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To: David Clugston, USACE Portland District

From: Matt Keefer, Mike Jepson, Chris Caudill (University of Idaho) and Brian Burke (NOAA Fisheries)

RE: Preliminary Evaluation of Radio-telemetry Data for Spring Chinook Salmon at Bonneville Dam - 2009

Date: 29 June 2009

Introduction

Modifications to the Cascades Island (CI) fishway opening designed to improve entry rates for adult Pacific lamprey were installed prior to the 2009 Chinook salmon migration. Because the changes may affect behavior and passage success of adult salmonids, a radiotelemetry study of spring Chinook salmon is underway. This report summarizes preliminary data on passage times, fallback rates, and behaviors of radio-tagged Chinook salmon at Bonneville Dam through 01 June 2009. It also compares preliminary dam passage time metrics and CI entrance use and passage efficiency metrics from 2009 with similar metrics from spring Chinook salmon data collected in 1997-1998, 2000-2004, and 2006-2007. These data represent the best analyses currently available but all analyses and conclusions should be considered provisional until release of the final report for the project.

Methods

From 26 April through 01 June 2009, we collected and intra-gastrically radio-tagged 382 Chinook salmon at the Adult Fish Facility of Bonneville Dam and released them approximately nine kilometers downstream from the dam (Figure 1). A description of the tagging methods used is presented in Keefer et al. (2004). A total of 104,788 adult Chinook salmon were counted passing the dam during the tagging interval. Radio-tagged salmon represented ~0.4% of the salmon counted at the dam during the tagging period.

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. Flow, spillway discharge, and river temperatures in the Bonneville Dam tailrace varied considerably during the ten study years (Figure 2), which likely compromises our comparisons in a strict statistical sense. Other potentially confounding factors in multi-year comparisons were the deployment of sea lion exclusion devices (SLEDs) in 2006-2007, 2009 and variations in spill patterns among years. In 2009, SLEDS were deployed at all main fishway openings (Figure 3) until 28 May (Cascade Island), 2 June (Powerhouse 2 and Bradford Island), or 3 June 2009 (Powerhouse 1). Through the study period, the spill pattern has also shifted toward proportionately more spill through outer spillbays, and marine mammal predators have increased.

We additionally compiled a multi-year summary of fallback percentages and re-ascension rates of radio-tagged Chinook salmon that fell back at Bonneville Dam prior to 10 June, the last date pinnipeds have been observed in the tailrace there since 2002 (R. Stansell, personal communication). We included only tagged salmon that were released downstream from the dam within years in the analyses because of the potential for past experience ascending the dam and fallback-related injury to affect behavior during re-ascension. Fallback may also increase the risk of pinniped predation.

CI Passage metrics – We considered five passage time and passage efficiency metrics to help assess potential effects of the CI entrance modifications on adult spring Chinook 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.

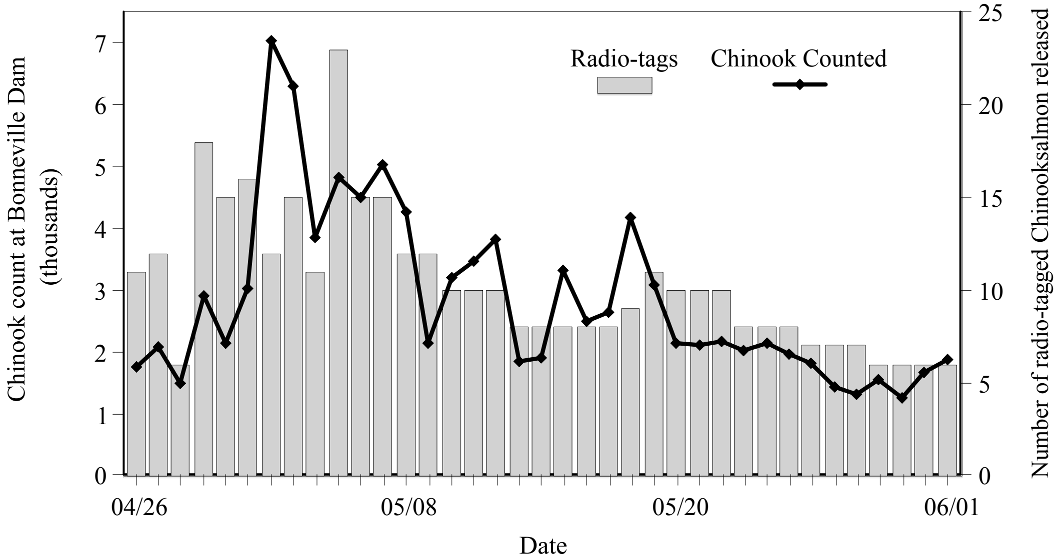

Figure 1. The number of Chinook salmon radio-tagged and released downstream from Bonneville Dam and the count of adult Chinook salmon passing the dam through 1 June 2009.

Figure 2. Mean daily flow, spillway discharge, and tailrace water temperature at Bonneville Dam during April – May, 1997-1998, 2000-2004, 2006-2007, and 2009.

