Technical Report 2011-1

IDAHO COOPERATIVE FISH AND WILDLIFE RESEARCH UNIT

PASSAGE BEHAVIOR OF ADULT SPRING CHINOOK SALMON AT BONNEVILLE DAM INCLUDING EVALUATIONS OF PASSAGE AT THE MODIFIED CASCADES ISLAND FISHWAY, 2010

by

M.A. Jepson, M.L. Keefer, C.C. Caudill
Idaho Cooperative Fish and Wildlife Research Unit
Department of Fish and Wildlife Resources
University of Idaho, Moscow, Idaho 83844-1141

and

B.J. Burke
Northwest Fisheries Science Center,
National Marine Fisheries Service (NOAA Fisheries),
2725 Montlake Blvd. East, Seattle, Washington 98112

for

U.S. Army Corps of Engineers
Portland District

2011

Technical Report 2011-1

IDAHO COOPERATIVE FISH AND WILDLIFE RESEARCH UNIT

PASSAGE BEHAVIOR OF ADULT SPRING CHINOOK SALMON AT BONNEVILLE DAM INCLUDING EVALUATIONS OF PASSAGE AT THE MODIFIED CASCADES ISLAND FISHWAY, 2010

by

M.A. Jepson, M.L. Keefer, C.C. Caudill
Idaho Cooperative Fish and Wildlife Research Unit
Department of Fish and Wildlife Resources
University of Idaho, Moscow, Idaho 83844-1141

and

B.J. Burke
Northwest Fisheries Science Center,
National Marine Fisheries Service (NOAA Fisheries),
2725 Montlake Blvd. East, Seattle, Washington 98112

for

U.S. Army Corps of Engineers
Portland District

2011

Abstract

In 2010, we conducted a second year of radiotelemetry studies 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 2010 with similar metrics calculated using spring Chinook salmon data collected in 1997-1998, 2000-2004, 2006-2007 (pre-modification years), and 2009 (post-modification). It also compares these same metrics from June 2010 with results from summer Chinook salmon radio-tagged in June 2002–2004 and 2009.

Results from 2009 indicated some behavioral differences near the CI fishway opening relative to pre-modification years but the 2010 results were less conclusive. Specifically, a relatively low proportion of spring Chinook salmon that approached the CI fishway opening subsequently entered through it in 2009 and those that did enter took a relatively longer time to do so. In contrast, the entrance efficiency estimate in 2010 was 0.90, at the high end of the range from the pre-modification years (*range* = 0.56-0.98). The median CI approach-entrance time in 2010 was 42 minutes, also within the range of median times from pre-modification years (*range* = 2-46 min). For summer Chinook salmon, the entrance efficiency estimate was 0.70 in 2009 and 0.71 in 2010, the two lowest efficiencies of the five study years but similar to 2004. Median CI approach-entrance times for summer Chinook salmon in 2010 was < 1 minute, compared to 6-12 minutes in pre-modification years.

While river conditions explained some of the differences in 2009, there was also some evidence that hydraulic conditions created by the new CI variable-width weir and/or altered olfactory conditions related to the modifications contributed to the low entrance efficiency and longer salmon passage times that year. We conclude that any adverse effects associated with the modifications were reduced in magnitude in 2010 compared to 2009. We speculate that the concentration of any disruptive olfactory cues originating from the modification has declined since 2009 and the new structures may have "seasoned" by leaching and by the accumulation of biofilms. Because effects on salmon appeared to occur principally outside the fishway in both years, we conclude that the hydraulic effects of the floor-mounted bollards and the new lamprey passage structure (LPS) had negligible effects on salmon passage behavior inside the CI fishway.

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: Dennis Quaempts, Dan Joosten, Eric Johnson, Steve Lee, and George Naughton for performing the radiotagging of adult salmon, Matt Knoff and Mark Morasch 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 Sean Tackley, Tammy Mackey, Jon Rerecich, and Robert Stansell.

Table of Contents

Introduction

In 2009, the USACE modified the Cascades Island (CI) fishway opening at Bonneville Dam to reduce maintenance costs 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 during winter 2008-2009 prior to the 2009 spring Chinook salmon (*Oncorhynchus tshwaytscha)* migration. In 2009, we conducted a radiotelemetry study of spring and early summer Chinook salmon to test whether the CI modifications affected behavior and passage success of adult salmonids.

Results from 2009 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 speculated 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 also hypothesized 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.
A parallel study evaluated behaviors of adult lampreys in 2009 and was continued in 2010 (see Clabough et al. 2010; *in prep*).

Results from 2009 prompted a continuation of the study in 2010. This final report summarizes results for both Chinook salmon runs including passage times, fallback rates, and behaviors of radio-tagged at Bonneville Dam in 2010. Dam passage time metrics and CI entrance use and passage efficiency metrics collected in April-May 2010 were compared with similar metrics from spring Chinook salmon data collected in 1997-1998, 2000-2004, 2006-2007, and 2009. Similar metrics for Chinook salmon tagged in June 2010 were compared to data from Chinook salmon radio-tagged in June 2002–2004 and 2009. The variability in overall dam passage and fallback metrics among years was evaluated to provide context for the more specific CI evaluations. Reporting in both years is separated into spring and early summer components in response to reporting requests from USACE in 2009 (see Keefer et al. 2009a, 2009b).

Our primary objective was to compare estimates for pre-modification years to post-modification years while simultaneously considering interannual variation in environmental, operational, and ecological (i.e., the abundance of marine mammal predators) conditions. We also compared passage behavior between 2009 and 2010 to test for evidence that the hydraulic or olfactory mechanisms may have contributed to the longer passage times observed in 2009. We expected that hydraulic conditions would produce consistent effects in both years. We hypothesized that the “seasoning” of the structures through leaching and formation of biofilms might lead to reduced or absent effects in the second study year.

Below we describe variation in environmental parameters, general patterns of adult salmon passage over Bonneville Dam, and then we present the detailed results of passage behavior at the modified CI fishway opening.

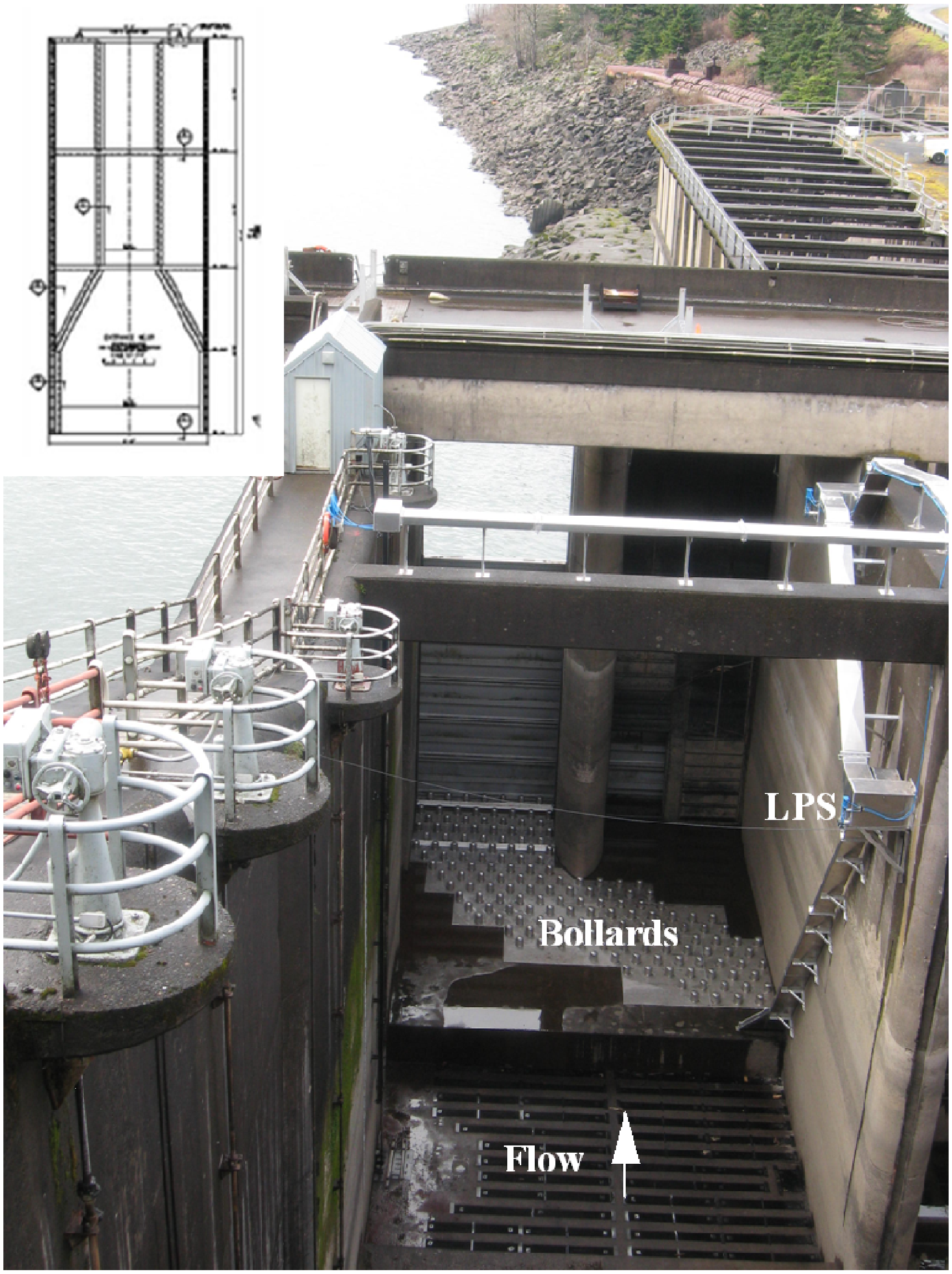

Figure 1. Photograph of the area immediately inside the Cascades Island fishway opening. The variable-width weir was installed on the opposite side of the left bulkhead, downstream from the bollards and lamprey passage structure (LPS). Drawing (inset) shows the profile of the variable width weir which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

Methods

Radio-tagging

From 10 April through 31 May 2010, we collected and intragastrically radio-tagged 447 spring Chinook salmon at the Adult Fish Facility of Bonneville Dam and released them approximately nine kilometers downstream from the dam (Figure 2). We similarly collected and tagged 153 summer Chinook salmon from 1-30 June 2010. A description of the collection and tagging methods is presented in Keefer et al. (2004a). A total of 313,142 adult spring Chinook salmon and 72,322 adult summer Chinook salmon were counted passing the dam during the tagging period. Radio-tagged salmon represented ~0.2% of the salmon counted at the dam during the tagging period.

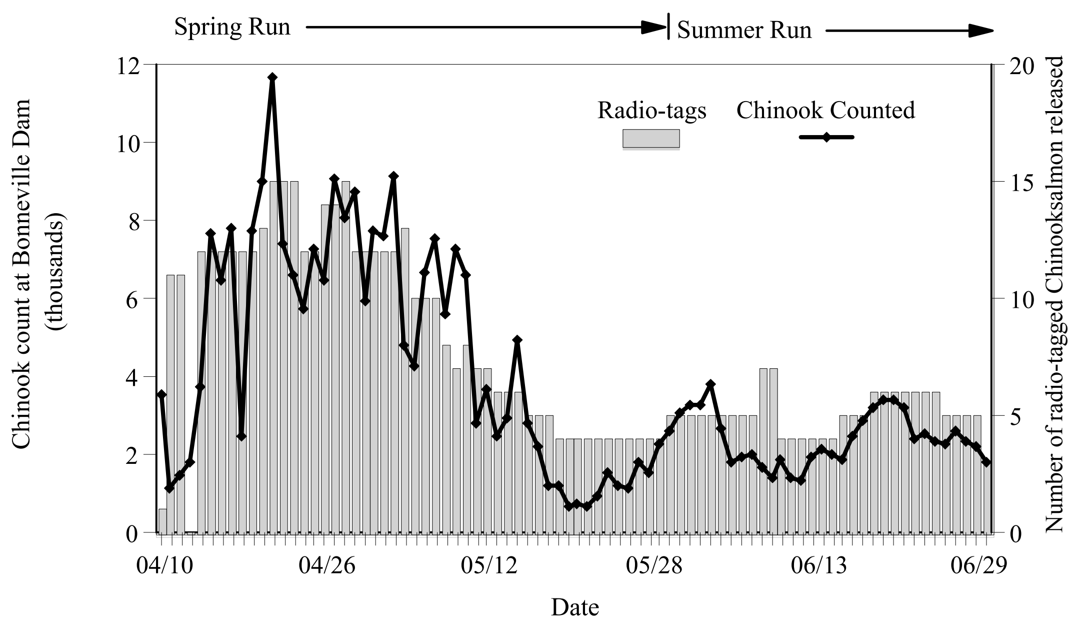

Figure 2. The number of Chinook salmon radio-tagged and released downstream from Bonneville Dam and the count of adult Chinook salmon passing the dam from 10 April through 30 June 2010.

