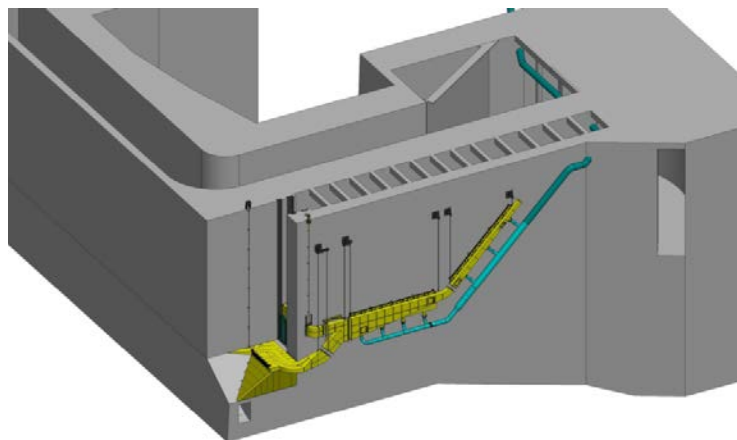**Technical Report 2014-10**

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EVALUATION OF ADULT SALMON PASSAGE BEHAVIOR IN RELATION TO FISHWAY MODIFICATIONS AT BONNEVILLE DAM - 2013

Study Code: **ADS-P-13-1**

E.L. Johnson, T.S. Clabough, M.L. Keefer, C.C. Caudill,
S.R. Lee, J. Garnett, L. Layng, T. Dick, and M.A. Jepson
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And

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2725 Montlake Blvd. East, Seattle, Washington 98112

For

U.S. Army Corps of Engineers
Portland District

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Acknowledgements

Table of Contents

Executive Summary

In 2013, we evaluated the passage and migration behavior of radio-tagged spring and summer Chinook salmon (*Oncorhynchus tshawytscha*) and sockeye salmon (*O. nerka*) in relation to the installation of the Lampey Flume System (LFS) at the north downstream entrance (NDE) of the powerhouse 2 (PH2) fishway at Bonneville Dam. We also conducted a third year of radiotelemetry studies of spring–summer Chinook salmon at Bonneville Dam to evaluate if modifications made at the Cascades Island (CI) fishway in winter 2008-2009 to facilitate passage of adult Pacific lamprey (*Entosphenus tridentatus*) and improve hydraulics at the entrance for salmon adversely affected passage of adult salmon. Our primary study objective was to compare passage times and behaviors from pre-modification years to those from post-modification years while considering inter-annual variation in environmental, operational, and ecological conditions using a set of 5-7 quantitative passage metrics. The metrics included: entrance efficiency, exit ratio, approach-to-entry time, entry-to-ladder base time, proportion of adults requiring > 1 hour to pass these segments. We also compared behaviors at NDE and CI to similar sites (PH2 south downstream entrance and Bradford-Island B-Branch entrance).

A total of 600 adult spring-summer Chinook, 300 jack spring-summer Chinook, and 400 adult sockeye salmon were collected and radio-tagged at the adult fish facility at Bonneville Dam in 2013. All tagged fish were released below Bonneville Dam near Dodson, OR or Skamania, WA. Movements of radio-tagged salmon were monitored with aerial and underwater antennas attached to fixed-site radio receivers in the tailrace and at the dam. Data were compared to results from 1996-1998, 2000-2004, 2005 (summer Chinook only), 2006 (spring Chinook), 2007 (spring Chinook), 2009, and 2010; no previous data were available for jack Chinook salmon and data from a single year (1997) were deemed unsuitable for comparison to 2013 results for sockeye salmon due to large differences in environmental conditions.

Inter-annual variation in passage metrics collected at the NDE of Bonneville Dam PH2 was high in pre-modification years. Some variation was attributable to differences in environmental factors and operations among years. For instance, 1996-1998 were relatively high flow, cool years and 2000-2001 were low flow years with warm temperatures. Slightly below average discharge and spill levels and above average temperatures were observed in 2013. For adult spring Chinook salmon, mean entrance efficiencies at NDE were slightly lower and entrance times were slightly longer in 2013 than in pre-modification years. In contrast, mean entrance efficiencies were higher and entrance times were faster than values from pre-modifications years for spring and summer jack Chinook and sockeye salmon. Differing results in the same passage metrics among runs and species suggest the observed values were not directly related to the newly-constructed LFS. Exit ratios, times from the PH2 NDE entrance to the base of the ladder, and the ratio of fish approaching and entering the NDE versus the SDE were within the range of values observed in pre-modification years. Taken together, observed differences in passage metrics between 2013 and pre-modification years suggest that any effects of the LFS installation were small relative to environmental factors, the presence of sea lions in the tailrace, and other unmeasured factors.

At the CI fishway opening, exit ratios, times from entry to the base of the ladder, and the proportion of fish taking longer than 1 h to pass through the lower CI fishway in 2013 suggested that the modifications made in 2008-2009 were not adversely affecting spring Chinook salmon passage. The 2013 CI entrance efficiency for adult spring Chinook salmon (67%) was similar to values from both pre- and post-modification years. However, lower entrance efficiencies were observed for

summer Chinook salmon in 2013 (47%) vs. pre-modification years (*mean* = 83%). Sockeye salmon entrance efficiency was 61% in 2013. Times to enter the CI fishway opening for Chinook salmon in post-modification years were collectively higher than those from pre-modification years but the times were lower in 2010 and 2013 compared to 2009. Slower approach-to-entry times in 2009 (the first post-modification year) may have been produced by changes in hydraulic or olfactory conditions outside the Cascades Island entrance directly caused by the modifications and/or other conditions in the fishways. Since then, potentially disruptive olfactory cues may have declined as the new structures have "seasoned" by leaching and the accumulation of biofilms.

Introduction

Adult salmon and steelhead migrating to their natal streams in tributaries of the Columbia River must pass up to nine dams, four in the lower Columbia and Snake rivers and five in the mid-Columbia River. Losses and delays in migration at each hydroelectric project must be minimized to maintain the native fish runs and achieve the recovery goals outlined by the Northwest Power Planning Council (NWPPC) and by NOAA Fisheries (NOAA). This study address priority research areas related to improving passage and survival of adult salmonids identified by the Corps of Engineers, fish agencies, and NOAA in the Columbia River Federal Power System (FCRPS) Biological Opinion released in 2008 related to recovery of threatened and endangered Columbia and Snake River salmon and steelhead.

Major and minor fishway modifications intended to improve passage of adult Pacific lamprey and/or adult salmonids have recently been completed and as with any significant changes to the passage facilities, the modifications must be evaluated for effectiveness and to ensure that salmonid passage is not adversely affected. This study provides information relevant to implementation of the USACE Pacific Lamprey Passage Improvements Draft Implementation Plan 2008-2018 because many recent and planned modifications to fishways must also be suitable for ESA-listed adult salmonid passage. Increases in passage delay are of concern because salmon migrate upstream using fixed energetic reserves and relatively long passage is associated with unsuccessful passage (Caudill et al. 2007). At Bonneville Dam, slowed passage into the fishways may also increase the probability of predation by sea lions in the tailrace or anglers for spring and early summer Chinook salmon (Keefer et al. 2012).

In 2010, a prototype lamprey flume system (LFS) was designed for the Washington-shore fishway North Downstream Entrance (NDE) at Powerhouse 2 (PH2) Bonneville Dam (Figure 1). Design elements for this structure were drawn from experience with the Bonneville Dam Lamprey Passage Structure (LPS) collectors and from behavioral observations in the experimental lamprey fishway (Keefer et al. 2010, 2011; Moser et al. 2011). The flume system included two alternative entrances with lower entrance velocities and a duct system leading to a LPS collector that terminated on the tailrace deck. A primary objective of work at PH2 in 2013 was to assess adult salmonid movements at the NDE after the LFS was installed.
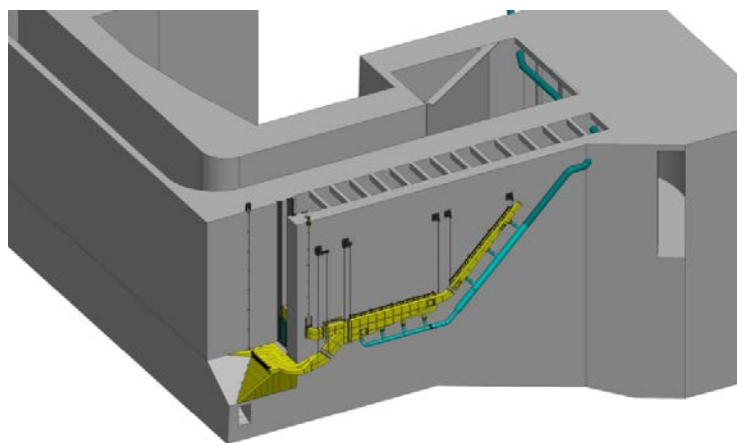

Figure 1. Lamprey flume system (LFS) designed for the Washington-shore NDE.

A variable-width entrance weir and bollards were installed at the Cascades Island (CI) entrance at Bonneville Dam in 2008-2009 (Figure 2; Clabough et al. 2010) to improve the passage of both salmon and Pacific lamprey. The variable-width weir is thought to improve attraction flows for salmonids while reducing operation and maintenance costs. This design also eliminated lower bulkheads that may have interfered with adult lamprey entering this fishway. Monitoring radio-tagged, adult Chinook salmon at the site indicated some evidence of slowed passage in the first year post-construction (Jepson et al. 2010). Specifically, a relatively low percentage of spring Chinook salmon that approached the CI fishway opening subsequently entered it and those that did enter took a relatively long time to do so in 2009. While river conditions explained some of the differences, there was also some evidence that the modified CI opening was associated with the decline in entrance efficiency. Data from 2010 indicated that passage metrics were more typical of pre-modification passage at Cascades Island (Jepson et al. 2011), though the mechanism(s) creating the differences between pre- and post- modificaiton years was unclear. Variation in CI passage metrics from 2009 to 2010 may have been related to short-term effects of construction and "seasoning" of the structure, interannual variation in overall environmental conditions, and/or hydraulic effects of the new weir design. Monitoring in 2013 provided a third year of post-modification data on passage behavior at the location.