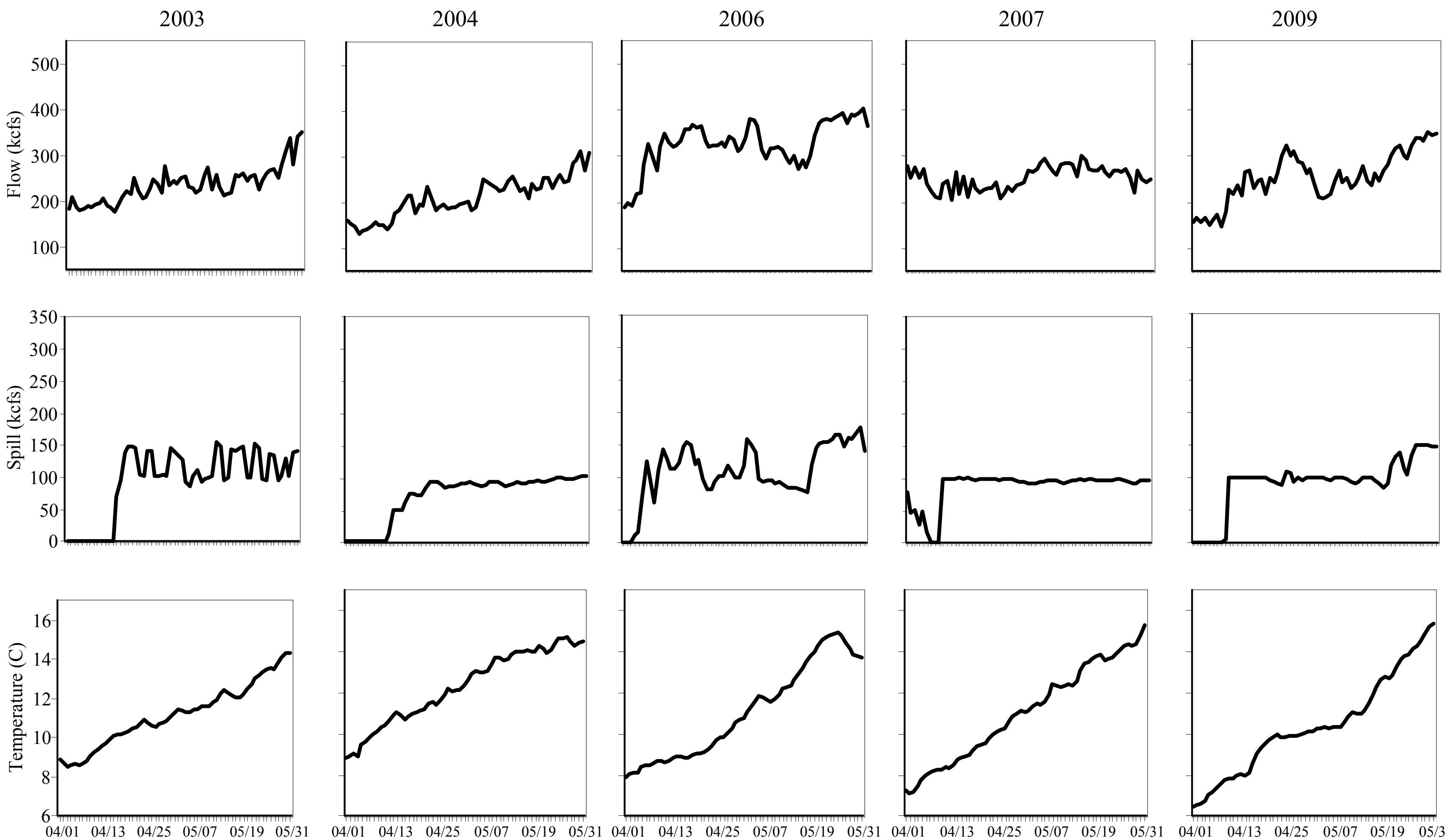

Figure 2 (continued). Mean daily flow, spillway discharge, and tailrace water temperature at Bonneville Dam in April – May, 1997-1998, 2000-2004, 2006-2007, and 2009.

