University of Idaho
College of Natural Resources

Department of Fish and Wildlife Resources
PO Box 441136
Moscow, Idaho 83844-1136

Phone: 208-885-6434
Fax: 208-885-9080
fish_wildlife@uidaho.edu
www.cnrhome.uidaho.edu/fishwild

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 June-tagged Chinook Salmon at Bonneville Dam - 2009

Date: 22 September 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 and early summer Chinook salmon was conducted. This report summarizes preliminary data on passage times, fallback rates, and behaviors of Chinook salmon that were radio-tagged at Bonneville Dam from 1–30 June 2009. It also compares preliminary dam passage time metrics and CI entrance use and passage efficiency metrics from 2009 with similar metrics from Chinook salmon data for fish radio-tagged in June 2002–2004. These data represent the best analyses currently available but all analyses and conclusions should be considered provisional until release of the final project report.

A similar interim report was provided for spring Chinook salmon only (i.e., fish tagged through 1 June) on 29 June 2009 (Keefer et al. 2009). Results for the spring group indicated some behavioral differences near the CI entrance in 2009 relative to earlier years. More specifically, a relatively low percentage of spring Chinook that approached the CI entrance subsequently entered the CI entrance and those that did enter took a relatively longer time to do so. While river conditions explained some of the differences, there was also some evidence that the new CI configuration contributed to the decline in entrance efficiency.

Methods

From 1-30 June 2009, we collected and intra-gastrically radio-tagged 223 Chinook salmon at the Adult Fish Facility of Bonneville Dam and released them approximately nine kilometers downstream from the dam (Figure 1). A total of 60,539 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 salmon passage times and first fishway approach and entry distributions at Bonneville Dam for fish tagged in June 2009 to corresponding values from June-tagged Chinook salmon in 2002-2004. Flow, spillway discharge, river temperature (at the Water Quality Monitoring site), and tailwater elevation at Bonneville Dam tailrace were relatively similar among the four study years, though 2002 was characterized by somewhat higher flow, spill, and tailwater elevation (Figure 2). The 2009 telemetry monitoring array was similar to those used in prior years (Figure 3). In 2009, sea lion exclusion devices (SLEDs) were removed from the CI fishway opening on 28 May and so did not affect the June analyses.

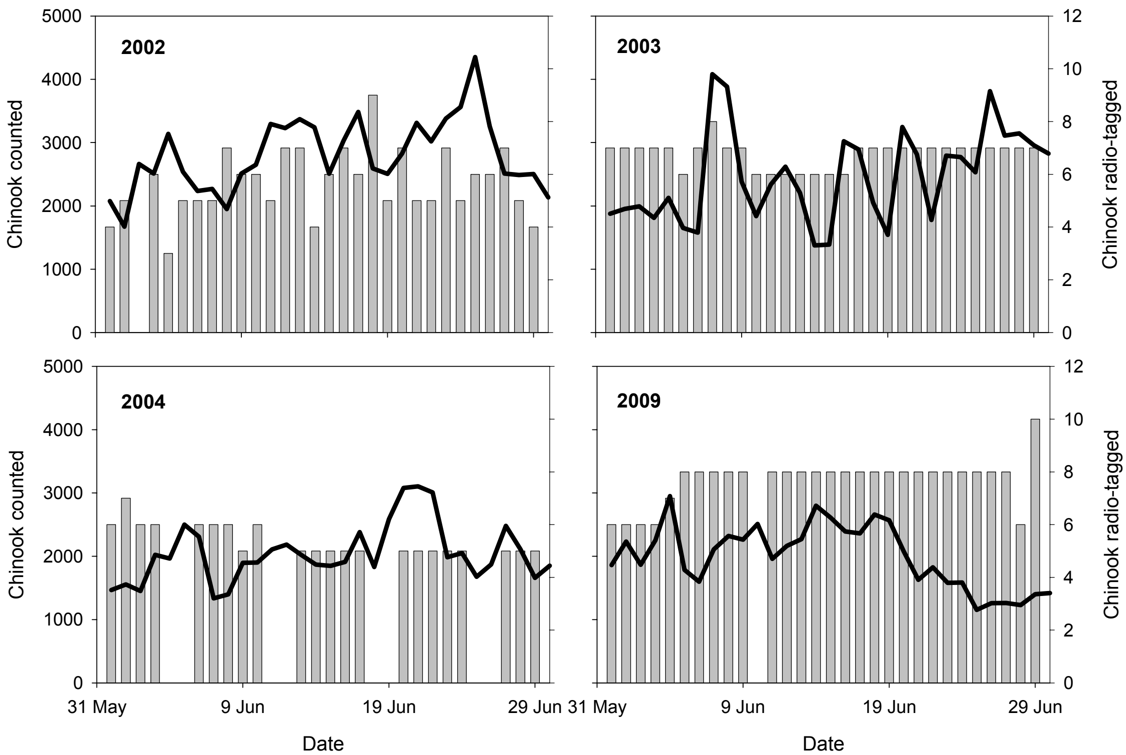

Figure 1. The numbers of Chinook salmon radio-tagged and released downstream from Bonneville Dam (bars) and the count of adult Chinook salmon passing the dam (lines) from 1–30 June, 2002–2004 and 2009.