Our primary objective at both NDE PH2 and CI entrances was to compare fish performance metrics for pre-modification years to post-modification years while simultaneously considering interannual variation in environmental, operational, and ecological conditions. Below we describe variation in environmental parameters, general fishway use patterns of adult salmon at Bonneville Dam, and then we present the detailed results of passage behavior at the modified PH2 NDE and CI fishways.
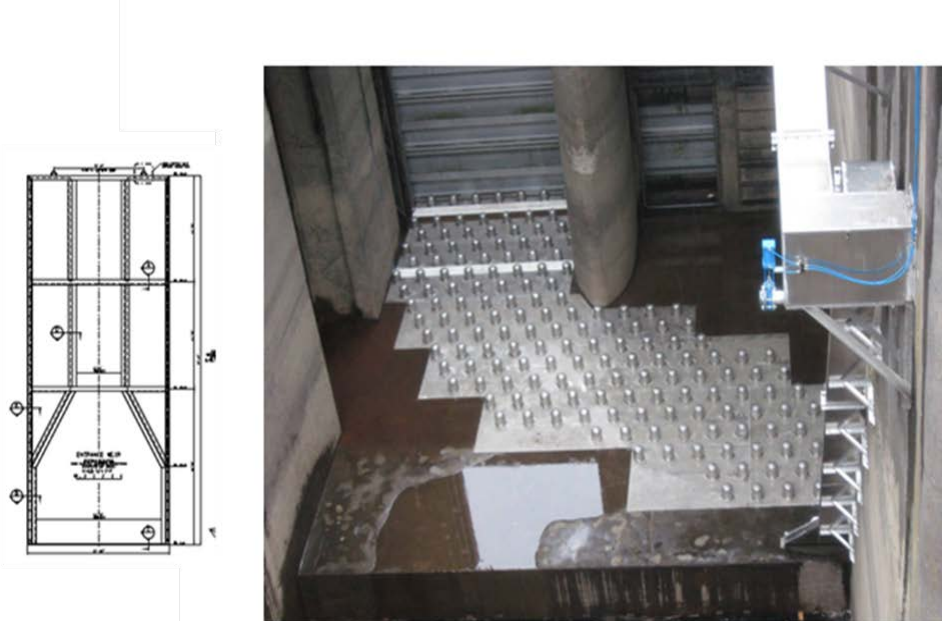

Figure 2. Variable-width entrance weir (line drawing, left) and Bonneville Dam Cascades Island entrance during installation of bottom rocks, Lamprey Passage System (LPS, ascending wall to right in photo), and Half-Duplex PIT antennas (white bars spanning opening near entrance bulk head). The variable-width weir was installed to the entrance slot in spring 2009.

Methods

Radio-tagging and monitoring

We collected and radio-tagged adult Chinook and sockeye salmon at the Adult Fish Facility (AFF), located adjacent to the Washington-shore ladder. Sockeye salmon were collected and tagged in approximate proportion to the 10-year average run timing. The early portion of the spring Chinook salmon run was not sampled in 2013 due to delayed receipt of radio transmitters. Fish were selected haphazardly in the order they entered the trap each day, though the sample cannot be considered a random sample of the run at large because only adults passing the Washington-shore ladder were sampled and no known-origin (i.e., previously PIT-tagged) fish were radio tagged. Protocols for collection and outfitting salmon and steelhead with transmitters at Bonneville Dam, downloading of data from receivers, coding of the data, and data analysis were similar to those developed in prior years (e.g., Keefer et al. 2004, 2005; Jepson et al. 2011). Fish receiving a radio transmitter were anesthetized in a ~18 mL/L solution of AQUI-S 20E (Aquatactics, Kirkland, WA). We used four types of digitally-encoded radio transmitters developed by Lotek Wireless (Newmarket, Ontario). The transmitter models used to tag adult Chinook salmon were the 7-volt MCFT-7F (16mm $\times$ 83mm; 29 g in air) and the MCFT-7A (16mm $\times$ 83mm; 29 g in air). Jack spring and summer Chinook salmon, defined as having a fork length $<$ 60 cm, were tagged with a nano transmitter (NTC-4-2L; 8mm $\times$ 18mm; 2 g in air) and adult sockeye were tagged with a 3-volt MCFT2-3BM transmitter (11mm $\times$ 43mm; 7.7 g in air). All adults were also tagged with a full duplex PIT-tag inserted to the abdominal cavity as a secondary tag (e.g., Keefer et al. 2005) that allowed estimation of tag loss rates, detection efficiencies and conversion rates using both radio- and PIT-detections. Fish that were radio-tagged were weighed, measured for fork length, and had scale and caudal fin punches for DNA samples collected. After recovery from anesthesia, all radio-tagged fish were transported by truck and released ~ 8 km downstream from Bonneville Dam. Fish were supplied with continuous oxygen until their release.

We used an array of fixed-site radio receivers to monitor locations of tagged fish. Receivers were installed to intensively monitor movements at the modified areas: the BON PH2/ Washington Shore NDE and the CI fishways. It is important to note that the PH2 NDE and CI entrances were monitored using an aerial Yagi antenna in 2013 (due to limited access to underwater locations in winter 2012-2013) whereas these sites were monitored using underwater antenna arrays historically (Figure 3). Past direct comparison of detection records using simultaneously deployed Yagi and underwater antennas have indicated similar detection rates. Data collected in 2013 were compared to passage performance metrics collected during previous passage evaluations (1996-2007, 2009-2010), with comparisons focusing on years with the most similar structural and operational conditions to 2013.

Data Analyses

A variety of passage time and passage efficiency metrics were examined as defined below to evaluate whether the fishway modifications may have affected Chinook and sockeye salmon behavoirs. For this evaluation, we report metrics that are consistent with the previous 12 study

years which inluded 1996-1998, 2000-2004, 2005 (summer Chinook only), 2006 (spring Chinook), 2007 (spring Chinook), 2009, and 2010. No previous data were available for jack Chinook salmon and data for sockeye salmon from a single year (1997) were deemed unsuitable for comparison to 2013 results due to near-record high flow conditions in 1997. We compared 2013 passage metrics from locations with major modifications at Bonneville Dam to corresponding values for Chinook salmon from previous years. Passage records for April were removed from previous years to provide equivalent comparisons at PH2. Early passage data were not removed from the Cascasdes Island analysis to preserve an adaquate sample size for comparisons.

We used correlation techniques to evaluate the degree of association between PH2 NDE and CI approach-to-entry times and four enviromental factors: total discharge (flow), spillway discharge, water temperature, and tailwater elevation. We additionally evaluated the degree of association bwtween PH2 and CI entry times with date and time of day. Statistical tests of between-year effects was performed using ANOVA (Zar 1999). Potentially confounding factors in our multi-year comparisons were the deployment of sea lion exclusion devices (SLEDs) in all years after 2005, variations in spill patterns, orifice gate closures, and the powerhouse priority shift from PH1 to PH2 in 2001. Across study years, the spill pattern also shifted toward proportionately more spill through end spillbays. In addition, marine mammal predators increased over the study period (Stansell et al. 2009; Keefer et al. 2012).

Passage metrics

We estimated several passage time and passage efficiency metrics to evaluate potential effects of the PH2 NDE and CI entrance modifications on adult spring-summer Chinook and adult sockeye salmon behavior. The metrics estimate different elements of fishway approach and entry behaviors and passage times.

1) *Entrance efficiency*. The ratio of unique fish recorded entering a fishway to the number that approached the same fishway. A drop in entrance efficiency would suggest that the environment near the entrance has become less attractive to salmon.

2) *Exit ratio*. The ratio of unique fish recorded exiting the fishway into the tailrace to the number that entered the fishway. An increase in the exit ratio would suggest that conditions inside the fishway entrance have become less favorable.

3) *Entrance time*. The passage time from first approach to first entrance. An increase in entrance time would suggest that passage conditions at the entrance have degraded.

4) *Entrance to base of ladder time*. The passage time from the entrance antenna to the antenna located in the transition pool at the base of the ladder. An increase in passage time through this section would suggest that the modifications had a negative effect on adult salmon behavior inside the fishway at or near the lamprey modifications. Vibration related to pumps at the LFS is of concern at NDE and the bollards may have affected hydraulics inside the entrance at CI.

5) ***Extended passage times***. Salmon passage times are strongly right-skewed and can be challenging to analyze and interpret. We used the percentage of fish that require > 1 h to pass through the lower fishway (entrance to base of ladder) as a standardized metric of slowed passage. Increases in this metric would suggest that passage has become more difficult.

6) ***PH2 entry locations of successful dam passages (PH2 NDE only)***. Salmon that successfully passed Bonneville Dam via the Washington-shore fishway received an LP code when they exited the transition area and entered the overflow section of the ladder for the final time (i.e., before they passed the dam). We calculated the percentage of LP events that were preceded by an entry at NDE. A decrease in this metric could indicate reduced use or reduced effectiveness of NDE.

7) ***Percentage of PH2 NDE approaches and entries in relation to SDE***. Among-year differences in the proportions of fish approaching and entering the PH2 north downstream entrance compared to the PH2 south downstream entrance may help explain among-year differences at PH2 or a shift in fishway use if adults avoided PH2 NDE.
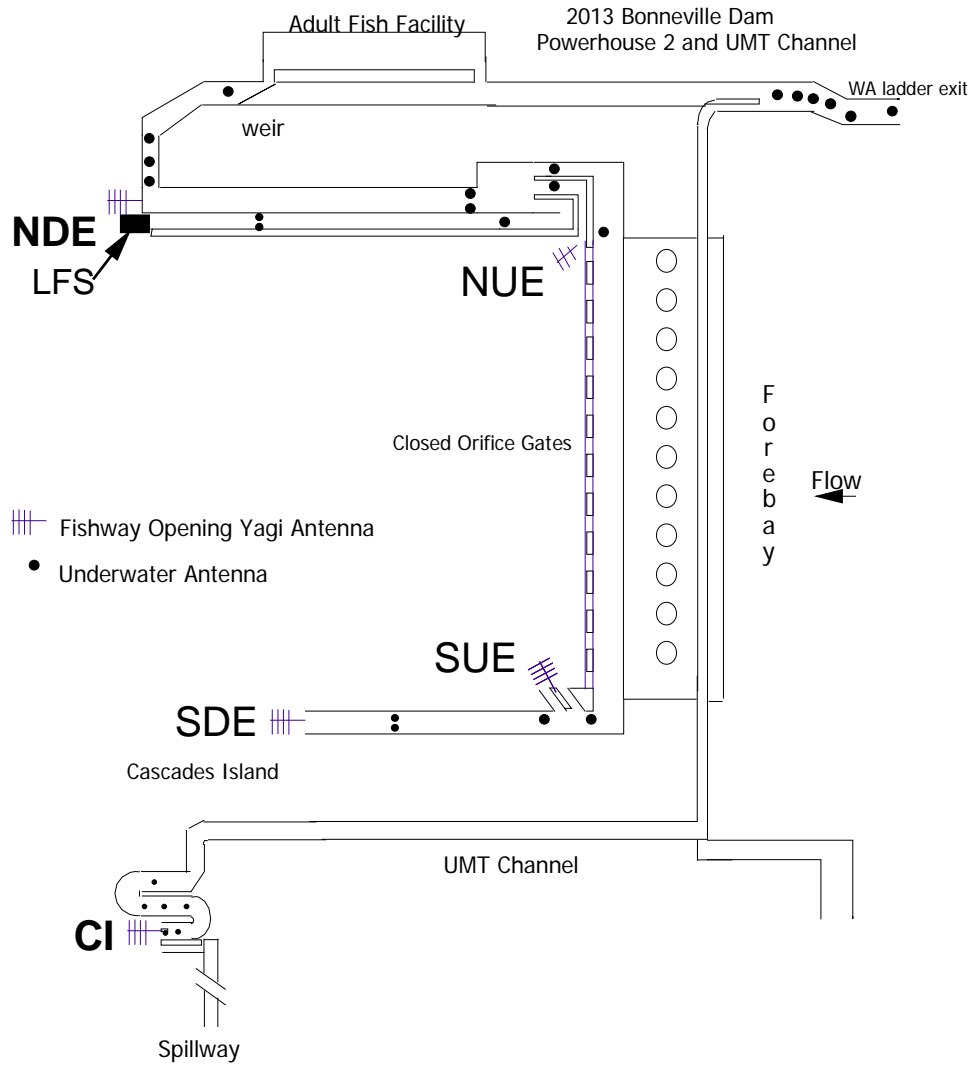
Figure 3. Dam diagram of underwater and aerial antennas used at Bonneville Dam to monitor movements of radio-tagged Chinook and sockeye salmon in 2013. Solid square indicates the location of the modified north downstream entrance (NDE) and lamprey flume system (LFS). Note that the Bradford Island fishway is not shown.

