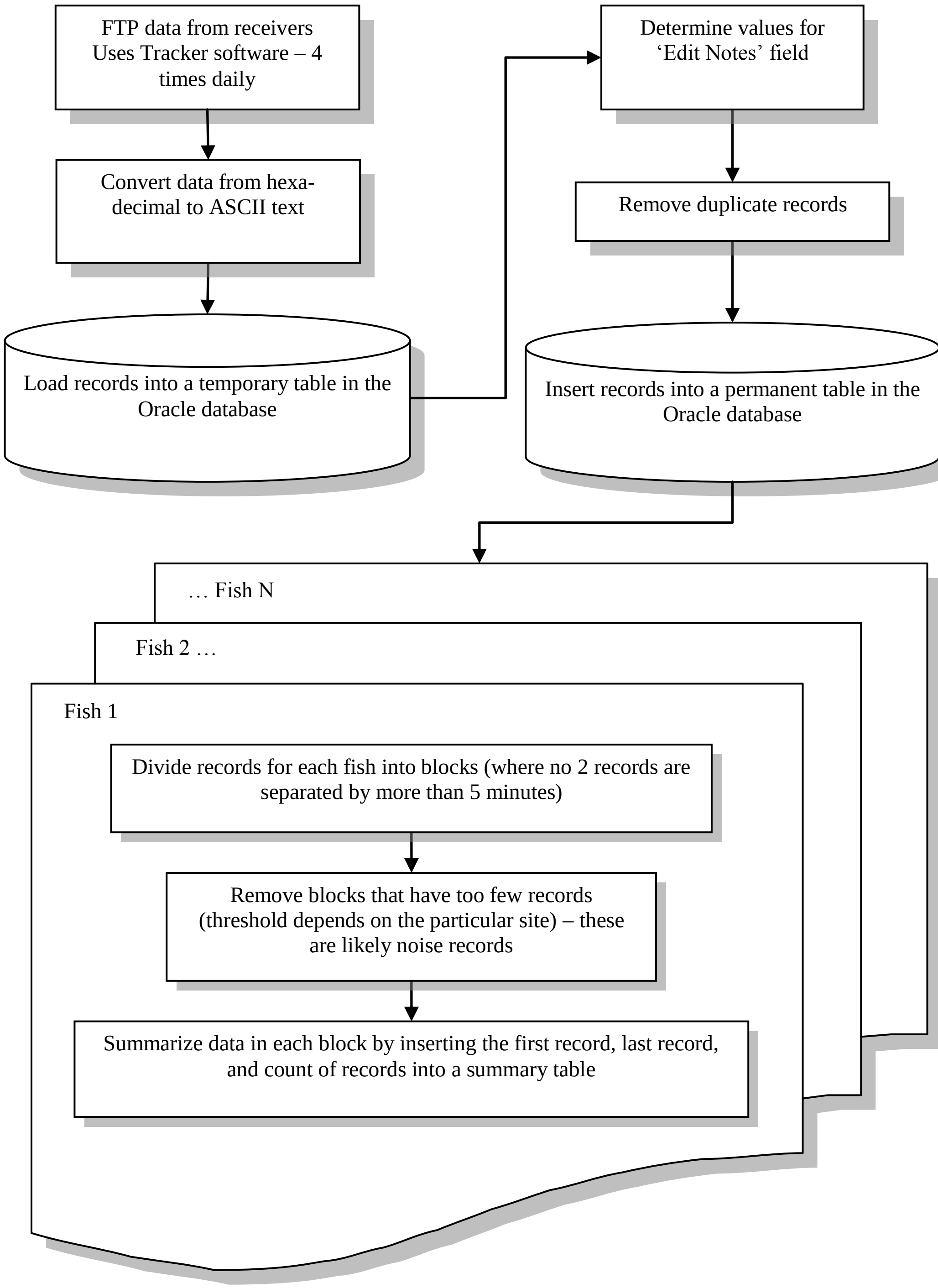
Gt end_time: Assigned to records occurring after the end time on a tag (they run for 10 days once activated).