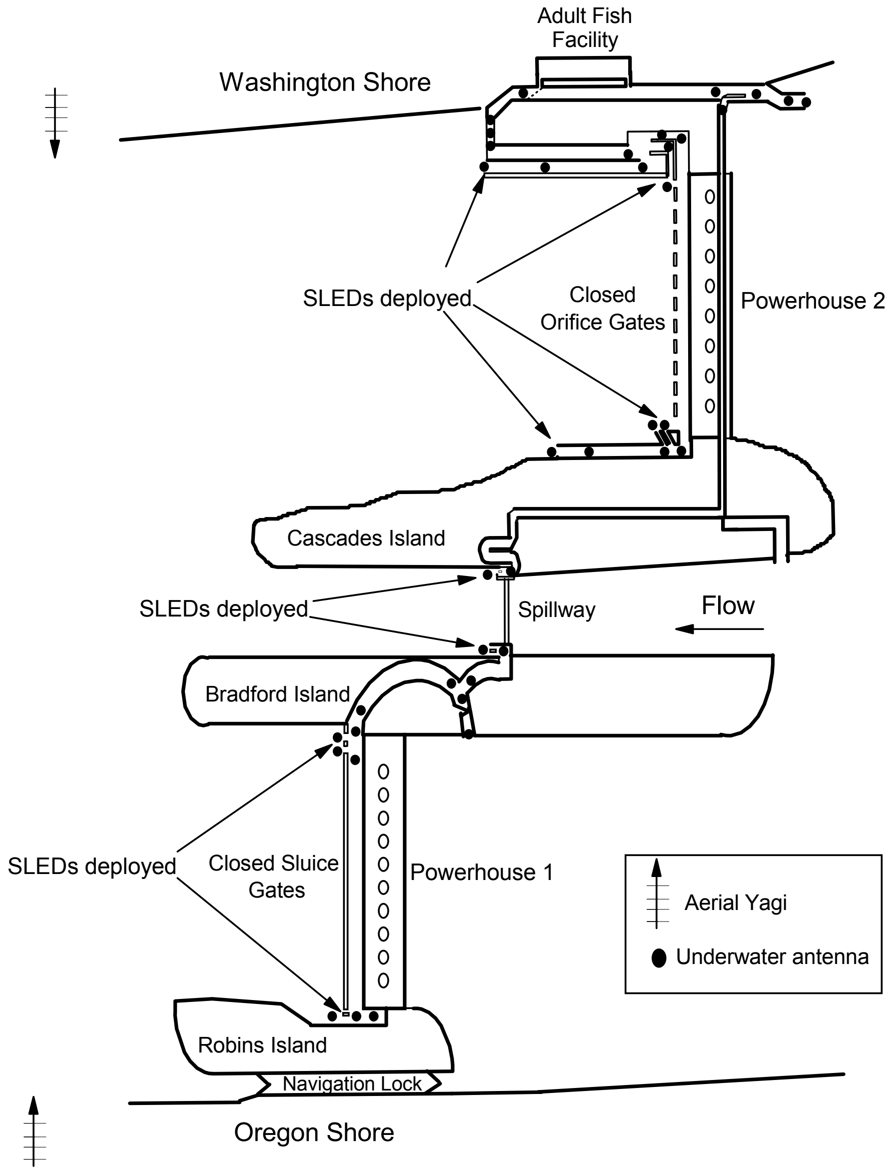

Figure 3. Aerial view of radio antenna and SLED deployments at Bonneville Dam in 2009.

Results

Of the 382 salmon outfitted with transmitters and released through 01 June 2009, 358 (94%) resumed upstream movements and were recorded on receiver sites at the dam and 24 (6%) had no valid telemetry records. Of the 382 released, 327 (86%) had passed the dam (Table 1). One hundred and sixty-two 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 observed 23 fallback events by 22 unique salmon; 21 events by salmon that passed via the Bradford Island ladder and 2 by salmon that passed via the Washington-shore ladder. Seventeen of the 23 (77%) unique, tagged salmon that fell back re-ascended the dam.

Table 1. Range of release dates, number of adult radio-tagged spring Chinook 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	4/26-6/1
Released downstream	680	675	728	641	658	793	349	358	286	382
Recorded at dam	666	672	725	627	653	757	340	348	273	358
Known to pass dam	656	663	713	617	641	706	312	317	246	327
Recorded first tailrace passage	636	623	693	516	533	663	301	316	230	303
Recorded first fishway approach	638	656	716	605	632	668	319	316	259	342
Recorded first fishway entrance	526	587	592	546	545	587	283	253	246	308
Recorded ladder exit	650	646	707	601	640	698	306	268	246	321
	Percentage of radio-tagged salmon released									
Recorded at dam	98	99	99	98	99	95	97	97	95	94
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	79
Recorded first fishway approach	94	97	98	94	96	84	91	88	89	90
Recorded first fishway entrance	77	87	81	85	83	74	81	71	76	81
Recorded ladder exit	96	96	97	94	97	88	88	75	86	84

Distributions of first approaches and entries

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 3). First fishway approaches at the Cascade Island 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 (Figure 3). Approximately 16% of all first fishway entries were at the Bradford Island opening and 14% were at the Cascade Island opening.

First fishway approach efficiencies

Approximately half of all first fishway approaches by radio-tagged salmon were recorded at Powerhouse 2 but overall, less than 10% (10 first entries /108 first approaches) of them resulted in a first fishway entry (Figure 4). First fishway approaches at Powerhouse 1 were modestly more efficient, with an average of 16% of the first fishway approaches resulting in first fishway entries. In contrast, the spillway fishway openings were the most efficient, with 38% of all first fishway approaches at the Cascade Island fishway opening resulting in a first fishway entry and 46% at the Bradford Island fishway opening resulting in a first fishway entry.

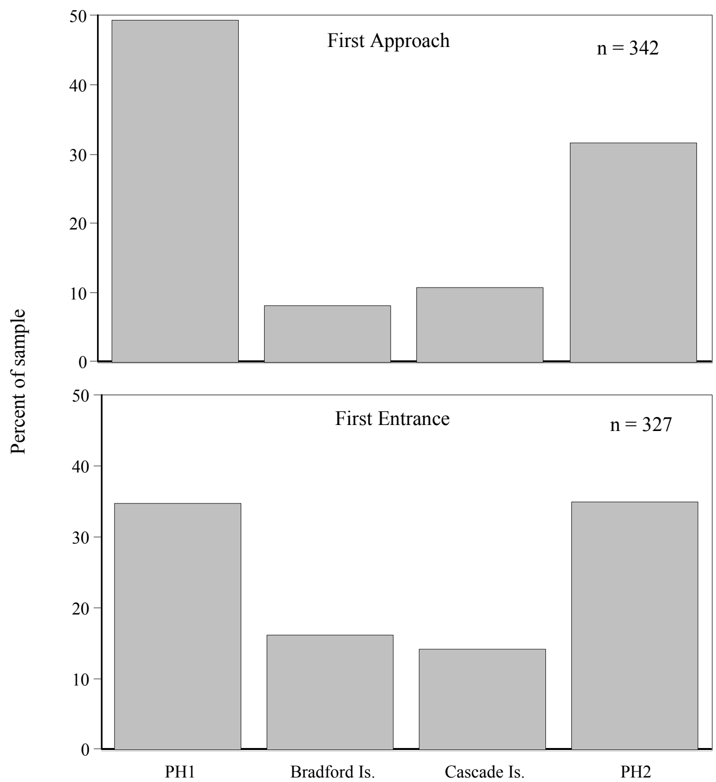

Figure 3. Distributions of first fishway approach and entrance sites used by radio-tagged spring Chinook salmon at Bonneville Dam through 01 June 2009.

