Technical Report 2010-1

IDAHO COOPERATIVE FISH AND WILDLIFE RESEARCH UNIT

ADULT CHINOOK SALMON PASSAGE BEHAVIOR AT BONNEVILLE DAM IN RELATION TO STRUCTURAL MODIFICATIONS TO THE CASCADES ISLAND FISHWAY-2009

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2725 Montlake Blvd. East, Seattle, WA 98112

For

U. S. Army, Corps of Engineers

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Abstract

We conducted a radiotelemetry study of spring–summer Chinook salmon at Bonneville Dam to evaluate if modifications made at the Cascades Island (CI) fishway to facilitate passage of adult Pacific lamprey and reduce maintenance requirements adversely affected passage of adult salmon. This report compares Bonneville Dam passage time metrics and CI entrance use and passage efficiency metrics collected in April-May 2009 with similar metrics calculated using spring Chinook salmon data collected in 1997-1998, 2000-2004, and 2006-2007. It also compares passage time metrics and CI entrance use and passage efficiency metrics from June 2009 with similar metrics from summer Chinook salmon radio-tagged in June 2002–2004.

Results indicated some behavioral differences near the CI entrance in 2009 relative to previous years. Specifically, a relatively low percentage of spring Chinook salmon that approached the CI fishway opening subsequently entered through it and those that did enter took a relatively longer time to do so in 2009. While river conditions explained some of the differences, there was also some evidence that the modified CI opening may have contributed to the decline in entrance efficiency. We speculate that hydraulic conditions created by the new variable-width weir and/or altered olfactory conditions related to the modifications contributed to the longer salmon passage times. Because effects on salmon appeared to occur principally outside the fishway, we conclude that the hydraulic effects of the floor-mounted bollards and the new lamprey passage structure (LPS) inside the CI fishway had insignificant effects on salmon passage behavior.

This study will be repeated in 2010 to augment the 2009 conclusions and to further evaluate any effects of the CI modifications on adult spring–summer Chinook salmon passage.

Acknowledgements

Many people assisted with the field work and data compilation for this report and its successful completion was made possible through their efforts. They include: Steve Lee and Dennis Quaempts for overseeing the radiotagging of adult salmon, Mark Morasch, Travis Dick, and Dan Joosten for downloading receivers, and Kinsey Frick for administering the database in Seattle. This study was funded by the U.S. Army, Corps of Engineers (USACE), Portland District, with assistance provided by David Clugston, Tammy Mackey, Jon Rerecich, and Robert Stansell.

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Introduction

In 2009, the USACE modified the Cascades Island (CI) fishway opening at Bonneville Dam to reduce maintenance and improve entry efficiency for adult Pacific lampreys (*Lampetra tridentata*). The modifications included a variable-width entrance weir, bollards (a.k.a. "artificial rocks") designed to provide refuges (i.e., reduced water velocities near the fishway floor) for lampreys, and a new lamprey passage structure (LPS) inside the fishway opening designed to provide volitional passage for lampreys to the elevation of the dam forebay (Figure 1). The work was completed prior to the 2009 spring Chinook salmon (*Oncorhynchus tshwaytscha)* migration during winter 2008-2009. Because the CI modifications could affect behavior and passage success of adult salmonids, a radiotelemetry study of spring and early summer Chinook salmon was conducted. A parallel study evaluated behaviors of adult lampreys (see Clabough et al. 2010).

The Chinook salmon study was separated into spring and early summer components in response to mid-season reporting requests from USACE (see Keefer et al. 2009a, 2009b). This final report summarizes results for both runs including passage times, fallback rates, and behaviors of radio-tagged spring and summer Chinook salmon at Bonneville Dam in 2009. Dam passage time metrics and CI entrance use and passage efficiency metrics collected in April-May 2009 were compared with similar metrics from spring Chinook salmon data collected in 1997-1998, 2000-2004, and 2006-2007. Similar metrics for Chinook salmon tagged in June 2009 were compared with data from Chinook salmon radio-tagged in June 2002–2004. The variability in overall dam passage and fallback metrics among years was evaluated to provide context for the more specific CI evaluations. While variation in environmental, operational, and ecological (i.e., the abundance of marine mammal predators) conditions complicated inter-annual comparisons in a strict statistical sense, these comparisons should afford managers insights into any substantive effects the CI modifications may have had on adult Chinook salmon passage at Bonneville Dam in 2009.

Below we describe variation in environmental parameters and dam-wide patterns of adult salmon passage over Bonneville Dam. We then we present the detailed results of passage behavior at the modified Cascades Island fishway opening.

Methods

Radio-tagging

From 26 April through 31 May 2009, we collected and intra-gastrically radio-tagged 376 spring Chinook salmon at the Adult Fish Facility of Bonneville Dam and released them approximately nine kilometers downstream from the dam (Figure 2). The 2009 spring Chinook run was approximately four weeks later than the 10-year average (Columbia River DART: http://www.cbr.washington.edu/dart/adultpass.html) and consequently, 26 April was the latest start date for radio-tagging spring Chinook salmon in all previous study years. We similarly collected and tagged 223 summer Chinook salmon from 1-30 June 2009. A description of the collection and tagging methods is presented in Keefer et al. (2004). A total of 163,466 adult Chinook salmon were counted passing the dam and radio-tagged salmon represented ~0.4% of the salmon counted at the dam during the tagging period.

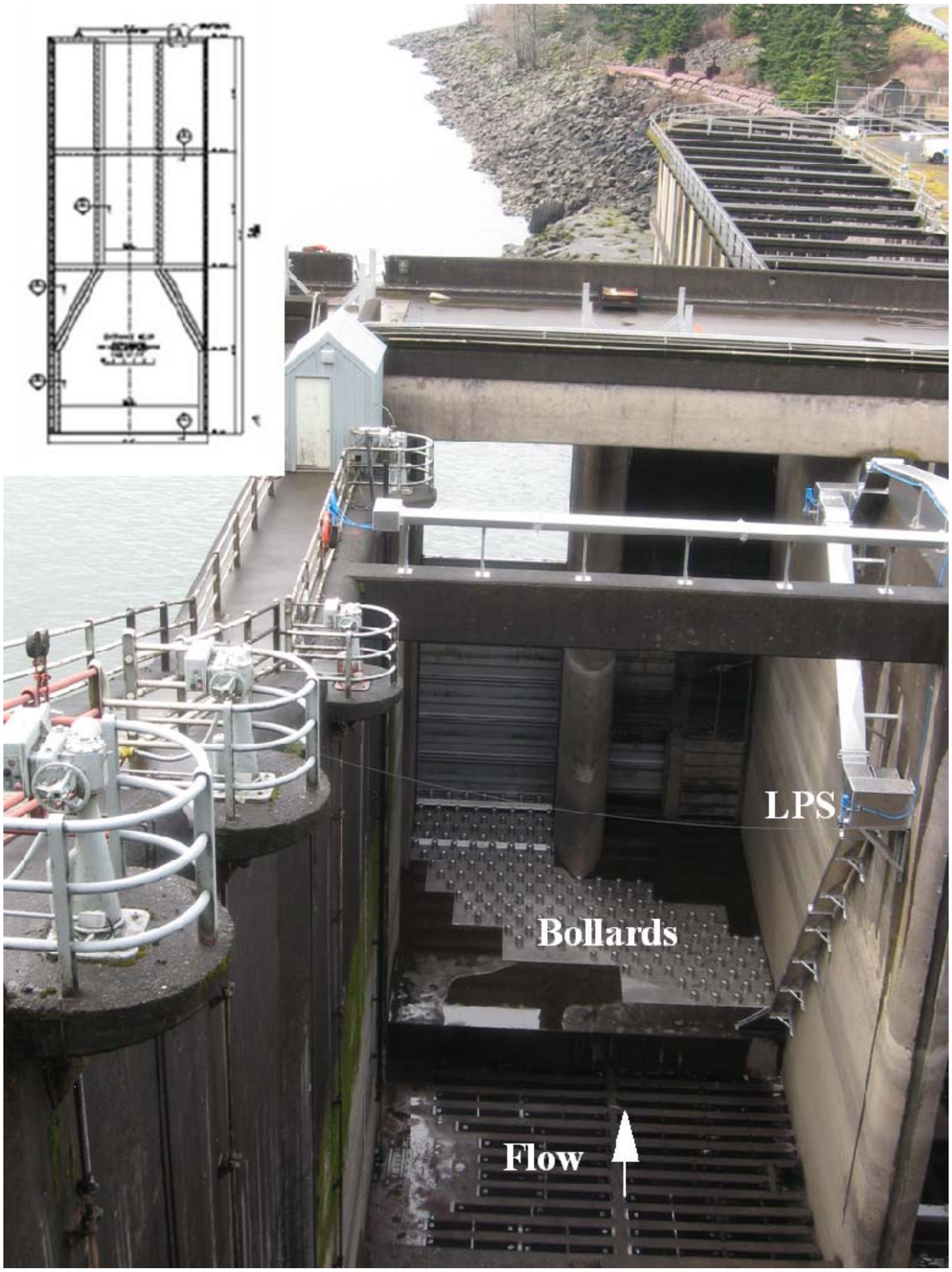

Figure 1. Photograph of area immediately inside the Cascades Island fishway opening. The variable-width weir was installed on the opposite side of the bulkhead downstream from the bollards and lamprey passage structure (LPS). Drawing (inset) shows the profile of the variable width weir, which tapers to a narrower opening near the top.

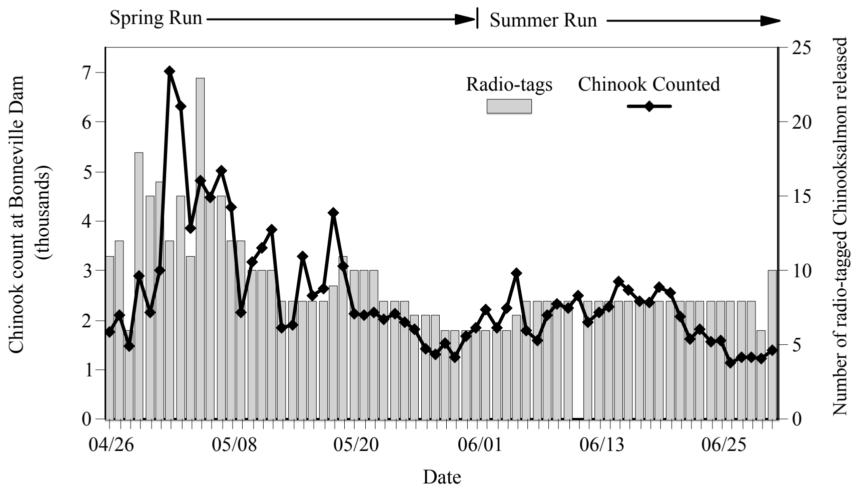

Figure 2. The number of Chinook salmon radio-tagged and released downstream from Bonneville Dam and the count of adult Chinook salmon passing the dam from 26 April through 30 June 2009.

Evaluations of Environmental Data, Passage Times, and Fallback Percentages

For spring Chinook salmon, we compared passage times from April – May 2009 to corresponding values from 1997-1998, 2000-2004, and 2006-2007 for each month and the full tagging season. For summer Chinook salmon, we compared salmon passage times and first fishway approach and entry distributions at Bonneville Dam to corresponding values from June-tagged Chinook salmon in 2002-2004. Potentially confounding factors in our multi-year comparisons were the deployment of sea lion exclusion devices (SLEDs) in 2006-2007, 2009 and variations in spill patterns among years. Across the study years, the spill pattern also shifted toward proportionately more spill through end spillbays, and marine mammal predators have increased. In 2009, sea lion exclusion devices (SLEDs) were deployed at all main fishway openings (Figure 3) until 28 May (Cascades Island), 2 June (Powerhouse 2 and Bradford Island (BI)), or 3 June 2009 (Powerhouse 1). SLEDs were removed from the CI fishway opening on 28 May and so did not affect the June (summer Chinook salmon) analyses.

We used correlation techniques to evaluate the degree of association between CI approach to entry times and four environmental factors: total discharge (flow), spillway discharge, water temperature, and tailwater elevation.