Gt 40 recs: Denotes tags that registered more than 40 records per minute on an individual receiver. This is not possible as the tags emit a signal every 2 seconds (30/minute). Such patterns indicate noise.

In addition, duplicate records (records for which the channel, code, site, antenna, date and time are the same as those of another record). Finally, the records are copied from the preliminary tables into the appropriate storage table based on study year. The database can accommodate multiple years with differing site and antenna configuration. Once a record's study year has been determined, its study year, site, and antenna are used to match it to a record in the sites table.

C. **Generation of Summary Tables.** The summary table summarizes the first detection, last detection, and count of detections for blocks of records within a site for a single fish where no two consecutive records are separated by more than a specified number of minutes (currently using 5 minutes).

Flow Chart



Appendix Figure B1. Flowchart of telemetry data processing and reduction used in evaluating behavior and survival at Ice Harbor Dam for yearling Chinook salmon, steelhead, and subyearling Chinook salmon, 2009.

APPENDIX C

Detection history data for yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon

Appendix Table C1. Detection histories of radio-tagged fish released above Ice Harbor Dam to evaluate ***dam*** passage survival during spring spill treatments for Chinook salmon and steelhead and during summer spill treatments for subyearling Chinook salmon, 2009. Arrays are shown in Figure 1. Detection histories are 1 = detected, 0 = not detected.

	Detection history		
Virtual releases (n)	Primary survival array	Post primary array	n
	Yearling Chinook salmon		
BiOp Treatment group (660)	0	0	75
	1	0	146
	0	1	14
	1	1	425
30% Treatment group (585)	0	0	50
	1	0	141
	0	1	8
	1	1	386
	Juvenile steelhead		
BiOp Treatment group (761)	0	0	75
	1	0	190
	0	1	14
	1	1	482
30% Treatment group (591)	0	0	60
	1	0	143
	0	1	9
	1	1	379
	Subyearling Chinook salmon		
BiOp Treatment group (1,216)	0	0	188
	1	0	256
	0	1	18
	1	1	754
30% Treatment group (1,245)	0	0	186
	1	0	235
	0	1	21
	1	1	803

Appendix Table C2. Detection histories of radio-tagged fish released above Ice Harbor Dam to evaluate ***concrete*** passage survival during spring spill treatments for Chinook salmon and steelhead and during summer spill treatments for subyearling Chinook salmon, 2009. Arrays are shown in Figure 1. Detection histories are 1 = detected, 0 = not detected.

	Detection history		
Virtual releases (n)	Primary survival array	Post primary array	n
	Yearling Chinook salmon		
BiOp Treatment group (770)	0	0	68
	1	0	178
	0	1	16
	1	1	508
30% Treatment group (571)	0	0	40
	1	0	145
	0	1	9
	1	1	377
	Juvenile steelhead		
BiOp Treatment group (839)	0	0	51
	1	0	227
	0	1	21
	1	1	540
30% Treatment group (572)	0	0	36
	1	0	149
	0	1	11
	1	1	376
	Subyearling Chinook salmon		
BiOp Treatment group (1,201)	0	0	125
	1	0	265
	0	1	19
	1	1	792
30% Treatment group (1,223)	0	0	110
	1	0	249
	0	1	23
	1	1	841

Appendix Table C3. Detection histories of radio-tagged fish released above Ice Harbor Dam to evaluate ***spillway*** passage survival during spring spill treatments for Chinook salmon and steelhead and during summer spill treatments for subyearling Chinook salmon, 2009. Arrays are shown in Figure 1. Detection histories are 1 = detected, 0 = not detected.

	Detection history		
Virtual releases (n)	Primary survival array	Post primary array	n
	Yearling Chinook salmon		
BiOp Treatment group (725)	0	0	60
	1	0	170
	0	1	13
	1	1	482
30% Treatment group (446)	0	0	29
	1	0	114
	0	1	4
	1	1	299
	Juvenile steelhead		
BiOp Treatment group (742)	0	0	36
	1	0	192
	0	1	15
	1	1	499
30% Treatment group (402)	0	0	26
	1	0	96
	0	1	3
	1	1	277
	Subyearling Chinook salmon		
BiOp Treatment group (1,004)	0	0	120
	1	0	233
	0	1	15
	1	1	636
30% Treatment group (720)	0	0	83
	1	0	143
	0	1	9
	1	1	485

Appendix Table C4. Detection histories of radio-tagged fish released above Ice Harbor Dam to evaluate passage survival through the ***JBS*** during spring spill treatments for Chinook salmon and steelhead and during summer spill treatments for subyearling Chinook salmon, 2009. Arrays are shown in Figure 1. Detection histories are 1 = detected, 0 = not detected.