Evaluations of Environmental Data, Passage Times, and Fallback Percentages

For spring Chinook salmon, we compared passage times from April – May 2010 to corresponding values from 1997-1998, 2000-2004, 2006-2007, and 2009 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, and 2009. Potentially confounding factors in our multi-year comparisons were the deployment of sea lion exclusion devices (SLEDs) in 2006-2007, 2009, and 2010 and variations in spill patterns among years. Across the study years, the spill pattern also shifted toward proportionately more spill through end spillbays. In addition, marine mammal predators have increased (Stansell et al. 2009). In 2010, SLEDs were deployed at all main fishway openings (Figure 3) until 21 June (Powerhouse 1 and

Powerhouse 2), 22 June (Bradford Island [BI]), or 30 June 2010 (Cascades Island [CI]). In contrast, SLEDS were removed from all fishway opening by 3 June 2009 so comparisons of 2009 and 2010 data for the June (summer Chinook salmon) analyses were modestly confounded. Sea lion exclusion bars were deployed at 11 of 12 Powerhouse 2 floating orifice gates in 2010 (which allowed salmon to enter or exit the collection channel) and one floating orifice gate was out for maintenance, with a bulkhead installed in its place.

In December 2009, the Cascades Island fishway was outfitted with a prototype electrical deterrent system designed to deter marine mammal predation on fish. The installation was intended to evaluate the behavior of fish exposed to a mild electrical field. A DIDSON (Dual-frequency Identification Sonar) camera was also installed in the Cascades Island fishway on 9 April 2010 to monitor fish behavior during the testing of the electrical deterrent system. Researchers from the U.S. Geologic Survey at Cook, WA, tested the array at the lowest setting on 23 April 2010 and a negative reaction was observed by Chinook salmon (Smith 2010). On 28 April 2010, a bulkhead was installed where the Upstream Migration Tunnel meets the WA shore ladder at approximately 1030 hrs. This allowed the Cascades Island fishway to be dewatered for the removal of the electrical deterrent system and DIDSON camera. The bulkhead was removed at about 1345 hrs and flows were returned to normal shortly thereafter (J. Rerecich, USACE, *personal communication*).

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. We additionally evaluated the degree of association between CI approach-entry times and date.

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 hr to swim through the two passage segments.

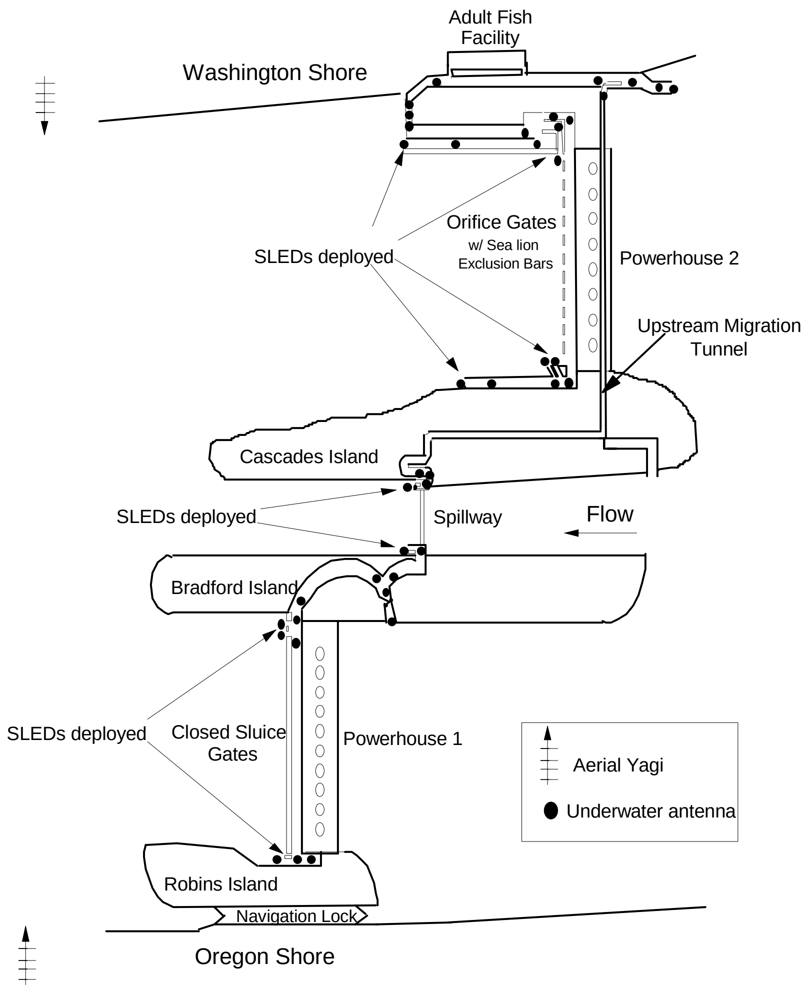

Figure 3. Aerial view of radio antennas, SLED deployments, and floating orifice gates with sea lion exclusion bars (that allowed salmon passage) at Bonneville Dam in 2010.

Results

Environmental Data

Flow, spillway discharge, and river temperatures in the Bonneville Dam tailrace varied considerably during the spring Chinook salmon runs over the eleven study years (Figure 4). This 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. Environmental conditions at Bonneville Dam for 2010 spring Chinook salmon were characterized by lower than average flows, spill levels less than 100 kcfs, and cooler than average temperatures. For the 2010 summer run of Chinook salmon, environmental conditions were characterized by modestly higher total river discharge, spill volumes, and tailwater elevations compared to the four other study years (Figure 5). June to mid-July water temperatures were generally cooler than those from previous years.

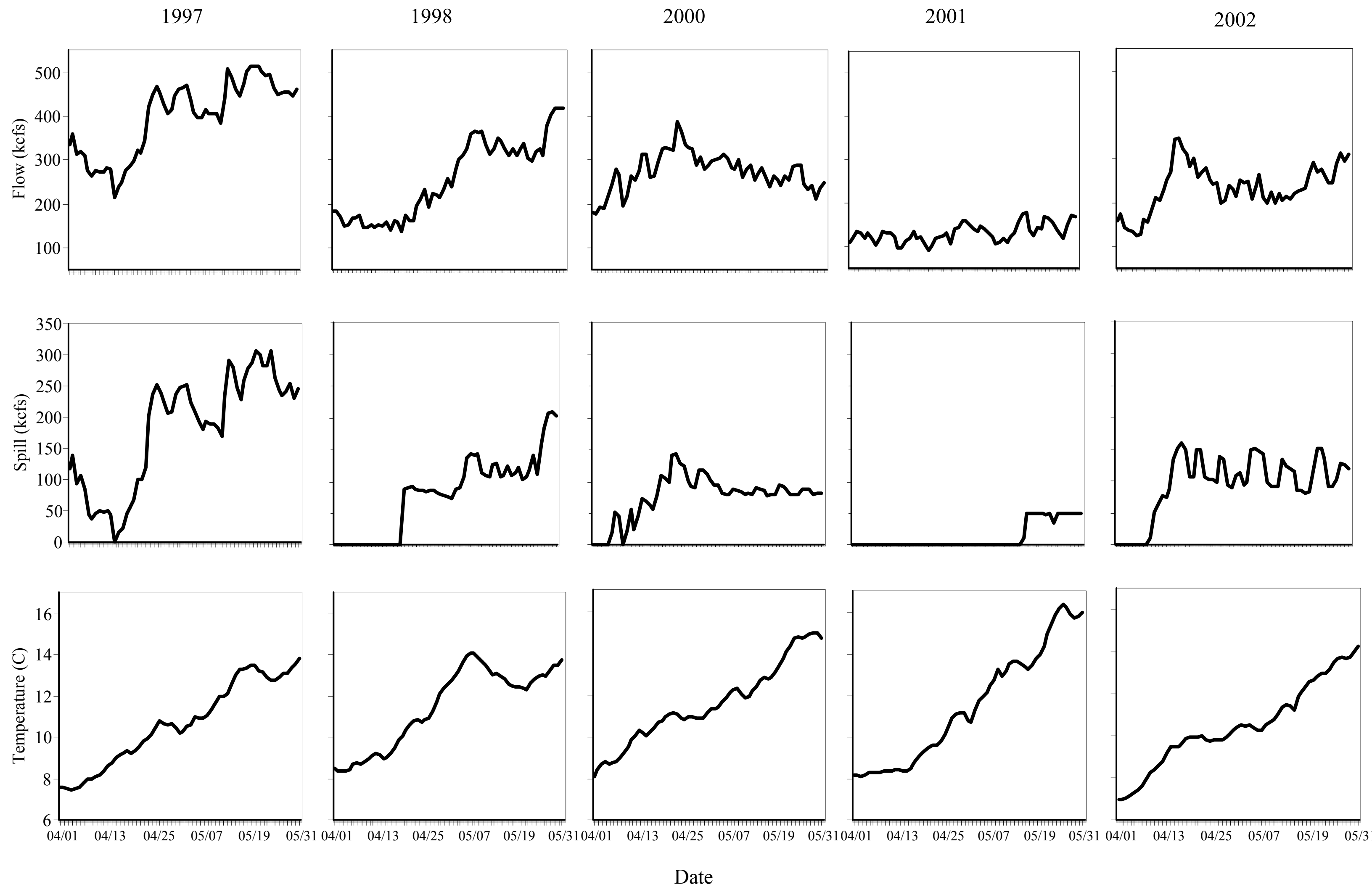

Figure 4. Mean daily flow, spillway discharge, and tailrace water temperature at Bonneville Dam during the spring Chinook salmon run (April – May), 1997-1998, 2000-2004, 2006-2007, and 2009-2010.

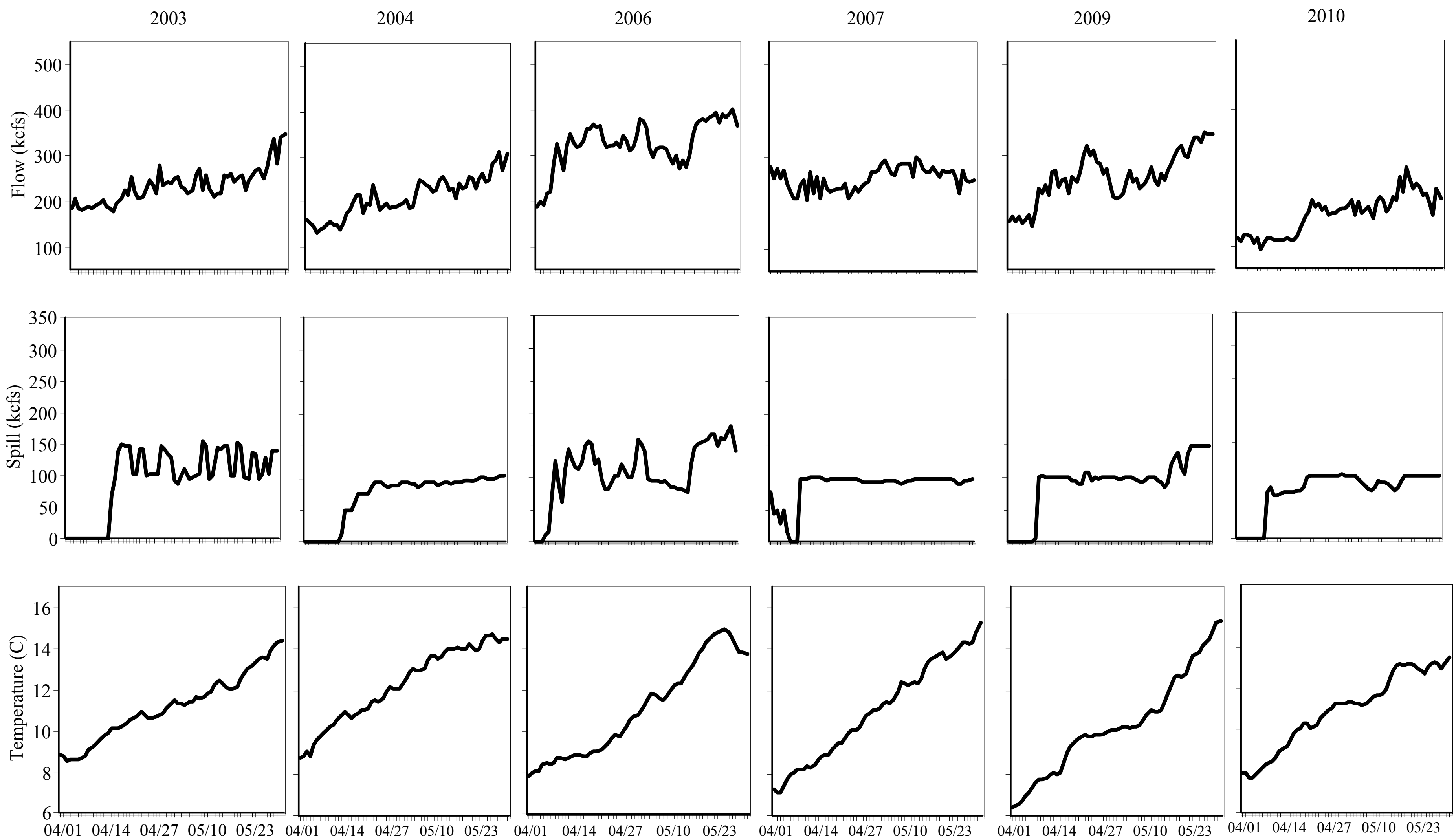

Figure 4 (continued).