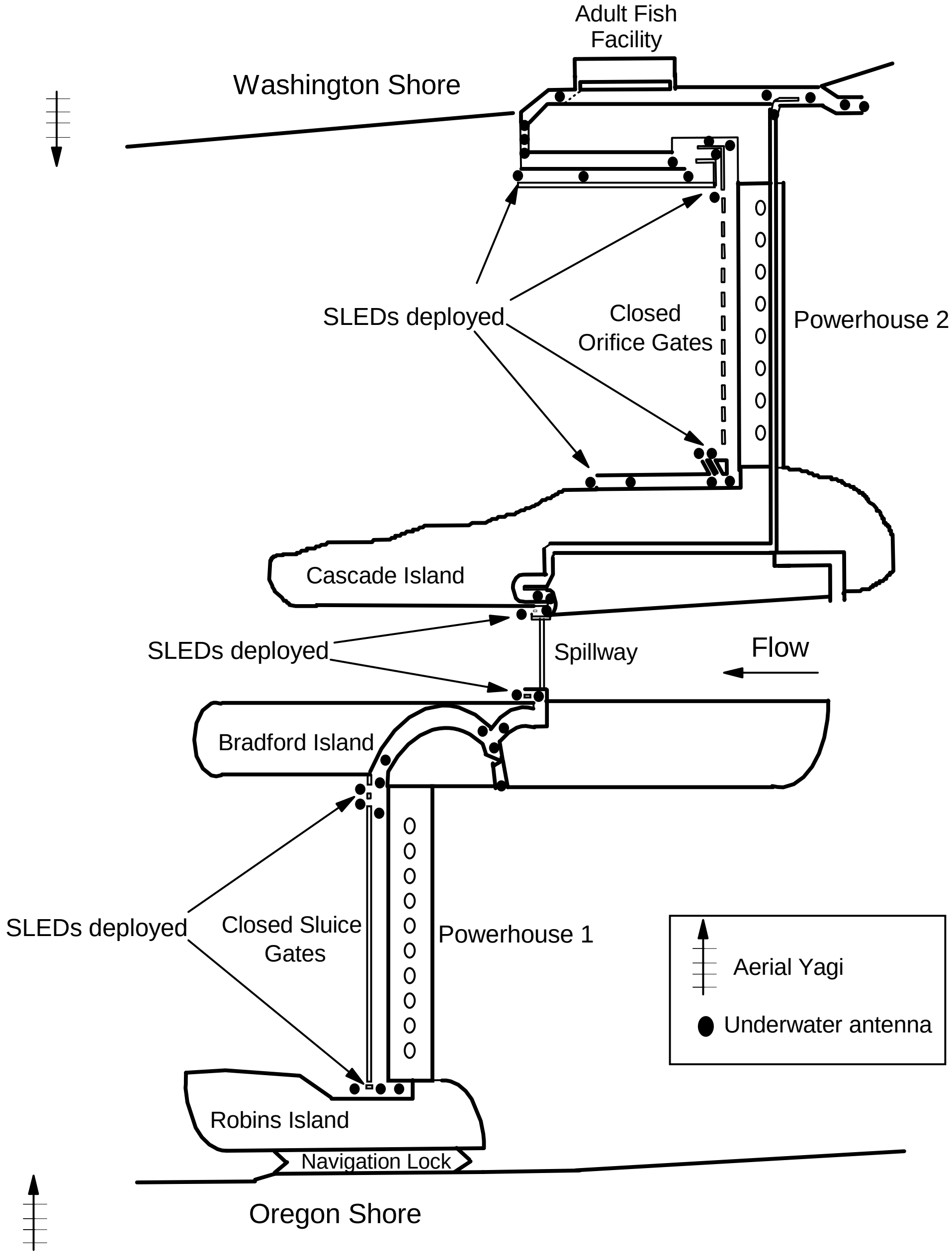

Figure 3. Aerial view of radio antenna and SLED deployments at Bonneville Dam in 2009.

Cascades Island Passage Metrics

We considered five passage time and passage efficiency metrics to help assess potential effects of the CI entrance modifications on adult spring–summer Chinook salmon behavior:

1) CI entrance efficiency. The ratio of unique fish recorded approaching the CI fishway to the number that entered the CI fishway (entrances/approaches).

2) CI exit ratio. The ratio of unique fish recorded exiting the CI fishway into the tailrace to the number that entered the CI fishway (exits/entrances).

3) CI entrance time. The passage time from first CI fishway approach to first CI fishway entrance.

4) CI entrance to base of ladder time. The passage time from first CI fishway entrance to the first record at the antenna located in the transition pool at the base of the ladder.

5) Extended passage time percentages. Because passage times were strongly right-skewed in all years, we calculated the percentage of fish that required > 1 h to pass through the two passage segments (CI approach to CI entrance and CI entrance to the first ladder antenna).

Results

Dam-wide results

Environmental Data

Flow, spillway discharge, and river temperatures in the Bonneville Dam tailrace varied considerably during the spring Chinook salmon runs over the ten study years (Figure 4), which likely contributed to the large observed interannual variation in passage behavior. For example, total river discharge ('flow') ranged from near-record low levels in 2001 (mostly less than 200 kcfs) to about 500 kcfs in 1997. For the summer run of Chinook salmon, total river discharge, spillway discharge, river temperature, and tailwater elevation at Bonneville Dam tailrace were relatively similar among the four study years, though 2002 was characterized by somewhat higher flow, spill, and tailwater elevation (Figure 5).

Figure 4. Mean daily flow, spillway discharge, and tailrace water temperature at Bonneville Dam during the spring Chinook salmon run (April – May), 1997-1998, 2000-2004, 2006-2007, and 2009.

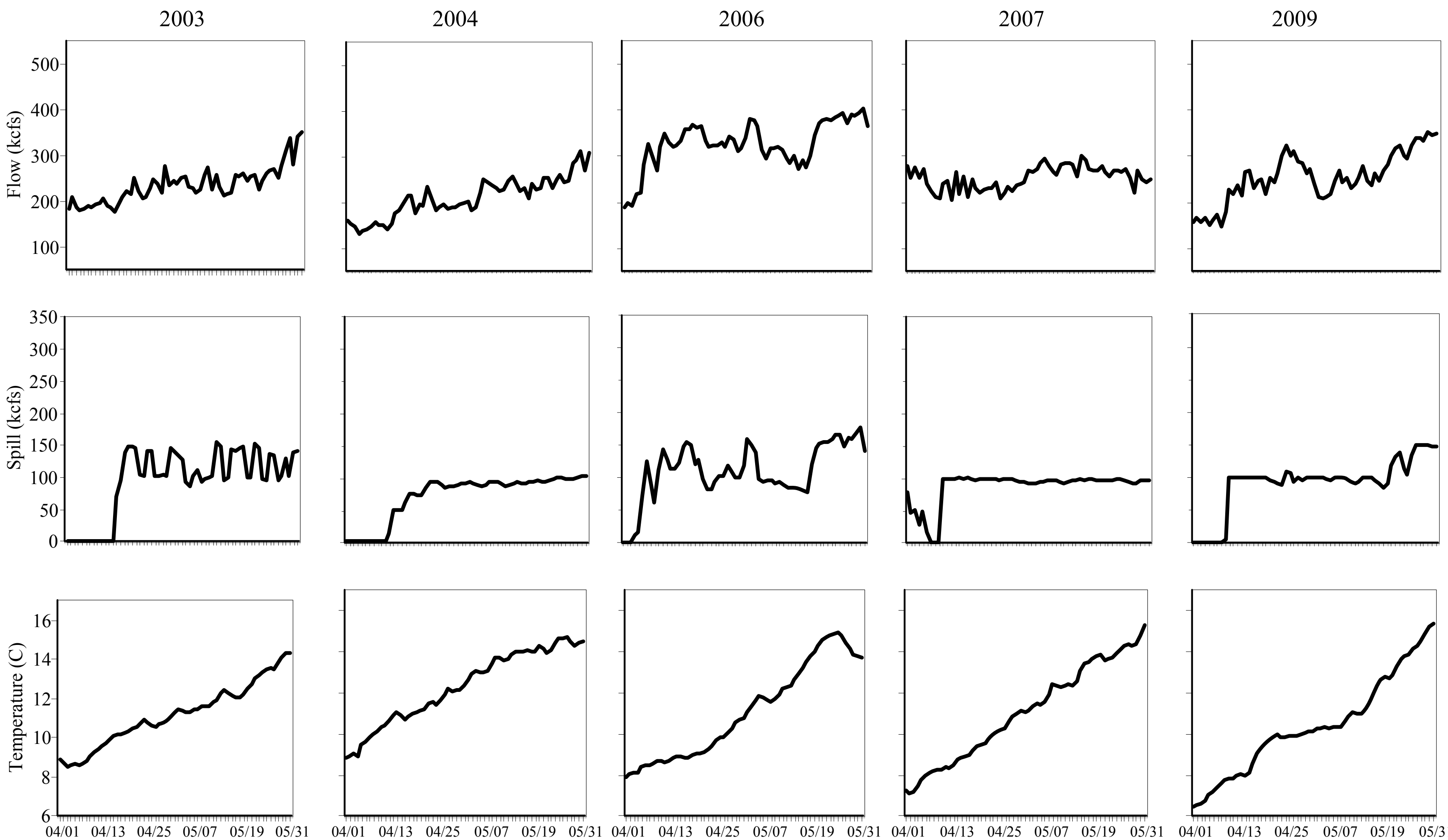

Figure 4 (continued).

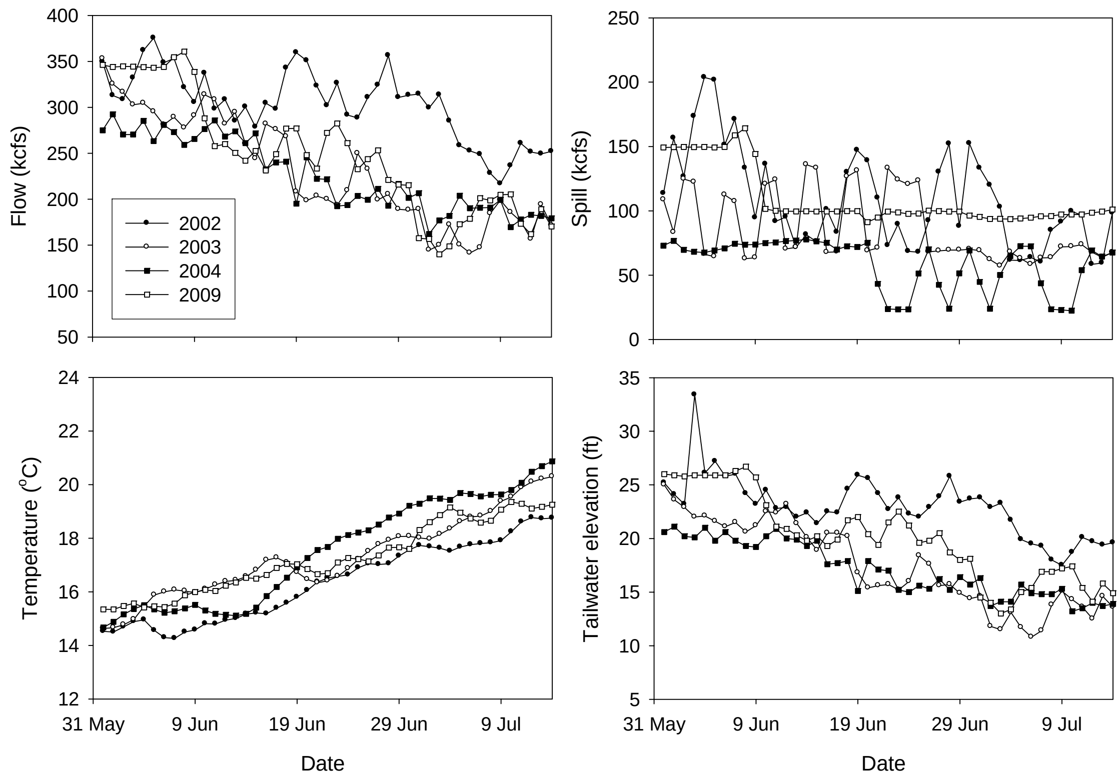

Figure 5. Mean daily flow, spillway discharge, water temperature, and tailrace elevation at Bonneville Dam from 1 June to 15 July, 2002-2004 and 2009.