	Detection history		
Virtual releases (n)	Primary survival array	Post primary array	n
	Yearling Chinook salmon		
BiOp Treatment group (45)	0	0	8
	1	0	8
	0	1	3
	1	1	26
30% Treatment group (124)	0	0	10
	1	0	31
	0	1	5
	1	1	78
	Juvenile steelhead		
BiOp Treatment group (91)	0	0	12
	1	0	34
	0	1	6
	1	1	39
30% Treatment group (169)	0	0	9
	1	0	53
	0	1	8
	1	1	99
	Subyearling Chinook salmon		
BiOp Treatment group (71)	0	0	4
	1	0	14
	0	1	1
	1	1	52
30% Treatment group (402)	0	0	21
	1	0	81
	0	1	12
	1	1	288

Appendix Table C5. Detection histories of radio-tagged fish released above Ice Harbor Dam to evaluate ***RSW*** passage survival during spring spill treatments for Chinook salmon and steelhead and during summer spill treatments for subyearling Chinook salmon, 2009. Arrays are shown in Figure 1. Detection histories are 1 = detected, 0 = not detected.

	Detection history		
Virtual releases (n)	Primary survival array	Post primary array	n
	Yearling Chinook salmon		
BiOp Treatment group (243)	0	0	21
	1	0	58
	0	1	7
	1	1	157
30% Treatment group (331)	0	0	22
	1	0	92
	0	1	4
	1	1	213
	Juvenile steelhead		
BiOp Treatment group (227)	0	0	21
	1	0	56
	0	1	6
	1	1	144
30% Treatment group (271)	0	0	22
	1	0	61
	0	1	2
	1	1	186
	Subyearling Chinook salmon		
BiOp Treatment group (258)	0	0	33
	1	0	48
	0	1	6
	1	1	171
30% Treatment group (459)	0	0	41
	1	0	89
	0	1	8
	1	1	321

APPENDIX D

Ice Harbor Dam Operations

Appendix Table D1. Average daily flow (kcfs) by turbine unit and spill bay at Ice Harbor Dam during spring BiOp spill operations, 2009.