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

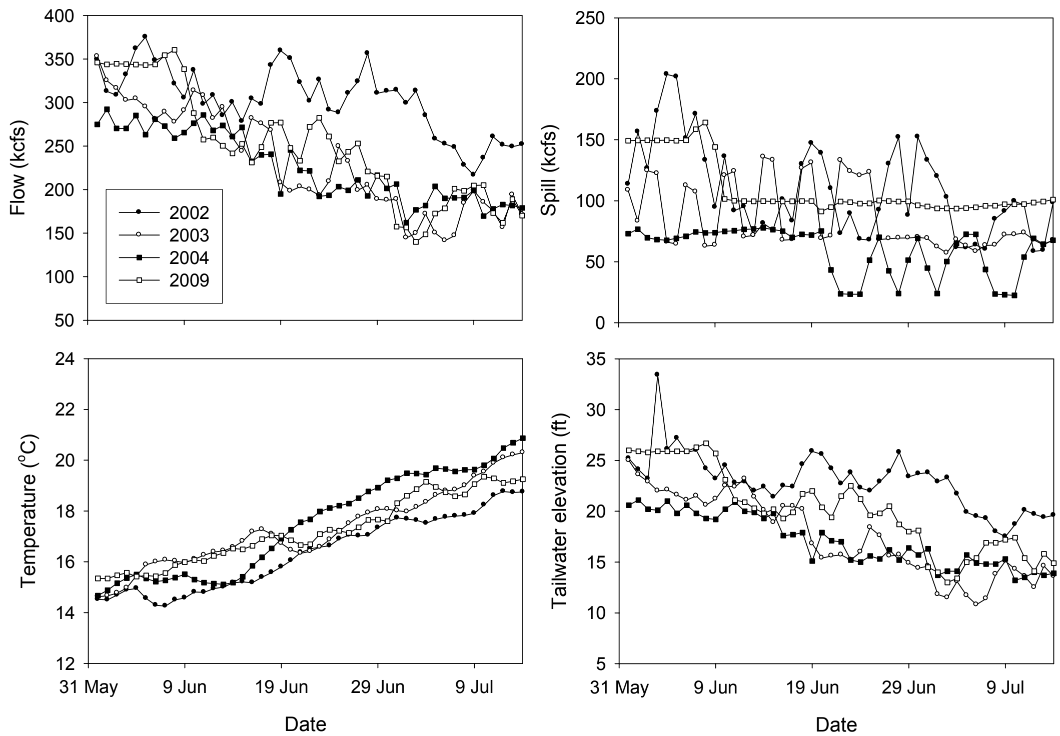

Figure 2. Mean daily flow, spillway discharge, water temperature, and tailrace elevation at Bonneville Dam from 1 June to 15 July, 2002-2004 and 2009.