Passage Events, Routes, and Fallback - 2009

Of the 376 spring Chinook salmon radio-tagged and released through 31 May 2009, 360 (96%) resumed upstream movements and were recorded on receiver sites at the dam and 16 (4%) had no valid telemetry records. Of the 376 released, 335 (86%) passed the dam (Table 1). One hundred and sixty-six passage events (49%) were recorded via the Bradford Island ladder, 159 (49%) were recorded via the Washington-shore ladder, and 6 (2%) likely passed the dam via the unmonitored navigation lock. We recorded 26 fallback events by 24 unique salmon; 23 events by salmon that passed via the Bradford Island ladder and 3 by salmon that passed via the Washington-shore ladder. Eighteen of the 24 (75%) unique, tagged salmon that fell back re-ascended a fishway.

Of the 223 summer Chinook salmon tagged and released in June 2009, 222 (99%) resumed upstream movements and were recorded on receiver sites at the dam and 1 (1%) had no valid telemetry records. Of the 223 released, 219 (98%) passed the dam (Table 2). One hundred and fifteen passage events (53%) were recorded via the Bradford Island ladder, 102 (47%) were via the Washington-shore ladder, and 2 (1%) likely passed the dam via the unmonitored navigation lock. We recorded 10 fallback events by 8 individual salmon. All 10 events followed passage via the Bradford Island ladder and all 8 fallback fish re-ascended a fishway.

Table 1. Range of release dates, number of adult radio-tagged spring Chinook salmon released downstream from Bonneville Dam, and number and percentage of those released that were recorded at the dam, that passed the dam, that were recorded on their first passage of the tailrace, first approach at a fishway opening, first fishway entry, and exit from the top of a ladder, 1997-1998, 2000-2004, 2006-2007, and 2009.

	Frequency									
	1997	1998	2000	2001	2002	2003	2004	2006	2007	2009
Release date range	4/3-5/31	4/1-5/31	4/4-5/31	4/3-5/31	3/31-5/31	3/27-5/31	4/5-5/29	4/14-6/1	4/16-5/29	4/26-5/31
Released downstream	680	675	728	641	658	793	349	358	286	376
Recorded at dam	666	672	725	627	653	757	340	348	273	360
Known to pass dam	656	663	713	617	641	706	312	317	246	335
Recorded first tailrace passage	636	623	693	516	533	663	301	316	230	304
Recorded first fishway approach	638	656	716	605	632	668	319	316	259	344
Recorded first fishway entrance	526	587	592	546	545	587	283	253	246	313
Recorded ladder exit	650	646	707	601	640	698	306	268	246	329
	Percentage of radio-tagged salmon released									
Recorded at dam	98	99	99	98	99	95	97	97	95	96
Known to pass dam	96	98	98	96	97	89	89	89	86	86
Recorded first tailrace passage	94	92	95	80	81	84	86	88	80	81
Recorded first fishway approach	94	97	98	94	96	84	91	88	89	91
Recorded first fishway entrance	77	87	81	85	83	74	81	71	76	83
Recorded ladder exit	96	96	97	94	97	88	88	75	86	88

Table 2. Range of release dates, number of adult radio-tagged summer Chinook salmon released downstream from Bonneville Dam, and numbers and percentages of those released that were recorded at the dam, that passed the dam, that were recorded on their first passage of the tailrace, first approach at a fishway opening, first fishway entry, and exit from the top of a ladder, 2002-2004 and 2009.

	Number (% of released)			
	2002	2003	2004	2009
Release date range	6/1-6/30	6/1-6/30	6/1-6/30	6/1-6/30
Released downstream	165	203	119	223
Recorded at dam	165 (100%)	202 (99%)	115 (97%)	222 (99%)
Known to pass dam	163 (99%)	199 (98%)	114 (96%)	219 (98%)
Recorded 1st tailrace passage	159 (96%)	184 (91%)	109 (92%)	215 (96%)
Recorded 1st fishway approach	161 (98%)	196 (97%)	113 (95%)	215 (96%)
Recorded 1st fishway entrance	146 (88%)	183 (90%)	107 (90%)	201 (90%)
Recorded ladder exit	162 (98%)	195 (96%)	113 (95%)	217 (97%)

Distributions of First Approaches and Entries

In 2009, slightly less than half of all the first fishway approaches made by radio-tagged spring Chinook salmon were recorded at Powerhouse 1 and approximately 32% were recorded at Powerhouse 2 (Figure 6). First fishway approaches at the CI opening comprised approximately 11% of all first fishway approaches and those at the Bradford Island fishway opening comprised the smallest percentage (8%). Equal percentages (35%) of all first fishway entrances made by radio-tagged spring Chinook salmon were recorded at Powerhouse 1 and Powerhouse 2. Approximately 16% of all first fishway entries were at the Bradford Island opening and 14% were at the Cascades Island opening.

First approaches at the powerhouses were more common among summer Chinook salmon tagged in June than in spring Chinook salmon (Figure 6). Slightly more than half of all the first fishway approaches made by radio-tagged summer Chinook salmon were recorded at Powerhouse 1 and approximately 40% were at Powerhouse 2. The remaining first fishway approaches were at Bradford Island (6%) and CI (2%) fishway openings. Similar percentages (38-42%) of all first fishway entrances made by radio-tagged Chinook salmon were recorded at Powerhouse 1 and Powerhouse 2. Approximately 15% of all first fishway entries were at the Bradford Island opening and 6% were at the CI opening.

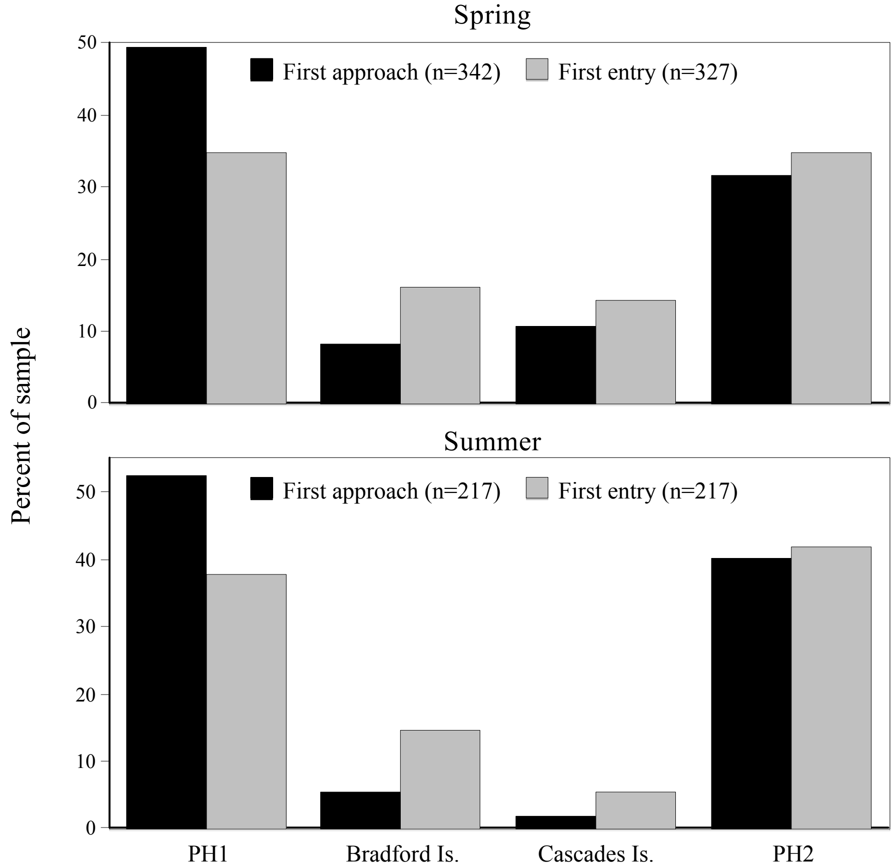

Figure 6. Distributions of first fishway approach and entrance sites used by radio-tagged spring (upper panel) and summer (lower panel) Chinook salmon at Bonneville Dam in 2009.

First Fishway Approach Efficiencies

Approximately half of all first fishway approaches by radio-tagged spring Chinook salmon were recorded at Powerhouse 2. However, only 9% (10 first entries /108 first approaches) resulted in a first fishway entry (Figure 7). First fishway approaches at Powerhouse 1 were modestly more efficient, with an average of 16% resulting in first fishway entries. In contrast, the spillway fishway openings were the most efficient, with 38% of all first fishway approaches at the CI fishway opening and 46% at the Bradford Island fishway opening resulting in a first fishway entry.

For summer Chinook salmon, 37% of 113 first fishway approaches at Powerhouse 1 resulted in first fishway entries at the same sites (Figure 7). About 40% of all first fishway approaches by radio-tagged summer Chinook salmon were recorded at Powerhouse 2, where first fishway approach efficiency was 16%; (14 first entries /87 first approaches). The spillway fishway openings were lightly used, resulting in low sample sizes, but were relatively efficient, with 33% (n = 3) of all first fishway approaches at the CI fishway opening and 67% (n = 12) at the Bradford Island fishway opening resulting in a first fishway entry.

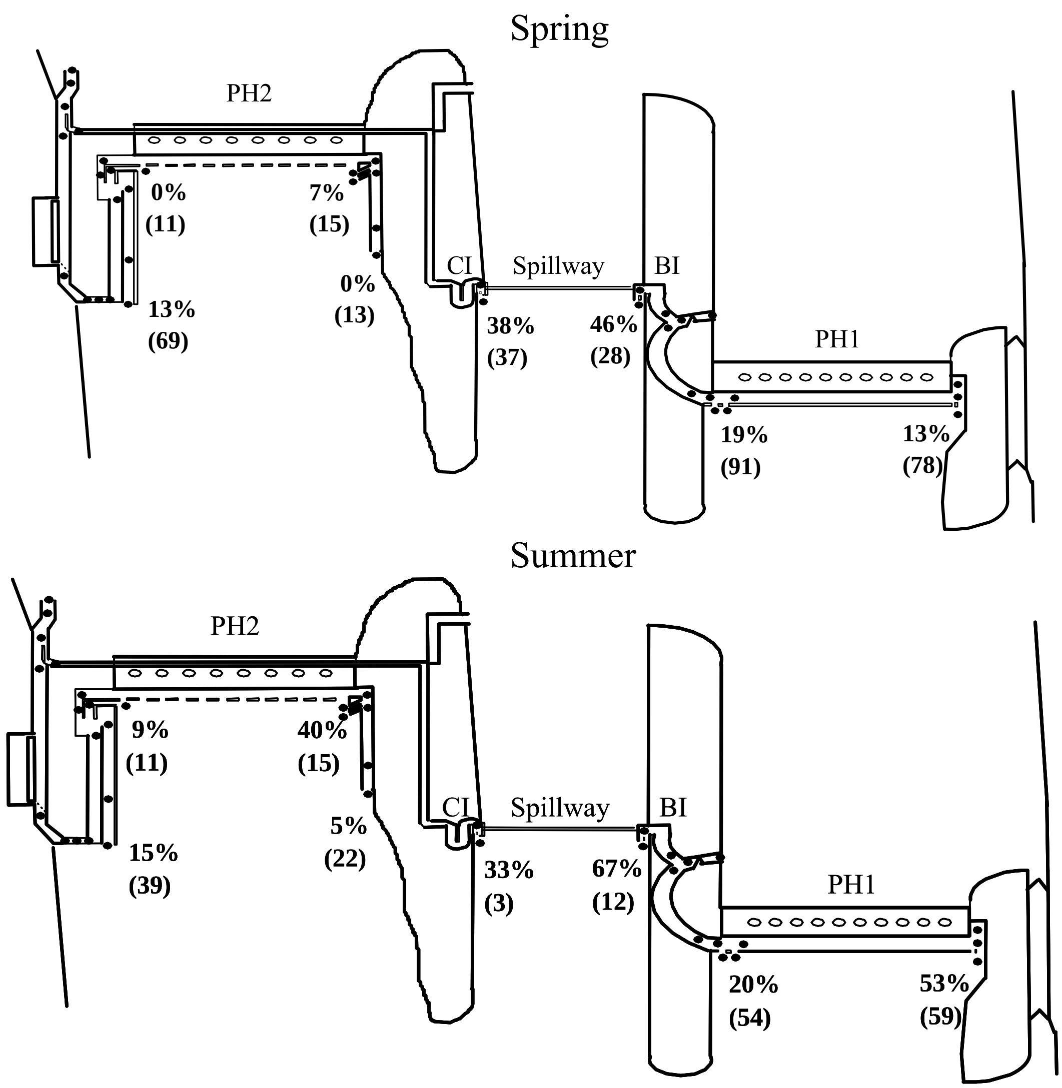

Figure 7. Percentage of first fishway approaches by radio-tagged spring (upper panel) and summer (lower panel) Chinook salmon resulting in first fishway entries for all monitored fishway openings at Bonneville Dam in 2009. Sample sizes (approaches) are in parentheses.