	Turbines—BiOp						Spill bays—BiOp									
Date	1	2	3	4	5	6	1	RSW	3	4	5	6	7	8	9	10
28 April	6.0	0.0	10.5	6.7	5.5	0.0	0.0	7.8	4.1	10.4	4.6	8.8	8.8	6.1	6.0	3.5
29 April	5.8	1.3	10.4	6.4	4.8	0.0	0.0	7.8	4.2	10.1	4.7	8.6	8.6	6.0	5.8	3.5
30 April	0.3	0.2	9.9	0.3	0.2	0.0	0.0	7.8	9.9	9.8	10.1	8.4	8.2	8.5	8.1	3.5
02 May	9.1	0.0	12.1	0.6	0.0	0.0	0.0	7.8	1.6	10.0	3.1	8.5	8.5	5.0	5.0	3.5
03 May	5.0	0.0	9.3	5.4	0.0	0.0	0.0	7.8	1.0	10.0	4.5	8.5	8.5	5.7	5.6	3.5
04 May	0.4	0.0	10.2	0.1	0.0	0.0	0.0	7.8	5.2	10.0	10.1	8.4	8.2	8.2	8.1	3.5
06 May	10.7	7.5	11.0	8.8	8.7	7.0	0.0	7.8	4.3	10.6	3.7	9.5	9.5	6.0	6.0	3.5
07 May	5.9	5.0	10.7	6.4	6.4	4.1	0.0	7.8	6.4	11.2	6.0	10.1	10.2	7.3	7.3	3.6
08 May	0.5	0.1	10.6	0.4	0.3	0.0	0.0	7.8	13.3	13.0	13.3	12.9	13.2	11.6	11.6	3.8
12 May	7.9	0.0	9.8	8.5	2.8	0.7	0.0	7.7	2.6	10.1	3.1	8.6	8.5	5.2	5.1	3.5
13 May	5.1	0.8	10.2	6.2	5.8	0.0	0.0	7.7	1.7	10.1	4.5	8.6	8.7	6.0	5.7	3.5
14 May	0.3	0.0	10.0	0.1	0.1	0.0	0.0	7.7	10.0	9.9	10.0	9.8	9.8	9.9	8.3	3.4
16 May	7.6	5.3	10.8	8.3	6.3	0.0	0.0	8.1	3.3	10.4	3.2	8.8	8.8	5.3	5.3	3.5
17 May	6.1	5.7	10.7	6.5	6.4	0.0	0.0	8.1	5.3	10.8	5.0	9.4	9.4	6.4	6.4	3.6
18 May	8.4	5.9	10.5	9.0	6.5	0.8	0.0	8.1	5.8	10.9	5.0	9.6	9.6	6.8	6.8	3.6
19 May	12.1	8.6	12.0	13.1	11.7	10.1	0.0	7.9	5.7	10.8	8.2	9.9	9.9	7.1	7.5	3.7
20 May	10.2	10.5	9.9	10.9	11.2	10.1	0.0	7.8	11.7	11.7	11.6	11.6	11.6	11.6	10.0	4.3

Appendix Table D2. Average daily flow (kcfs) by turbine unit and spill bay at Ice Harbor Dam during spring 30% spill operations, 2009.

	Turbines—30%						Spill bays—30%									
Date	1	2	3	4	5	6	1	RSW	3	4	5	6	7	8	9	10
30 April	10.5	11.0	10.5	11.6	11.4	0.0	0.0	7.8	8.4	0.0	3.0	0.0	1.1	1.1	1.1	1.7
01 May	10.3	11.0	10.4	11.1	11.1	0.0	0.0	7.8	8.4	0.0	0.0	0.4	1.8	1.7	1.7	1.7
02 May	10.1	11.0	9.9	10.7	10.2	0.0	0.0	7.8	8.3	0.0	0.0	0.0	1.7	1.6	1.6	1.6
04 May	12.6	9.1	12.7	12.3	12.4	2.7	0.0	7.8	8.3	0.0	5.8	0.3	0.6	0.6	1.8	1.8
05 May	10.8	10.8	11.0	12.1	12.1	1.8	0.0	7.8	8.3	0.0	1.8	1.4	1.4	1.7	1.7	1.7
06 May	10.9	11.0	10.7	11.5	12.0	11.0	0.0	7.8	8.2	0.0	8.2	0.1	0.1	1.7	1.6	1.6
08 May	12.2	11.0	12.2	13.3	13.2	13.0	0.0	7.8	8.5	0.0	8.4	0.0	0.0	1.8	1.9	3.8
09 May	10.5	10.8	10.6	11.6	11.5	10.1	0.0	7.8	8.4	0.0	8.4	0.0	0.0	0.7	1.0	2.2
10 May	12.2	11.0	12.3	13.4	13.3	0.0	0.0	7.8	8.3	0.0	6.2	0.5	0.5	1.1	1.1	1.8
11 May	11.2	6.0	11.2	12.4	12.0	0.3	0.0	7.7	8.5	0.0	0.0	0.7	0.7	1.1	1.9	2.2
12 May	11.6	0.0	11.4	12.5	12.4	0.0	0.0	7.7	8.8	0.0	0.0	0.0	0.0	0.0	2.0	2.6
14 May	11.2	10.9	11.6	12.6	12.7	2.0	0.0	7.7	8.5	0.0	1.8	1.4	1.4	1.7	2.0	2.1
15 May	11.3	8.8	11.1	12.2	12.1	8.4	0.0	7.8	7.9	0.0	6.0	0.1	0.2	1.5	2.0	2.2
16 May	12.2	11.0	12.2	13.6	13.4	12.8	0.0	7.7	8.3	0.3	8.2	0.2	0.2	1.9	3.3	3.3

Appendix Table D3. Average gate openings (stops) by spill bay at Ice Harbor Dam during spring BiOp spill operations, 2009.