Results

Radio-tagging

We collected and intragastrically radio-tagged 328 adult spring (May 2-May 31) and 272 adult summer (June 1-July 15) Chinook salmon at the AFF and released them approximately eight kilometers downstream from the dam (Figure 4). We similarly collected and tagged 300 jack Chinook salmon (178 spring and 122 summer) and 400 adult sockeye salmon (June 7-July 13). Early run adult and jack Chinook salmon were not sampled. A total of 52,128 adult spring Chinook salmon, 82,460 adult summer Chinook salmon and 172,140 adult sockeye salmon were counted passing the dam during the tagging period. Radio-tagged salmon represented ~0.4% of the Chinook and ~0.2% of the sockeye salmon counted at the dam during the tagging period.
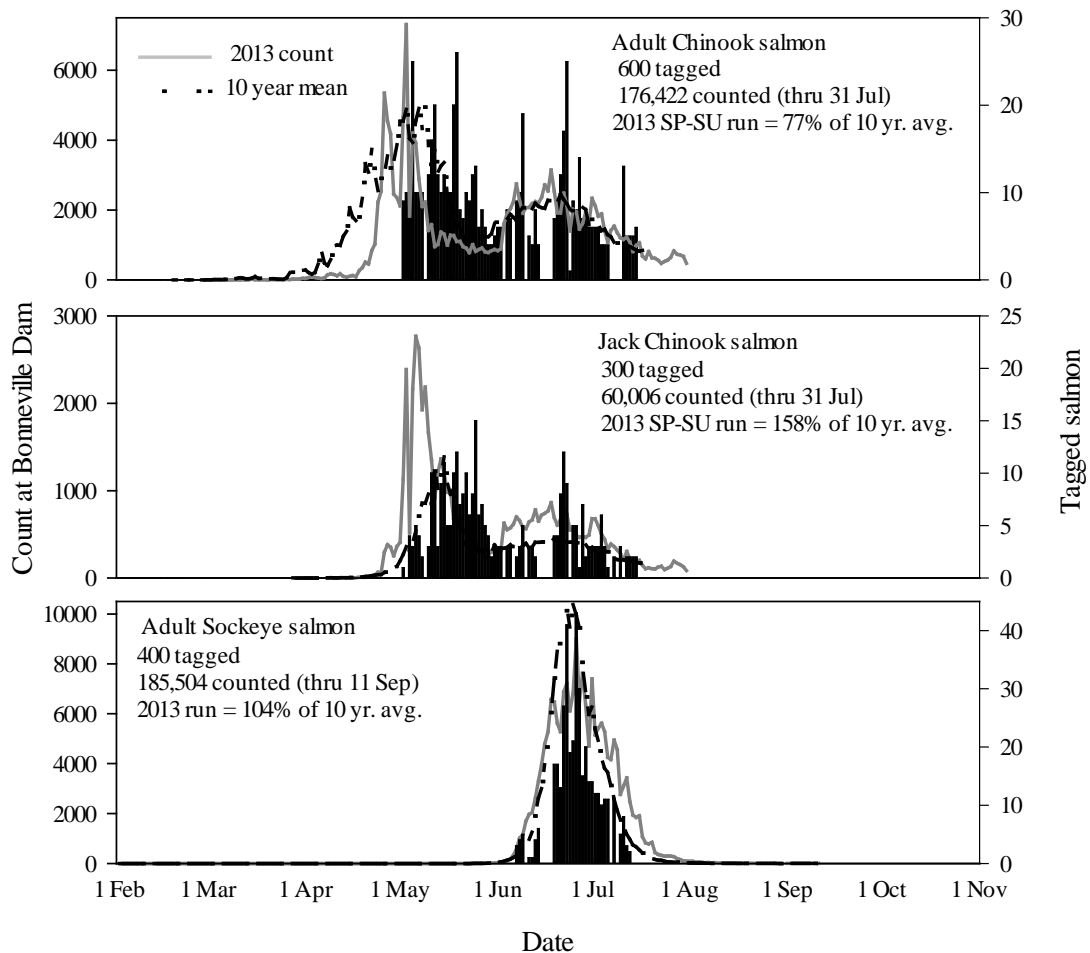

Figure 4. The number of adult and jack Chinook salmon and sockeye salmon radio-tagged and released downstream from Bonneville Dam and the count of adult salmon passing the dam in 2013.

7

Environmental Data

Flow, spillway discharge, and river temperatures in the Bonneville Dam tailrace varied considerably during the Chinook salmon runs over the thirteen study years (Figure 5-7). This contributed to the large inter-annual variation in salmon passage behavior. For example, total river discharge ('flow') and spill ranged from near-record low levels in 2001 (flow mostly less than 200 kcfs) to near-record high levels (flow ~500 kcfs) in 1997. Environmental conditions at Bonneville Dam during 2013 salmon tagging were characterized by slightly lower than average flows, spill levels less than 146 kcfs, and above average temperatures.

Figure 5. Mean daily flow at Bonneville Dam from May through August in 1996-1998, 2000-2004, 2006-2007, and 2009-2010 (black line) versus 2013 (red line). Note y-axes differ.

Figure 6. Mean daily spill volume at Bonneville Dam from May through August in 1996-1998, 2000-2004, 2006-2007, and 2009-2010 (black line) versus 2013 (red line). Note y-axes differ.