Passage Times

The median time from release to first record in the tailrace was 23.9 h (n = 24) for spring Chinook salmon tagged and released in April 2009 and decreased to 19.5 h (n = 279) for fish tagged and released in May 2009 (Table 3). The median release-tailrace time for all radio-tagged spring Chinook salmon was 20.5 h. Overall, this 2009 median time ranked third among the ten study years (ranking from slow years to fast years; Table 3).

The median time from first tailrace record to first fishway approach in April 2009 (42.3 h, n = 22) was the second slowest time observed during April of the ten study years. The median tailrace to first approach time for May 2009 (5.0 h, n = 265) was about average. The median time to first approach a fishway after being detected in the tailrace during April-May combined in 2009 was also about average (Table 3).

Table 3 Number of adult radio-tagged spring Chinook salmon and median times to pass (h) from release to first tailrace record, and from first tailrace record to first fishway approach, to first fishway entrance, and to pass Bonneville Dam based on month fish were first detected in the tailrace, 1997-1998, 2000-2004, 2006-2007, and 2009. Rankings for 2009 values (1 = slowest time and 10 = fastest time) are listed to the right.

	1997		1998		2000		2001		2002		2003		2004		2006		2007		2009		
	n	Med.	n	Med.	n	Med.	n	Med.	n	Med	n	Med.	n	Med.	n	Med.	n	Med.	n	Med.	Rank
Release to tailrace																					
April	314	**22.6**	341	**7.0**	461	**15.2**	253	**17.1**	255	**29.5**	434	**25.9**	124	**23.6**	46	**47.8**	70	**25.8**	24	**23.9**	**5**
May	311	**23.9**	275	**7.0**	222	**6.7**	258	**13.0**	272	**16.1**	225	**20.1**	173	**17.2**	253	**21.0**	158	**6.0**	279	**19.5**	**3**
All	625	**23.2**	616	**7.0**	683	**12.8**	511	**14.1**	527	**20.2**	659	**24.0**	297	**18.2**	299	**23.6**	228	**6.8**	303	**20.5**	**3**
Tailrace to 1st approach																					
April	296	**3.4**	337	**3.9**	454	**6.9**	247	**20.3**	241	**17.5**	366	**23.5**	117	**46.7**	39	**15.7**	66	**19.6**	22	**42.3**	**2**
May	300	**2.6**	271	**2.0**	218	**2.5**	251	**9.0**	268	**12.1**	213	**9.2**	163	**29.7**	230	**5.2**	148	**2.6**	265	**5.0**	**6**
All	596	**3.0**	608	**2.7**	672	**3.8**	498	**13.2**	509	**14.1**	579	**17.6**	280	**33.4**	269	**6.5**	214	**4.0**	287	**5.7**	**6**
Tailrace to 1st entry																					
April	226	**17.0**	294	**14.3**	373	**25.3**	228	**37.6**	214	**34.6**	313	**47.0**	101	**78.6**	27	**68.3**	63	**49.6**	21	**92.7**	**1**
May	249	**9.7**	250	**10.2**	185	**13.2**	231	**11.5**	228	**23.8**	195	**23.2**	148	**37.2**	182	**21.8**	140	**18.4**	253	**21.5**	**5**
All	475	**12.9**	554	**12.5**	558	**20.7**	459	**19.7**	442	**29.7**	508	**34.2**	249	**42.6**	209	**24.1**	203	**23.6**	274	**23.4**	**6**
Tailrace to pass dam																					
April	306	**47.4**	330	**23.8**	449	**44.8**	237	**58.7**	248	**52.4**	400	**53.4**	110	**87.2**	33	**98.9**	63	**53.5**	21	**124.7**	**1**
May	304	**22.7**	267	**19.6**	219	**22.7**	254	**22.2**	267	**50.6**	206	**33.7**	158	**54.1**	193	**25.7**	140	**27.5**	249	**26.9**	**4**
All	610	**33.2**	597	**21.6**	668	**32.6**	491	**32.8**	515	**51.4**	606	**49.1**	268	**62.4**	226	**30.3**	203	**37.7**	270	**34.7**	**5**
First approach to first entry																					
April	237	**4.8**	312	**4.2**	390	**16.2**	266	**3.0**	290	**4.3**	351	**1.6**	123	**1.5**	31	**8.0**	72	**6.5**	25	**5.5**	**5**
May	266	**2.3**	273	**2.9**	193	**4.6**	267	**1.2**	250	**4.8**	225	**1.4**	158	**1.8**	208	**3.2**	170	**6.5**	302	**3.8**	**4**
All	503	**2.7**	585	**3.5**	583	**10.2**	533	**1.8**	540	**4.6**	576	**1.6**	281	**1.8**	239	**3.3**	242	**6.5**	327	**3.9**	**4**

The median time from first tailrace record to first fishway entry in April 2009 was the slowest among all study years whereas the median time in May 2009 ranked fifth. The grand median for April-May 2009 was ranked sixth among the ten study years.

The median time for radio-tagged spring Chinook salmon to pass Bonneville Dam (tailrace to ladder top) in April 2009 was 124.7 h (n = 21) the slowest among all study years and also the smallest April sample among all years, reflecting the start of radio-tagging in late April. The median value for May 2009 and the combined April-May 2009 times ranked fourth and fifth among the study years, respectively (Table 3).

The median time from first approach to first entry during April 2009 was the fifth among April values and the median time for May 2009 was the slowest among all May values. The grand median time from first approach to first entry during 2009 ranked as the fourth slowest among all study years.

The median time tagged spring Chinook salmon used to swim from first fishway entry to the ladder top was 3.0 h in April (n = 25), 3.0 h in May (n = 296), and 3.0 h overall (n = 321). Only 3% of tagged salmon that exited a ladder top used more than 24 hrs to pass the dam after entering a fishway. These values were consistent with passage through the fishways in previous years.

For radio-tagged summer Chinook salmon in 2009, median passage times were generally lower than medians in 2002-2004, indicating faster passage rates (Figure 8). In 2009, the median time from release to first record in the tailrace was 5.9 h (n = 215), lower than in 2002 (12.1 h), 2003 (14.5 h), and 2004 (6.9 h). The median times from first tailrace record to first fishway approach (1.8 h, n = 209), first fishway entry (4.4 h, n = 195), and to pass the dam (19.2 h, n = 211) in 2009 were the fastest among all study years (Figure 8). The 2009 median time from first approach to first entry (1.5 h, n = 201) was intermediate. The median time tagged salmon used to swim from first fishway entry to the ladder top was 8.3 h in 2009 (n = 201). This was shorter than in the three other years (*medians* = 9.7–11.3 h).

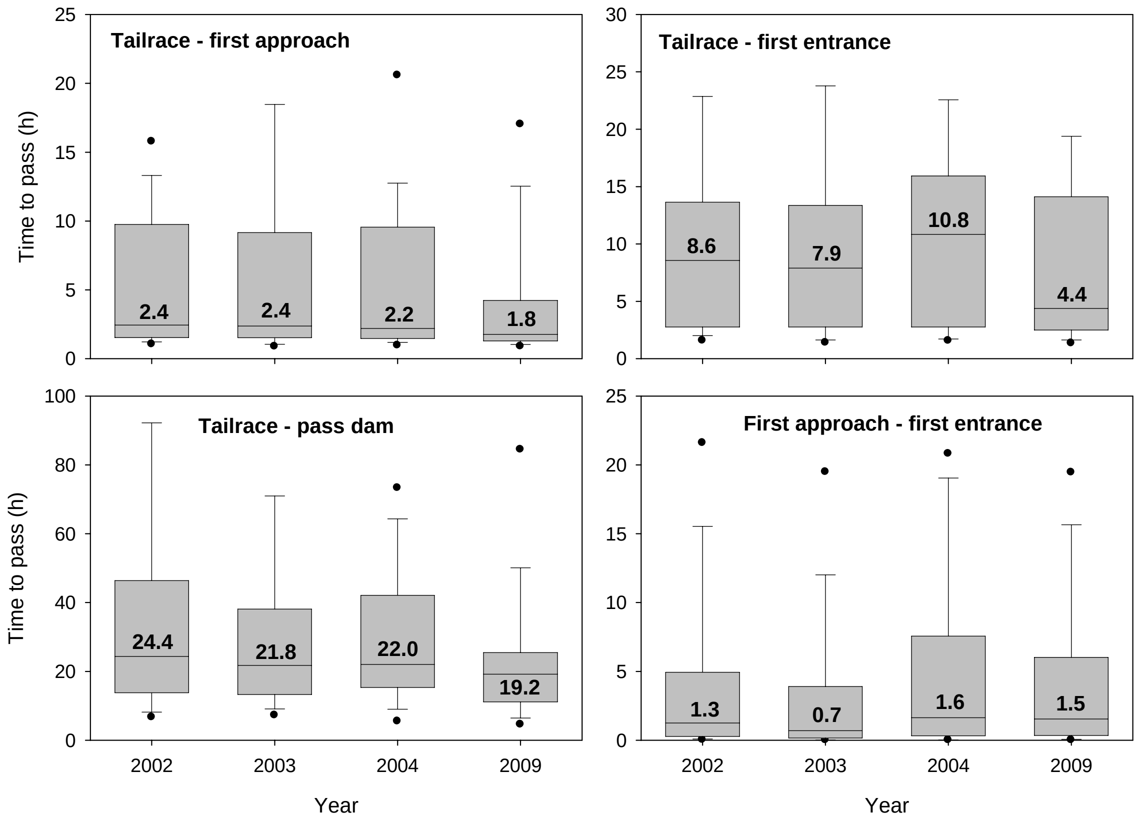

Figure 8. Distributions of summer Chinook salmon passage times (h) from first tailrace record at Bonneville Dam to first fishway approach, first fishway entry, and to pass the dam and from first fishway approach to first fishway entry, 2002-2004 and 2009. Box plots show: median, quartile, 5^{th}, 10^{th}, 90^{th} and 95^{th} percentiles. Numbers inside boxes are median times. Note different y-axis scales.

Dam Passage Times and Exit Percentages

Forty-one of the 327 radio-tagged spring Chinook salmon that entered a fishway in 2009 exited a fishway to the tailrace at least once (12.5%; Table 4). Exit percentages (unique fish exited / unique fish entered) for radio-tagged Chinook salmon in April-May of nine comparison years ranged from 8 to 61%, with 2006 having the minimum percentage and 2009 having the second lowest percentage. In almost all previous evaluations, salmon that exit fishways back to the tailrace have had significantly longer dam passage times than salmon that do not exit (see Keefer et al. 2008). In 2009, however, the median dam passage time for radio-tagged salmon that made at least one fishway exit was 25.0 h (n = 31) compared to 37.2 h (n = 233) for radio-tagged salmon that made no exit.

Table 4. Numbers of radio-tagged spring Chinook salmon that entered a Bonneville Dam fishway and the frequency and percentage of those salmon that exited a fishway to the tailrace at least once.

Year	No. tagged salmon that entered fishway	No. tagged salmon that exited fishway	Percent
1997	654	398	60.8
1998	651	256	39.3
2000	700	273	39.0
2001	594	166	27.9
2002	630	198	31.4
2003	700	176	25.1
2004	298	99	33.2
2006	296	24	8.2
2007	246	47	19.1
2009	327	41	12.5

Of the 217 tagged summer Chinook salmon that entered a fishway in 2009, 144 (66%) exited a fishway to the tailrace at least once (Table 5). This was within the range recorded in previous years. As in previous evaluations, salmon that exited a fishway took longer to pass the dam (*median* = 23.3 h, n = 139) than those that did not exit (13.9 h, n = 72).

Table 5. Numbers of radio-tagged summer Chinook salmon that entered and exited Bonneville Dam fishways, and percentages that exited to the tailrace at least once, 2002-2004 and 2009.