	Spill bays—BiOp									
Date	1	RSW	3	4	5	6	7	8	9	10
28 April	0.0	4.7	2.5	6.2	2.7	5.2	5.2	3.6	3.6	2.0
29 April	0.0	4.7	2.5	6.0	2.8	5.1	5.1	3.6	3.4	2.0
30 April	0.0	4.7	5.9	5.9	6.1	5.0	4.9	5.1	4.8	2.0
02 May	0.0	4.6	0.9	6.0	1.8	5.1	5.1	3.0	2.9	2.1
03 May	0.0	4.7	0.6	6.0	2.7	5.1	5.1	3.4	3.3	2.1
04 May	0.0	4.7	3.1	6.0	6.0	5.0	4.9	4.9	4.8	2.0
06 May	0.0	4.6	2.6	6.4	2.2	5.7	5.7	3.6	3.6	2.1
07 May	0.0	4.7	3.8	6.8	3.6	6.1	6.1	4.4	4.4	2.1
08 May	0.0	4.7	8.1	7.8	8.0	7.8	8.0	7.0	7.0	2.2
12 May	0.0	4.6	1.6	6.1	1.8	5.1	5.1	3.1	3.0	2.1
13 May	0.0	4.6	1.0	6.0	2.7	5.1	5.2	3.6	3.4	2.1
14 May	0.0	4.6	6.0	5.9	6.0	5.9	5.9	5.9	4.9	2.0
16 May	0.0	4.8	2.0	6.2	1.9	5.2	5.2	3.2	3.1	2.1
17 May	0.0	4.8	3.2	6.5	3.0	5.6	5.6	3.8	3.8	2.1
18 May	0.0	4.8	3.5	6.5	3.0	5.7	5.7	4.1	4.1	2.1
19 May	0.0	4.7	3.4	6.5	4.9	5.9	5.9	4.3	4.5	2.2
20 May	0.0	4.6	7.0	7.0	7.0	7.0	7.0	7.0	6.0	2.5

Appendix Table D4. Average gate openings (stops) by spill bay at Ice Harbor Dam during spring 30% spill operations, 2009.

	Spill bays—30%									
Date	1	RSW	3	4	5	6	7	8	9	10
30 April	0.0	4.6	5.0	0.0	1.7	0.0	0.7	0.7	0.6	1.0
01 May	0.0	4.7	5.0	0.0	0.0	0.2	1.0	1.0	1.0	1.0
02 May	0.0	4.7	5.0	0.0	0.0	0.0	1.0	1.0	0.9	0.9
04 May	0.0	4.6	5.0	0.0	3.4	0.2	0.3	0.3	1.1	1.1
05 May	0.0	4.7	4.9	0.0	1.0	0.8	0.8	1.0	1.0	1.0
06 May	0.0	4.7	4.9	0.0	4.9	0.0	0.0	1.0	1.0	1.0
08 May	0.0	4.6	5.1	0.0	5.0	0.0	0.0	1.1	1.1	2.2
09 May	0.0	4.6	5.0	0.0	5.0	0.0	0.0	0.4	0.6	1.3
10 May	0.0	4.6	4.9	0.0	3.7	0.3	0.3	0.6	0.6	1.1
11 May	0.0	4.6	5.1	0.0	0.0	0.4	0.4	0.6	1.1	1.3
12 May	0.0	4.6	5.3	0.0	0.0	0.0	0.0	0.0	1.2	1.5
14 May	0.0	4.6	5.0	0.0	1.1	0.8	0.8	1.0	1.2	1.2
15 May	0.0	4.7	4.7	0.0	3.6	0.1	0.1	0.9	1.2	1.3
16 May	0.0	4.6	4.9	0.1	4.9	0.1	0.1	1.1	1.9	1.9

Appendix Table D5. Average daily flow (kcfs) by turbine unit and spill bay at Ice Harbor Dam during summer BiOp spill operations, 2009.