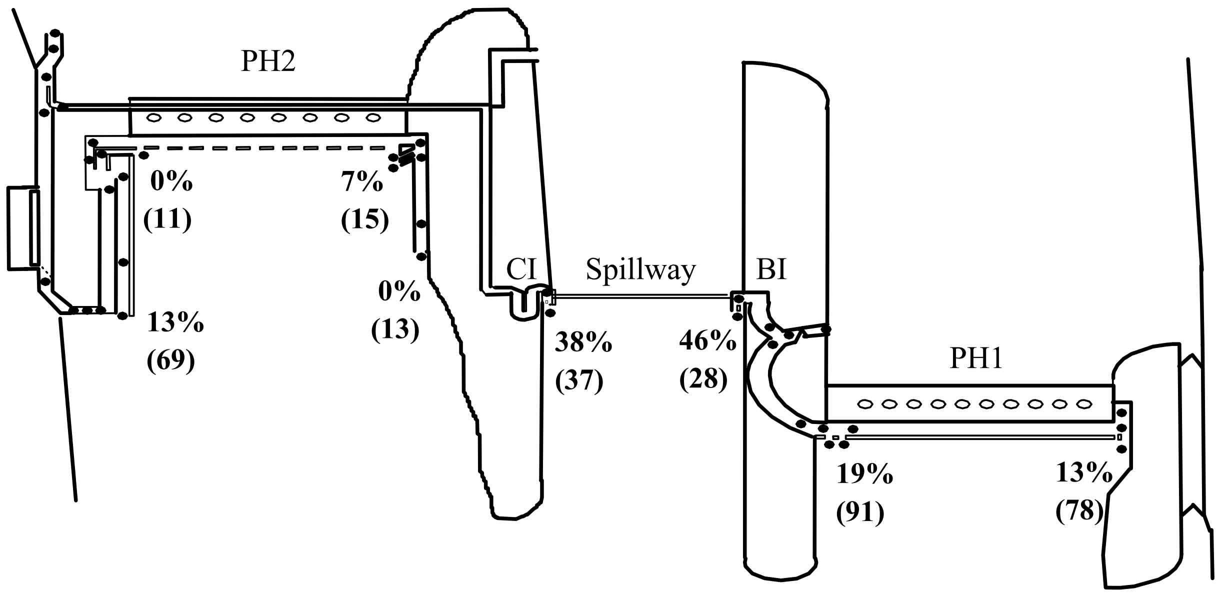

Figure 4. Percentage of first fishway approaches resulting in first fishway entries for all fishway openings at Bonneville Dam through 01 June 2009. Sample sizes are in parentheses.

Passage Times

The median time from release to first record in the tailrace was 23.9 h (n = 24) for fish tagged and released in April 2009 and decreased to 19.5 h (n = 279) for fish tagged and released in May 2009 (Table 2). The median release-tailrace time for all radio-tagged salmon was 20.3 h during April-May 2009. Overall, this 2009 median time ranked as the fifth slowest (sixth fastest) among the ten study years.

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 the sixth slowest among the ten study years. The median time to first approach a fishway after being detected in the tailrace during April-May 2009 was the sixth slowest. The distribution of tailrace to first approach times by date of tailrace entry revealed that many tagged salmon recorded on a tailrace receiver from early- through mid-May failed to approach the dam for several days (Figure 5). Specifically, approximately 33% of all tagged salmon with both a tailrace and first approach record used more than 24 h to approach a fishway opening and 23% used more than 48 hrs.

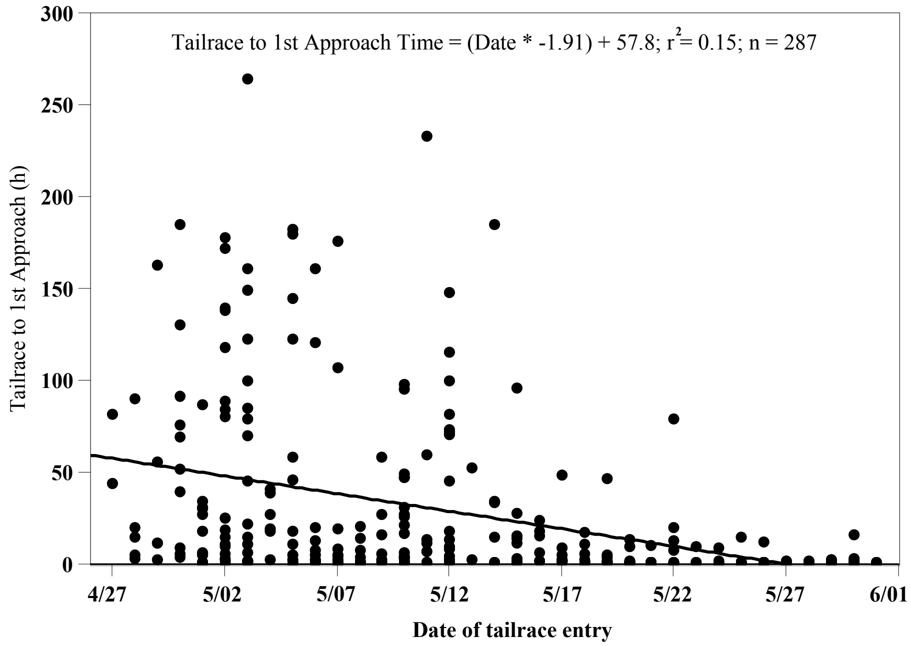

Figure 5. Scatterplot of tailrace to first fishway approach times by radio-tagged spring Chinook salmon at Bonneville Dam through 01 June 2009.

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

The median time for radio-tagged 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. The median value for May 2009 was the fourth slowest and the April-May 2009 ranked as the fifth slowest among corresponding values from all other study years (Table 2).

The median time from first approach to first entry during April 2009 was the fifth slowest 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 distribution of first fishway approach to first entry times by date of tailrace entry suggested that many tagged salmon recorded making their first fishway approach failed to enter a fishway for several days (Figure 6). Specifically, approximately 27% of all tagged salmon with both a tailrace and first approach record used more than 24 h to approach a fishway opening and 16% used more than 48 hrs.