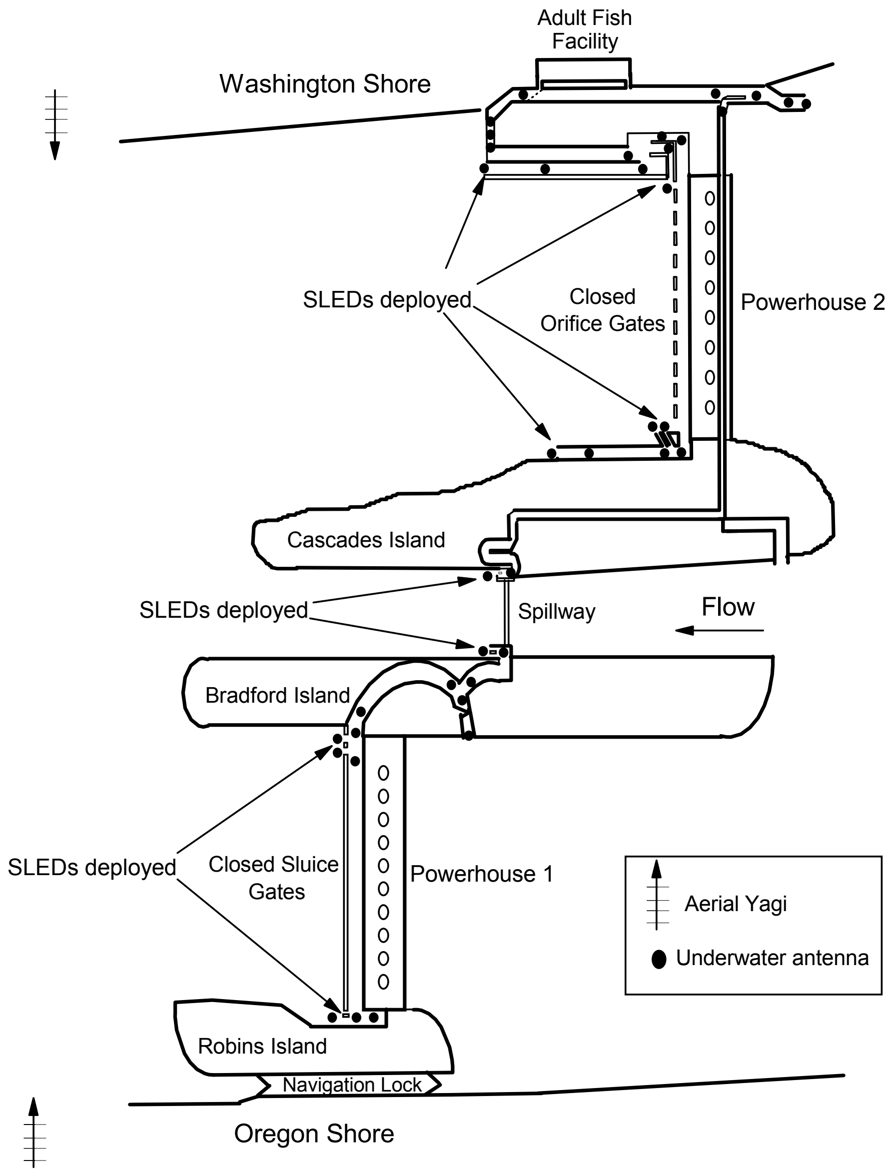

Figure 3. Aerial view of radio antenna and sea lion exclusion devices (SLEDs) deployments at Bonneville Dam in 2009. Note: SLEDs were removed in late May (CI) or the first couple days of June (other sites).

Results

Of the 223 salmon outfitted with transmitters and released in June 2009, 221 (99%) resumed upstream movements and were recorded on receiver sites at the dam and 2 (1%) had no valid telemetry records. Of the 223 released, 218 (98%) passed the dam (Table 1). One hundred and fifteen first passage events (53%) were recorded via the Bradford Island ladder, 102 (47%) were via the Washington-shore ladder, and 1 (<1%) likely passed the dam via the unmonitored navigation lock. We recorded 10 fallback events by 8 individual salmon. All 10 events followed passage via the Bradford Island ladder and all 8 fallback fish re-ascended the dam.

Table 1. Range of release dates, number of adult radio-tagged Chinook released downstream from Bonneville Dam, and numbers and percentages of those released that were recorded at the dam, that passed the dam, that were recorded on their first passage of the tailrace, first approach at a fishway opening, first fishway entry, and exit from the top of a ladder, 2002-2004 and 2009.

	Number (% of released)			
	2002	2003	2004	2009
Release date range	6/1-6/30	6/1-6/30	6/1-6/30	6/1-6/30
Released downstream	165	203	119	223
Recorded at dam	165 (100%)	202 (99%)	115 (97%)	221 (99%)
Known to pass dam	163 (99%)	199 (98%)	114 (96%)	218 (98%)
Recorded 1st tailrace passage	159 (96%)	184 (91%)	109 (92%)	215 (96%)
Recorded 1st fishway approach	161 (98%)	196 (97%)	113 (95%)	215 (96%)
Recorded 1st fishway entrance	146 (88%)	183 (90%)	107 (90%)	201 (90%)
Recorded ladder exit	162 (98%)	195 (96%)	113 (95%)	217 (97%)

Distributions of first approaches and entries

Slightly more than half of all the first fishway approaches made by radio-tagged Chinook salmon were recorded at Powerhouse 1 and approximately 40% were at Powerhouse 2 (Figure 4). The remaining first fishway approaches were at Bradford Island (6%) and Cascade Island (2%) fishway openings.

Similar percentages (38-42%) of all first fishway entrances made by radio-tagged Chinook salmon were recorded at Powerhouse 1 and Powerhouse 2 (Figure 4). Approximately 15% of all first fishway entries were at the Bradford Island opening and 6% were at the Cascade Island opening.

First fishway approach efficiencies

First fishway approaches at Powerhouse 1 resulted in 37% (n = 113) in first fishway entries at the same sites (Figure 5). About 40% of all first fishway approaches by radio-tagged salmon were recorded at Powerhouse 2, and first fishway approach efficiency was lower (16%; 14 first entries /87 first approaches). The spillway fishway openings were lightly used, resulting in low sample sizes, but were relatively efficient, with 33% (n = 3) of all first fishway approaches at the CI fishway opening and 67% (n = 12) at the Bradford Island fishway opening resulting in a first fishway entry.