	Turbines—BiOp						Spill bays—BiOp									
Date	1	2	3	4	5	6	1	RSW	3	4	5	6	7	8	9	10
12 June	6.7	7.5	9.8	7.3	7.4	6.6	0.0	7.7	4.2	11.0	3.6	9.8	9.4	5.9	5.9	3.3
13 June	0.3	0.0	10.3	0.2	0.1	0.0	0.0	7.7	13.0	12.8	11.4	11.2	11.2	11.3	11.2	3.3
15 June	4.1	6.5	10.4	7.9	7.9	3.8	0.0	7.7	4.2	11.1	3.6	9.4	9.4	6.0	5.9	3.4
16 June	7.9	5.6	11.1	6.3	6.2	0.0	0.0	7.7	6.2	11.2	5.8	10.0	10.0	7.1	7.0	3.5
17 June	10.3	0.3	10.3	0.4	0.5	0.0	0.0	7.7	11.4	11.2	11.5	11.3	11.5	9.8	9.9	3.6
19 June	7.1	7.6	10.2	7.8	7.6	0.1	0.0	7.7	3.7	10.5	3.7	10.0	9.2	6.0	5.4	3.3
20 June	5.2	0.0	9.8	5.7	5.7	0.0	0.0	7.7	4.9	10.2	4.9	9.8	8.9	6.3	5.9	3.3
21 June	0.4	0.0	10.0	0.2	0.1	0.0	0.0	7.7	9.9	9.6	9.9	9.2	8.0	8.1	8.0	3.3
25 June	7.4	0.0	10.6	5.4	5.1	0.0	0.0	7.7	0.0	10.2	3.2	8.5	8.5	3.8	5.0	3.5
26 June	5.7	0.0	10.4	6.3	5.3	0.0	0.0	7.7	2.2	10.2	4.7	8.8	8.8	5.9	4.6	3.6
27 June	5.7	0.0	10.3	6.1	1.7	0.0	0.0	7.7	1.1	10.2	4.7	8.8	8.7	5.2	4.8	3.6
28 June	6.0	0.0	10.7	5.5	2.1	0.0	0.0	7.7	1.5	10.0	4.6	8.4	8.4	5.1	5.7	3.6
29 June	0.5	0.0	10.1	0.4	0.2	0.0	0.0	7.7	6.0	9.8	9.8	8.2	8.0	8.0	8.0	3.3
01 July	7.1	0.0	10.2	2.7	0.0	0.0	0.0	7.7	0.7	9.9	3.2	9.0	8.3	4.8	4.9	3.3
02 July	5.4	0.0	10.1	0.0	0.0	0.0	0.0	7.7	0.0	10.1	4.6	8.5	8.4	3.6	4.5	3.6
03 July	0.2	0.0	10.0	0.4	0.1	0.0	0.0	7.8	0.3	9.9	9.9	8.3	8.4	5.3	8.6	3.9
05 July	3.3	0.0	10.5	1.2	0.0	0.0	0.0	7.7	0.8	10.0	3.0	8.4	8.4	5.0	5.0	3.4
06 July	0.0	0.0	9.8	0.0	0.0	0.0	0.0	7.7	0.0	9.9	2.7	9.2	8.3	3.0	3.2	3.3
07 July	0.1	0.0	9.8	0.1	0.0	0.0	0.0	7.7	0.0	9.8	2.8	8.8	8.2	2.7	3.0	3.3

Appendix Table D6. Average daily flow (kcfs) by turbine unit and spill bay at Ice Harbor Dam during summer 30% spill operations, 2009.