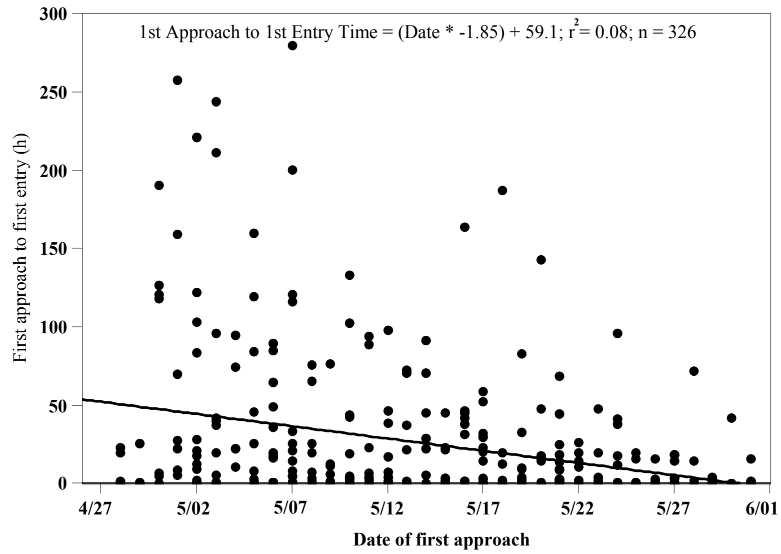

Figure 6. Scatterplot of first fishway approach to first entry times by radio-tagged spring Chinook salmon at Bonneville Dam through 01 June 2009.

The median time tagged 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 (Figure 7). These values were consistent with passage through the fishways in previous years.

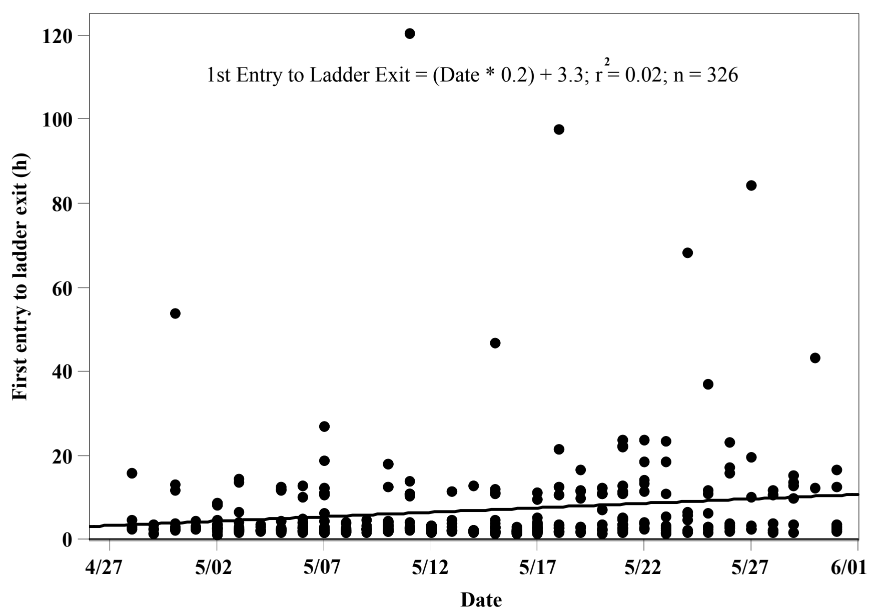

Figure 7. Scatterplot of first fishway entry to ladder exit times by radio-tagged spring Chinook salmon at Bonneville Dam through 01 June 2009.

Table 2. 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**

Dam passage times and exit percentages

Forty-one of the 327 radio-tagged Chinook salmon that entered a fishway in 2009 (12.5%) exited a fishway to the tailrace at least once (Table 3). 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% for fishway entrants, 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. 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. We believe the relatively high tailrace-approach and approach-entry times (included in total dam passage time calculations) for some tagged fish that also did not make an exit (Figures 5-6) are likely responsible for this unusual result.

Table 3. Number of radio-tagged Chinook salmon that entered a Bonneville Dam fishway prior to 1 June and the frequency and percentage of those salmon that exited a fishway to the tailrace at least once.

Year	No. tagged salmon that entered dam	No. tagged salmon that exited dam	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

Re-ascension of radio-tagged salmon that fell back

Prior to 2001, the first year when pinniped abundance began increasing noticeably, re-ascension rates of unique radio-tagged salmon that fell back at Bonneville Dam before 10 June ranged from 84 to 96% (Table 4). These were also years when fallback percentages were relatively high (12-17%), at least in part because more flow was passed at Powerhouse 1 and more salmon passed the dam via the Bradford Island ladder. 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 an accurate 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 4. 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

Preliminary 2009 Cascade Island Results

Of the fish tagged through June 1 in 2009, 92 (24%) were recorded approaching the CI fishway entrance and 14% were recorded entering (Figure 8). These percentages are 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 8), presumably because spill provides attraction flow. The 2009 detection rate was in line with previous years given river conditions.

Metric 1. The CI first entrance efficiency estimates in previous years ranged from 0.56–0.98 (*mean* = 0.79, Figure 9), with the lowest estimate in 2001 when river flow and spill were low and few fish used the CI fishway. The preliminary 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.

Metric 2. Exit ratios were relatively more variable than entrance efficiencies in previous years, and ranged from 0.00–0.46 (*mean* = 0.24) (Figure 10). 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 there are no (or at the most limited) problems occurring after fishway entrance. 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, flow). It is not clear why there were so few recorded CI exits in 2006-2007 and 2009.