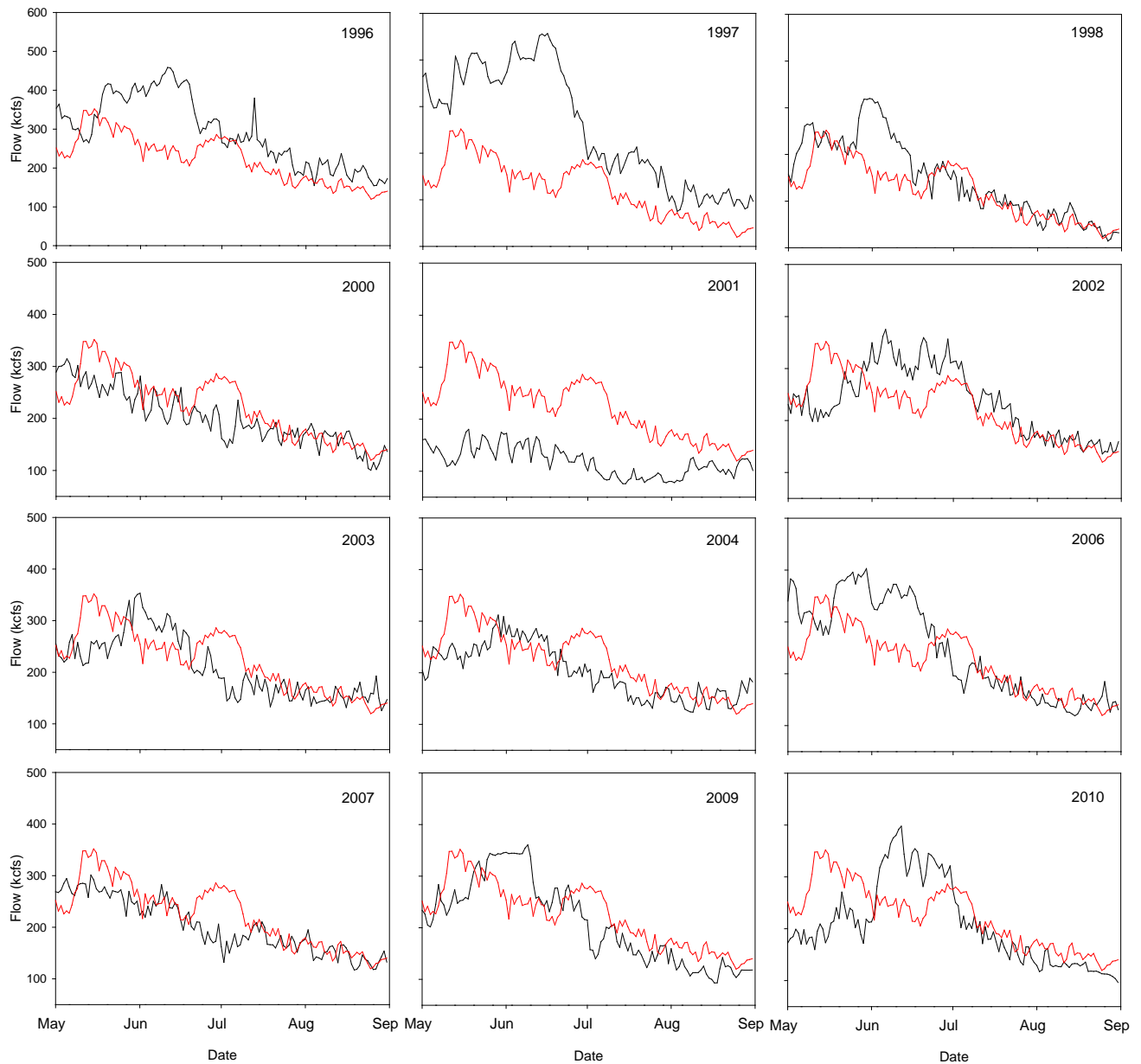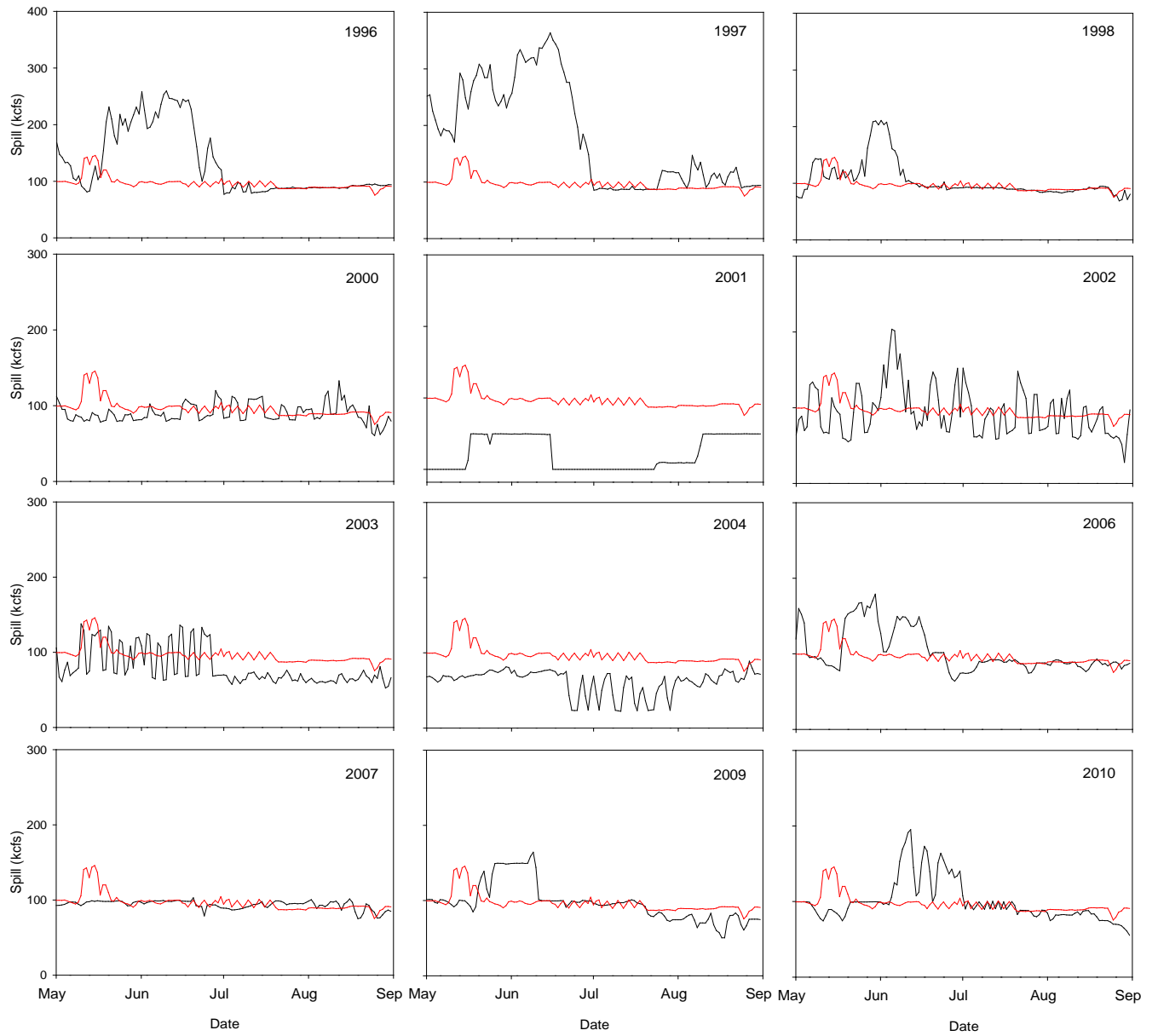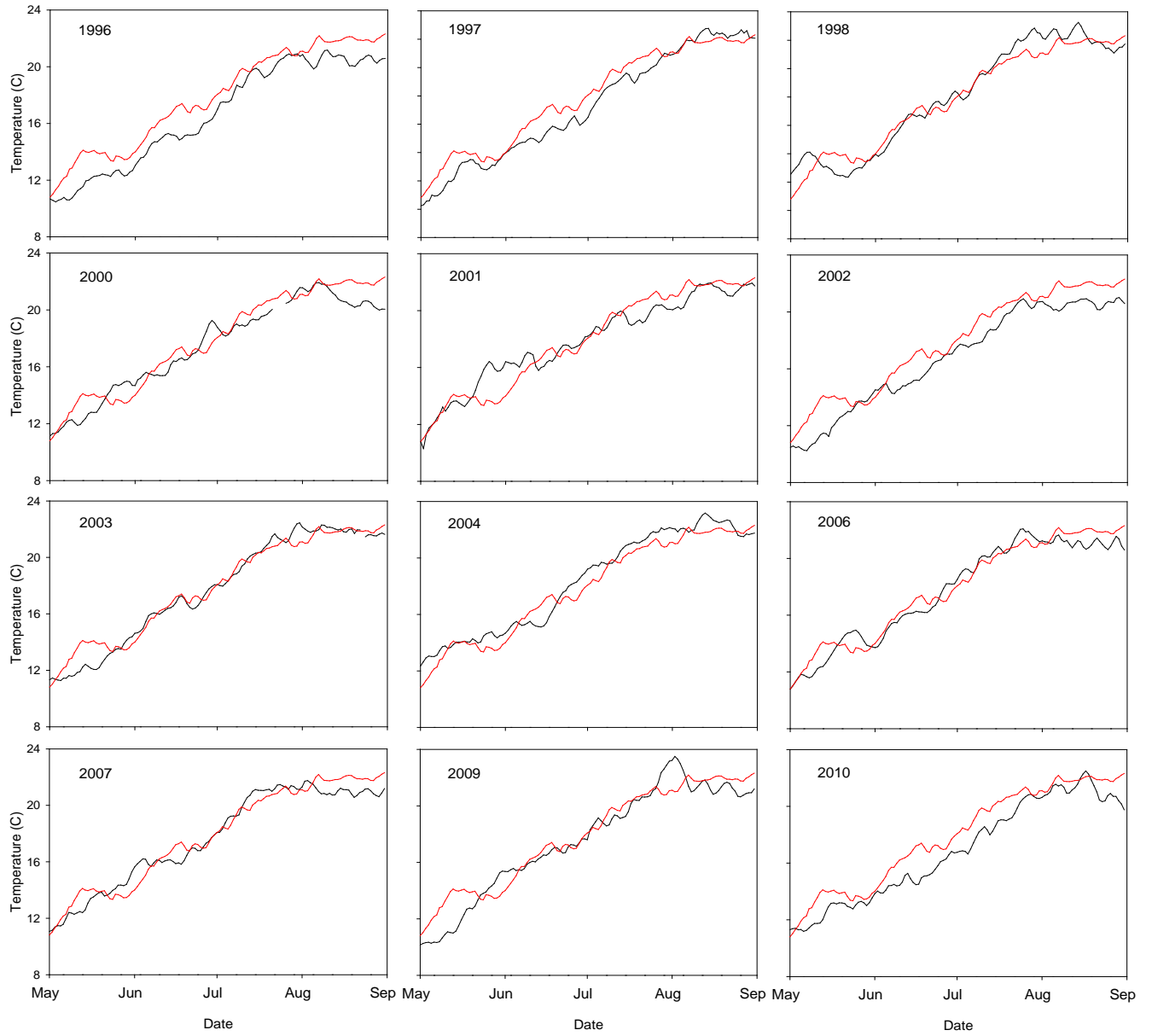Figure 7. Mean daily tailrace water temperature at Bonneville Dam from May through August in 1996-1998, 2000-2004, 2006-2007, and 2009-2010 (black line) versus 2013 (red line).

PH2 NDE Results

Of the 328 adult spring Chinook salmon tagged through 31 May 2013, 128 (39%) were recorded approaching and 33 (10%) were recorded entering the NDE (Figure 8). These percentages were lower than the means from pre-modification years, which were 51% and 21%, respectively. The adult entrance values were similar to those in 2009 (~10%) and to those for jack Chinook salmon (13%) in 2013.

Of the 272 adult summer Chinook salmon tagged in 2013, 70 (26%) were recorded approaching and 49 (18%) were recorded entering the NDE (Figure 9). Approach percentages for adult summer and jack Chinook in 2013 were less than mean values from pre-modification years but were within the ranges of values from those years. Adult tagged sockeye salmon had similar NDE approach (27%) and entry (22%) values as summer Chinook salmon.

The annual percentage of fish detected approaching the NDE increased slightly with increasing river discharge (Figure 10). The 2013 detection rates were in line with rates in previous years given river conditions. No relationship was found with the annual percentage of fish detected approaching the SDE and river discharge.
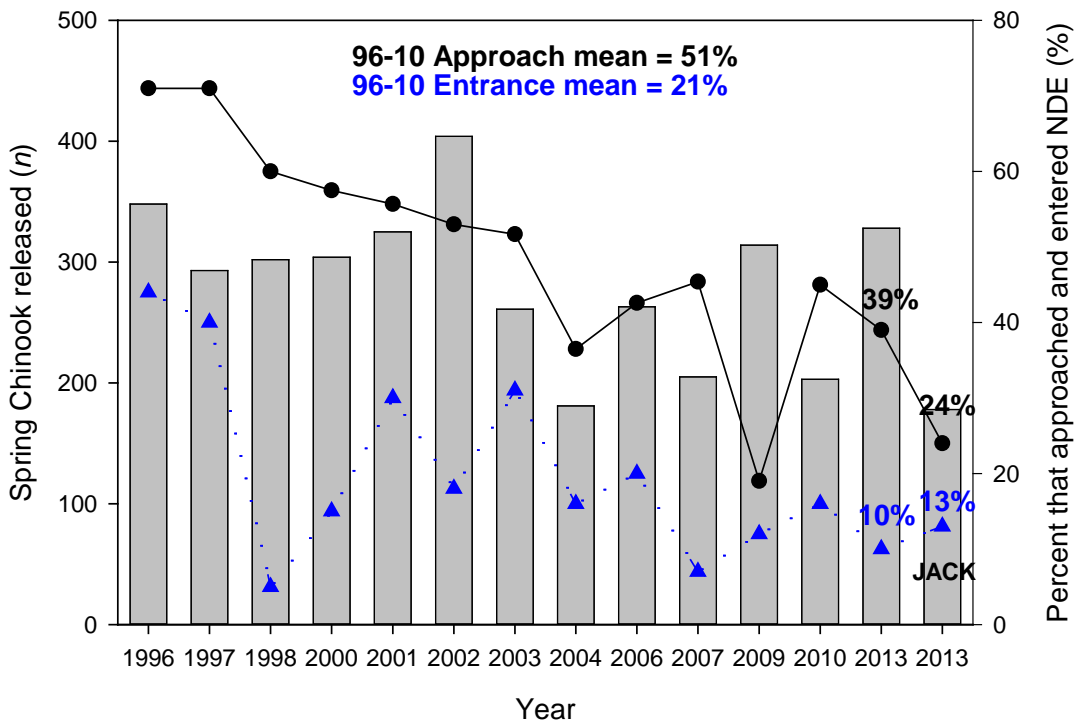
Figure 8. Number of spring Chinook salmon radio-tagged (bars) and the percentages that were recorded approaching (circles and solid line) and entering (triangles and dashed line) the PH2 NDE. Note last bar on graph denotes spring jack Chinook.