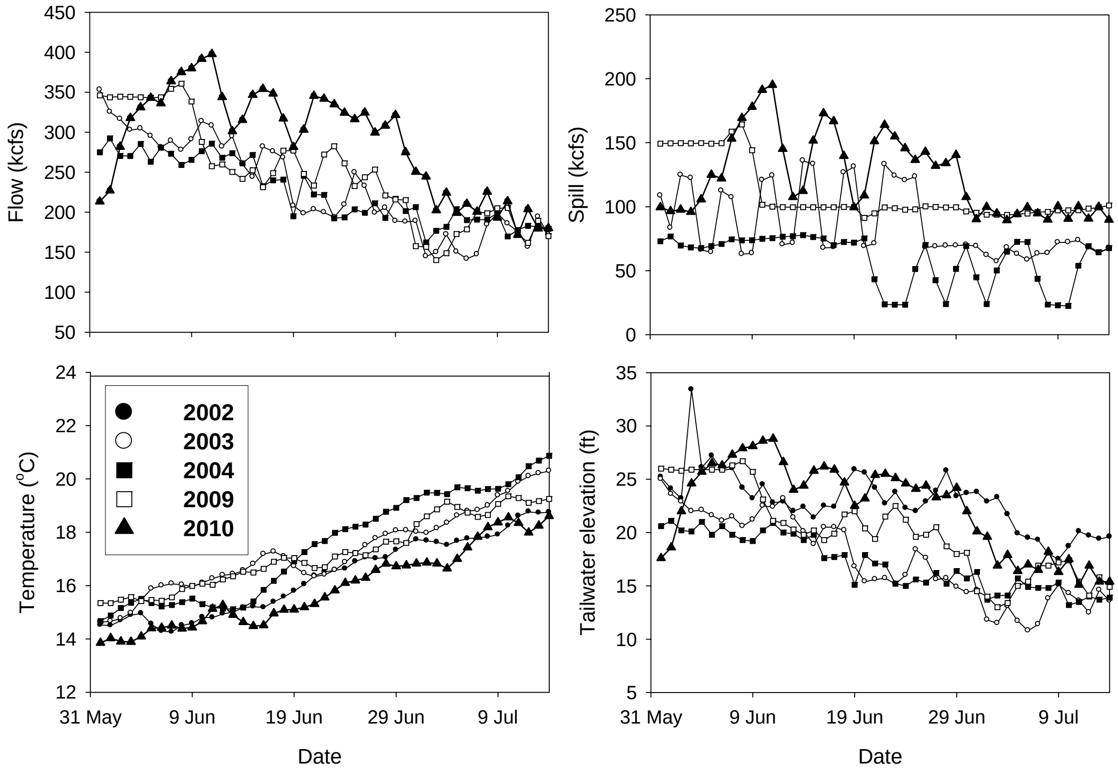

Figure 5. Mean daily flow, spillway discharge, water temperature, and tailrace elevation at Bonneville Dam from 1 June to 15 July, 2002-2004 and 2009–2010.

Passage events, routes, and fallback - 2010

Of the 447 spring Chinook salmon radio-tagged and released through 31 May 2010, 429 (96%) resumed upstream movements and were recorded on receiver sites at the dam and 16 (4%) had no valid telemetry records. Of the 447 released, 407 (91%) passed the dam (Table 1). One hundred and twenty-seven passage events (33%) were recorded via the Bradford Island ladder, 270 (65%) were recorded via the Washington-shore ladder, and 10 (2%) likely passed the dam via the unmonitored navigation lock. We recorded 14 fallback events by 12 unique salmon; nine events by salmon that passed via the Bradford Island ladder and five by salmon that passed via the Washington-shore ladder. Nine of the 14 (64%) unique, tagged salmon that fell back re-ascended a fishway.

Of the 153 summer Chinook salmon tagged and released in June 2010, 151 (99%) resumed upstream movements and were recorded on receiver sites at the dam and 2 (1%) had no valid telemetry records. Of the 153 released, 149 (97%) passed the dam (Table 2). Seventy-four passage events (50%) were recorded via the Bradford Island ladder and 75 (50%) were via the Washington-shore ladder. We recorded 16 fallback events by 16 individual salmon. Fifteen events followed passage via the Bradford Island ladder and one was via the Washington-shore ladder. Fourteen of the 16 (88%) 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 2009-2010.

	Frequency										
	1997	1998	2000	2001	2002	2003	2004	2006	2007	2009	2010
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	4/10-5/31
Released downstream	680	675	728	641	658	793	349	358	286	376	447
Recorded at dam	666	672	725	627	653	757	340	348	273	360	429
Known to pass dam	656	663	713	617	641	706	312	317	246	335	407
Recorded 1st tailrace passage	636	623	693	516	533	663	301	316	230	304	350
Recorded 1st fishway approach	638	656	716	605	632	668	319	316	259	344	381
Recorded 1st fishway entrance	526	587	592	546	545	587	283	253	246	313	280
Recorded ladder exit	650	646	707	601	640	698	306	268	246	329	387
	Percentage of radio-tagged salmon released										
Recorded at dam	98	99	99	98	99	95	97	97	95	96	96
Known to pass dam	96	98	98	96	97	89	89	89	86	86	91
Recorded 1st tailrace passage	94	92	95	80	81	84	86	88	80	81	78
Recorded 1st fishway approach	94	97	98	94	96	84	91	88	89	91	85
Recorded 1st fishway entrance	77	87	81	85	83	74	81	71	76	83	63
Recorded ladder exit	96	96	97	94	97	88	88	75	86	88	87

Table 2. Range of release dates, number of adult radio-tagged summer Chinook salmon released downstream from Bonneville Dam, and numbers (%) 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 2009-2010.

	Number (% of released)				
	2002	2003	2004	2009	2010
Release date range	6/1-6/30	6/1-6/30	6/1-6/30	6/1-6/30	6/1-6/30
Released downstream	165	203	119	223	153
Recorded at dam	165 (100%)	202 (99%)	115 (97%)	222 (99%)	151 (99%)
Known to pass dam	163 (99%)	199 (98%)	114 (96%)	219 (98%)	149 (97%)
Recorded 1st tailrace passage	159 (96%)	184 (91%)	109 (92%)	215 (96%)	146 (95%)
Recorded 1st fishway approach	161 (98%)	196 (97%)	113 (95%)	215 (96%)	148 (96%)
Recorded 1st fishway entrance	146 (88%)	183 (90%)	107 (90%)	201 (90%)	129 (84%)
Recorded ladder exit	162 (98%)	195 (96%)	113 (95%)	217 (97%)	149 (97%)

Distributions of first approaches and entries

In 2010, 43% of all the first fishway approaches made by radio-tagged spring Chinook salmon were recorded at Powerhouse 2 and approximately 25% were recorded at Powerhouse 1 (Figure 6). First fishway approaches at the CI opening comprised approximately 20% of all first fishway approaches and about 12% first approached at the BI fishway opening. For first entrances, fishway use was similar to first approaches; the highest percentage of all first fishway entrances made by radio-tagged spring Chinook salmon was recorded at Powerhouse 2 (40%). Twenty-nine percent of all first fishway entries were at the CI opening and percentages were 16% at the BI opening and 15% at Powerhouse 1.

Summer Chinook salmon were more likely to first approach one of the powerhouses than were spring Chinook salmon (Figure 6). Approximately two-thirds of all the first fishway approaches made by radio-tagged summer Chinook salmon were recorded at Powerhouse 1 and approximately 30% were at Powerhouse 2. The remaining first fishway approaches were at BI (<1%) and CI (3%) fishway openings. Slightly less than half (47%) of all first fishway entrances by radio-tagged summer Chinook salmon were recorded at Powerhouse 1. Approximately 36% of all first fishway entries were at Powerhouse 2, 12% were at the CI opening, and 5% were at the BI opening. For both spring and summer Chinook salmon, entrances at Cascade Island and Bradford Island were more common than first approaches.

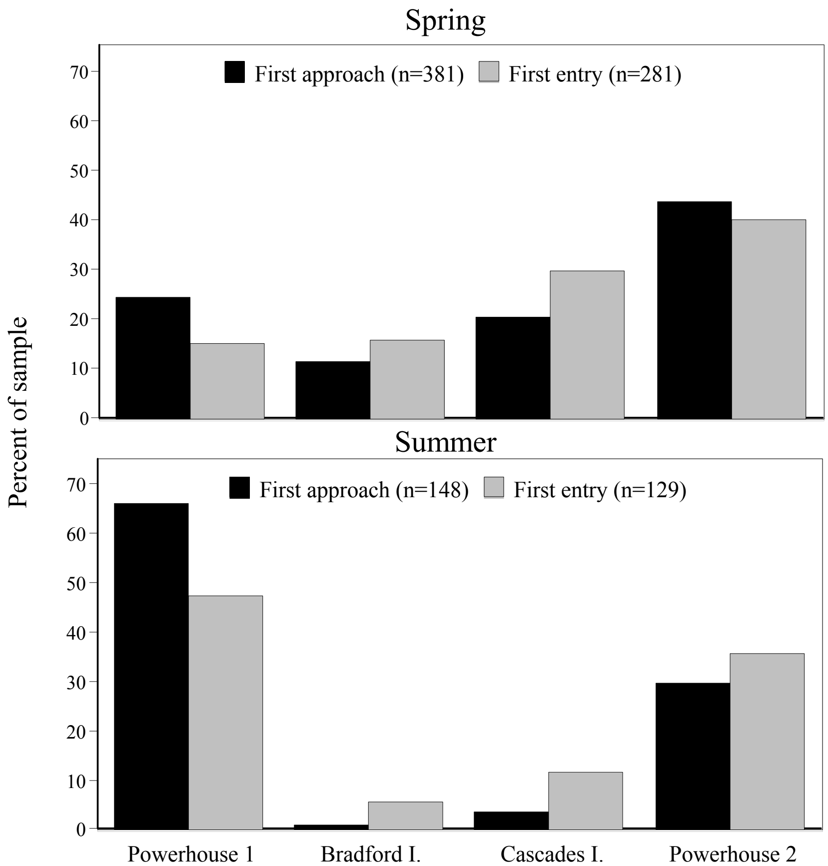

Figure 6. Distributions of known first fishway approach and entrance sites used by radio-tagged spring (upper panel) and summer (lower panel) Chinook salmon at Bonneville Dam in 2010.

Percentages of first fishway approaches resulting in entries

The highest percentage of first fishway approaches by radio-tagged spring Chinook salmon was at Powerhouse 2 (43%) but only 22% (36 first entries / 166 first approaches) of them resulted in a first fishway entry (Figure 7). First fishway approaches at Powerhouse 1 were slightly less efficient, with 20% of them resulting in first fishway entries (19 first entries / 93 first approaches). In contrast, the spillway fishway openings were the most efficient, with 77% (n = 78) of all first fishway approaches at the CI fishway opening and 66% (n = 44) at the Bradford Island fishway opening resulting in a first fishway entry.

For summer Chinook salmon, the percentage of first fishway approaches resulting in entries were 16% (n = 98 approaches) at Powerhouse 1 and 9% (n = 44) at Powerhouse 2 (Figure 7). The spillway fishway openings were lightly used, resulting in low sample sizes, but percentages were relatively high at 40% (n = 5) at the CI fishway opening and 100% (n = 1) at the Bradford Island fishway opening.