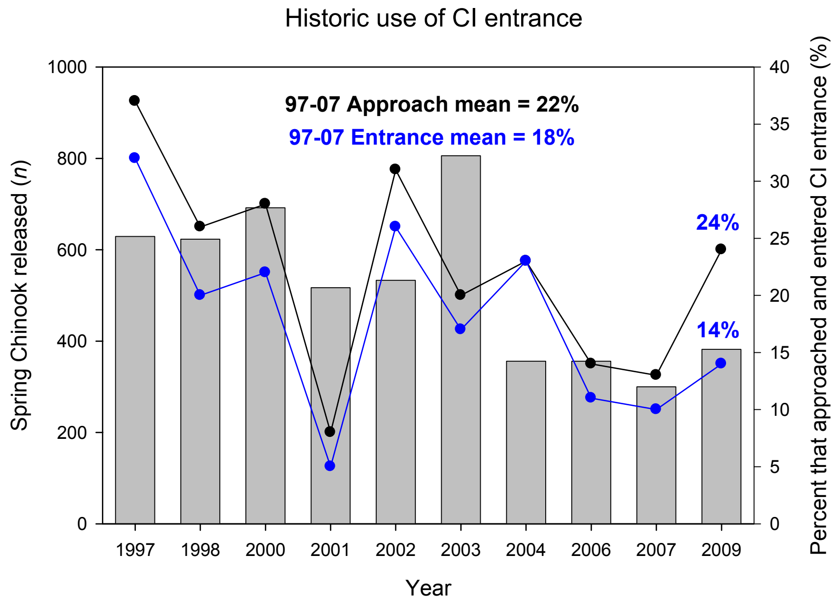

Figure 8. Number of spring Chinook salmon radio-tagged and the percentages that were recorded approaching and entering the Cascades Island fishway.

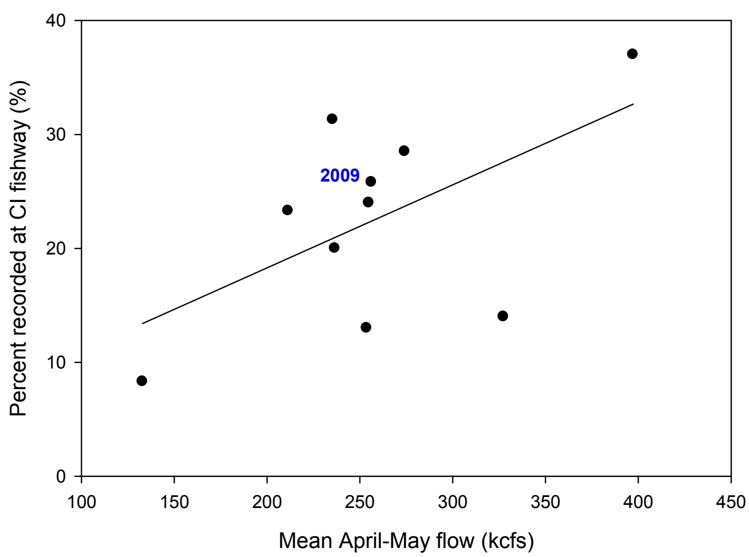

Figure 9. Relationship between mean April-May discharge at Bonneville Dam and the percentage of spring Chinook salmon recorded at the Cascades Island fishway.

Metric 3. Passage times from first CI approach to first CI entry were strongly right-skewed in all previous years (Figure 11). 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. 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. The small sample ($n = 20$) in 2007 also had relatively long passage times.

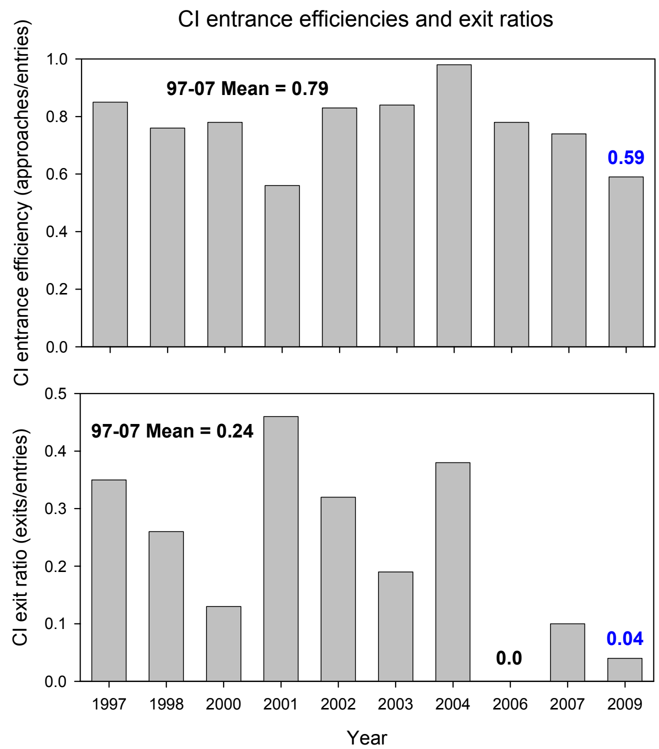

Figure 10. Spring Chinook salmon entrance efficiency and exit ratio estimates for the Cascades Island fishway.

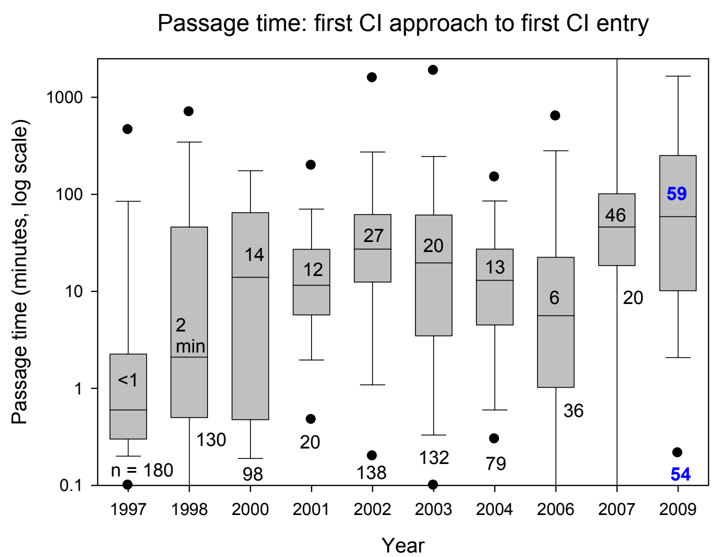

Figure 11. Spring Chinook salmon passage time distributions (plotted on log scale) from approach to entry at the Cascades Island fishway. Values inside boxes are median times.