Year	No. tagged salmon that entered fishway	No. tagged salmon that exited fishway	Percent
2002	163	121	74%
2003	198	136	69%
2004	114	74	65%
2009	217	144	66%

Re-ascension of Radio-tagged Salmon that Fell Back

Prior to 2001, fishway re-ascension rates of unique radio-tagged salmon that fell back at Bonneville Dam before 10 June ranged from 84 to 96% (Table 6). These were also years when fallback percentages were relatively high (12-17%), at least in part because more flow was passed through Powerhouse 1 and more salmon passed the dam via the Bradford Island ladder (see Reischel and Bjornn 2003; Boggs et al. 2004). Fallback percentages were relatively low (*range* = 3 to 7%) from 2001 through 2004 when priority was shifted to Powerhouse 2 and re-ascension rates of unique salmon generally decreased in these years, reaching a minimum of 70% in 2004. In 2005, few Chinook salmon were radio-tagged and released downstream from the dam prior to 10 June (25 total, $n = 2$ fallbacks) so the 100% re-ascension rate is probably was not a reliable estimate. Re-ascension rates of unique salmon in 2006 and 2007 decreased each year and reached a minimum of 56% in 2007. The 2009 re-ascension rate of 77% ranked as the fourth lowest among the 12 study years.

Table 6. Fallback percentage (unique salmon that fell back / unique salmon that passed dam), number of fallback and re-ascension events by radio-tagged spring–summer Chinook salmon (prior to 10 June) and the number of unique radio-tagged Chinook salmon that fell back and re-ascended Bonneville Dam, 1996-1998, 2000-2007, and 2009.

Year	Fallback percentage	Fallback events	Re-ascension events	Percent re-ascended (events)	Unique salmon that fell back	Unique salmon that re-ascended	Percent re-ascended (unique salmon)
1996	14.6	122	111	91	103	93	90
1997	17.0	151	144	95	114	109	96
1998	12.2	113	96	85	84	71	84
2000	15.4	149	142	95	116	109	94
2001	5.0	51	44	86	33	29	88
2002	6.8	50	41	82	45	37	82
2003	5.3	56	48	86	41	39	95
2004	2.9	11	8	73	10	7	70
2005	12.5	2	2	100	2	2	100
2006	13.2	50	32	64	43	28	65
2007	6.1	16	9	56	16	9	56
2009	6.7	23	18	78	22	17	77

In 2009, the fallback percentage at Bonneville Dam was 3.7% for June-tagged summer Chinook salmon and all salmon that fell back subsequently re-passed the dam (Table 7). Both the fallback and re-ascension rates in 2009 were within the range recorded for June-tagged salmon in 2002-2004.

Table 7. Fallback percentage (unique salmon that fell back / unique salmon that passed dam), number of fallback and re-ascension events by June-tagged Chinook salmon and the number of unique radio-tagged Chinook salmon that fell back and re-ascended Bonneville Dam, 2002-2004 and 2009.

Year	Fallback percentage	Fallback events	Re-ascension events	Percent re-ascended (events)	Unique salmon that fell back	Unique salmon that re-ascended	Percent re-ascended (unique salmon)
2002	4.9	10	10	100	8	8	100
2003	3.0	6	5	83	6	5	86
2004	3.5	4	2	50	4	2	50
2009	3.7	10	10	100	8	8	100

2009 Cascades Island Results

Of the spring Chinook salmon tagged through 31 May in 2009, 92 (24%) were recorded approaching the CI fishway entrance and 14% were recorded entering (Figure 9). These percentages were similar to the previous years' data, when from 8–37% (*mean* = 22%) were detected approaching the CI fishway one or more times and 5–32% (*mean* = 18%) were recorded entering the CI fishway. The annual percentage of fish detected at the CI fishway increased with increasing river discharge (Figure 10), presumably because spill provides attraction flow. The 2009 detection rate was in line with previous years given river conditions.

Of the 223 fish tagged in June 2009, 46 (21%) were recorded approaching and 32 (14%) were recorded entering the CI fishway entrance. Both percentages were lower than in 2002-2004, when 30-32% approached the CI fishway and 22-28% entered. In contrast to tagged spring Chinook salmon, the annual percentage of June-tagged salmon detected at the CI fishway did not have a clear correlation with mean June flow, spill, water temperature, or tailwater elevation (not shown). In part, this may have been because fewer years were used in the June evaluation and environmental conditions among years were relatively similar (Figure 5).

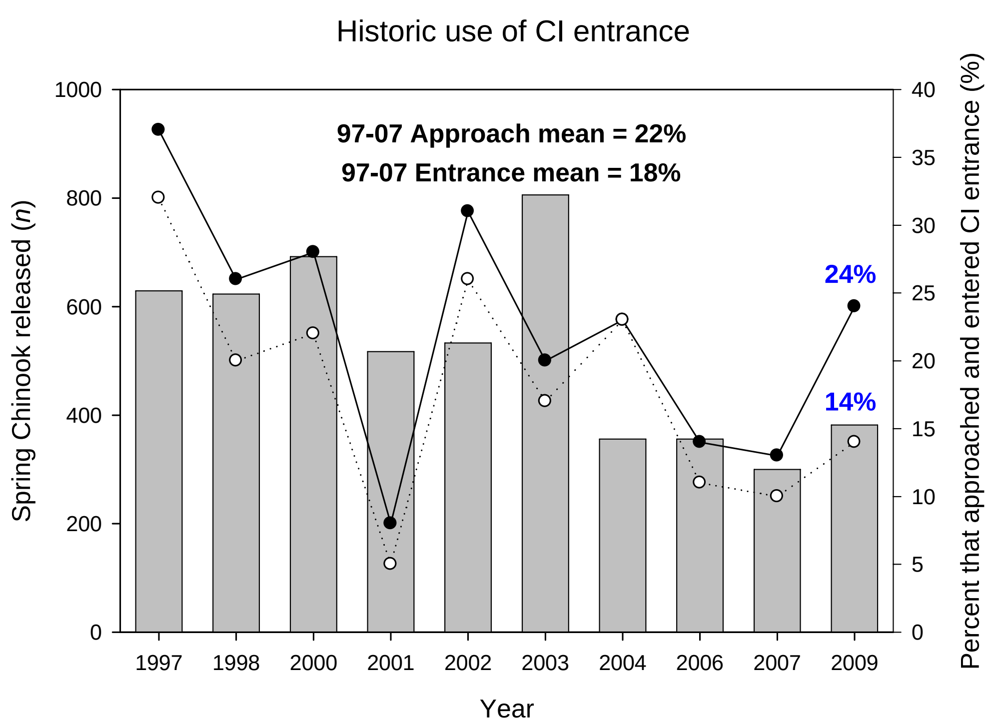

Figure 9. Number of spring Chinook salmon radio-tagged and the percentages that were recorded approaching and entering the Cascades Island fishway. Solid line= approaches and dotted line=entrances.

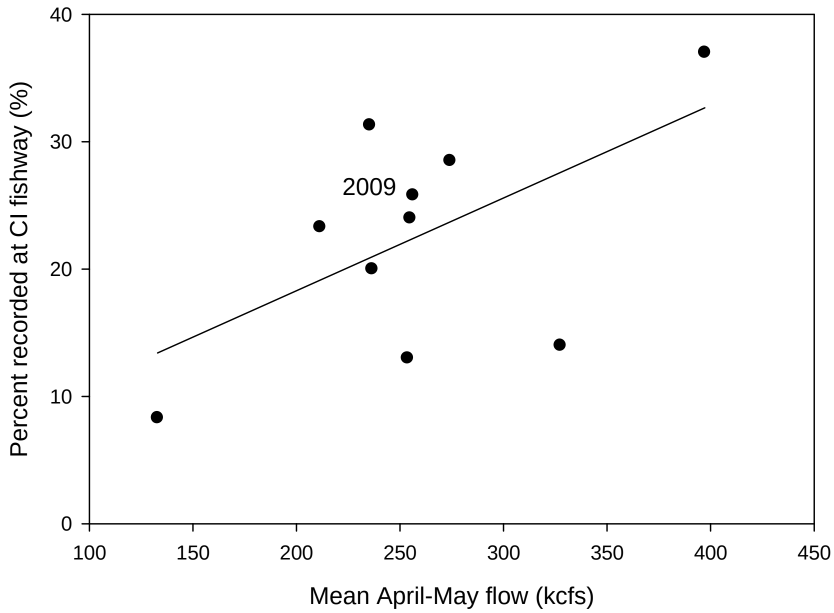

Figure 10. Relationship between mean April-May discharge at Bonneville Dam and the percentage of spring Chinook salmon recorded at the Cascades Island fishway.

Metric 1. The CI first entrance efficiency estimates in previous years ranged from 0.56–0.98 for radio-tagged spring Chinook salmon (*mean* = 0.79, Figure 11), with the lowest estimate in 2001 when river flow and spill were low and few fish used the CI fishway. The entrance efficiency estimate in 2009 was 0.59, at the low end of the range from previous years. This may indicate a problem at the entrance area. For tagged summer Chinook salmon, the CI first entrance efficiency estimates in previous years ranged from 0.72–0.89 (*mean* = 0.83, Figure 11). The preliminary entrance efficiency estimate in 2009 was 0.70, the lowest of the four years but similar to 2004.

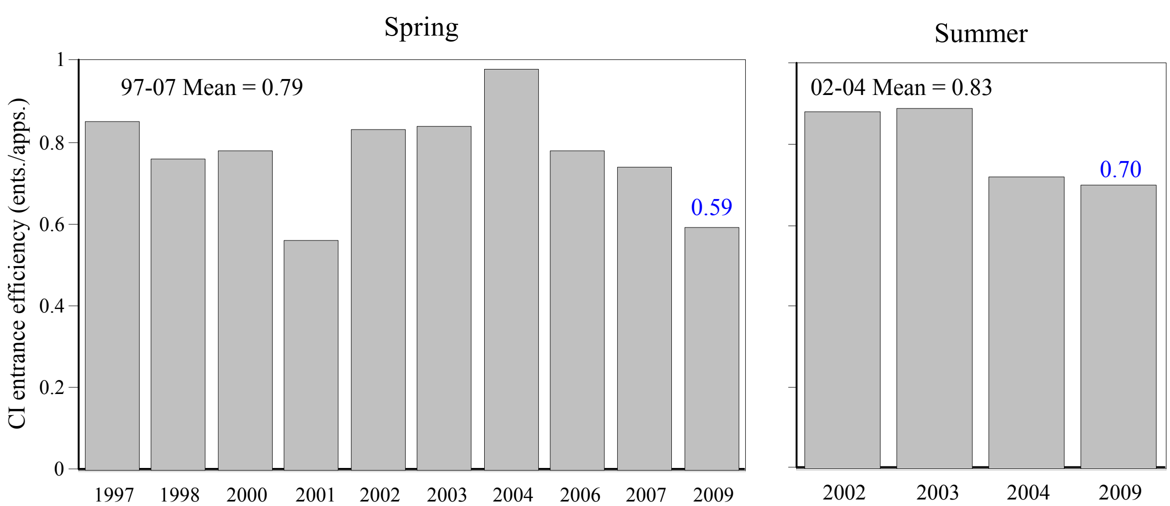

Figure 11. Cascades Island entrance efficiency (unique entrances/unique approaches) for radio-tagged spring Chinook salmon (left panel) and summer Chinook salmon (right panel).

Metric 2. Exit ratios for tagged spring Chinook salmon were relatively more variable than entrance efficiencies in previous years, and ranged from 0.00–0.46 (*mean* = 0.24; Figure 12). The preliminary 2009 estimate was 0.04, or at the very low end of the range. Only two fish exited back into the tailrace after entering at CI, suggesting favorable passage conditions once inside the fishway entrance. Observed interannual variability in the exit ratio presumably reflects differences in conditions inside the fishway entrance and transition pool, which can vary with tailwater elevation and river conditions (i.e, temperature, discharge). It was not clear why there were relatively few recorded CI exits in 2006-2007 and 2009.

For tagged summer Chinook salmon, exit ratios were also relatively more variable than entrance efficiencies in previous years, ranging from 0.35–0.77 (*mean* = 0.62). The 2009 estimate was 0.63, an intermediate value.