Figure 9. Number of summer Chinook salmon radio-tagged (bars) and the percentages that were recorded approaching (circles and solid line) and entering (triangles and dashed line) the PH2 NDE. Note last bar on graph denotes summer jack Chinook.
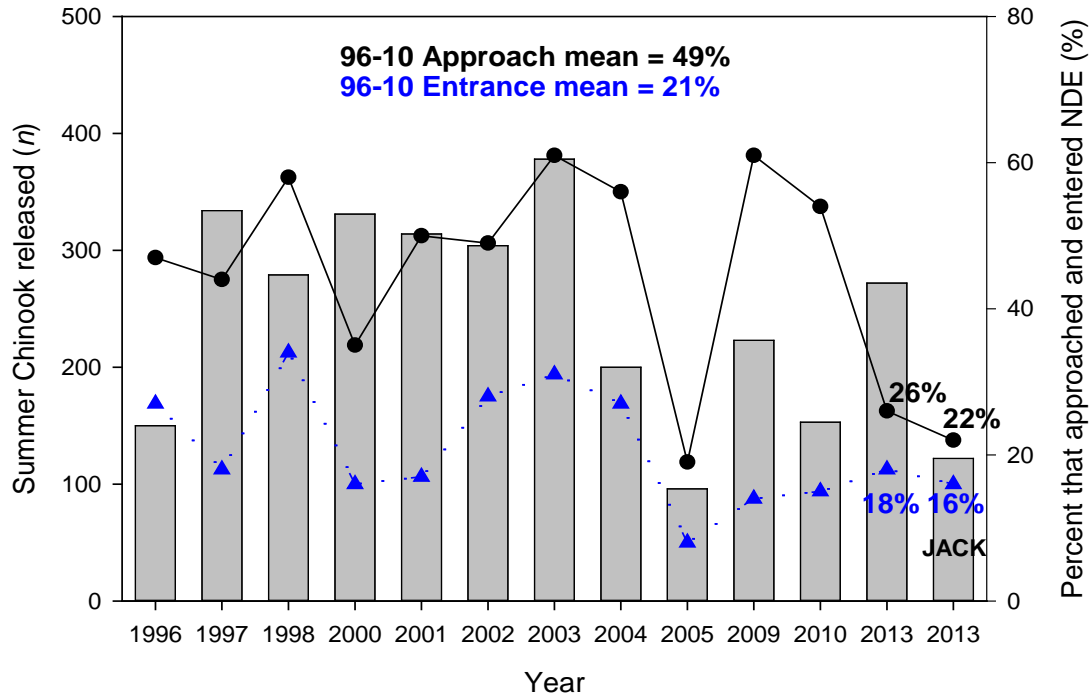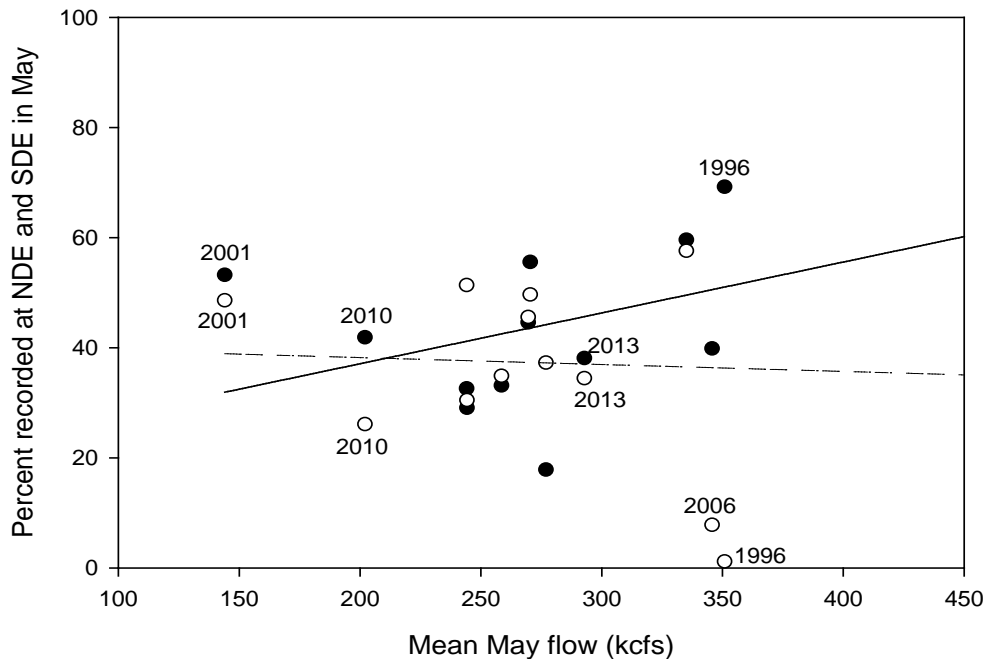

Figure 10. Linear relationship between mean May discharge at Bonneville Dam and the percentage of spring Chinook salmon recorded at NDE (solid circles; $r^2 = 0.21$) and SDE (open circles; $r^2 = 0.003$).

Metric 1: Entrance efficiency. The NDE entrance efficiency estimate for radio-tagged adult spring Chinook salmon in 2013 (0.26) was less than the mean across pre-modification years (0.42) but similar to, or higher than entrance efficiencies from 1998, 2000, and 2007. Entrance efficiency at SDE in 2013 for spring Chinook salmon (0.22) was also less than the mean across pre-modification years (0.30). In contrast, the spring jack Chinook NDE efficiency in 2013 (0.56) was higher than the adult mean from pre-modification years (Figure 11). Adult and jack summer Chinook NDE entrance efficiencies (0.70 and 0.70; Figure 11) were higher than the means from pre-modification years (0.44) at NDE, as was the 2013 NDE efficiency for sockeye salmon in 2013 (0.83). Efficiencies at SDE for adult (0.25) and jack (0.37) summer Chinook and sockeye (0.41) salmon were at or below the mean (0.39) adult value across pre-modification years.
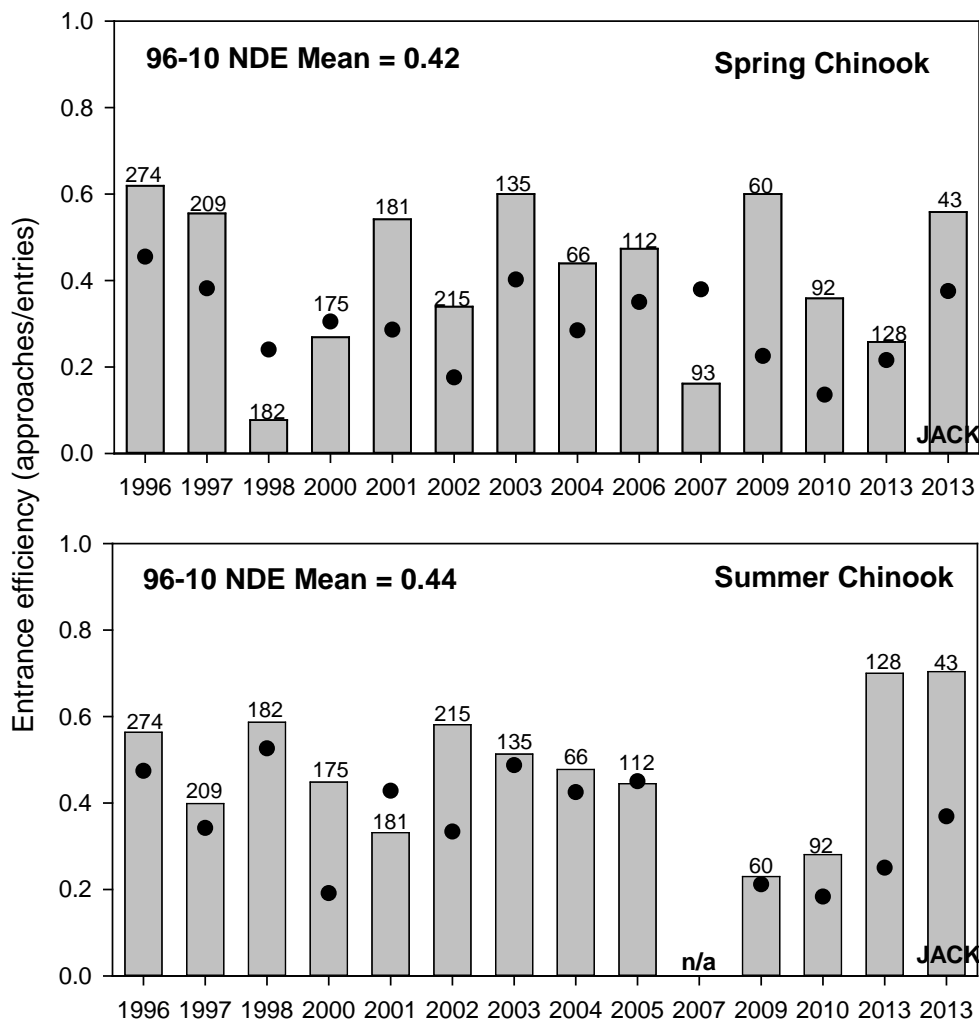
Figure 11. NDE (gray bars) and SDE (solid circles) efficiency (unique entrances/unique approaches) for radio-tagged spring Chinook salmon (top panel) and summer Chinook salmon

(bottom panel). Note last bar on graph denotes jack Chinook. Samples sizes above each bar are for NDE efficiencies.