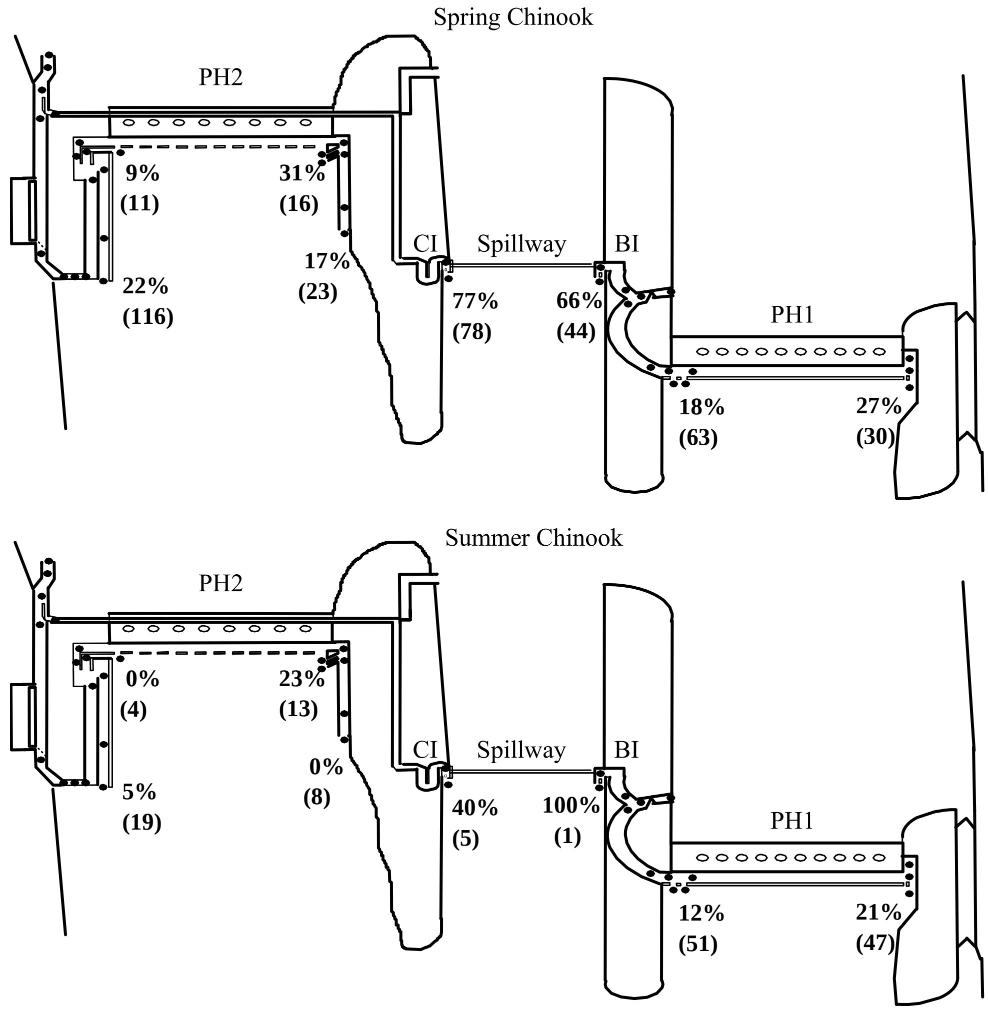

Figure 7. Percentage of first fishway approaches by radio-tagged spring (upper panel) and summer (lower panel) Chinook salmon resulting in first fishway entries (at those openings) for all monitored fishway openings at Bonneville Dam in 2010. Sample sizes (number of first approaches) are in parentheses.

Passage times

The median time from release to first record in the tailrace was 42.9 h (n = 139) for spring Chinook salmon tagged and released in April 2010 and decreased to 31.3 h (n = 211) for fish tagged and released in May 2010 (Table 3). The median release-tailrace time for all radio-tagged spring Chinook salmon was 39.2 h. Overall, the 2010 median time ranked as the slowest among the eleven study years (Table 3).

The median time from first tailrace record to first fishway approach in April 2010 (15.6 h, n = 119) was the fourth fastest time observed in April of the eleven study years. The median tailrace to first approach time for May 2010 (14.8 h, n = 190) was the second slowest among the eleven study years. The median time to first approach a fishway after being detected in the tailrace in April-May 2010 was the third slowest (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 2009-2010. Rankings for 2010 values (1 = slowest time and 11 = fastest time) are listed to the right.

	1997		1998		2000		2001		2002		2003		2004		2006		2007		2009		2010		
	n	Med.	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**	139	**42.9**	**2**
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**	211	**31.3**	**1**
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**	350	**39.2**	**1**
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**	119	**15.6**	**8**
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**	190	**14.8**	**2**
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**	309	**15.2**	**3**
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**	77	**33.6**	**8**
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**	148	**29.1**	**2**
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**	225	**30.0**	**3**
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**	129	**45.7**	**8**
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**	186	**33.0**	**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**	315	**34.9**	**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**	105	**1.3**	**11**
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**	175	**1.1**	**11**
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**	280	**1.1**	**11**

The median time from first tailrace record to first fishway entry in April 2010 was the fourth slowest among all study years whereas the median time in May 2010 ranked as the second slowest. The grand median for April-May 2010 was the third slowest among the eleven study years.

The median time for radio-tagged spring Chinook salmon to pass Bonneville Dam (tailrace to ladder top) in April 2010 was 45.7 h (*n* = 129), the fourth fastest among all study years. The median value for May 2010 was the fourth slowest and the combined April-May 2010 median ranked as the third slowest among all study years (Table 3).

The median times from first approach to first entry in both April and May 2010 were the fastest among all years. The grand median time was also the fastest among all study years.

The median time tagged spring Chinook salmon used to swim from first fishway entry to the ladder top was 3.8 h in April (*n* = 168), 3.4 h in May (*n* = 230), and 3.6 h overall (*n* = 398). Only 2% 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.

In 2010, the median time from release to first record in the tailrace was 16.1 h (*n* = 146; Figure 8), the slowest median time among all comparison years (2002 = 12.1 h, 2003 = 14.5 h, 2004 = 6.9 h, and 2009 = 5.9 h). Similarly, the median time from first fishway approach to first fishway entry (2.5 h, *n* = 129) was the slowest among all study years. In contrast, the median times from first tailrace record to first fishway approach (1.7 h, *n* = 143) and to pass the dam (18.8 h, *n* = 144) in 2010 were the fastest among all study years (Figure 8). The median time from first tailrace record to first fishway entry (9.3 h, n = 124) was intermediate. The median time from first fishway entry to the ladder top was 5.9 h in 2010 (*n* = 149). This was the fastest median time among all study years (*medians* = 8.3–11.3 h).

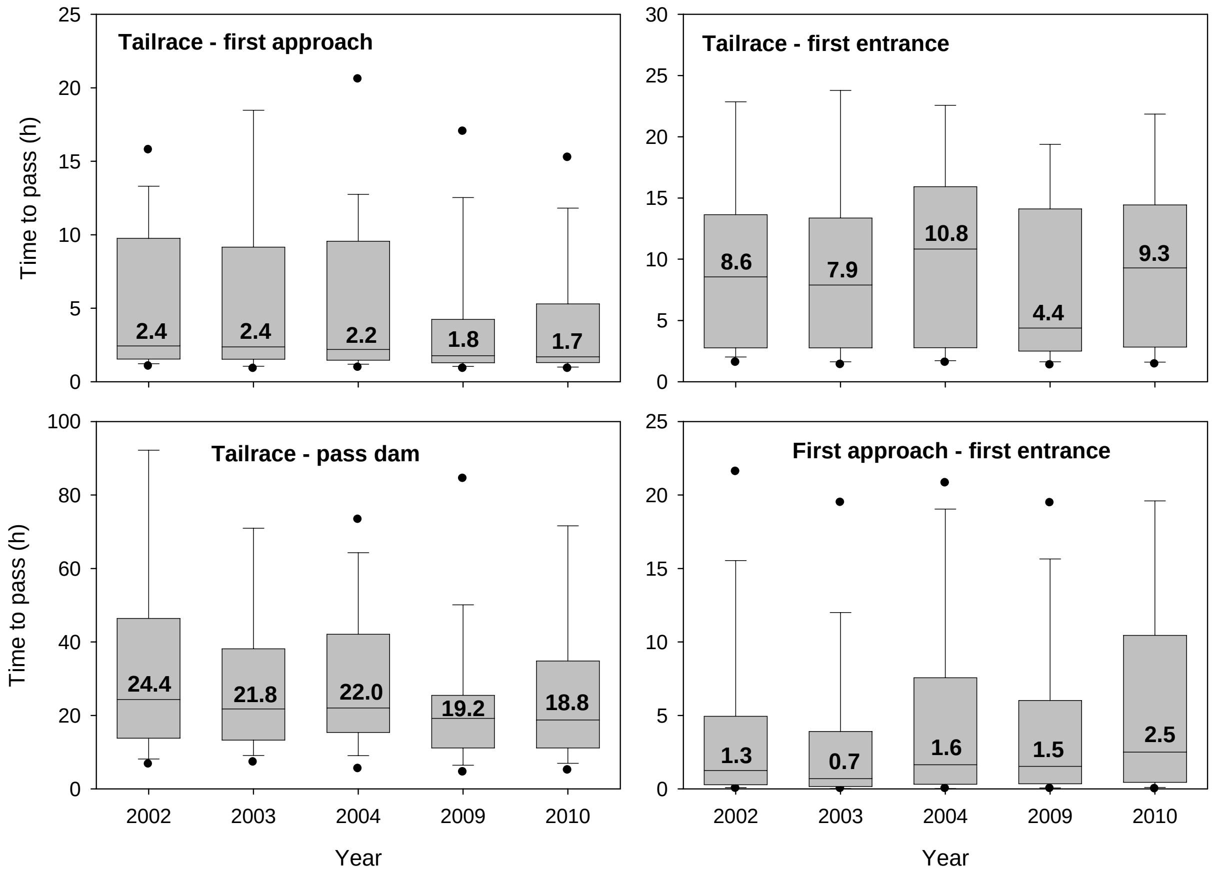

Figure 8. Distributions of summer Chinook salmon passage times (h) from first tailrace record at Bonneville Dam to first fishway approach, first fishway entry, and to pass the dam and from first fishway approach to first fishway entry, 2002-2004 and 2009-2010. Box plots show: median, quartile, 5th, 10th, 90th and 95th percentiles. Numbers inside boxes are median times. Note different y-axis scales.

Dam passage times and exit percentages

Nineteen of the 385 (4.9%) radio-tagged spring Chinook salmon that entered a fishway in 2010 exited a fishway to the tailrace at least once (Table 4). This was a lower exit percentage (unique fish exited/unique fish entered) for radio-tagged spring Chinook salmon than in all previous years (*range* = 8-61%). In almost all previous evaluations, salmon that exited fishways back to the tailrace have had significantly longer dam passage times than salmon that do not exit (see Keefer et al. 2008). In 2010, the median dam passage time for radio-tagged spring Chinook salmon that made at least one fishway exit was 38.5 h (*n* = 13) compared to 34.8 h (*n* = 302) for those that did not exit.

Table 4. Numbers of radio-tagged spring Chinook salmon that entered a Bonneville Dam fishway prior to 1 June and the numbers and percentages 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
2010	385	19	4.9

Of the 150 tagged summer Chinook salmon that entered a fishway in 2010, 78 (52%) exited a fishway to the tailrace at least once (Table 5). This was lower than in the four previous years (*range* = 65-74%). As in previous evaluations, summer Chinook salmon that exited a fishway took longer to pass the dam (*median* = 22.6 h, n = 77) than those that did not exit (*median* = 13.9 h, n = 67).

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 2009-2010.

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%
2010	150	78	52%

Re-ascension of radio-tagged salmon that fell back

Prior to 2001, the first year when substantial numbers of pinnipeds were present in the tailrace, fishway re-ascension rates of unique, radio-tagged spring Chinook salmon that fell back at Bonneville Dam ranged from 86 to 96% (Table 6). These were also years when fallback percentages were relatively high (13-17%), at least in part because more flow was passed through Powerhouse 1 and more salmon passed the dam via the Bradford Island ladder (Reischel and Bjornn 2003; Boggs et al. 2004). Fallback percentages were relatively low (*range* = 4 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 low of 67% in 2004. Re-ascension rates of unique salmon in 2006 and 2007 ranged between 71-74%. The 2009 re-ascension rate of 77% ranked as the fifth lowest among the 11 study years. In 2010, the salmon fallback percentage (3.4%) and re-ascension rate (50%) were the lowest values among all 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 Chinook salmon (released at Skamania Landing or Dodson boat ramp only) and the number of unique radio-tagged Chinook salmon that fell back and re-ascended Bonneville Dam, 1997-1998, 2000-2004, 2006-2007, and 2009-2010.