Figure 12 shows the river environment encountered by radio-tagged fish 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.

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. We are awaiting spill pattern data before proceeding with this evaluation.

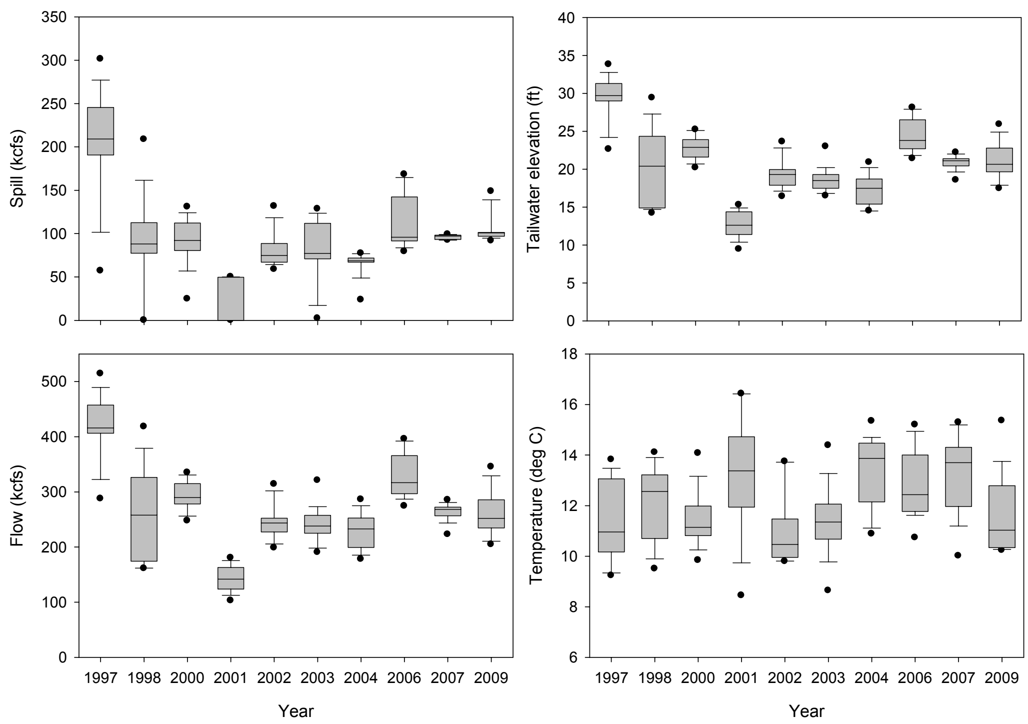

Figure 12. Box plots of the total discharge, spill, tailwater elevation, and temperature on the days that radio-tagged spring Chinook salmon first approached the Cascades Island fishway opening.

Metric 4. After fish 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 13). 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 past the modified area to the base of the ladder.

Metric 5. In previous years, the percentage of salmon with long passage times (> 1 h) through the two passage segments ranged from 10–28% (*mean* = 22%) from CI approach to CI entrance and from 0–14% (*mean* = 8%) from CI entrance to the first ladder antenna (Figure 14). The percentages were 48% and 7%, respectively, in 2009. As with Metric 4, this result suggests that there was a problem 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 $\chi^2 = 46.5$, $P < 0.0001$).

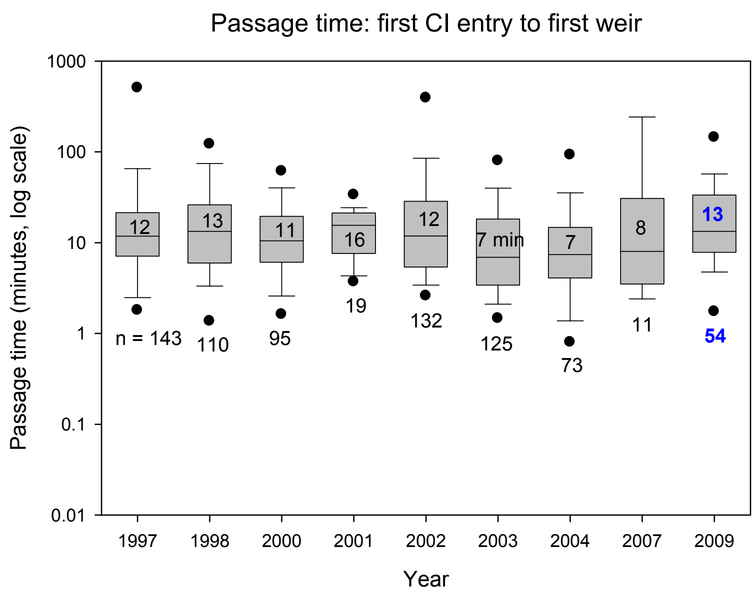

Figure 13. Spring Chinook salmon passage time distributions (plotted on log-scale) from Cascades Island fishway entry to the antenna at the base of the ladder (not monitored in 2006). Numbers inside boxes are median times.