   Metric 2: Exit ratio. Exit ratios varied considerably among years and Chinook salmon runs. Adult and jack spring Chinook exit ratios in 2013 (0.03-0.11) were low compared to pre-modification years (*mean*= 0.29) and compared to the 2013 summer Chinook value (0.39) (Figure 12). Adult and jack summer Chinook exit ratios in 2013 (0.39 and 0.45, respectively) were also less than the mean from pre-modification years (0.49). The 2013 sockeye salmon exit ratio (0.37) was similar to the 2013 exit ratio for adult summer Chinook (0.39).
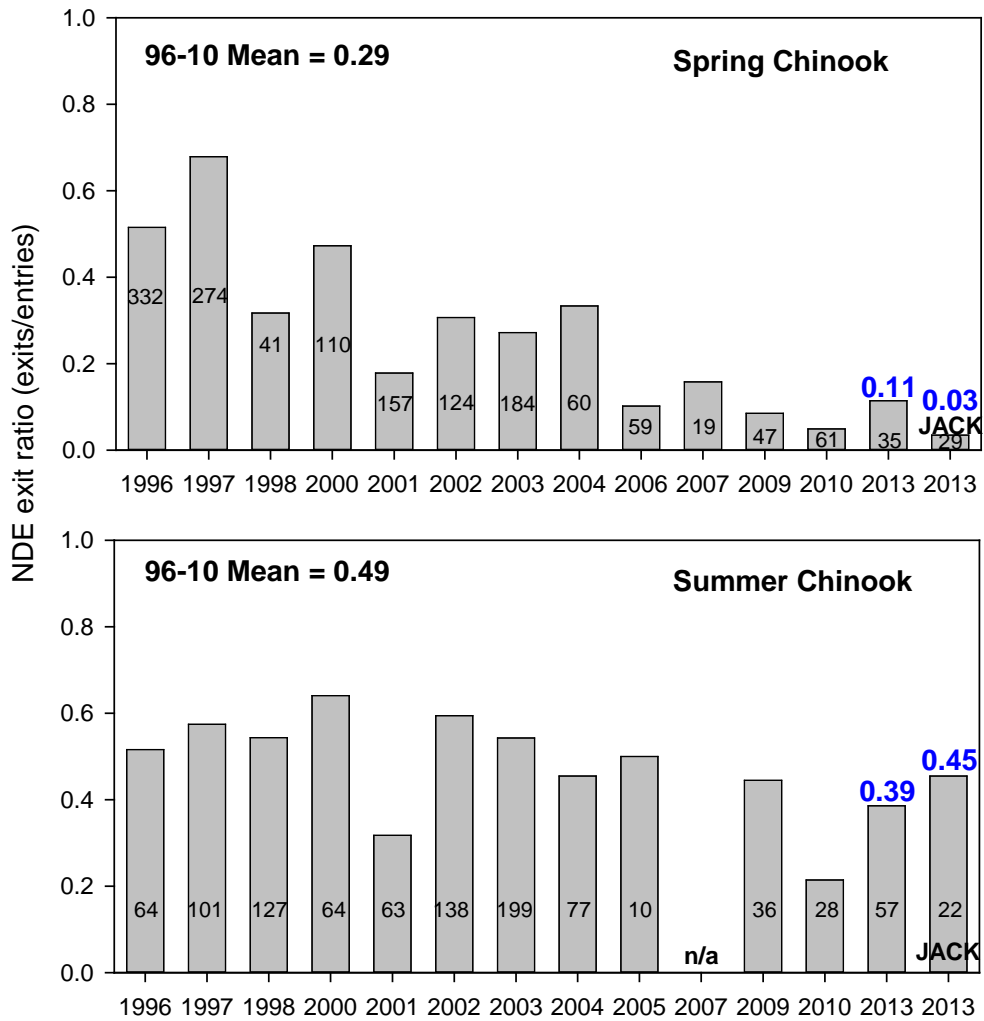
Figure 12. NDE exit ratios (unique salmon that exited /unique salmon that entered) for radio-tagged spring Chinook salmon (top panel) and summer Chinook salmon (bottom panel). Note last bar on graph denotes jack Chinook and years on x-axes are different. Sample sizes (number of entries) are listed inside each bar.

Metric 3: Entrance time. Generally, radio-tagged fish moved rapidly into the NDE in most years, 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 in 2013, approach-entrance times ranged from a couple minutes to 27 h with a median of 2 h (Figure 13). In comparison, the median passage times for post-modification years ranged from 1 min in 2010 to 9.6 h in 2009. ANOVA results for log-transformed passage times indicated significant amoung-year differences for adult spring Chinook salmon ($df = 12$, F = 3.47, $P < 0.001$). Pairwise comparisons using the Tukey test indicated differences in means occurred only among pre-modification years and the 2013 mean was not significantly different from the means in the 12 other years. The spring jack Chinook salmon median in 2013 was less than 1 min with all passage times less than 10 min except for one (6 h).

Figure 13. Spring Chinook salmon passage time distributions (plotted on log scale) from approach to entry at the NDE. Values inside boxes are median times. Distributions show 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles; sample sizes are shown at bottom. Note last bar on graph denotes spring jack Chinook.

Summer Chinook salmon passage times overall were faster than adult spring Chinook salmon at NDE in 2013 (Figure 14) and the 2013 point estimates were the shortest in the time series. The median time for summer Chinook salmon was 6 min (ranged from < 1 min to 35 hrs). ANOVA results for log-transformed passage times indicated significant amoung-year differences for adult summer Chinook salmon ($df = 11$, F = 4.47, $P < 0.001$). Tukey's pairwsie comparisons indicated no significant differences in mean passage times between 2013 and the

15

previous 11 years. Jack summer Chinook salmon entry times in 2013 were generally faster than the adults (*median* = 1 min). Sockeye salmon passage (*median* = 0.5 min) was similar to spring and summer jack Chinook salmon.

Figure 14. Summer Chinook salmon passage time distributions (plotted on log scale) from approach to entry at the NDE. Values inside boxes are median times. Distributions show 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles; sample sizes are shown at bottom. Note last bar on graph denotes summer jack Chinook.
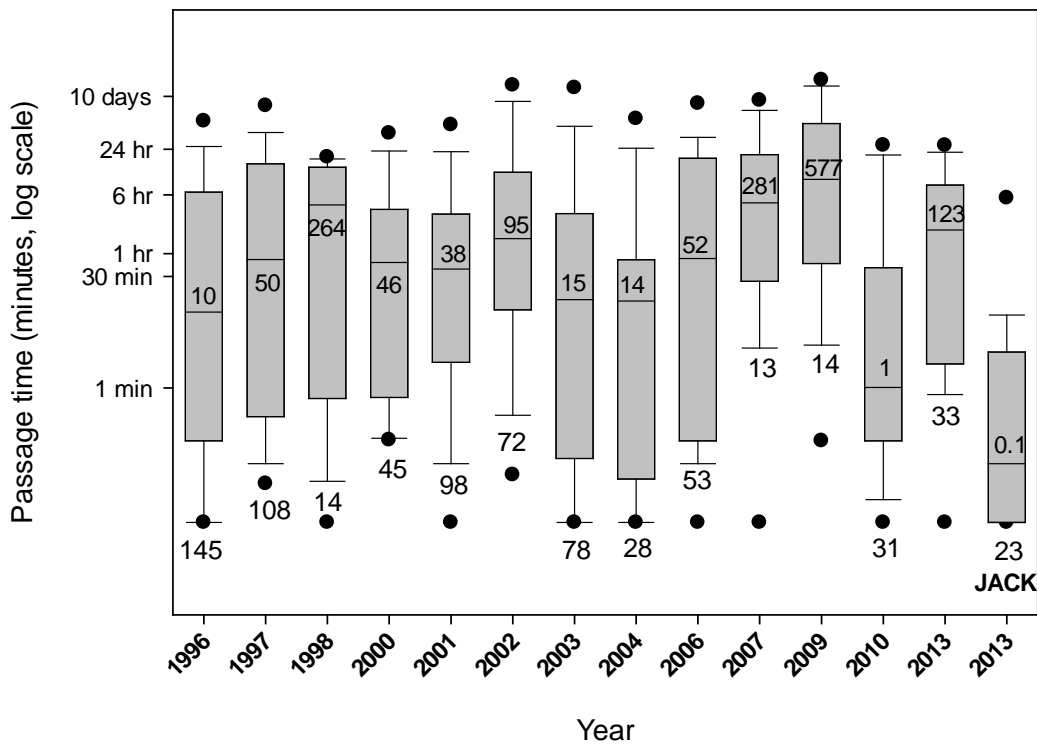
Figure 15. Spring Chinook salmon passage time distributions (plotted on log scale) from approach to entry at the SDE. Values inside boxes are median times. Distributions show 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles; sample sizes are shown at bottom. Note last bar on graph denotes spring jack Chinook.

In comparison, passage times at SDE, a useful comparison site, were generally faster than those at NDE for spring and summer Chinook salmon (Figures 15 and 16). Median SDE approach-entry times for spring Chinook salmon ranged from 8 min (2003) to 3.6 hrs (1997). The median in 2013 was 6 and 7 minutes for jack and adult spring Chinook, respectively. ANOVA results for log-transformed spring Chinook passage times indicated significant among-year differences ($df = 12$, F = 4.96, P < 0.001). Tukeys pairwise comparisons indicated mean entry times (log tranformed) in 2013 were significanly faster than in 2002 and 2006 (Figure 15). ANOVA results for log-transformed summer Chinook salmon passage times were also significant ($df = 12$, F = 3.9, $P < 0.001$). Yearly pairwise comparison of the log-tranformed means (Tukey test) were significantly faster in 2013 compared to in 2009, 2004, 2002, and 2001 (Figure 16).
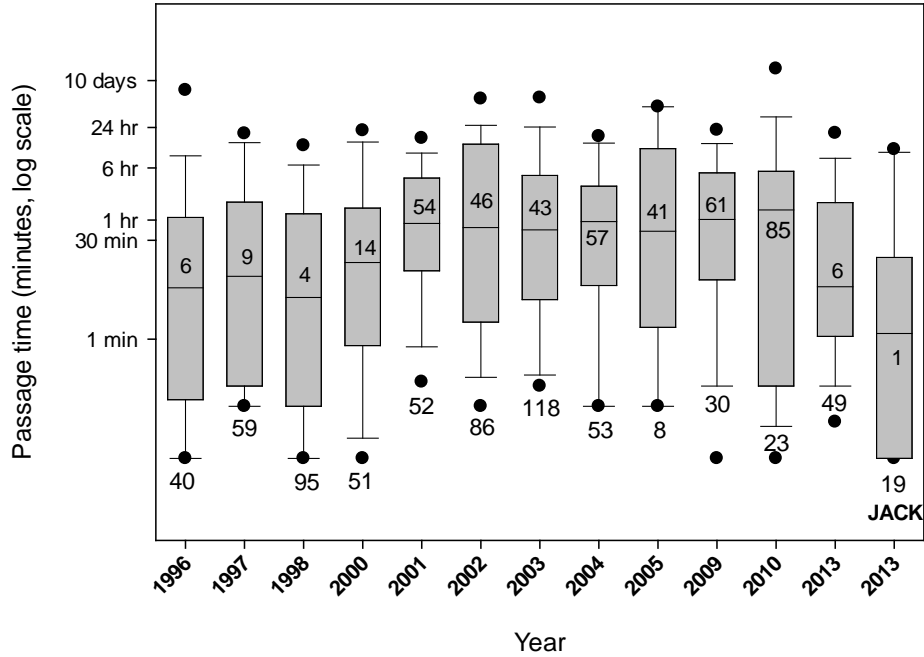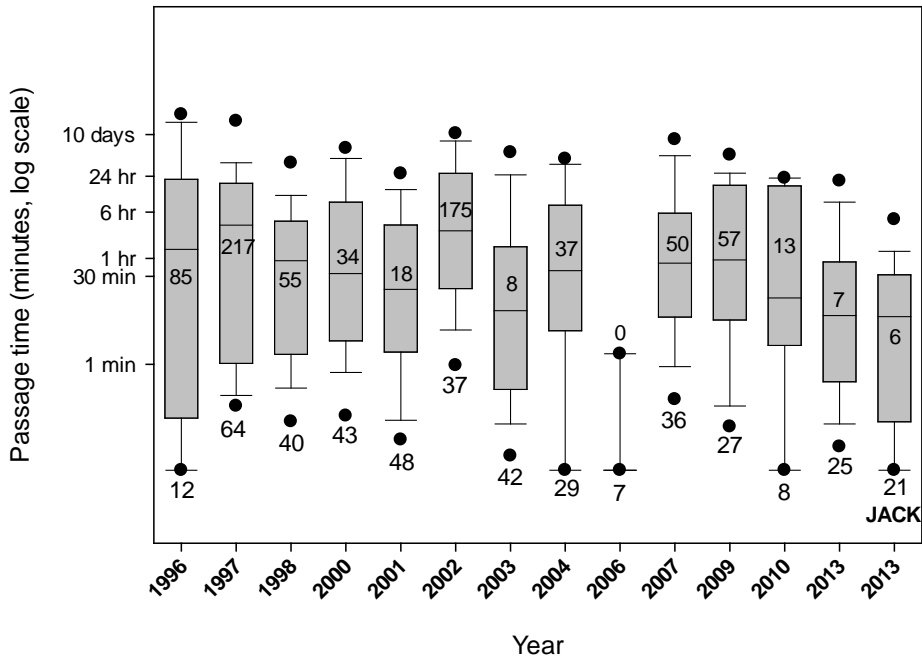
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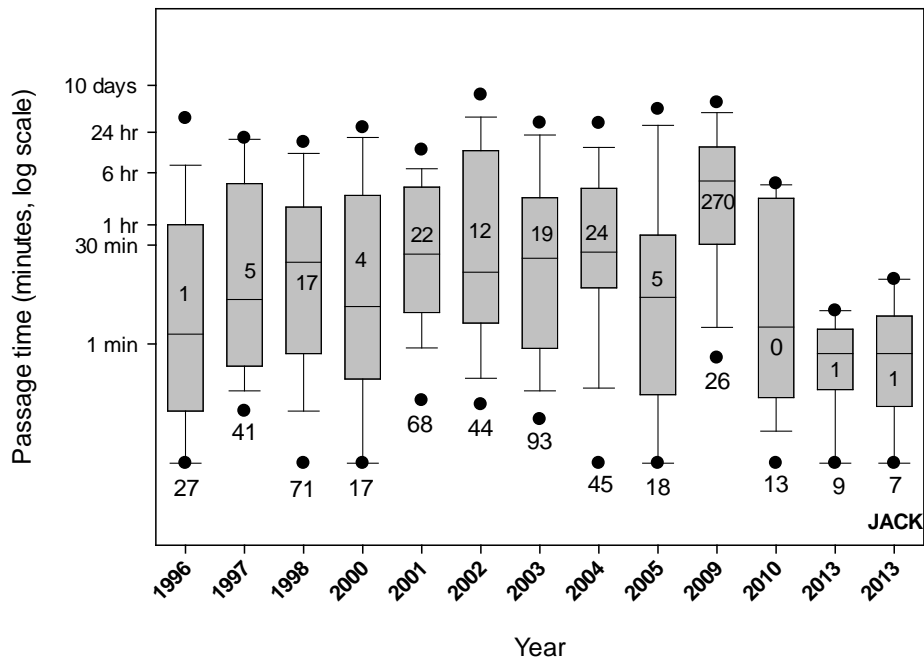
Figure 16. Summer Chinook salmon passage time distributions (plotted on log scale) from approach to entry at the SDE. Values inside boxes are median times. Distributions show 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles; sample sizes are shown at bottom. Note last bar on graph denotes summer jack Chinook.