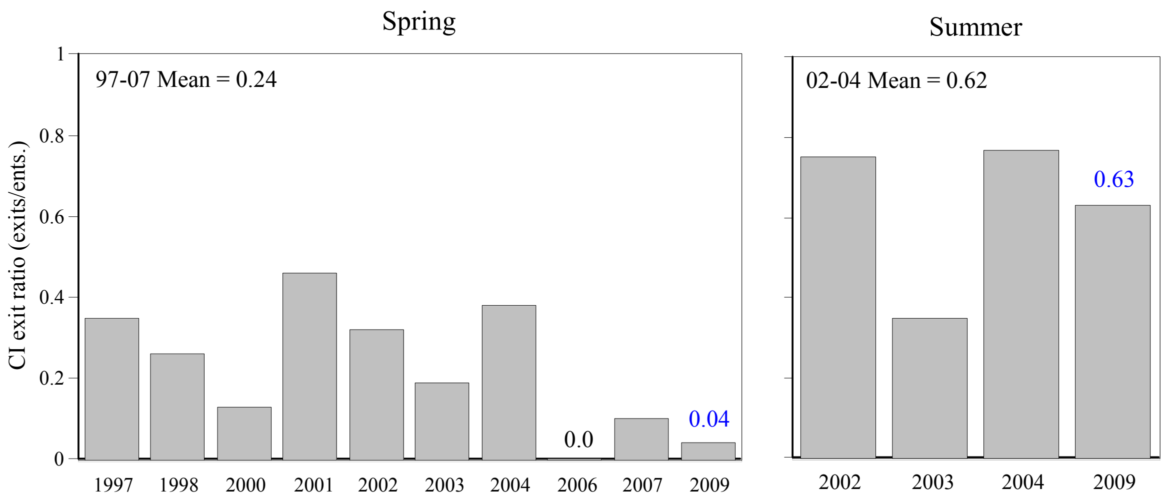

Figure 12. Cascades Island exit ratios (unique exits/unique entries) for radio-tagged spring Chinook salmon (left panel) and summer Chinook salmon (right panel).

Metric 3. Passage times for both spring and summer Chinook salmon from first CI approach to first CI entry were strongly right-skewed in all previous years (Figure 13). Generally, the majority of fish moved rapidly into the fishway, but a few had long passage times when they repeatedly approached the fishway without entering or moved to the tailrace or to other fishways and then returned to enter. For spring Chinook salmon, median approach-entrance times ranged from a couple minutes to 46 minutes in previous years. In contrast, the median in 2009 was 59 minutes. ANOVA results for log-transformed passage times indicated significant among-year differences in means ($df = 9$, $F = 17.0$, $P < 0.0001$). In pairwise comparisons, the 2009 mean was significantly higher than means in 5 of the 9 previous years. Similarly, a Kruskal-Wallis test of medians (untransformed data) indicated significant differences ($\chi^2 = 142.2$, $P < 0.0001$), with the 2009 median the highest among years. This result suggests some difference in conditions outside or immediately adjacent to the fishway entrance in 2009. Tagged salmon in the small 2007 sample ($n = 20$) also had relatively long passage times.

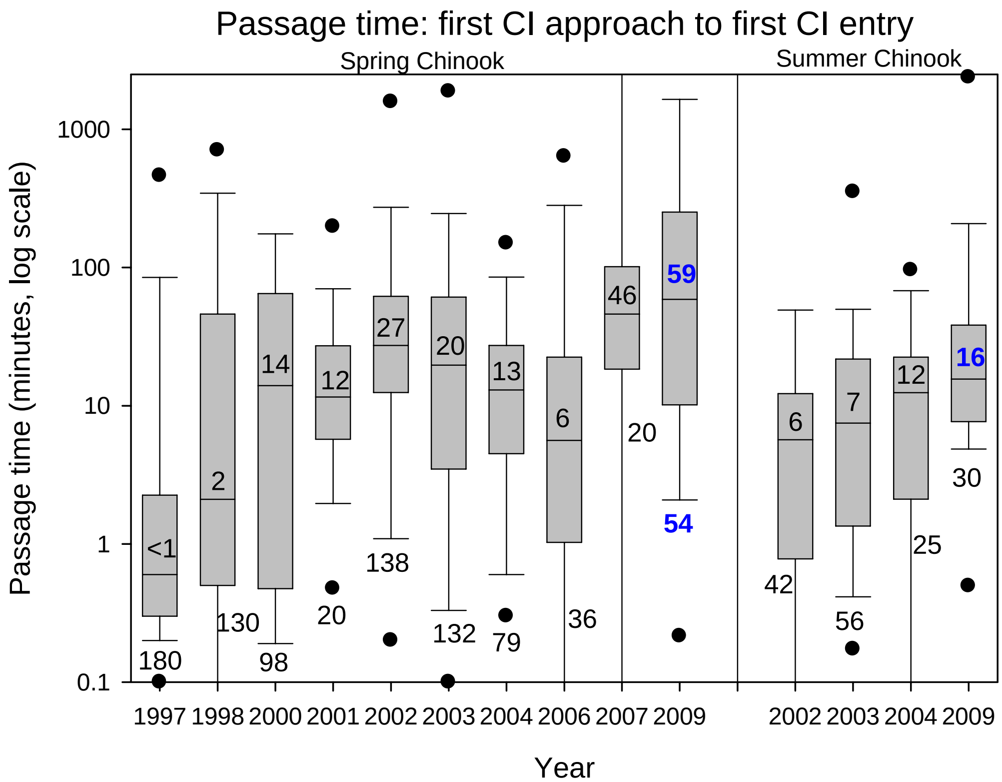

Figure 13. Spring and summer Chinook salmon passage time distributions (plotted on log scale) from approach to entry at the Cascades Island fishway. Values inside boxes are median times. Distributions show 5th, 10th, 25th, 50th, 75th, and 90th percentiles; sample sizes are listed at bottom.

Median CI approach-entrance times for summer Chinook salmon in previous years were 6–12 minutes (*mean* = 8; Figure 13). The median in 2009 was 16 minutes. ANOVA results for log-transformed passage times indicated significant among-year differences in means (df = 3, F = 3.0, P = 0.035). In pairwise comparisons, the 2009 mean was significantly higher than the 2002 mean; no other differences were significant (P > 0.05). Similarly, a Kruskal-Wallis test of medians (untransformed data) indicated significant differences (χ^2 = 11.5, P = 0.009), with the 2009 median the highest among years. This result suggests some difference in conditions outside or immediately adjacent to the fishway opening in 2009.

Prior to 2009, spring Chinook salmon had median approach to entry times at the BI fishway opening, a useful comparison site, that were less than or equal to those at the CI fishway opening (Figure 14), with 2001 being the lone exception. In contrast, the 2009 CI median approach to entry time for spring Chinook salmon was over two times higher than the BI median time. For summer Chinook salmon, the median CI approach to entry times were equal to the BI median times in 2002 and 2003 and was modestly higher (12 min vs. 7 min) than the median BI fishway approach to entry time in 2004. In 2009, the median approach to entry time for the CI fishway opening was eight times higher than that for the BO fishway opening. This lends some additional support to the conclusion that behavior may have changed outside the CI fishway in 2009.

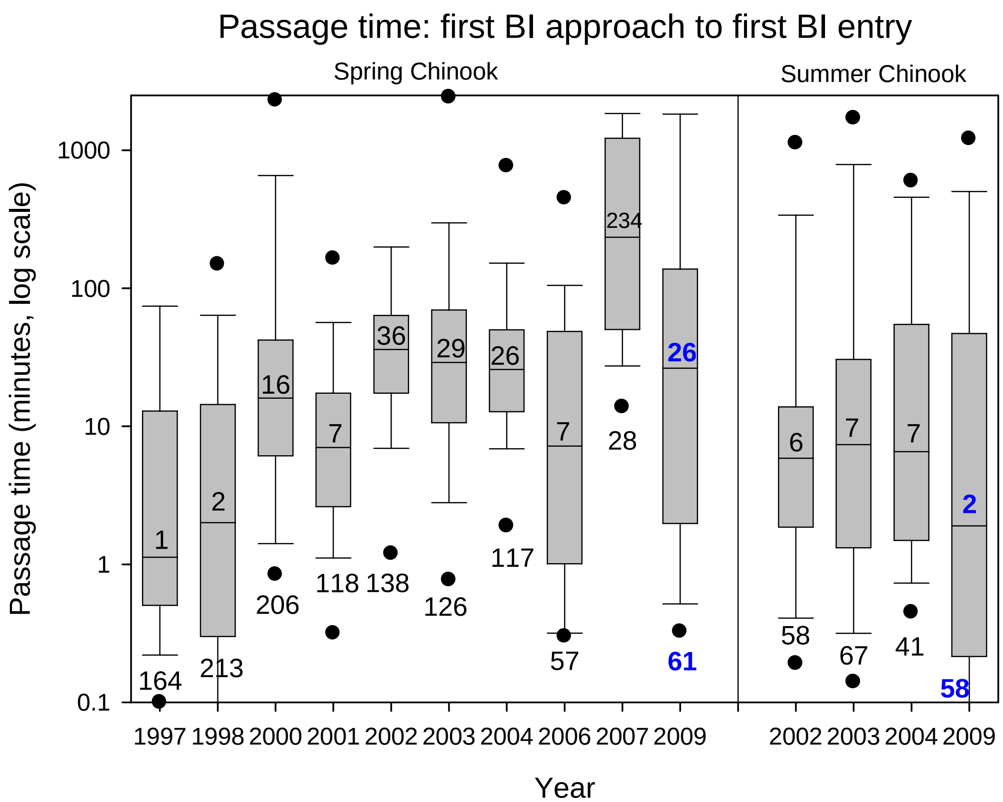

Figure 14. Spring and summer Chinook salmon passage time distributions (plotted on log scale) from approach to entry at the Bradford Island fishway. Values inside boxes are median times. Distributions show 5th, 10th, 25th, 50th, 75th, and 90th percentiles; sample sizes are listed at bottom.

Figure 15 shows the river environment encountered by radio-tagged spring Chinook salmon recorded approaching the CI entrance for each year. When we compared passage time among years for only fish that experienced spill levels between 90 and 150 kcfs (the 2009 range encountered by tagged fish on days they approached CI), the 2009 mean was longer than means in 4 of 7 previous years (df = 7, F = 4.7, P < 0.0001). An ANOVA limited to fish that encountered similar tailwater elevations as in 2009 indicated the 2009 mean was higher then means in 4 of 8 previous years (df = 8, F = 7.6, P < 0.0001). In comparison for water temperature, the 2009 mean was higher then means in 5 of 9 previous years (df = 9, F = 14.2, P < 0.0001). In a test limited to individuals from previous years that experienced similar spill, tailwater elevation and temperature to 2009, the 2009 mean was higher then means in 2 of 6 previous years (df = 6, F = 5.3, P < 0.0001). The 2007 and 2002 means were also significantly longer than other years in some tests. Overall, these results suggest that environmental factors were not the cause of the poorer performance by Chinook salmon in 2009.

Note that we did not examine the potential effects of spill patterns on these results. A shift from concentrated spill in the center spillbays in early study years to greater spill from end spillbays adjacent to the CI and Bradford fishway openings in later years may have been an important factor acting on passage behavior.

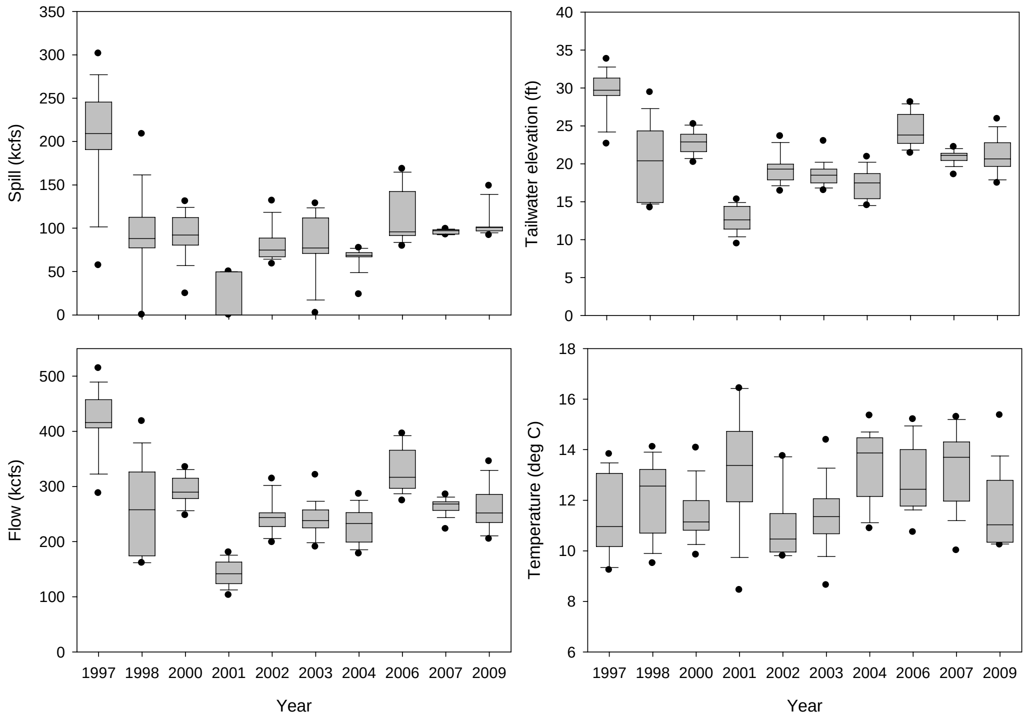

Figure 15. Box plots of the total discharge ('flow'), spill, tailwater elevation, and temperature on the days that radio-tagged spring Chinook salmon first approached the Cascades Island fishway opening. Distributions show 5th, 10th, 25th, 50th, 75th, and 90th percentiles.