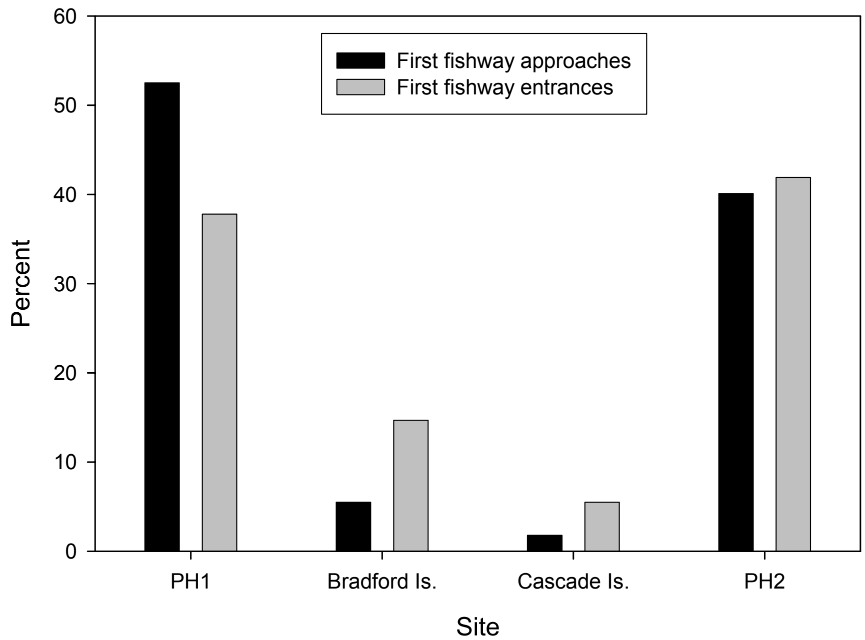

Figure 4. Distributions of first fishway approach and entrance sites used by radio-tagged Chinook salmon at Bonneville Dam in 2009.

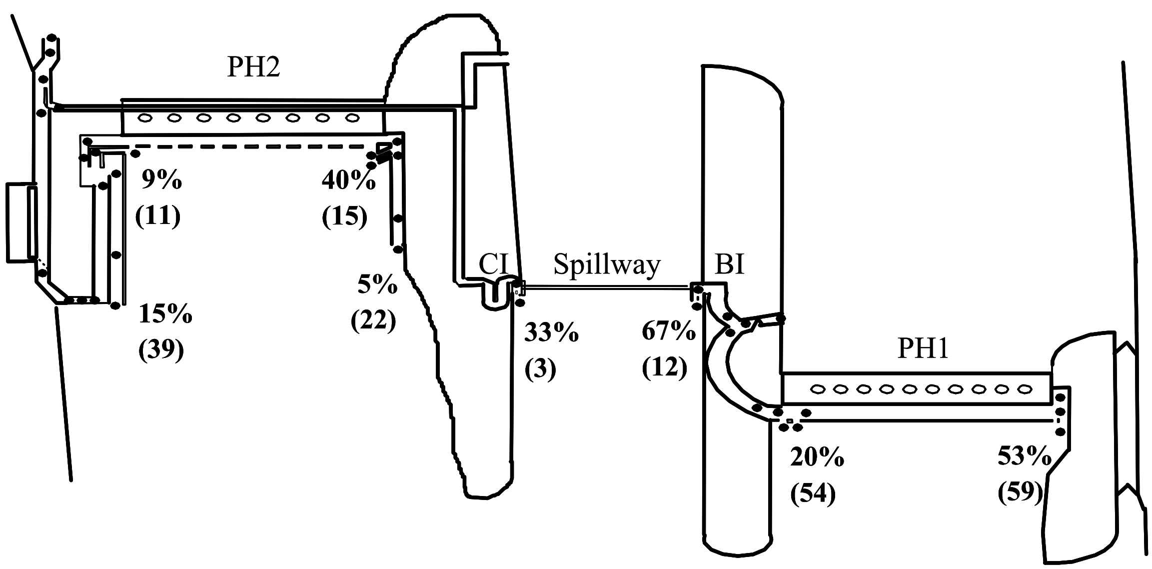

Figure 5. Percentage of first fishway approaches resulting in first fishway entries for all monitored fishway openings at Bonneville Dam in 2009. Sample sizes are in parentheses.

Passage Times

Median passage times for June-tagged fish in 2009 were generally lower than medians in 2002-2004, indicating faster passage rates. In 2009, the median time from release to first record in the tailrace was 5.9 h (*n* = 215), lower than in 2002 (12.1 h), 2003 (14.5 h), and 2004 (6.9 h). The median times from first tailrace record to first fishway approach (1.8 h, *n* = 209), first fishway entry (4.4 h, *n* = 195), and to pass the dam (19.2 h, *n* = 211) in 2009 were the fastest among all study years (Figure 6). The 2009 median time from first approach to first entry (1.5 h, *n* = 201) was intermediate. The median time tagged salmon used to swim from first fishway entry to the ladder top was 8.3 h in 2009 (*n* = 201). This was shorter than in the three other years (*medians* = 9.7–11.3 h).