For tagged spring Chinook salmon, the median NDE approach-to-entry time in 2009 was unexpectedly long compared to past approach-to-entry times at NDE and SDE (Figure 17). In contrast, the relationship between NDE and SDE entry times for spring and summer Chinook was relatively constant in the 2000-2006 data. Both 1996 and 2009 were spring Chinook outliers, with the small 1996 sample ($n = 11$) having relatively long SDE approach-to-entry times and the 2009 sample having long NDE approach-to-entry times. Median approach to entry times in 2013 were faster for summer Chinook than spring Chinook salmon and both were similar to previous years.
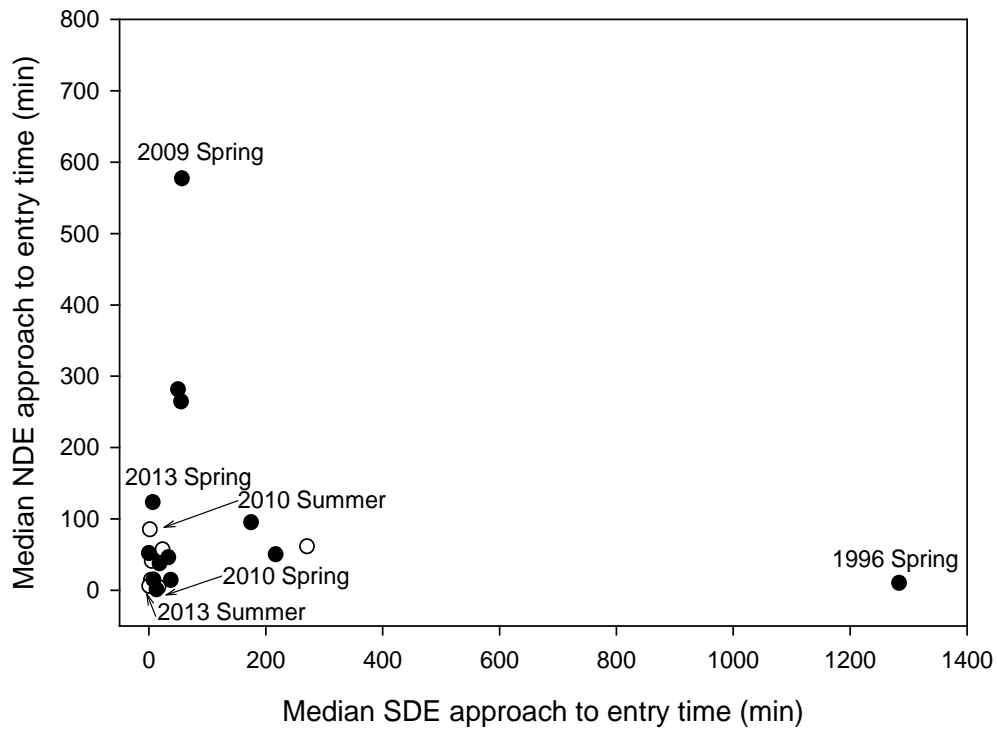
Figure 17. Scatterplot of annual median first approach to first entry times (min) at the NDE and SDE entrances for radio-tagged spring (solid circles) and summer (open circles) Chinook salmon.

Compared to pre-modification years, there tended to be stronger correlations between spring Chinook salmon NDE approach-to-entry times and environmental variables within each year (Table 1). Spill levels in 2010 when tagged spring Chinook salmon approached PH2 NDE fluctuated around 100 kcfs which was near average compared to previous years (Figure 18). May flows and water temperatures were generally higher in 2013 than in previous years and tailwater elevations were slightly lower when tagged salmon first approached the PH2 NDE (Figure 18). Higher flows and temperature and lower tailwater elevations in 2013 may explain some of the variability in 2013 approach-to-entry times and have been associated with longer passage times in the past. Negative correlations indicated longer approach-to-entry times when temperature, flow, spill, and tailwater elevations were lower in 2013.

19

Table 1. Correlation coefficients (*r*) between environmental conditions spring Chinook salmon encountered when they first approached the Powerhouse 2 north downstream opening and log-transformed approach-to-entry times, by year. Bold font indicates *P* < 0.05.

Year	Flow	Spill	Temp	Tailwater elev.	Date
1996	-0.01	0.07	**0.20**	-0.03	**0.17**
1997	-0.08	-0.04	-0.05	-0.05	-0.07
1998	-0.25	-0.17	-0.53	-0.22	-0.01
2000	0.08	0.18	-0.10	0.05	-0.11
2001	0.02	0.03	-0.04	0.03	-0.01
2002	0.09	0.24	0.01	0.09	0.03
2003	**0.28**	**0.33**	**0.40**	**0.28**	**0.36**
2004	0.17	0.34	0.41	0.24	0.28
2006	**0.32**	**0.34**	-0.23	**0.33**	**0.29**
2007	-0.19	-0.08	0.14	-0.17	0.21
2009	-0.21	-0.14	-0.37	-0.19	-0.33
2010	0.23	-0.01	**0.51**	0.25	**0.51**
2013	**-0.58**	**-0.77**	**-0.35**	**-0.57**	**0.69**

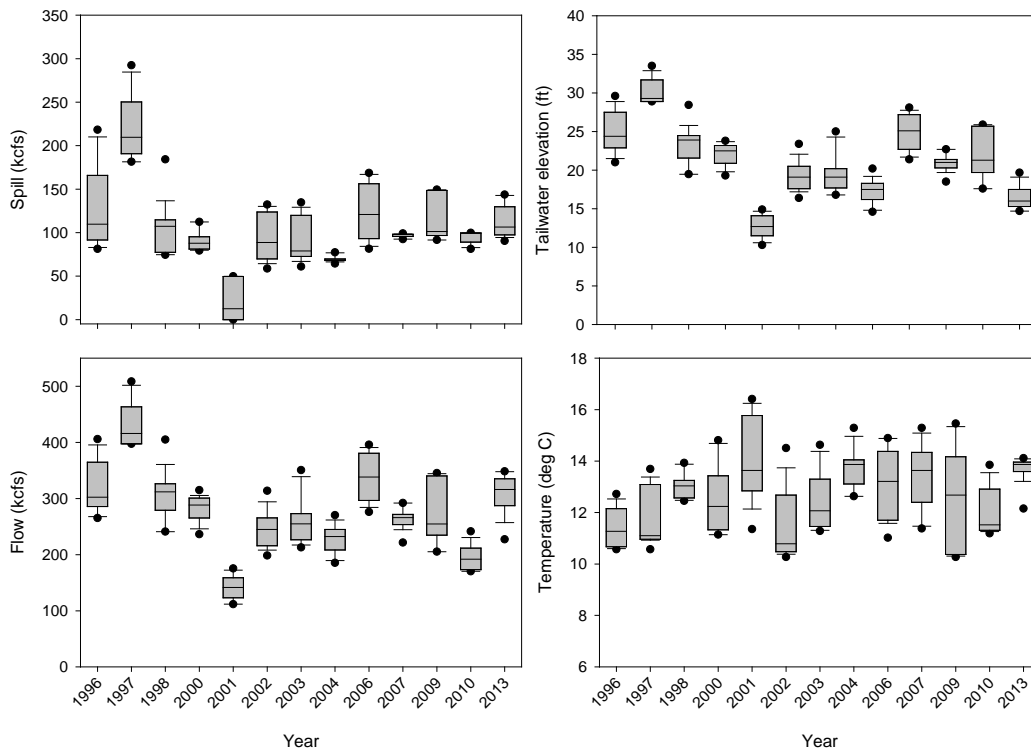Figure 18. Box plots of the total discharge ('flow'), spill, tailwater elevation, and temperature on the days that radio-tagged adult spring Chinook salmon first approached the NDE. Distributions show 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles.

In contrast, adult summer Chinook correlation coefficients suggest the degree of association between environmental factors and passage times within years was diminished (Table 2). Water temperature and date fish first approached PH2 NDE were the only significant factors associated with approach-to-entry times. As with spring Chinook, negative correlations indicated longer approach-to-entry times associated with lower water temperatures. These results are consistent with those from previous years where few environmental variables have shown a strong linear relationship with summer Chinook approach-to-entry passage times. In 2013, median approach-to-entry times for summer Chinook were near average for flow, spill, water temperature and tailwater elevation compared to pre-modification years (Figure 19).