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)
1997	17.4	158	152	96	114	109	96
1998	13.3	128	107	84	88	76	86
2000	15.9	147	138	94	113	106	94
2001	5.5	53	45	85	34	29	85
2002	7.2	51	43	84	46	38	83
2003	6.0	59	49	83	43	39	91
2004	3.9	13	9	69	12	8	67
2006	12.2	46	34	74	39	29	74
2007	6.5	17	12	71	17	12	71
2009	6.7	23	18	78	22	17	77
2010	3.4	14	9	64	12	7	50

In 2010, the fallback percentage at Bonneville Dam was 10.7% for June-tagged summer Chinook salmon and 88% that fell back subsequently re-passed the dam (Table 7). The 2010 fallback percentage was the highest among study years and the re-ascension rate in 2010 was within the range recorded for June-tagged salmon in 2002-2004, and 2009.

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 2009-2010.

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
2010	10.7	16	14	88	16	14	88

2010 Cascades Island Results

Of the spring Chinook salmon tagged through 31 May 2010, 116 (26%) were recorded approaching and 23% were recorded entering the CI fishway opening (Figure 9). These percentages were within the range of values from pre-modification years, 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 slightly with increasing river discharge (Figure 10), presumably because spill provides attraction flow. The 2009 and 2010 detection rates were in line with rates in previous years given river conditions.

Of the 153 fish tagged in June 2010, 38 (25%) were recorded approaching and 27 (18%) were recorded entering the CI fishway opening. Both percentages were lower than in 2002-2004, when 30-32% approached the CI fishway and 22-28% entered, but were higher than summer Chinook salmon recorded approaching (21%) and entering (14%) the CI fishway opening in 2009.

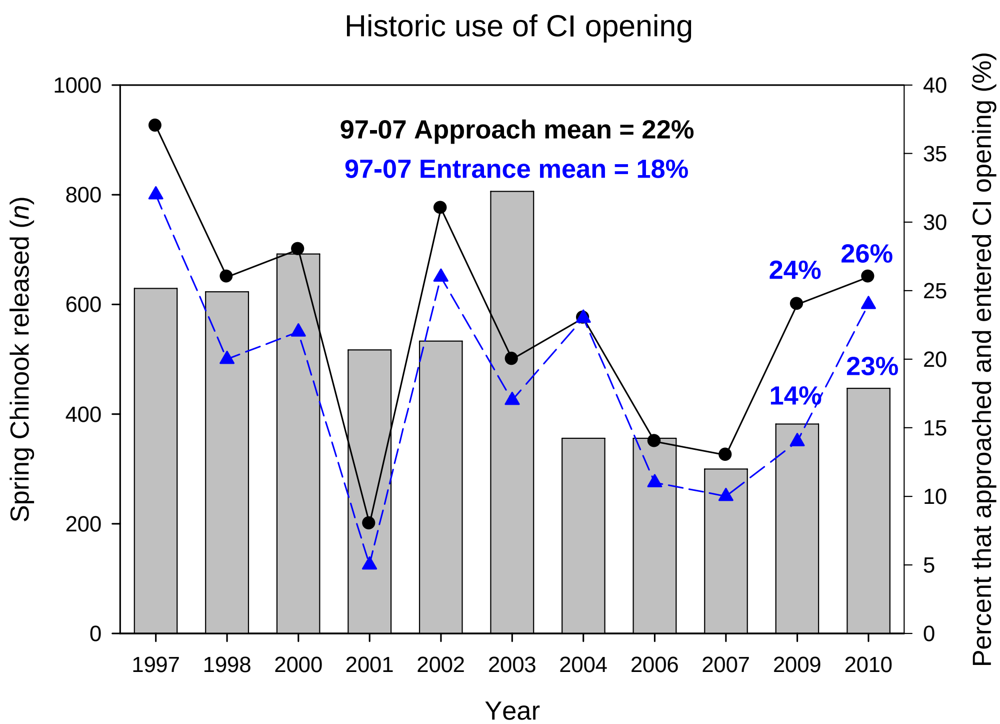

Figure 9. Number of spring Chinook salmon radio-tagged (bars) and the percentages that were recorded approaching (circles and solid line) and entering (triangles and dashed line) the Cascades Island fishway.

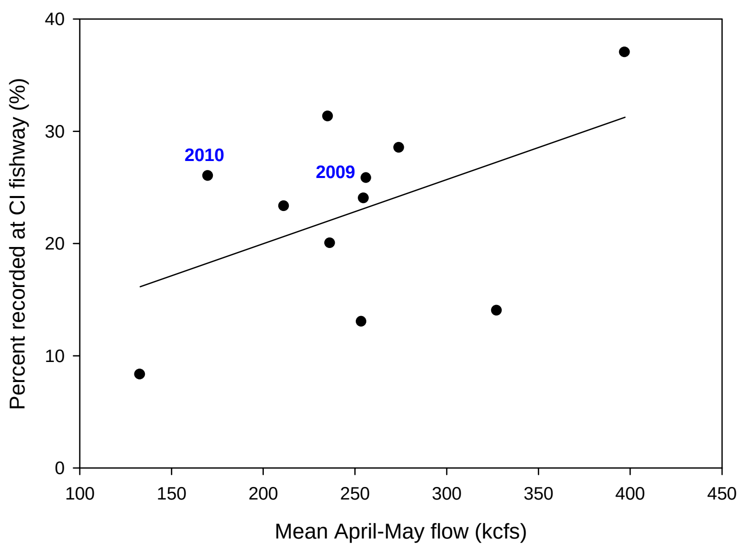

Figure 10. Linear relationship between mean April-May discharge at Bonneville Dam and the percentage of spring Chinook salmon recorded at the Cascades Island fishway ($r^2 = 0.23$).

Metric 1. The CI entrance efficiency estimates in pre-modification 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 2010 was 0.90, at the high end of the range from previous years. In contrast, the entrance efficiency in 2009, the other post-modification year, was at the low end of the range (0.59). Both post-modification years were within the range of previous years. For radio-tagged summer Chinook salmon, the CI entrance efficiency estimates in previous years ranged from 0.72–0.89 (*mean* = 0.83; Figure 11). The entrance efficiency estimate was 0.70 in 2009 and 0.71 in 2010, the two lowest of the five years but similar to 2004.

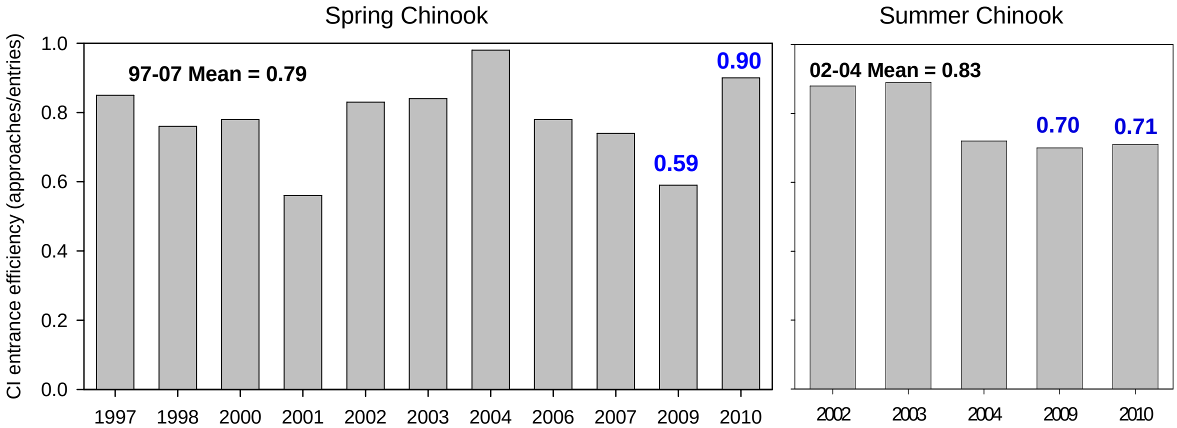

Figure 11. Cascades Island entrance efficiency (unique entrances/unique approaches) for radio-tagged spring Chinook salmon (left panel) and summer Chinook salmon (right panel).

Metric 2. Exit ratios for radio-tagged spring Chinook salmon were more variable than entrance efficiencies in previous years, and ranged from 0.00–0.46 (*mean* = 0.24; Figure 12). The 2009 estimate was 0.04 and the 2010 estimate was 0.00, both values at the very low end of the range. No spring fish exited back into the tailrace after entering at CI in 2010, suggesting favorable passage conditions once inside the fishway opening. 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) and sampling error. It was not clear why there were relatively few recorded CI exits in 2006-2007 and 2009-2010 but the presence of marine mammals in the tailrace or SLEDs may have some role in the decreasing exit percentages of spring Chinook salmon observed at the dam as a whole (see Table 4). 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, and the 2010 value was the lowest (0.26) among the five study years.

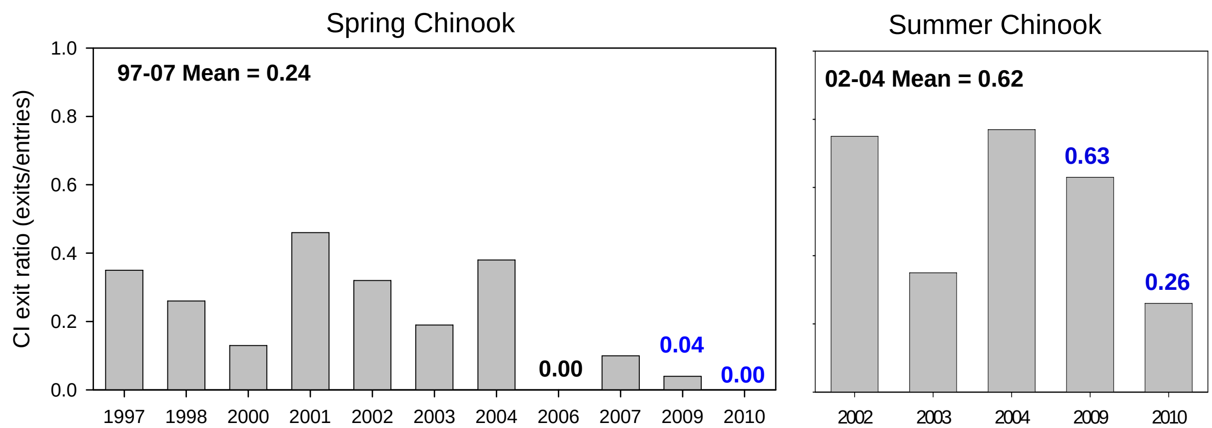

Figure 12. Cascades Island exit ratios (unique salmon that exited/unique salmon that entered) for radio-tagged spring Chinook salmon (left panel) and summer Chinook salmon (right panel).

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 study 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 pre-modification years, with tagged salmon in the small 2007 sample (n = 20) having the longest median passage time (46 min). In comparison, the median was 59 minutes in 2009 and 42 minutes in 2010. ANOVA results for log-transformed passage times (excluding 2009 data) indicated significant among-year differences in means (df = 9, F = 17.8, P < 0.0001). In pairwise comparisons, the 2010 mean was significantly higher than means in 5 of the 9 pre-modification years using the Tukey Test (Zar 1999). When we adjusted alpha to control for the comparison-wise error rate (experiment-wise α = 0.05 / number of comparisons (45) = 0.0011), the 2010 mean was significantly longer than the mean in 3 of 9 years. In an ANOVA restricted to 2009 and 2010 passage times, we found no significant difference between times from the two post-modification years (df = 1, F = 0.54, P = 0.46). A Kruskal-Wallis test of medians (ranks of untransformed data) indicated significant differences (χ^2 = 151.1, P < 0.0001) among years (excluding 2009), with the 2010 median being the second highest among years. These results suggest some adverse difference in conditions outside or immediately adjacent to the fishway opening in 2009 compared to pre-modification years; the effect appeared to be reduced in 2010 compared to 2009.