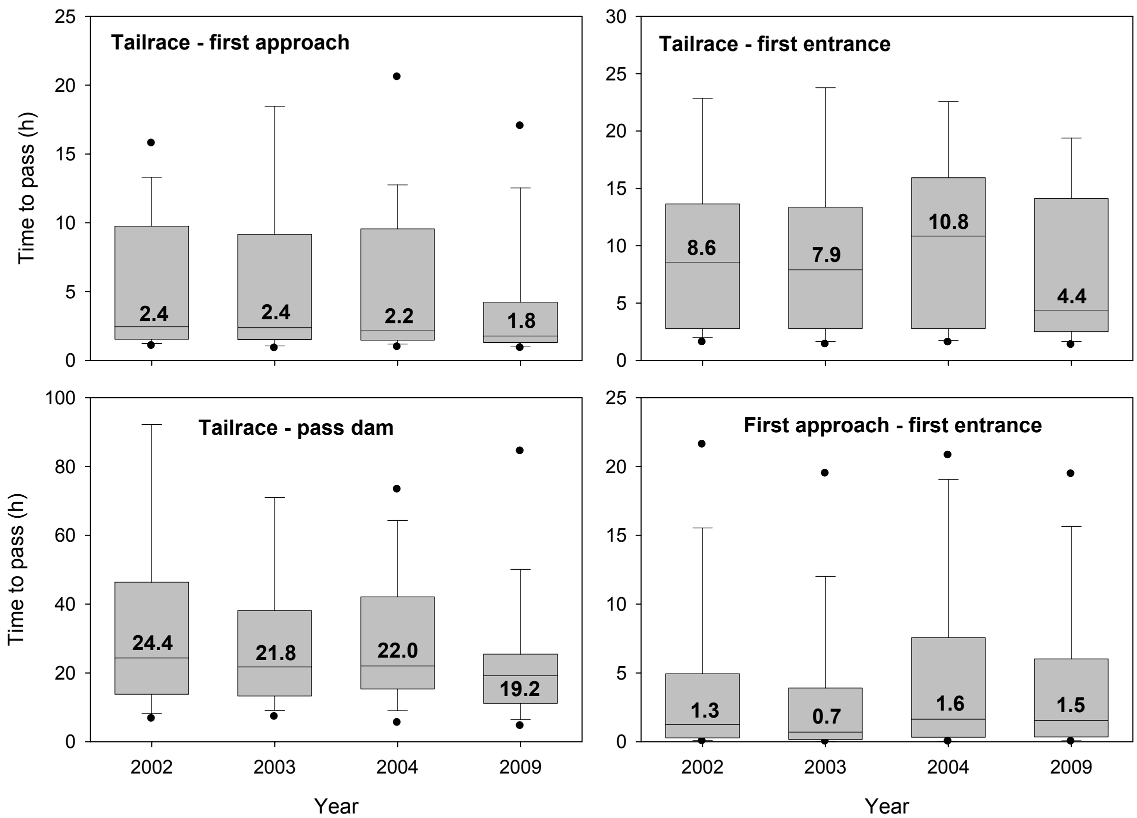

Figure 6. Distributions of June-tagged Chinook salmon passage times (h) from first tailrace record at Bonneville Dam to first fishway approach, first fishway entry, and to pass the dam and from first fishway approach to first fishway entry, 2002-2004 and 2009. Box plots show: median, quartile, 5th, 10th, 90th and 95th percentiles. Numbers inside boxes are median times. Note different scales.

Dam passage times and fishway exit percentages

Of the 217 salmon that entered a fishway in 2009, 144 (66%) exited a fishway to the tailrace at least once (Table 3). This was within the range recorded in previous years. In almost all previous evaluations, salmon that exit fishways back to the tailrace have had significantly longer dam passage times than salmon that do not exit (see Keefer et al. 2008). This was also true for June-tagged salmon in 2009, as the median dam passage time for fish that made at least one fishway exit was 23.3 h (*n* = 139) compared to 13.9 h (*n* = 72) for those that made no exit.

Table 2. Numbers of radio-tagged Chinook salmon that entered and exited Bonneville Dam fishways, and percentages that exited to the tailrace at least once, 2002-2004 and 2009.

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

Re-ascension of radio-tagged salmon that fell back

In 2009, the Bonneville Dam fallback percentage was 3.7% and all salmon that fell back subsequently re-passed the dam (Table 3). Both the fallback and reascension rates were within the range recorded for June-tagged salmon in 2002-2004.

Table 3. Fallback percentage (unique salmon that fell back / unique salmon that passed dam), number of fallback and re-ascension events by June-tagged Chinook salmon and the number of unique radio-tagged Chinook salmon that fell back and re-ascended Bonneville Dam, 2002-2004 and 2009.

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

Preliminary 2009 Cascade Island Results

Of the 223 fish tagged in June 2009, 46 (21%) were recorded approaching and 32 (14%) were recorded entering the CI fishway entrance. Both percentages were lower than in 2002-2004, when 30-32% approached the CI fishway and 22-28% entered. In contrast with spring Chinook, the annual percentage of June-tagged salmon detected at the CI fishway did not have a clear correlation with mean June flow, spill, water temperature, or tailwater elevation. In part, this may have been because fewer years were used in the June evaluation and environmental conditions among years were relatively similar (Figure 2).

Metric 1. The CI first entrance efficiency estimates in previous years ranged from 0.72–0.89 (*mean* = 0.83, Figure 7). The preliminary entrance efficiency estimate in 2009 was 0.70, the lowest of the four years but similar to 2004.