	Turbines—30%						Spill bays—30%									
Date	1	2	3	4	5	6	1	RSW	3	4	5	6	7	8	9	10
13 June	10.7	11.1	10.7	11.6	11.6	9.2	0.0	7.7	8.3	0.0	6.9	0.3	0.3	1.0	1.7	2.0
14 June	10.6	11.3	10.6	11.4	11.4	11.4	0.0	7.7	8.4	0.0	7.0	0.3	0.3	1.3	1.5	2.5
15 June	9.6	11.3	9.7	10.8	10.6	10.5	0.0	7.7	8.5	0.1	8.4	0.1	0.0	0.0	0.0	2.1
17 June	11.9	11.2	12.0	11.6	9.7	11.5	0.0	7.7	8.4	0.0	6.5	0.2	0.4	2.0	2.0	2.0
18 June	11.2	11.3	11.2	12.0	12.5	12.0	0.0	7.7	8.5	0.0	8.4	0.0	0.0	1.6	1.6	2.4
19 June	11.4	11.3	10.8	12.2	12.2	12.1	0.0	7.7	8.4	0.0	8.3	0.0	0.0	1.6	1.6	2.9
21 June	11.6	11.3	11.5	12.6	12.5	0.0	0.0	7.7	8.7	0.0	5.7	0.0	0.5	0.5	1.2	1.6
22 June	10.9	11.2	9.8	12.0	12.0	3.2	0.0	7.7	8.3	0.0	3.8	0.9	0.9	1.1	1.4	1.6
23 June	12.5	3.5	12.5	13.6	13.6	13.5	0.0	7.7	8.8	0.0	8.8	0.1	5.0	2.6	3.7	2.9
24 June	12.4	0.0	12.2	13.6	13.3	13.5	0.0	7.7	8.3	0.0	6.1	0.4	0.5	1.8	1.7	1.6
25 June	12.7	0.0	12.6	13.4	13.8	13.8	0.0	7.7	8.5	0.0	8.6	0.0	0.0	1.4	1.1	1.6
29 June	11.1	0.0	11.2	11.8	11.9	6.0	0.2	7.7	8.3	0.0	1.2	0.0	0.6	0.6	1.8	1.9
30 June	10.2	0.0	10.2	11.2	11.1	8.9	0.0	7.7	7.9	0.0	0.5	0.5	0.6	1.5	1.7	1.8
01 July	9.5	0.0	9.7	10.5	10.5	0.0	0.0	7.7	7.9	0.0	0.0	0.1	0.1	0.1	0.1	1.8
03 July	10.7	0.0	10.6	11.4	11.5	0.0	0.0	7.7	8.4	0.0	0.0	0.0	0.0	0.4	1.1	1.7
04 July	11.1	0.0	11.1	12.0	10.0	3.6	0.0	7.7	7.0	0.0	1.7	0.2	0.7	0.8	1.1	1.7
05 July	10.4	0.0	10.3	11.4	11.4	0.0	0.0	7.7	8.5	0.0	0.0	0.0	0.0	0.0	0.7	1.9
07 July	10.8	0.0	10.8	11.4	9.0	0.0	0.0	7.7	6.8	0.0	0.0	0.2	0.3	0.3	0.6	2.0
08 July	10.6	0.0	10.5	10.2	9.5	2.7	0.0	7.7	7.8	0.0	0.0	0.1	0.1	0.1	1.6	1.6
09 July	11.2	0.0	11.3	11.9	0.0	0.0	0.0	7.7	0.0	0.0	0.0	1.1	1.7	1.7	1.7	1.7
10 July	10.7	0.0	11.0	11.6	2.4	0.0	0.0	7.7	2.0	0.0	0.0	0.7	1.3	1.3	1.3	1.7

Appendix Table D7. Average gate openings (stops) by spill bay at Ice Harbor Dam during summer BiOp spill operations, 2009.