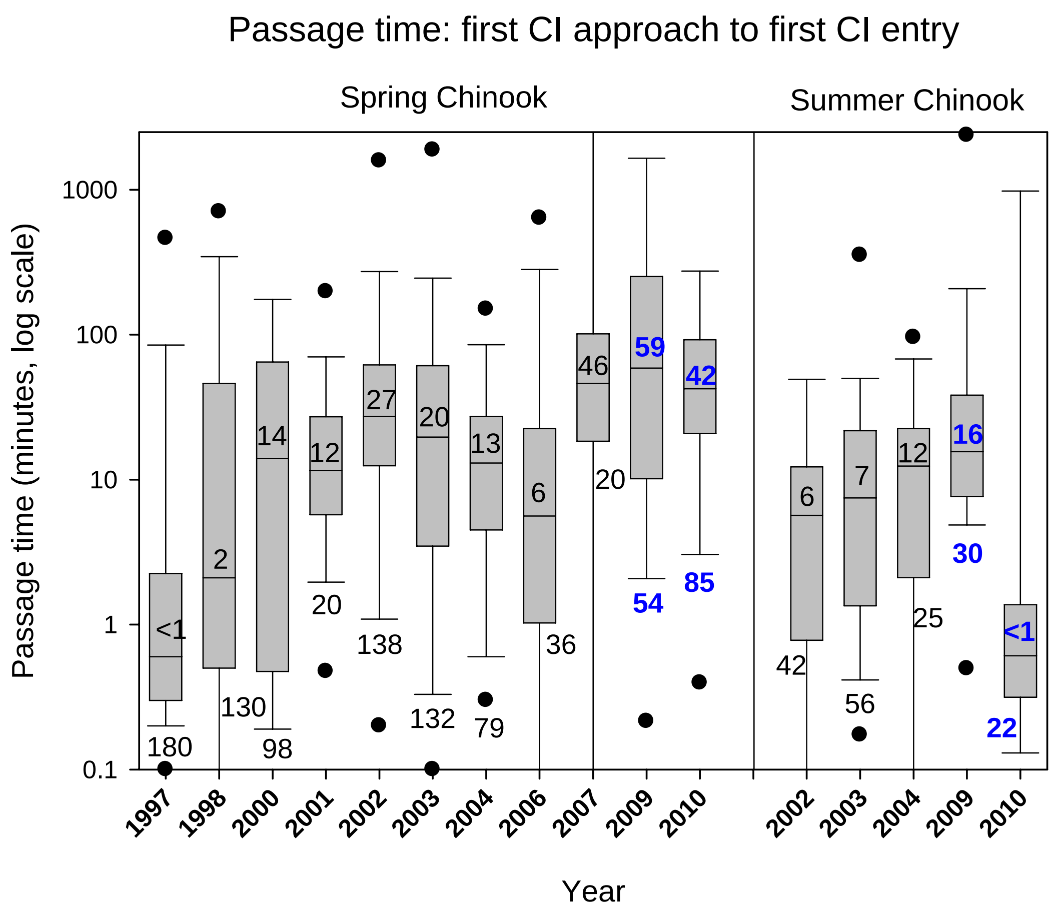

Figure 13. Spring and summer Chinook salmon passage time distributions (plotted on log scale) from approach to entry at the Cascades Island fishway. Values inside boxes are median times. Distributions show 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles; sample sizes are shown at bottom.

Median CI approach-entrance times for summer Chinook salmon in previous years were 6–12 minutes (*mean* = 8; Figure 13). The median in 2010 was less than one minute. ANOVA results for log-transformed passage times (excluding 2009 data) indicated no significant among-year differences in means (df = 3, F = 2.2, P = 0.09). In contrast, significant differences were found among years when we compared 2009 times with the three pre-modification years (df = 3, F = 3.0, P = 0.035). The 2009 mean was significantly higher than the 2002 mean (P > 0.05). In an ANOVA restricted to 2009 and 2010 times, there was a significant difference between the two post-modification years (df = 1, F = 16.9, P = <0.0001). A Kruskal-Wallis test of medians (excluding 2009 data) indicated significant differences among years (χ^2 = 13.8, P <0.0001), with the 2010 median the lowest among years. These results suggest adverse conditions outside or immediately adjacent to the fishway opening in 2009 whereas results from the second post-modification year (2010) suggests conditions near the fishway opening provided the best conditions observed across all study years for summer Chinook salmon.

Prior to 2009, spring Chinook salmon had median approach to entry times at the BI fishway opening, a useful comparison site, that were higher than or equal to those at the CI fishway opening in all years except 2001 (Figure 13 and 14). In contrast, the 2009 CI median approach to entry time for spring Chinook salmon was greater than two times higher than the 2009 BI median time. The 2010 median CI approach-entry time (42 min) was also higher (by ~62%) than the 2010 BI value (26 min). 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 at the CI fishway opening was eight times higher than at for the BI fishway opening, whereas the 2010 CI and BI approach-entry times were each < 1 min. The 2009 result lends some support to the conclusion that behavior may have changed outside the CI fishway, but the 2010 result suggests a minimal or no effect.

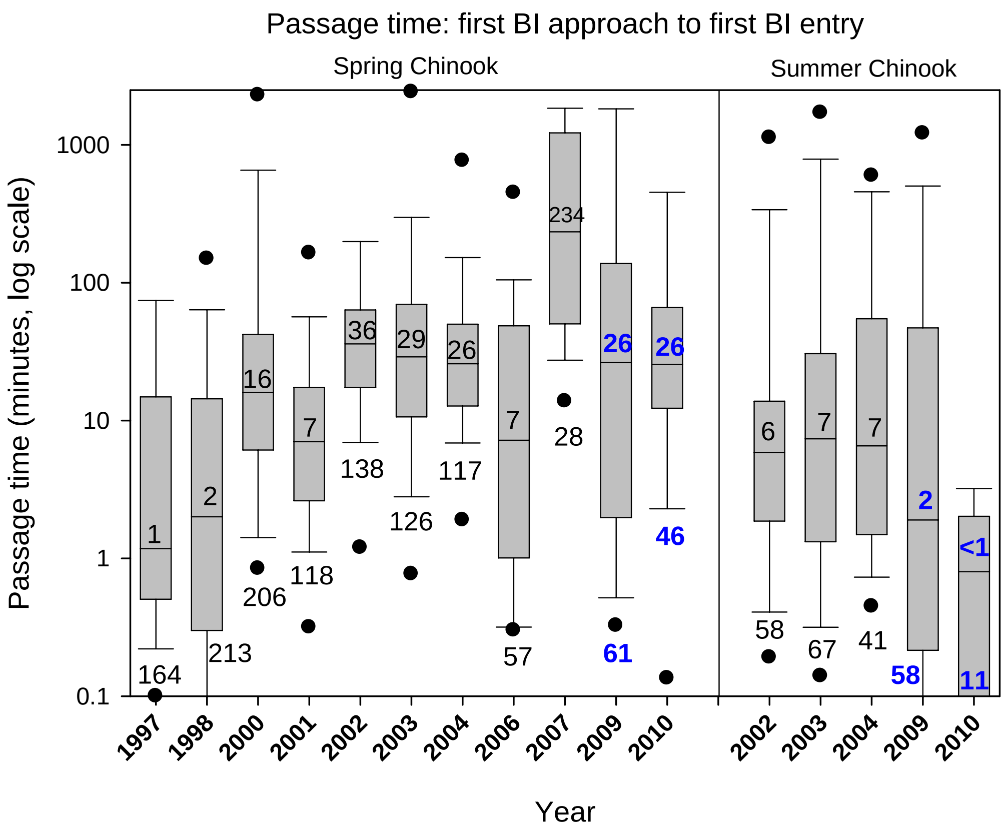

Figure 14. Spring and summer Chinook salmon passage time distributions (plotted on log scale) from approach to entry at the Bradford Island fishway. Values inside boxes are median times. Distributions show 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles; sample sizes are listed at bottom.

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 (Figure 15). 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 whereas in 2010, both times were equally low. Overall, the 2009 results suggest that there was a difference in the 2009 behavior at the CI opening compared to Bradford Island but the 2010 result suggests a minimal or no effect.

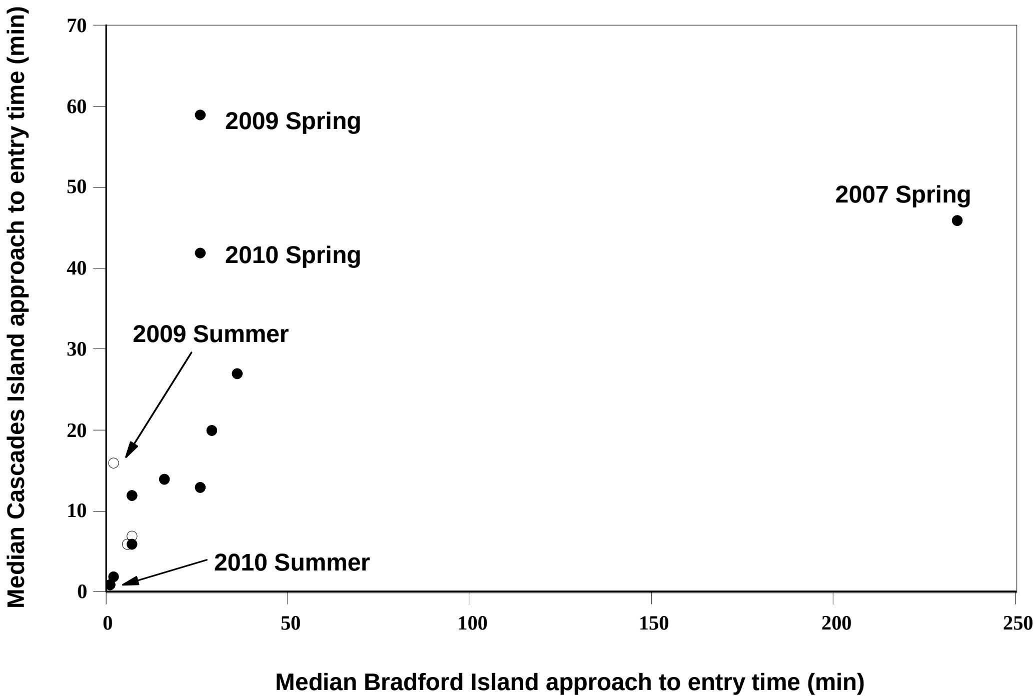

Figure 15. Scatterplot of annual median first approach to first entry times (min) at the Bradford Island and Cascade Island fishway entrances for radio-tagged spring (solid circles) and summer (open circles) Chinook salmon.

Compared to pre-modification years, there tended to be stronger correlations between spring Chinook CI approach-to-entry times and environmental conditions in 2009 but less so in 2010 (Table 8). In 2010, spill was near 100 kcfs for much of April-May and there was a wide range of passage times associated with that spill level. Flow and tailwater elevations were also slightly lower when tagged salmon first approached the CI opening in 2010 compared to 2009 (see Figure 15), which may have diminished the degree of association between environmental factors and 2010 passage times. There was also a single spring Chinook salmon that did not approach the CI opening until 08 June when flow was ~350 kcfs and spill was ~130 kcfs. All 2010 correlation coefficients were insignificant when this fish was excluded from the analysis. In 2009, longer entry times generally occurred 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 opening and log-transformed approach-to-entry times, by year. Bold font 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**
2010	**-0.24**	-0.09	**-0.22**	**-0.22**	-0.19
All years	**-0.35**	**-0.25**	**-0.10**	**-0.35**	**-0.08**

Compared to pre-modification years, correlations between CI approach-to-entry times for tagged summer Chinook salmon and environmental conditions in 2010 were similarly weak (Table 9). Negative correlation coefficients indicated faster approach-entry times when spill volumes, temperatures, and tailwater elevations were relatively high in 2010, which was similar to the 2010 spring Chinook results. Summer Chinook salmon experienced lower temperatures and more-varied and higher spill volumes in 2010 compared to in 2009 (see Figure 16), each of which tends to increase passage times. Summer Chinook approach-entry times in 2010 were typically short (i.e., 15 of 22 fish had times < 1 min), however, and the longest times were associated with environmental values in the middle of their respective ranges. Generally, the correlation results suggest that environmental factors encountered in June 2010 were not strongly related to the observed variability in summer Chinook salmon CI entrance times.

Table 9. Correlation coefficients (r) between environmental conditions June-tagged Chinook salmon encountered when they first approached the Cascades Island opening 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
2010	0.02	-0.07	-0.31	-0.04	-0.14
All years	**-0.23**	-0.13	**0.20**	**-0.16**	0.14

Figure 16 shows the river environment encountered by radio-tagged spring Chinook salmon recorded approaching the CI opening for each year. When we examined only fish that experienced spill levels between 72 and 130 kcfs (the 2010 range encountered by tagged fish on days they approached CI) and compared 2010 passage times to times from pre-modification years (i.e., we excluded 2009 data), we found significant differences among years (ANOVA df = 8, F = 5.4, $P < 0.0001$). The 2010 mean was significantly higher than means in 3 of 8 previous years based on all pairwise comparisons among years using the Tukey Test (Zar 1999). When we decreased alpha to control for the comparison-wise error rate, the 2010 mean was significantly longer than the mean for only one (1998) of eight years. In an ANOVA restricted to 2009 and 2010 passage times and spill levels between 72 and 130 kcfs, we found no significant difference between times from the two post-modification years (df = 1, F = 3.2, P = 0.07).

An ANOVA limited to fish that encountered similar tailwater elevations as in 2010 (and excluding all 2009 times) indicated significant differences in passage times among years (df = 9, F = 7.3, $P < 0.0001$). The 2010 mean was significantly higher than means in 5 of 9 previous years based on the Tukey Test and 3 of 9 years after adjusting for multiple comparisons. We found no significant difference between times from the two post-modification years (df = 1, F = 0.5, P = 0.46) in an ANOVA restricted to 2009 and 2010 passage times and the 2010 range of tailwater elevations experienced by tagged salmon.