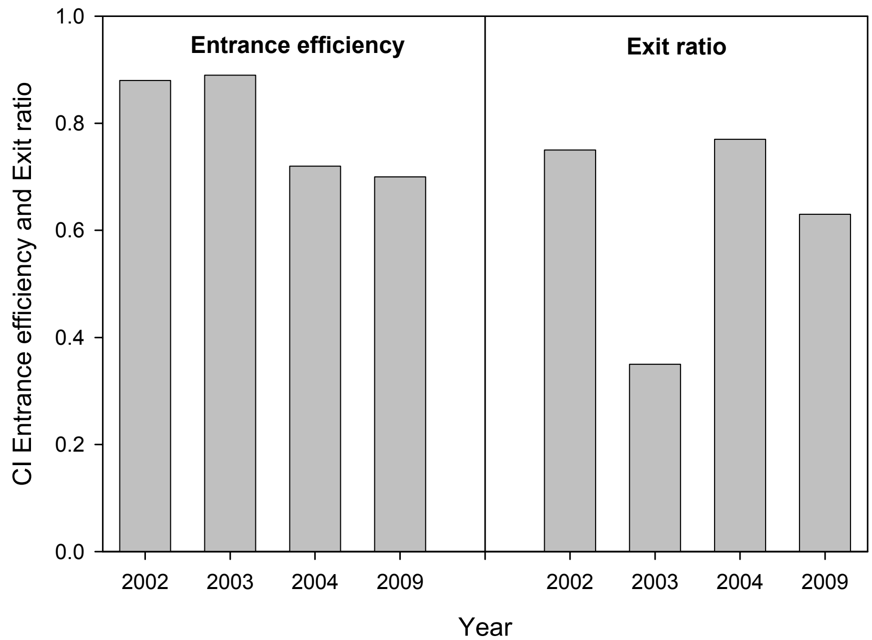

Figure 7. June-tagged Chinook salmon entrance efficiency (unique entrances/unique approaches) and exit ratio (unique exits/unique entrances) estimates for the Cascades Island fishway.

Metric 2. Exit ratios were relatively more variable than entrance efficiencies in previous years, ranging from 0.35–0.77 (*mean* = 0.62) (Figure 7). The preliminary 2009 estimate was 0.63, an intermediate value. 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).

Metric 3. Passage times from first CI approach to first CI entry were strongly right-skewed in all years (note $\log_{10}$ scale in Figure 8). Generally, the majority of fish moved rapidly into the CI 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 CI approach-entrance times were 6–12 minutes (*mean* = 8) in previous years. The median in 2009 was 16 minutes. ANOVA results for log-transformed passage times indicated significant among-year differences in means (df = 3, F = 3.0, P = 0.035). In pairwise comparisons, the 2009 mean was significantly higher than the 2002 mean; no other differences were significant (P > 0.05). Similarly, a Kruskal-Wallis test of medians (untransformed data) indicated significant differences (χ^2 = 11.5, P = 0.009), with the 2009 median the highest among years. The median passage time from entrance to the base of the ladder in 2009 was intermediate to other years, suggesting conditions within the fishway were similar to previous years. In combination, these results suggests some difference in conditions outside or immediately adjacent to the fishway entrance in 2009.

The median approach to entry times at the Bradford Island entrance, a useful comparison site, were 6–7 minutes in each of the previous years versus 2 minutes in 2009 (Figure 8). This lends some additional support to the conclusion that behavior may have changed near the CI fishway in 2009.

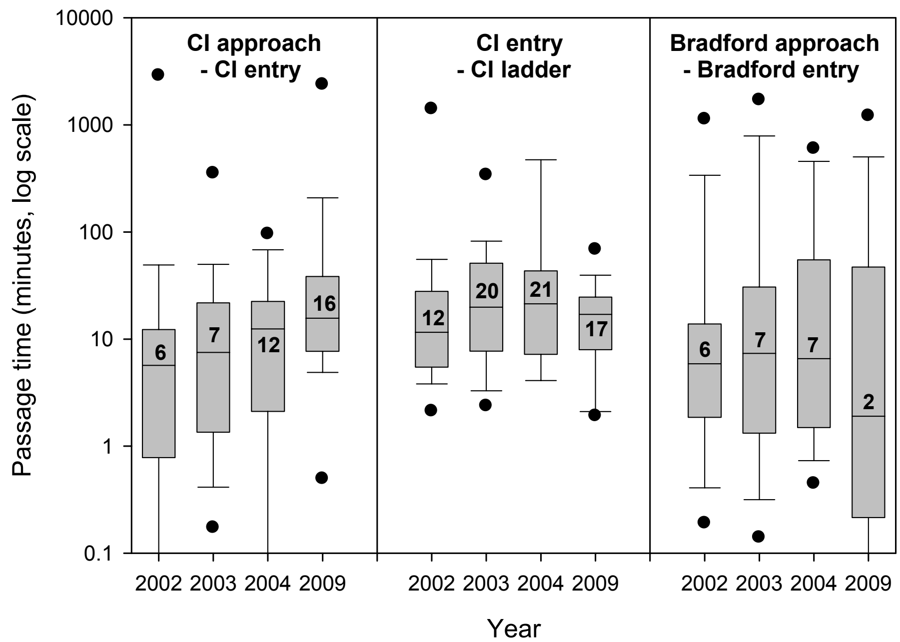

Figure 8. June-tagged Chinook salmon passage time distributions (plotted on log scale) from fishway approach to fishway entry and fishway entry to the antenna at the base of the ladder at the Cascades Island fishway and from approach to entry at the Bradford Island fishway. Values inside boxes are median times. Sample sizes were 42, 56, 25, and 30 for the CI approach-entry metric, 41, 50, 17, and 27 for the CI entry-ladder base metric, and 58, 67, 41, and 58 for the Bradford Island approach-entry metric.