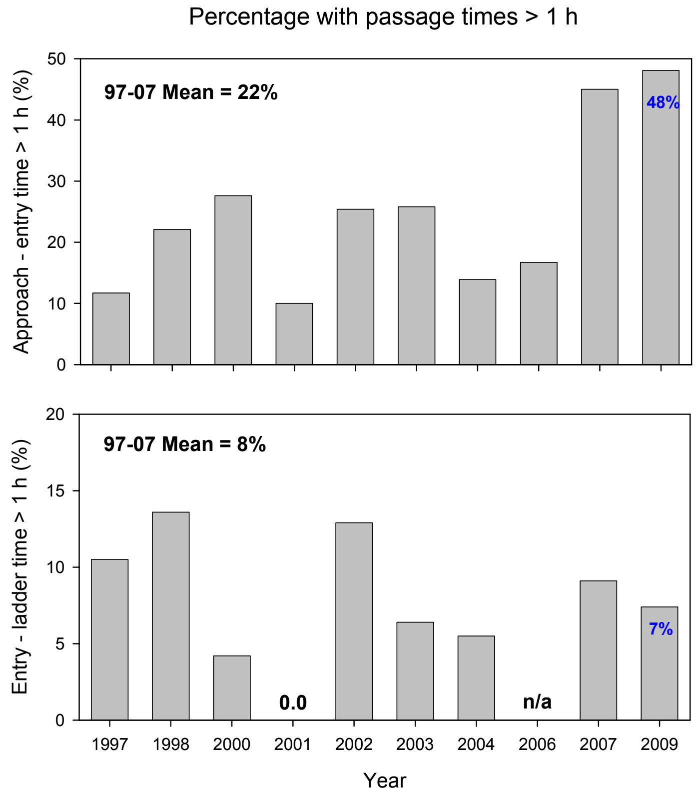

Figure 14. Percentages of spring Chinook salmon that took > 1 h to pass from Cascades Island fishway approach to fishway entrance and from entrance to the base of the ladder.

Preliminary Discussion

There are several things that might account for inter-annual variability in dam passage times by radio-tagged Chinook salmon at Bonneville Dam. Multivariate analyses of total dam passage time (tailrace entry to top of ladder) by Keefer et al. (2008) indicated that an exit from a fishway (to the tailrace) and water temperature were the most influential predictors. 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. Anomalously, we did not record longer dam passage times for fish that exited a fishway in 2009. 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 the fishways in 2006-2007 and 2009. Some salmon that may have otherwise exited the fishway remained inside as a predator avoidance strategy.

Median times of radio-tagged salmon to first approach, enter, and pass Bonneville Dam in April 2009 were very high compared to other study years, though we note the relatively small sample size for this sample, related to late run timing. Including the May 2009 passage time data into the bi-monthly medians produced values that were approximately in the middle of the range of 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), suggesting that tailrace conditions were related to the overall long dam passage times across the project.

The combined results thus far 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 entrance directly caused by the modifications and/or other conditions outside fishways and in the tailrace. Importantly, we have no reason to believe the observed differences are related to systematic changes in the telemetry array, tag type, or detection probabilities. The primary differences between 2009 and other years appeared to be outside of the 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. Our preliminary analyses suggest river conditions affected passage times in 2009, though some observations also suggest that the modification may have affected adult salmon behavior.

Spill level has strong effects on passage time. We note that spill during the 2009 study thus far has consistently been in the 95-150 kcfs range. This spill level has 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.

Compared to previous years, there were also considerably stronger correlations between CI approach-to-entry times and environmental conditions (Table 5), suggesting environmental factors may have been strong drivers of 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 passage times in the past. Interestingly, the percentage of first fishway approaches at the Bradford Island and Cascade Island fishway opening resulted in the highest percentages of first fishway entries observed to date; this may indicate that conditions inside these fishway entrances are favorable when compared to conditions outside the entrances.

CI approach-to-entry time in 2009 was unexpectedly long compared when compared to past approach-to-entry times at CI and the Bradford Island entrance (Figure 15). Whereas the relationship between CI and Bradford entry times was relatively constant in the 1997-2006 data, both 2007 and 2009 were outliers, with the small 2007 sample (n = 20) having relatively long Bradford Island approach-to-entry times and the 2009 sample having long approach-to-entry times. 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.

As mentioned previously, it is possible that spill patterns affected behavior near the CI entrance 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 entrance. We will more fully evaluate this hypothesis in a future report.

An alternative and speculative explanation is that the large surface area of metal added during the CI entrance modification has produced unfavorable olfactory cues for adult salmon.

If so, leaching and the development of biofilms on the new surfaces should diminish the concentration of cues through time and, simultaneously, the difference in passage metrics observed for Chinook salmon adults between the CI and Bradford entrances. We will be able to address this hypothesis when fish tagged in June are added to the analyses, though observations from the adult Pacific lamprey LPS installations suggest conditioning may take a full year (M. Moser, pers. comm.).

Table 5. 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**

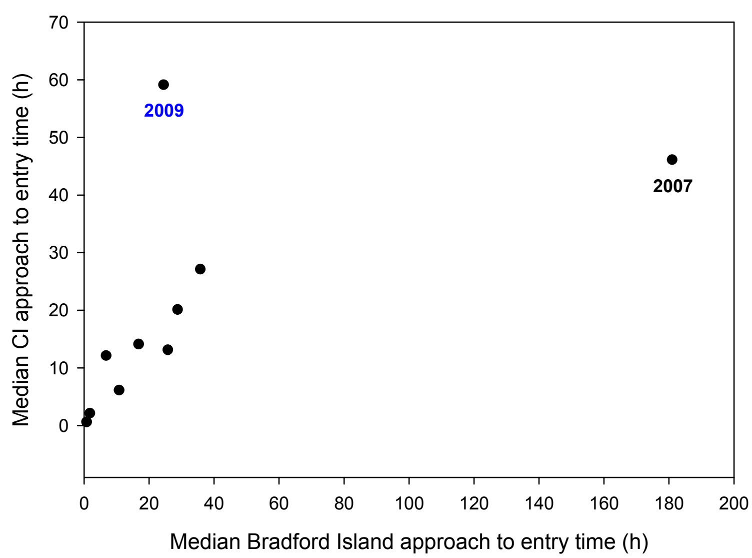

Figure 15. Scatterplot of annual median first approach to first entry times (h) at the Bradford Island and Cascades Island fishway entrances.

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