In comparisons for water temperature, we found significant differences in passage times among years (df = 9, F = 17.2, $P < 0.0001$) and the 2010 mean was higher than means from 4 of 9 pre-modification years. After adjusting alpha, the 2010 mean was higher than means from 2 of 9 pre-modification years. We found no significant difference between 2009 and 2010 times (df = 1, F = 0.9, P = 0.35).

We found significant differences in passage times among years in an ANOVA limited to individuals from the pre-modification years that experienced similar spill, tailwater elevation and temperature to 2010 (df = 8, F = 4.7, $P < 0.0001$). The 2010 mean was significantly higher than means in 2 of 8 pre-modification years based on the Tukey Test and in 1 of 8 after adjusting alpha. We found no significant difference between 2009 and 2010 times (df = 1, F = 0.9, P = 0.35).

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 was potentially important and may have contributed to the general pattern of longer approach to entry times at both CI and BI in later years.

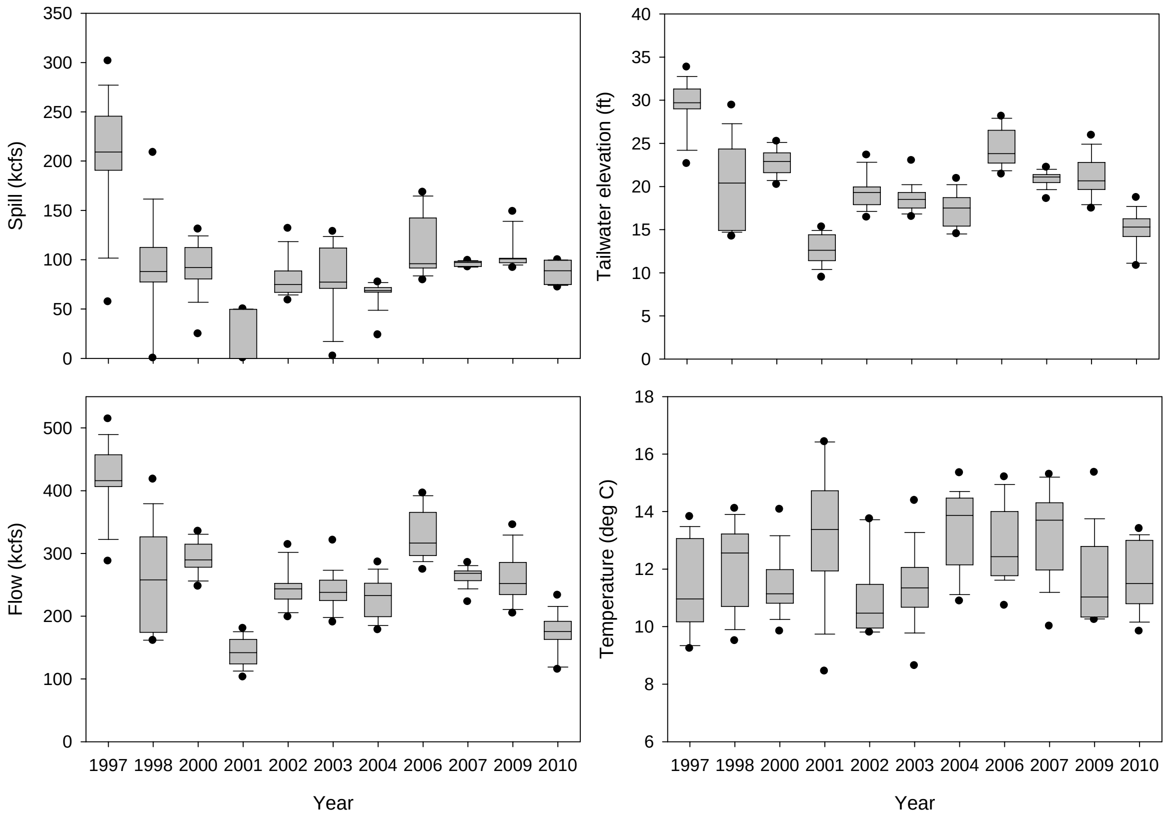

Figure 16. Box plots of the total discharge ('flow'), spill, tailwater elevation, and temperature on the days that radio-tagged spring Chinook salmon first approached the Cascades Island fishway opening. Distributions show 5^{th}, 10^{th}, 25^{th}, 50^{th}, 75^{th}, $90^{th,}$ and 95^{th} percentiles.

Figure 17 shows the river environment encountered by June-tagged salmon recorded approaching the CI entrance in each year. When we compared log-transformed passage times among years (excluding 2009) for only fish that experienced spill levels between 99 and 195 kcfs (the 2010 range encountered by tagged fish on days they approached CI), we found no significant differences among years ($df = 2$, F = 1.8, $P = 0.18$, $n = 56$). Similarly, in ANOVAs that restricted the sample to fish that encountered similar flow ($df = 3$, F = 0.7, $P = 0.56$, $n = 79$), tailwater elevation ($df = 2$, F = 1.0, $P = 0.38$, $n = 57$), or temperature ($df = 3$, F = 1.8, $P = 0.15$, $n = 100$) conditions as in 2010 each showed no significant differences among years. An ANOVA that further restricted the data so that all four environmental variables were within the 2010 ranges was not significant ($df = 1$, F = 1.2, $P = 0.28$, $n = 36$); 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.

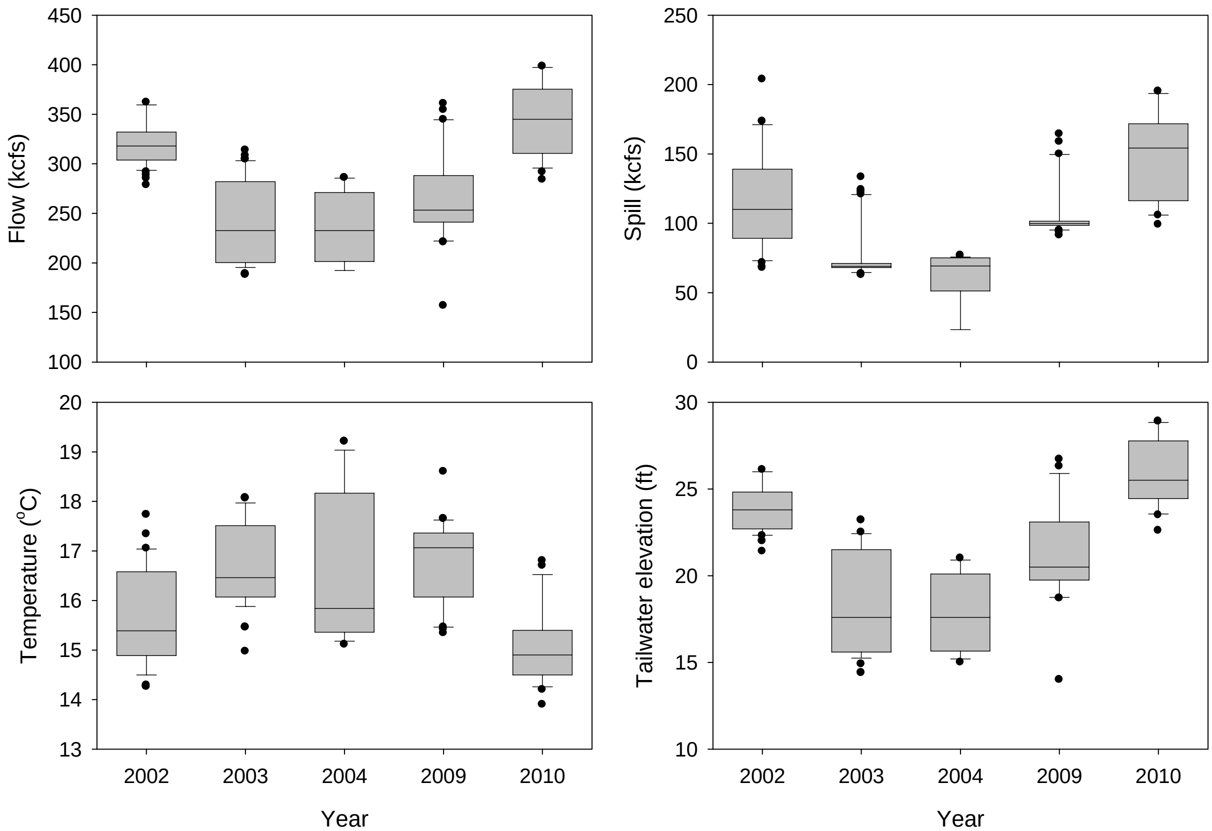

Figure 17. Box plots of the total discharge ('flow'), spill, water temperature, and tailwater elevation on the days that June-tagged Chinook salmon first approached the Cascades Island fishway opening. Distributions show 5^{th}, 10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 95^{th} percentiles.

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 pre-modification years. Both the 2009 and 2010 medians were 13 minutes and the distributions were similar to pre-modification years (Figure 18). 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 results from both post-modification years suggest that salmon did not have difficulty swimming from the CI opening 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 pre-modification years. The medians in 2009 and 2010 were 17 and 20 minutes, respectively, and distributions were similar to those in earlier years (Figure 18). These results suggest that once salmon from both runs passed the CI entrance weir, they did not have difficulty swimming past the modified area (i.e., past bollards and the LPS entrance) to the base of the ladder.

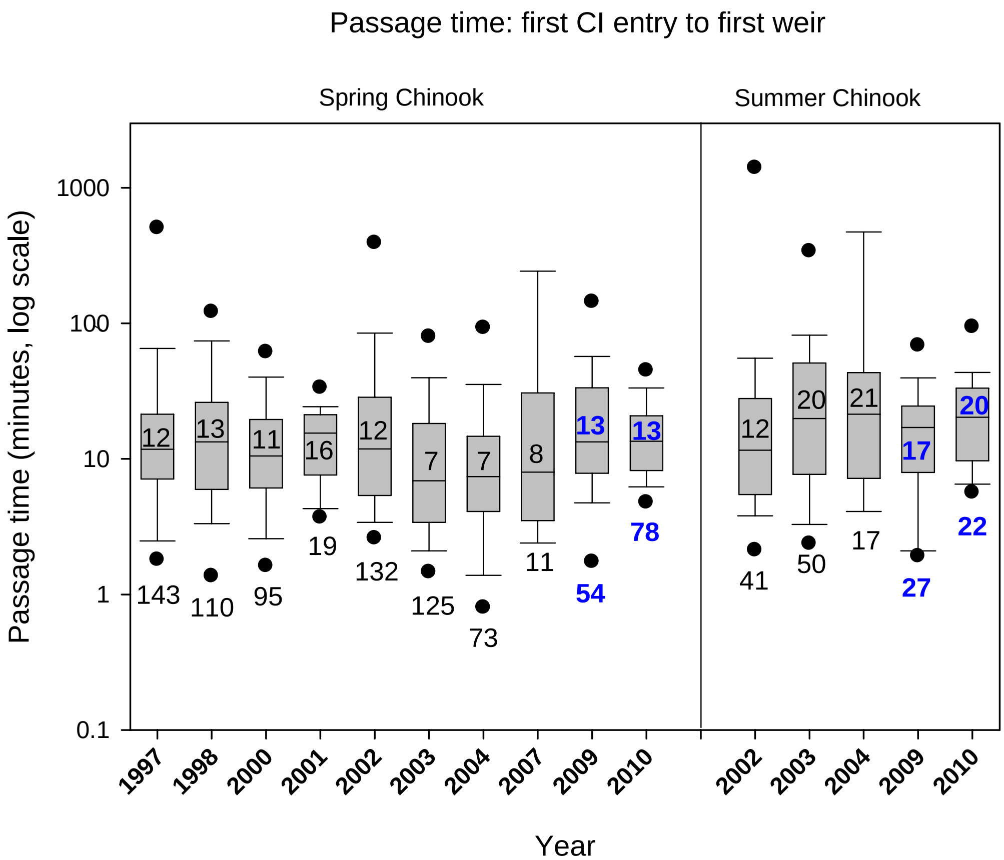

Figure 18. Spring and summer Chinook salmon passage time distributions (plotted on log-scale) from Cascades Island fishway entry to the antenna at the base of the ladder (not monitored in 2006). Numbers inside boxes are median times. Distributions show 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles; sample sizes are listed below boxes.