Figure 9 shows the river environment encountered by June-tagged salmon recorded approaching the CI entrance for each year. When we compared log-transformed passage times among years for only fish that experienced spill levels between 90 and 165 kcfs (the 2009 range encountered by tagged fish on days they approached CI), the 2009 mean was longer than the 2002 mean ($df = 2$, $F = 3.6$, $P = 0.034$, $N = 66$). Similarly, in ANOVAs that restricted the sample to fish that encountered similar flow ($df = 3$, $F = 2.7$, $P = 0.049$, $N = 152$), tailwater elevation ($df = 3$, $F = 3.8$, $P = 0.012$, $N = 151$), or temperature ($df = 3$, $F = 2.9$, $P = 0.040$, $N = 125$) conditions as in 2009 each showed significantly slower entry times in 2009 versus 2002. An ANOVA that further restricted the data so that all four environmental variables were within the 2009 ranges was not significant ($df = 2$, $F = 1.6$, $P = 0.222$, $N = 53$); however, sample sizes were then limited to less than half of those in most of the tests reported above.

Note that we did not examine the potential effects of spill patterns on these results. However, spill patterns in 2002–2004 and 2009 should have been quite similar, with relatively greater spill from end bays as compared to pre-2002 patterns (David Clugston, personal communication).

We are currently obtaining more detailed spill data and effects of spill pattern will be presented in the final report.

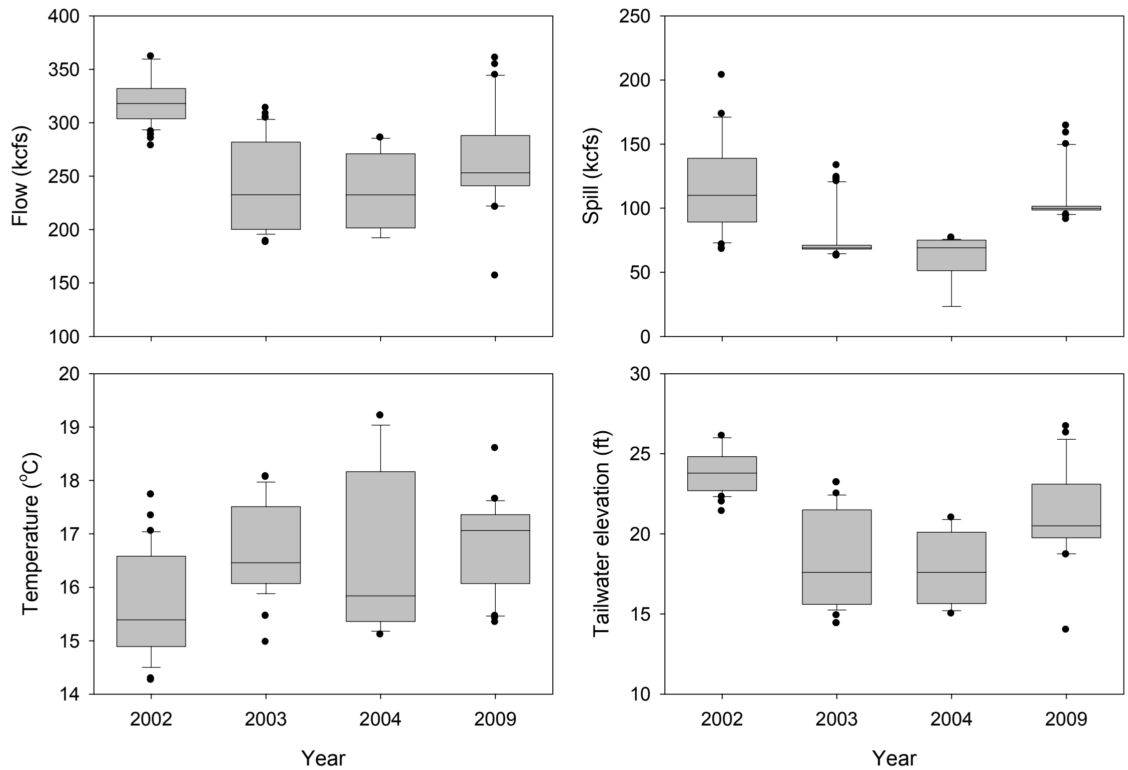

Figure 9. Box plots of the total discharge, spill, water temperature, and tailwater elevation on the days that June-tagged Chinook salmon first approached the Cascades Island fishway opening.

Metric 4. After fish entered the CI fishway, the median time to reach the ladder base ranged from 12–21 minutes in previous years. The 2009 median was 17 minutes and the distribution was similar to previous years (Figure 8). 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. ANOVA and Kruskal-Wallis tests of medians indicated passage times for this segment did not differ among years ($P > 0.30$ in both tests). The 2009 result suggests that once salmon passed the entrance weir they did not have difficulty moving over the modified bottom area with bollards and LPS entrance to the base of the ladder.

Metric 5. In 2002–2004, the percentage of 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 10). The percentages were 17% and 7%, respectively, in 2009. As with Metric 4, this trend suggests that there may have been factors acting outside or at the entrance to slow passage in 2009, but no evidence of altered behavior after entrance. However, comparisons of the percentages indicated no significant among-year differences in either metric (Pearson χ^2 tests, $P > 0.05$).