Figure 16 shows the river environment encountered by June-tagged salmon recorded approaching the CI entrance for each year. When we compared log-transformed passage times among years for only fish that experienced spill levels between 90 and 165 kcfs (the 2009 range encountered by tagged fish on days they approached CI), the 2009 mean was longer than the 2002 mean ($df = 2$, F = 3.6, $P = 0.034$, $n = 66$). Similarly, in ANOVAs that restricted the sample to fish that encountered similar flow ($df = 3$, F = 2.7, $P = 0.049$, $n = 152$), tailwater elevation ($df = 3$, F = 3.8, $P = 0.012$, $n = 151$), or temperature ($df = 3$, F = 2.9, $P = 0.040$, $n = 125$) conditions as in 2009 each showed significantly slower entry times in 2009 versus 2002. An ANOVA that further restricted the data so that all four environmental variables were within the 2009 ranges was not significant ($df = 2$, F = 1.6, $P = 0.222$, $n = 53$); however, sample sizes were then limited to less than half of those in most of the tests reported above. Note that we did not examine the potential effects of spill patterns on these results.

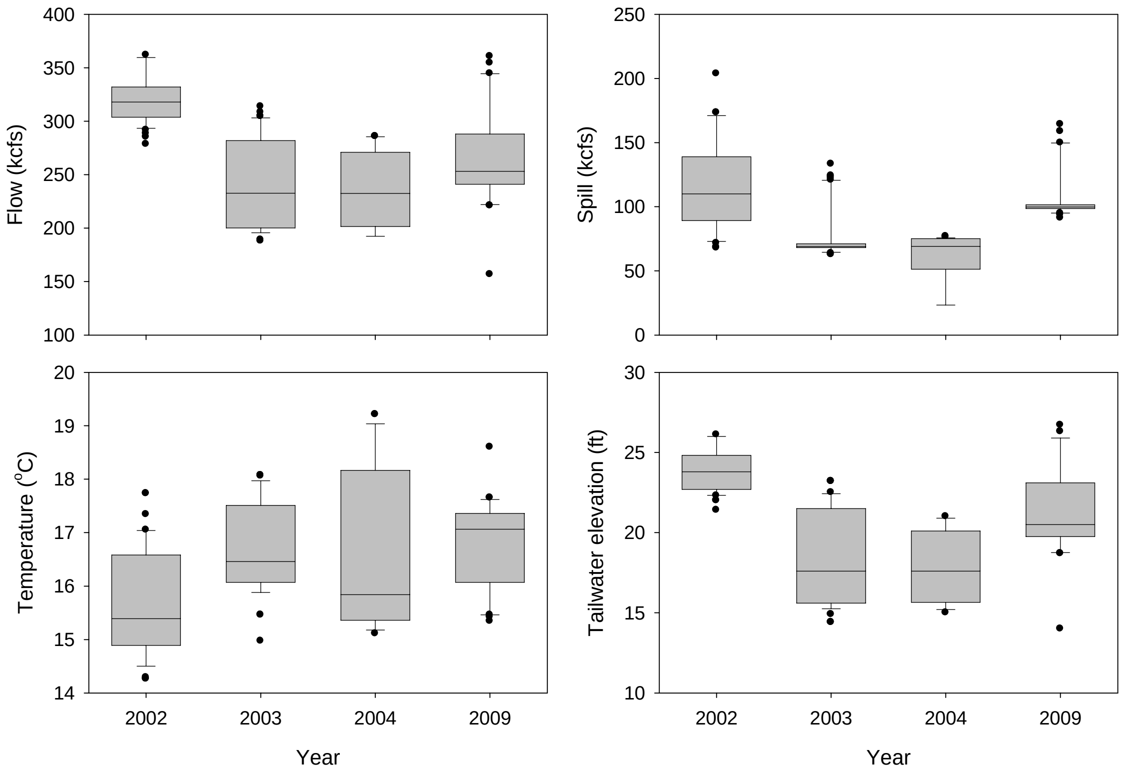

Figure 16. Box plots of the total discharge ('flow'), spill, water temperature, and tailwater elevation on the days that June-tagged Chinook salmon first approached the Cascades Island fishway opening. Distributions show 5th, 10th, 25th, 50th, 75th, and 90th percentiles.

Metric 4. After tagged spring Chinook salmon entered the CI fishway, the median time to reach the ladder base ranged from 7–16 minutes in previous years. The 2009 median was 13 minutes and the distribution was similar to previous years (Figure 17). Sample sizes for the passage time metrics were slightly smaller than the fishway approach and entry sample sizes because some fish did not enter the CI fishway and some did not reach the ladder antenna. In addition, there was no base-of-ladder antenna in 2006. The 2009 result suggests that salmon did not have difficulty moving from the CI entrance to the base of the ladder.

For tagged summer Chinook salmon, the median time to reach the ladder base ranged from 12–21 minutes in previous years. The 2009 median was 17 minutes and the distribution was similar to previous years (Figure 13). ANOVA and Kruskal-Wallis tests of medians indicated passage times for this segment did not differ among years ($P > 0.30$ in both tests). The 2009 results suggests that once salmon from both runs passed the entrance weir they did not have difficulty moving over the modified bottom area with bollards and LPS entrance to the base of the ladder.

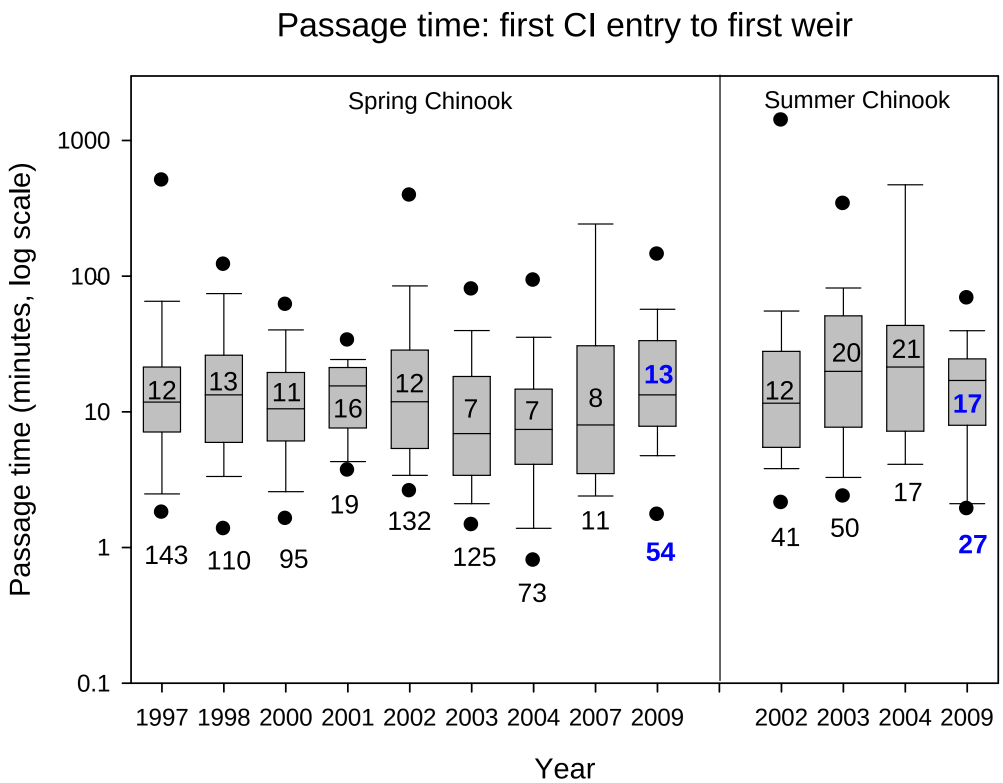

Figure 17. Spring and summer Chinook salmon passage time distributions (plotted on log-scale) from Cascades Island fishway entry to the antenna at the base of the ladder (not monitored in 2006). Numbers inside boxes are median times. Distributions show 5^{th}, 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentiles; sample sizes are listed below boxes.

Metric 5. In previous years, the percentage of tagged spring Chinook salmon with long passage times (> 1 h) through the two passage segments ranged from 10–28% (*mean* = 22%) for CI approach to CI entrance and from 0–14% (*mean* = 8%) from CI entrance to the first ladder antenna (Figure 18). The percentages were 48% and 7%, respectively, in 2009. As with Metric 4, this result suggests that there are likely problems entering the fishway but limited problems after entrance in 2009, relative to earlier years. Comparisons of the percentages indicated a significant among-year difference in the CI approach to CI entry percentage (Pearson $\chi^2 = 46.5$, $P < 0.0001$).

In 2002–2004, the percentage of tagged summer Chinook salmon with long passage times (> 1 h) through the two passage segments ranged from 7–12% (*mean* = 9%) from CI approach to CI entrance and from 7–20% (*mean* = 13%) from CI entrance to the first ladder antenna (Figure 18). The percentages were 17% and 7%, respectively, in 2009. Similar to spring Chinook salmon, these data suggest that there may have been factors acting outside or at the entrance to slow passage in 2009, but no evidence of altered behavior after entrance. However, comparisons of the percentages indicated no significant among-year differences in either metric for summer Chinook salmon (Pearson χ^2 tests, $P > 0.05$), though sample sizes were smaller than for spring Chinook salmon.

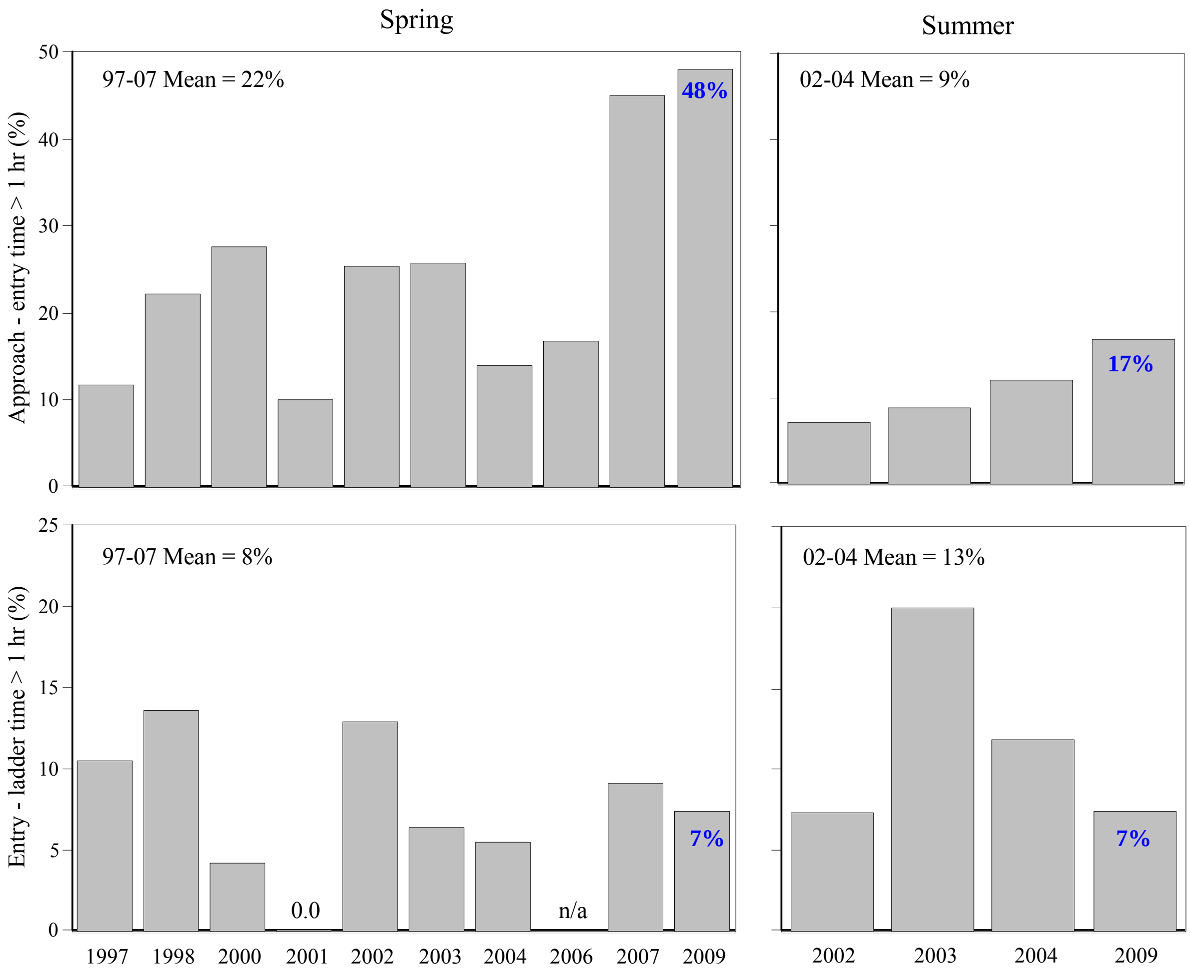

Figure 18. Percentages of radio-tagged spring and summer Chinook salmon that took > 1 h to pass from Cascades Island fishway approach to fishway entrance and from entrance to the base of the ladder.