Metric 5. In pre-modification years, the percentage of tagged spring Chinook salmon with long passage times (> 1 h) through the two passage segments ranged from 10–45% (*mean* = 22%) for CI approach to CI entrance and from 0–14% (*mean* = 8%) from CI entrance to the first ladder antenna (Figure 19). The percentages were 36% and 1%, respectively, in 2010. While the 2009 results suggested that there were likely problems entering the fishway (i.e., 2009 had the highest percentage with long passage times), the 2010 results were less supportive of this conclusion because the 2010 percentage (36%) fell within the range of values from pre-modification years. Both the 2009 and 2010 percentages having long passage times from CI entry to ladder base (7% and 1%, respectively) were less than the mean for pre-modification years (8%), which suggest there were limited problems after entrance in 2009 and 2010 relative to pre-modification years. There was a significant among-year difference in the CI approach to CI entry percentage.

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 19). The percentages were 17% and 7%, respectively, in 2009 and were 9% and 5% in 2010. These data suggest that there may have been factors outside or at the entrance that slowed passage in 2009, but there was no evidence of altered behavior after entrance.

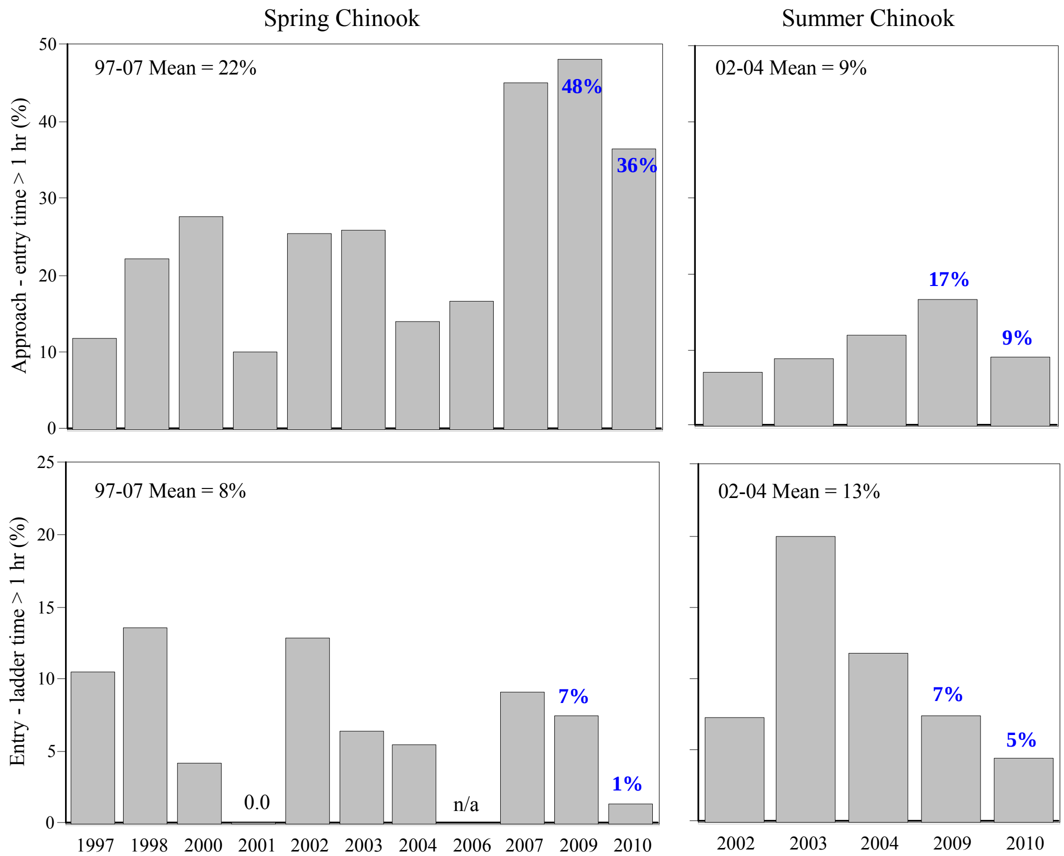

Figure 19. Percentages of radio-tagged spring and summer Chinook salmon that took > 1 h to pass from Cascades Island fishway approach to fishway entrance and from opening to the base of the ladder.

Discussion

The primary objective of this evaluation was to test for any negative effects of the modifications at the Cascades Island fishway opening on Chinook salmon passage behavior. Due to logistical constraints (e.g., winter de-watering schedules), several modifications were installed simultaneously: the entrance weir was modified, bollards were installed, and a new LPS was installed. All three modifications had potential to affect adult salmonid behavior by changing the hydraulic and/or olfactory environment at the opening or in the attraction plume outside of the fishway opening. The modified weir had the highest potential to affect hydraulics outside of the opening. The bollards had the potential to affect flow condition outside the opening to a lesser degree, potentially by decreasing mean velocity and 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 had minimum potential to affect hydraulics. Unfortunately, the modifications were 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 modifications simultaneously by comparing passage metrics at the CI entrance to those at Bradford Island within the 2009 and 2010 study years and by comparing metrics at CI to pre-modification years while attempting to statistically control for interannual differences in river environment.

There are several factors other than the modifications 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) have 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 (Keefer et al 2008), while passage times decreased as water temperatures rose within each year, especially for spring–summer Chinook salmon (Keefer et al. 2004b). These patterns continued in 2010, with longer dam passage times for spring Chinook salmon that exited a fishway and faster passage by later migrants. The percentage of radio-tagged salmon that exited Bonneville Dam fishways in 2010 was lower than in any prior year. It is not clear whether SLEDs or the presence of predators in the tailrace were responsible for the relatively low percentages of salmon exiting fishways in 2006-2007 and 2009-2010. It is possible that some salmon that might otherwise have exited a fishway may have remained inside as a predator avoidance strategy. Once tagged salmon entered a fishway in 2010, the time they used to exit the ladder top was reasonably low (*median* = 3.6 h).

Almost all (97%) June-tagged Chinook salmon in 2010 returned to Bonneville Dam and passed the dam. This was consistent with results from previous years for June-tagged fish. In 2010, summer Chinook salmon approached and passed the dam faster than in all pre-modification years, while the median time used to enter a fishway was in the middle of the range. 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 2010 was similar to or slightly better than in 2002–2004 and 2009. Thus, for both runs, the telemetry data suggest conditions in the tailrace and dam (averaged across all entrances) were approximately average.

The combined results indicate some behavioral differences in spring Chinook salmon at the CI fishway opening in 2009 relative to pre-modification years but the 2010 data were less conclusive. The pattern seen in 2009 may 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 in either year. The primary differences in passage between 2009- 2010 versus other years appeared to be outside of the CI opening because a relatively low percentage of salmon entered at CI, those that did took somewhat longer to enter than in pre-modification years, and behaviors inside the CI opening in 2010 were similar to those in earlier years. The relatively high entrance efficiencies of tagged spring Chinook salmon in 2010 suggest that if there were unfavorable passage conditions associated with the modifications in 2009, they were moderately ameliorated by 2010. This lends support to the hypothesis that a disruption in olfactory cues was responsible for the slow CI passage times in 2009. Alternatively, this pattern could have been produced by differing effects of the variable width weir on spring Chinook salmon between 2009 and 2010 because tailwater elevations were considerably lower in 2010 than 2009. The 2010 results for summer Chinook salmon indicated no evidence of slowed passage compared to pre-modification years. Specifically, summer Chinook salmon used much shorter times to enter the CI fishway after approaching. While 2009 spring and summer Chinook salmon had the highest median CI approach-entry times compared to pre-modification years, both 2010 medians were lower than corresponding 2009 medians. We note that the magnitude of the possible 'delay' in 2009 (59 min – range of medians in pre-modification years = 13 – 58 min) was higher for the spring Chinook salmon. The median time for June-tagged salmon in 2009 (16 min) was only slightly longer than the 6–12 minutes in previous years. It's not clear either range represents biologically significant increases in passage time.

We also note that the CI approach-entry time encompasses the time and behaviors of tagged salmon that may have made multiple approaches at the CI opening before entering it. As a consequence, the time tagged salmon used before re-approaching and subsequently entering the CI opening were likely influenced by conditions elsewhere at the dam and not with any attributes of the CI opening per se. Similarly, tagged salmon that approached but did not enter were excluded from these distributions. To this extent, we believe the entrance efficiency (Metric 1) may be a better overall index of the attractive or repulsive qualities of the modifications made at the CI fishway opening compared to approach-entry times (Metrics 3 and 5).

Spill level can have strong effects on salmon passage times. We note that spill during the 2010 spring Chinook salmon study was consistently in the 72-100 kcfs range. This was less than the 95-150 kcfs spill levels experienced by spring Chinook salmon in 2009 and may have contributed to the faster CI approach-to-entry times in 2010. Spill levels in the higher range have been associated with difficult entry conditions at the CI and BI fishway openings in years past because strong eddies can form near the openings. Spill levels encountered by June-tagged salmon in 2010 were generally higher than in the pre-modification years, which make the fast 2010 CI approach-entry times unexpected. 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 both post-modification years. At the 2009 spill levels, the relatively high proportion spilled through the end spillbays may also have affected conditions near the CI opening.

The slower CI approach-to-entry 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 speculate that the concentration of any disruptive olfactory cues originating from the modifications may have declined over time as the new structures have "seasoned" by leaching and by the accumulation of biofilms. If this was the case, we recommend pre-seasoning structures prior to their installation. 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 likely contributed to the longer observed passage in 2009, 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 in both post-modification years. We recommend that managers continue the deployments of the bollards, the LPS, and the variable-width weir because they do not appear to appreciably impede salmon passage and they appear to offer some passage benefits (i.e., increased entrance efficiencies) to lampreys (Clabough et al. 2011).

Literature Cited

Boggs, C. T., M. L. Keefer, C. A. Peery, T. C. Bjornn, and L. C. Stuehrenberg. 2004. Fallback, reascension and adjusted fishway escapement estimates for adult chinook salmon and steelhead at Columbia and Snake River dams. Transactions of the American Fisheries Society 133:932-949.

Clabough, T. S., E. L. Johnson, M. L. Keefer, C. C. Caudill, C. A. Peery, and M. L. Moser. 2010. Evaluation of adult Pacific lamprey passage at the Cascades Island fishway after entrance modifications, 2009. Technical Report 2010-2. Idaho Cooperative Fish and Wildlife Research Unit report to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Clabough, T. S., E. L. Johnson, M. L. Keefer, C. C. Caudill, and M. L. Moser. 2011. Evaluation of adult Pacific lamprey passage at the Cascades Island fishway after entrance modifications, 2010. Technical Report 2011-3. Idaho Cooperative Fish and Wildlife Research Unit report to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Keefer, M. L., C. A. Peery, R. R. Ringe, and T. C. Bjornn. 2004a. Regurgitation rates of intragastric radio transmitters by adult chinook salmon and steelhead during upstream migration in the Columbia and Snake rivers. North American Journal of Fisheries Management 24:47-54.

Keefer, M. L, C. A. Peery, T. C. Bjornn, M. A. Jepson, and L. C. Stuehrenberg. 2004b. Hydrodystem, dam, and reservoir passage rates of adult Chinook salmon and steelhead in the Columbia and Snake rivers. Transactions of the American Fisheries Society 133:1413-1439.

Keefer, M. L., D. C. Joosten, C. L. Williams, C. M. Nauman, M. A. Jepson, C. A. Peery, T. C. Bjornn, R. R. Ringe, K. R. Tolotti, S. R. Lee, L.C. Stuehrenberg, M. M. Moser, and B. J. Burke. 2008. Adult salmon and steelhead passage through fishways and transition pools at Bonneville Dam, 1997-2002. Technical Report 2008-5 of Idaho Cooperative Fish and Wildlife Research Unit report to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Keefer, M. L., M. A. Jepson, C. C. Caudill, and B. J. Burke. 2009a. Preliminary evaluation of radio-telemetry data for spring Chinook salmon at Bonneville Dam – 2009. Letter report dated 29 June.

Keefer, M. L., M. A. Jepson, C. C. Caudill, and B.J. Burke. 2009b. Preliminary evaluation of radio-telemetry data for June-tagged Chinook salmon at Bonneville Dam – 2009. Letter report dated 22 September.

Reischel, T. S., and T. C. Bjornn. 2003. Influence of fishway placement on fallback of adult salmon at the Bonneville Dam on the Columbia River. North American Journal of Fisheries Management 23:1215-1224.

Smith, G. A. 2010. Bonneville Lock and Dam, Fishway and Fish Activities for Week 17 of 2010, which covers the period from 18 through 24 April 2010. Memorandum for CENWP-OP.

Stansell, R., S. Tackley, W. Nagy, and K. Gibbons. 2009. Evaluation of Pinniped predation on adult salmonids and other fish in the Bonneville Dam tailrace. U.S. Army Corps of Engineers, Fisheries Field Unit, Cascade Locks, OR. 37 pp.

Zar, J. H. 1999. *Biostatistical Analyses – 4th Ed.* Upper Saddle River, New Jersey: Prentice Hall, Inc.