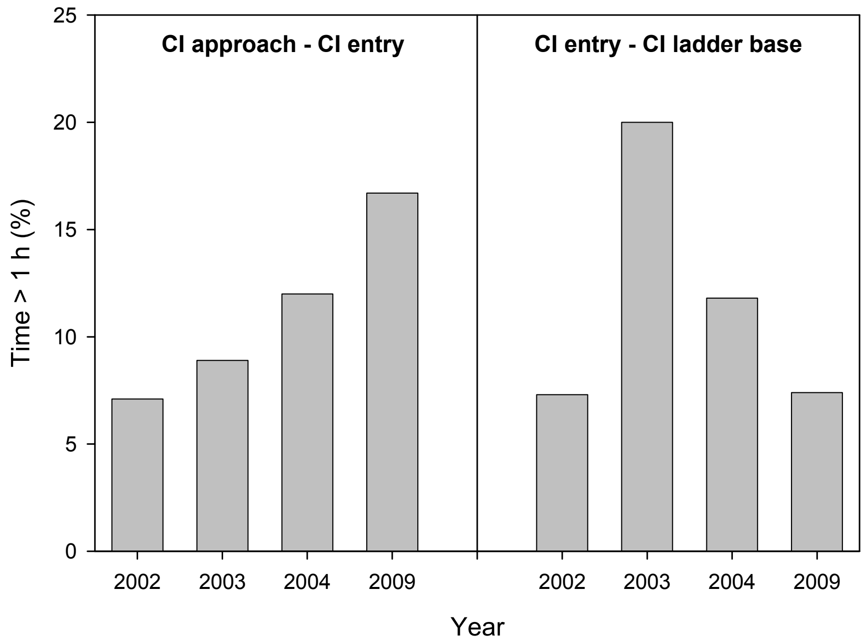

Figure 10. Percentages of spring–summer Chinook salmon that took > 1 h to pass from Cascades Island fishway approach to fishway entrance and from fishway entrance to the base of the ladder.

Preliminary Discussion

Almost all June-tagged Chinook salmon in 2009 returned to Bonneville Dam and passed the dam. This was consistent with results from previous years for June-tagged fish. In 2009, salmon approached, entered, and passed the dam faster than in previous years, while fallback and fishway exit percentages were similar to past results. Overall, these patterns suggest that the passage environment at the dam for fish tagged in June 2009 was similar to or slightly better than in 2002–2004.

Compared to previous years, there were stronger correlations between CI approach-to-entry times and environmental conditions in 2009, though they were still weak (Table 4). Correlation results indicated faster entry times when flow and spill were high and temperature was low, in contrast with spring Chinook results. However, the June results were largely driven by a few salmon that approached and quickly entered the CI fishway in early June. Our overall impression from the correlation results was that the relatively narrow range of conditions during June was not helpful for making inferences about the variability in CI entrance times.

For the June analyses, we limited the comparisons to years after the spill pattern change in 2001. Had we included data for June-tagged salmon from 1996–1998 and 2000–2001 more significant results may have been found (as was the case for spring Chinook). We will incorporate spill pattern to the analyses, pending receipt of the data from the COE.

Table 4. Correlation coefficients (r) between environmental conditions June-tagged Chinook salmon encountered when they first approached the Cascades Island entrance and log-transformed approach-to-entry times, by year. Bold indicates $P < 0.05$.

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

The 2009 CI results indicate some possible behavioral differences in June-tagged Chinook salmon at the CI entrance area relative to previous years. The primary difference was that salmon took slightly, but significantly, longer to enter the CI fishway after approaching. The slower 2009 passage at the CI entrance was evident after controlling for environmental differences among years. This result is consistent with what we reported for spring Chinook in the 29 June letter report. We note that the magnitude of the possible 'delay' was substantially higher for the spring Chinook. The median time for June-tagged salmon in 2009 (16 minutes) was only slightly longer than the 6–12 minutes in previous years. This was probably not a biologically significant increase in passage time.

The slower CI entrance times in 2009 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. For example, late in the season we discovered that an opening on the north side of the CI entrance was available for salmon entry (this opening was supposed to have been closed). It is not clear if this had any effect on fishway attraction flows or salmon entrance behavior. Importantly, we have no reason to believe the observed passage time differences were related to systematic changes in the telemetry array, tag type, or detection probabilities. Additionally, approach to entrance passage times across all entrances were similar to prior years (Figure 6) and the trend was for faster, not slower times, at Bradford Island in 2009 than in previous years (Figure 8).

The primary behavioral differences between 2009 and other years appeared to be at or 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. We speculate that hydraulic conditions created by the new weir and/or altered olfactory conditions related to both modifications in the entrance jet contributed to the longer observed passage, while the hydraulic effects of the bollards and new LPS entrance on passage behavior within the fishway had insignificant effects on passage behavior. A final report with more complete and detailed analyses will be available in early 2010.

Literature Cited

Keefer, M., M. Jepson, C. Caudill, and B. Burke. 2009. Preliminary evaluation of radio-telemetry data for spring Chinook salmon at Bonneville Dam – 2009. Letter report to David Clugson, USACE Portland District, 29 June 2009.

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