	Spill bays—BiOp									
Date	1	RSW	3	4	5	6	7	8	9	10
12 June	0.0	4.6	2.5	6.6	2.2	5.9	5.6	3.5	3.5	2.0
13 June	0.0	4.6	7.8	7.7	6.9	6.8	6.7	6.8	6.7	1.9
15 June	0.0	4.6	2.5	6.6	2.2	5.6	5.6	3.6	3.5	2.0
16 June	0.0	4.6	3.7	6.8	3.5	6.0	6.0	4.2	4.2	2.0
17 June	0.0	4.6	6.9	6.8	6.9	6.8	6.9	5.9	6.0	2.1
19 June	0.0	4.6	2.2	6.3	2.2	6.0	5.5	3.6	3.2	1.9
20 June	0.0	4.6	2.9	6.1	2.9	5.9	5.3	3.7	3.5	1.9
21 June	0.0	4.6	5.9	5.8	5.9	5.5	4.8	4.8	4.8	1.9
25 June	0.0	4.6	0.0	6.1	1.9	5.1	5.1	2.2	3.0	2.1
26 June	0.0	4.6	1.3	6.1	2.8	5.3	5.2	3.5	2.7	2.1
27 June	0.0	4.6	0.6	6.1	2.8	5.2	5.2	3.1	2.9	2.1
28 June	0.0	4.6	0.9	6.0	2.7	5.0	5.0	3.0	3.4	2.1
29 June	0.0	4.6	3.6	5.9	5.9	4.9	4.8	4.8	4.8	1.9
01 July	0.0	4.6	0.4	5.9	1.9	5.3	4.9	2.8	2.9	2.0
02 July	0.0	4.6	0.0	6.0	2.7	5.1	5.0	2.1	2.7	2.1
03 July	0.0	4.6	0.2	5.9	5.9	4.9	5.0	3.1	5.1	2.3
05 July	0.0	4.6	0.5	6.0	1.8	5.0	5.0	2.9	2.9	2.0
06 July	0.0	4.6	0.0	5.9	1.6	5.5	4.9	1.8	1.9	2.0
07 July	0.0	4.6	0.0	5.9	1.6	5.3	4.9	1.6	1.7	1.9

Appendix Table D8. Average gate openings (stops) by spill bay at Ice Harbor Dam during summer 30% spill operations, 2009.

	Spill bays—30%									
Date	1	RSW	3	4	5	6	7	8	9	10
13 June	0.0	4.6	5.0	0.0	4.1	0.1	0.1	0.6	1.0	1.1
14 June	0.0	4.6	5.0	0.0	4.2	0.2	0.2	0.8	0.9	1.4
15 June	0.0	4.6	5.1	0.0	5.0	0.0	0.0	0.0	0.0	1.3
17 June	0.0	4.6	5.0	0.0	3.9	0.1	0.2	1.2	1.2	1.2
18 June	0.0	4.6	5.0	0.0	5.0	0.0	0.0	1.0	0.9	1.4
19 June	0.0	4.6	5.0	0.0	4.9	0.0	0.0	1.0	0.9	1.7
21 June	0.0	4.6	5.2	0.0	3.4	0.0	0.3	0.3	0.7	1.0
22 June	0.0	4.6	4.9	0.0	2.2	0.5	0.5	0.7	0.8	1.0
23 June	0.0	4.6	5.3	0.0	5.3	0.0	3.0	1.6	2.2	1.7
24 June	0.0	4.6	5.0	0.0	3.6	0.2	0.3	1.1	1.0	1.0
25 June	0.0	4.6	5.0	0.0	5.1	0.0	0.0	0.8	0.6	1.0
29 June	0.1	4.6	5.0	0.0	0.7	0.0	0.3	0.4	1.1	1.1
30 June	0.0	4.6	4.7	0.0	0.2	0.3	0.3	0.9	1.0	1.1
01 July	0.0	4.6	4.7	0.0	0.0	0.0	0.0	0.0	0.0	1.0
03 July	0.0	4.6	5.0	0.0	0.0	0.0	0.0	0.2	0.6	1.0
04 July	0.0	4.6	4.2	0.0	1.0	0.1	0.4	0.5	0.6	1.0
05 July	0.0	4.6	5.1	0.0	0.0	0.0	0.0	0.0	0.4	1.1
07 July	0.0	4.6	4.0	0.0	0.0	0.1	0.2	0.2	0.3	1.2
08 July	0.0	4.6	4.6	0.0	0.0	0.0	0.0	0.0	1.0	1.0
09 July	0.0	4.6	0.0	0.0	0.0	0.6	1.0	1.0	1.0	1.0
10 July	0.0	4.6	1.2	0.0	0.0	0.4	0.7	0.8	0.7	1.0