Correlation coefficients between environmental data and CI approach to entry times

For tagged spring and summer Chinook salmon, the median CI approach-to-entry time in 2009 was unexpectedly long compared to past approach-to-entry times at CI and the Bradford Island fishway opening (Figures 19). In contrast, the relationship between CI and Bradford Island entry times was relatively constant in the 1997-2006 data. Both 2007 and 2009 were outliers, with the small 2007 sample (n = 28) having relatively long Bradford Island approach-to-entry times and the 2009 sample having long CI approach-to-entry times. For tagged summer Chinook salmon, the median CI approach-to-entry time in 2009 was also high compared to past approach-to-entry times at CI and the Bradford Island fishway opening. When we applied various environmental filters to the analyses of CI approach-to-entry times, results continued to suggest that there was a difference in the 2009 behavior at the CI opening compared to Bradford Island.

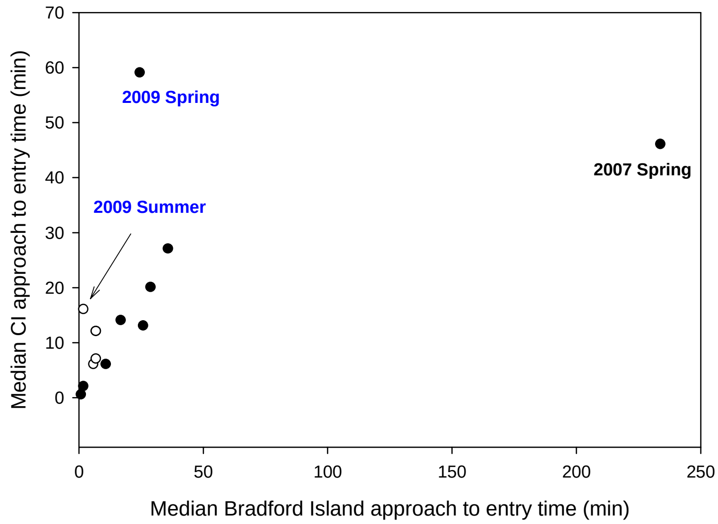

Figure 19. Scatterplot of annual median first approach to first entry times (min) at the Bradford Island and Cascades Island fishway entrances for radio-tagged spring (solid circles) and summer (open circles) Chinook salmon.

Compared to previous years, there were also considerably stronger correlations between CI approach-to-entry times and environmental conditions (Table 8), suggesting environmental factors may have affected adult spring Chinook salmon behavior in 2009. These indicated longer entry times early in the run, when spill was 90-110 kcfs, flow was < 260 kcfs, tailwater elevation was 17-21 ft and temperature was < 12° C. These tailwater elevation and temperature levels, in particular, have been associated with longer salmon passage times in the past.

Table 8. Correlation coefficients (*r*) between environmental conditions spring Chinook salmon encountered when they first approached the Cascades Island entrance and log-transformed approach-to-entry times, by year. Bold indicates P < 0.05.

Year	Flow	Spill	Temp	Tailwater elev.	Date
1997	0.03	0.03	-0.02	0.03	-0.02
1998	**-0.25**	-0.10	-0.18	**-0.25**	**-0.23**
2000	-0.13	**-0.21**	**-0.24**	-0.11	-0.17
2001	-0.14	0.37	0.38	-0.17	0.34
2002	-0.15	-0.18	-0.16	**-0.17**	-0.12
2003	-0.12	0.16	-0.12	-0.15	-0.13
2004	-0.08	-0.12	-0.13	-0.07	-0.13
2006	-0.25	-0.26	-0.23	-0.27	-0.19
2007	0.18	0.26	0.29	0.12	0.11
2009	**-0.51**	**-0.38**	**-0.39**	**-0.51**	**-0.43**
All years	**-0.32**	**-0.25**	**-0.10**	**-0.32**	**-0.08**

Compared to previous years, there were stronger correlations between CI approach-to-entry times for tagged summer Chinook salmon and environmental conditions in 2009, though they were still weak (Table 9). Correlation results indicated faster entry times when discharge and spill were high and temperature was low, in contrast with spring Chinook results. However, the June results were largely driven by a few salmon that approached and quickly entered the CI fishway in early June. Our overall impression from the correlation results was that the relatively narrow range of conditions encountered in June was not strongly related to the observed variability in summer Chinook salmon CI entrance times. For the June analyses, we limited the comparisons to years after the spill pattern change in 2001. Had we included data for June-tagged salmon from 1996–1998 and 2000–2001 more significant results may have been found (as was the case for spring Chinook salmon).

Table 9. Correlation coefficients (*r*) between environmental conditions June-tagged Chinook salmon encountered when they first approached the Cascades Island entrance and log-transformed approach-to-entry times, by year. Bold indicates $P < 0.05$.

Year	Flow	Spill	Temp	Tailwater elev.	Date
2002	-0.07	0.00	0.10	0.22	0.08
2003	-0.20	-0.13	0.08	-0.17	0.14
2004	-0.07	0.30	0.14	-0.09	0.18
2009	-0.32	**-0.37**	0.33	-0.33	0.30
All years	**-0.17**	-0.02	**0.17**	-0.07	**0.17**

Discussion

The primary aim of this evaluation was to test for any negative effects of entrance modifications on Chinook salmon passage behavior after the modifications to the Cascades Island fishway opening. Due to logistical constraints (e.g., winter de-watering schedules), several factors were altered simultaneously. Specifically, the entrance weir was modified, bollards were installed, and a new LPS entrance was installed. All three modifications had potential to affect adult salmonids behavior by changing the hydraulic and/or olfactory environment at the entrance or in the attraction plume outside of the fishway opening. The modified weir had the highest potential to affect hydraulics outside of the entrance. The bollards had the potential to affect flow condition outside the opening to a less degree, potentially by increasing turbulence in the bottom portion of the attraction plume emanating from the opening. Inside the opening, the bollards altered near-bottom flows, and the new LPS entrance had minimum potential to affect hydraulics. Unfortunately, logistical constraints required the modifications to be fixed in place and could not be independently installed and removed in an experimental manner, as in some evaluations of structural modifications at Bonneville Dam (e.g., SLEDs). Consequently, this evaluation relied on an observational approach to assess the combined effects of all the modification simultaneously by comparing passage metrics at the CI entrance to those at Bradford Island within the 2009 study year and by comparing metrics from CI to past years while attempting to account for interannual differences in river environment.

There are several factors that might account for seasonal and inter-annual variability in dam passage times by radio-tagged Chinook salmon at Bonneville Dam. Analyses of total dam passage time (tailrace entry to top of ladder) by Keefer et al. (2008) indicated that an exit to the tailrace after fishway entry and water temperature were the most closely related to passage time. Times were consistently longest for fish that exited fishways, while passage times decreased as water temperatures rose within each year, especially for spring–summer Chinook salmon. Years with late springs also tend to have slower passage during a specific interval. Anomalously, in 2009 we did not record longer dam passage times for spring Chinook salmon that exited a fishway. Compared to previous years, the percentage of radio-tagged salmon that exited Bonneville Dam fishways during 2009 was the second lowest. It is not clear to what extent the SLEDs or the presence of predators in the tailrace were responsible for the relatively low percentages of salmon exiting fishways in 2006-2007 and 2009. Some salmon that might otherwise have exited the fishway may have remained inside as a predator avoidance strategy.

In general, passage times at all Bonneville Dam fishways were similar to previous years for Chinook salmon (Table 3; Figure 8). Median times of radio-tagged spring Chinook salmon to first approach, enter, and pass Bonneville Dam in April 2009 were high compared to other study years, though we note the relatively small April sample size related to late run timing in 2009. Water temperatures were below the 10 year average during April and early May and probably contributed to the relatively slow April passage times. Including the May 2009 passage time data into the bi-monthly medians produced values that were approximately in the middle of the range of spring Chinook salmon values observed in all ten study years. Once tagged salmon entered a fishway in 2009, the time they used to exit the ladder top was reasonably low (median = 3.0 h). This suggests that the relatively long dam passage times across the project in April 2009 were primarily related to conditions in the tailrace or near fishway openings.

Almost all June-tagged Chinook salmon in 2009 returned to Bonneville Dam and passed the dam. This was consistent with results from previous years for June-tagged fish. In 2009, summer Chinook salmon approached, entered, and passed the dam faster than in previous years, while fallback and fishway exit percentages were similar to past results. Overall, these patterns suggest that the passage environment at the dam for fish tagged in June 2009 was similar to or slightly better than in 2002–2004. Thus, for both runs, the telemetry data suggest conditions in the tailrace and dam (averaging across all entrances) were approximately average.

The combined results indicate some behavioral differences in spring Chinook salmon at the CI entrance area in 2009 relative to previous years. This pattern could have been produced by changes in hydraulic or olfactory conditions outside the CI opening directly caused by the modifications and/or other conditions outside fishways and in the tailrace (including predators). Importantly, we have no reason to think the observed differences were related to systematic changes in the radiotelemetry array, tag type, or detection probabilities. The primary differences in passage between 2009 and other years appeared to be outside of the CI entrance, because a relatively low percentage of salmon entered at CI, those that did took somewhat longer to enter than in previous years, and behaviors inside the CI entrance were similar in 2009 to those in earlier years.

Similar to the results from tagged spring Chinook salmon, the 2009 CI results for June-tagged fish indicate some possible behavioral differences at the CI opening area relative to previous years. The primary difference was that salmon took slightly, but significantly, longer to enter the CI fishway after approaching. The slower 2009 passage at the CI entrance was evident after controlling for environmental differences among years. This result is consistent with results for spring Chinook salmon. We note that the magnitude of the possible 'delay' was substantially higher for the spring Chinook. The median time for June-tagged salmon in 2009 (16 minutes) was only slightly longer than the 6–12 minutes in previous years. This probably was not a biologically significant increase in passage time.

Spill level has strong effects on passage time. We note that spill during the 2009 study was consistently in the 95-150 kcfs range. Spill levels in this range have been associated with difficult CI and Bradford Island fishway entrance conditions in years past because strong eddies can form near the entrance areas making it difficult for adult salmon to enter. Spill encountered in 2009 was generally higher than average with the exception of the very high 1997 spill year. As mentioned previously, it is possible that spill patterns affected behavior near the CI fishway opening and contributed to the difference between the two ladders in 2009. At the 2009 spill levels, the relatively high proportion spilled through the end spillbays may have affected conditions near the CI opening.

The slower CI entrance times in 2009 may have been produced by changes in hydraulic or olfactory conditions outside the CI entrance directly caused by the modifications and/or other conditions outside fishways and in the tailrace. We expect that the concentration of any disruptive olfactory cues originating from the modification should decline over time as the new structures "season" by leaching and the accumulation of biofilms. On balance, however, we conclude that hydraulic conditions created by the new weir and/or altered olfactory conditions related to both modifications in the attraction plume jet likely contributed to the longer observed passage, while the hydraulic effects of the bollards and new LPS entrance on passage behavior within the fishway had insignificant effects on the passage behavior of tagged salmon.

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