Table 2. Correlation coefficients (*r*) between environmental conditions summer Chinook salmon encountered when they first approached the Powerhouse 2 north downstream opening and log-transformed approach-to-entry times, by year. Bold font indicates *P* < 0.05.

Year	Flow	Spill	Temp	Tailwater elev.	Date
1996	-0.12	-0.08	0.21	-0.16	0.18
1997	0.18	0.21	-0.22	0.20	-0.23
1998	-0.09	-0.10	0.01	-0.08	0.02
2000	0.06	0.15	-0.24	0.23	-0.16
2001	0.03	0.09	-0.05	0.03	-0.07
2002	-0.01	0.18	-0.17	-0.01	-0.17
2003	0.03	0.02	0.02	0.03	-0.02
2004	0.18	0.22	-0.18	0.18	-0.19
2005	-0.63	**0.81**	-0.31	**-0.75**	-0.32
2009	0.24	0.19	-0.31	0.24	**-0.39**
2010	-0.27	-0.40	-0.27	-0.16	-0.33
2013	0.22	-0.03	**-0.44**	-0.18	**-0.49**

Metric 4: Entrance to base of ladder time. After tagged adult spring Chinook salmon entered NDE, the median time to reach the ladder base ranged from 5–37 minutes in previous years (Figure 20). Median times for adult and jack spring Chinook in 2013 were at the lower end of that range with median times of 7 and 6 minutes, respectively. ANOVA tests identified significant differences in log-transformed lower fishway passage times between years (*df* = 12; F = 13.5; *P* < 0.001) with 2013 passage times being faster than 1996-97 lower ladder passage times. The point estimate of summer Chinook adult median time to reach the base of the ladder after entry was faster in 2013 (*median* = 4 min; Figure 21) than in previous years (*median* range 7-20 min), though the 2013 median was only significantly faster than in 1996 (ANOVA; *df* = 11; F = 2.43; *P* = 0.004). Summer jack Chinook and sockeye salmon took longer with a median time of 16 min and 11 min, respectively.
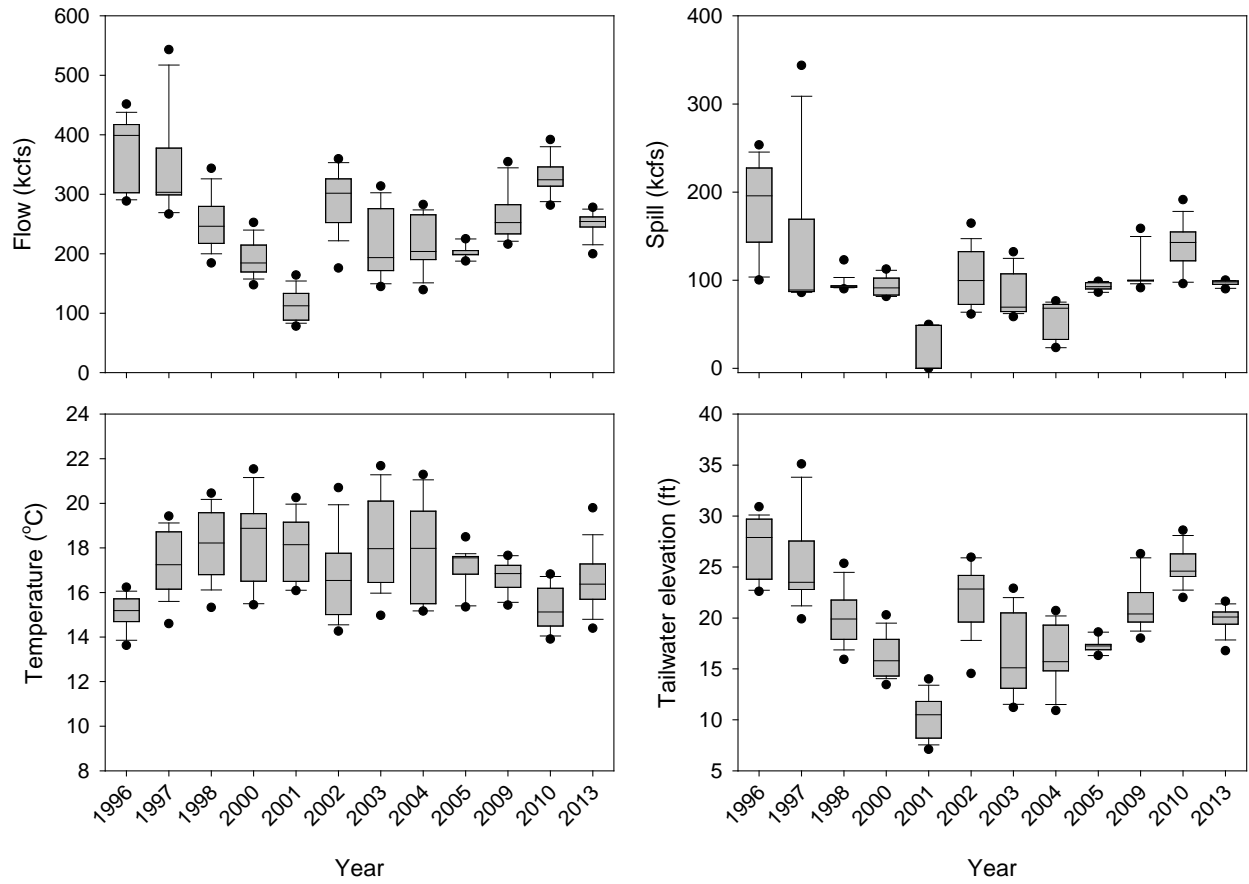
Figure 19. Box plots of the total discharge ('flow'), spill, water temperature, and tailwater elevation on the days that adult summer Chinook salmon first approached the NDE. Distributions show 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles.
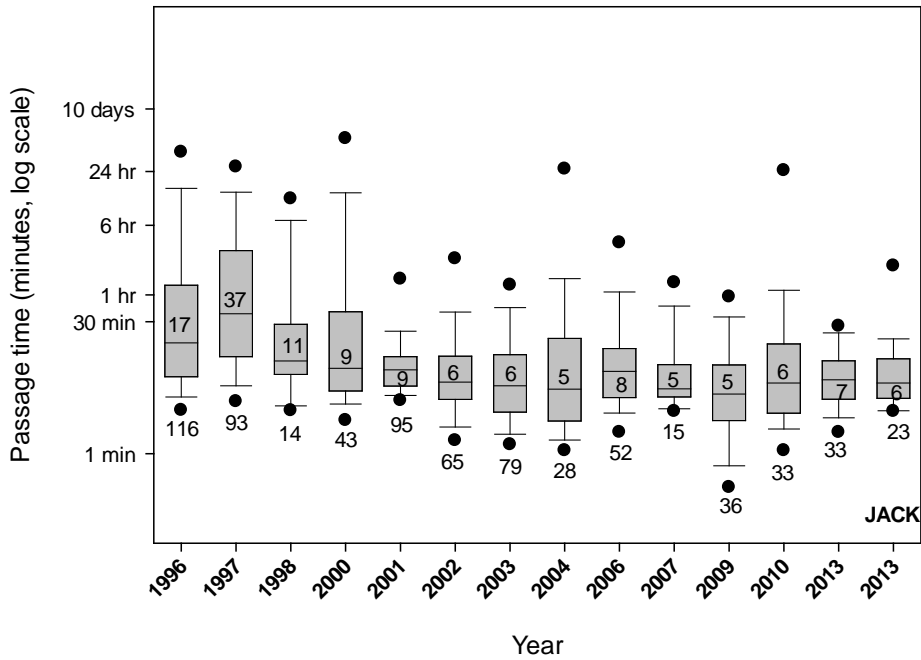
Figure 20. Spring Chinook salmon passage time distributions (plotted on log-scale) from NDE to the antenna at the base of the ladder. Numbers inside boxes are median times. Distributions show 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles; sample sizes are listed below boxes. Note last bar on graph denotes spring jack Chinook.
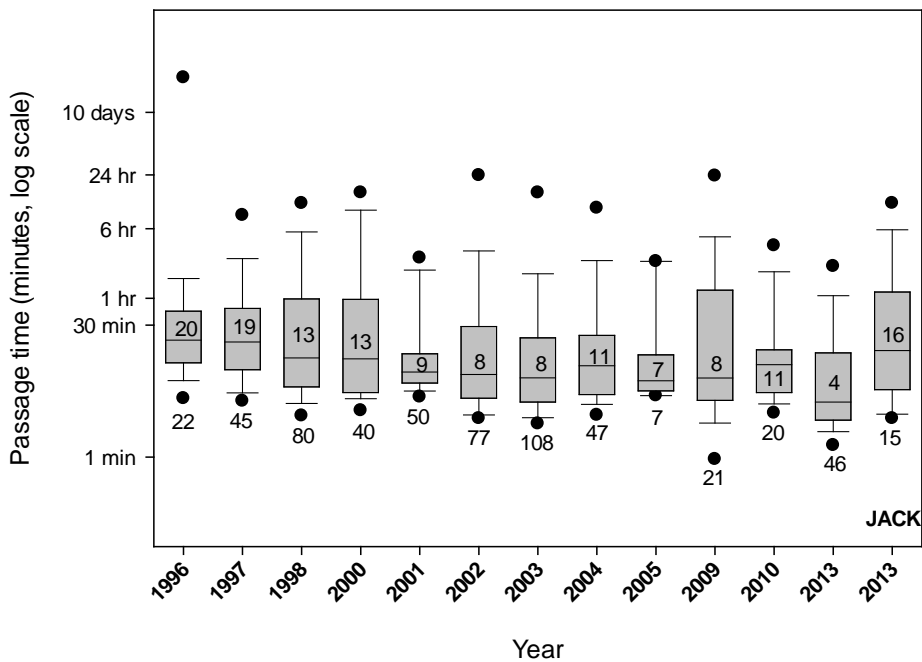
Figure 21. Summer Chinook salmon passage time distributions (plotted on log-scale) from NDE to the antenna at the base of the ladder. Numbers inside boxes are median times.

23

Distributions show 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles; sample sizes are listed below boxes. Note last bar on graph denotes summer jack Chinook.

Metric 5: Extended passage times. In previous years, the percentage of tagged spring Chinook salmon with long passage times (> 1 h) for NDE approach to NDE entrance and from NDE entrance to the first ladder antenna ranged from 21–71% (*mean* = 46%) and from 3–37% (*mean* = 13%), respectively (Figure 22). The 2013 percentage for adult spring Chinook salmon with > 1 hr approach-to-entry was 55% and was 4% for jacks. After entering at NDE all of the adult tagged spring Chinook reached the antenna at the base of the ladder in less than 1 hr while 4% of the jacks that entered took > 1 hr to reach the lower ladder.
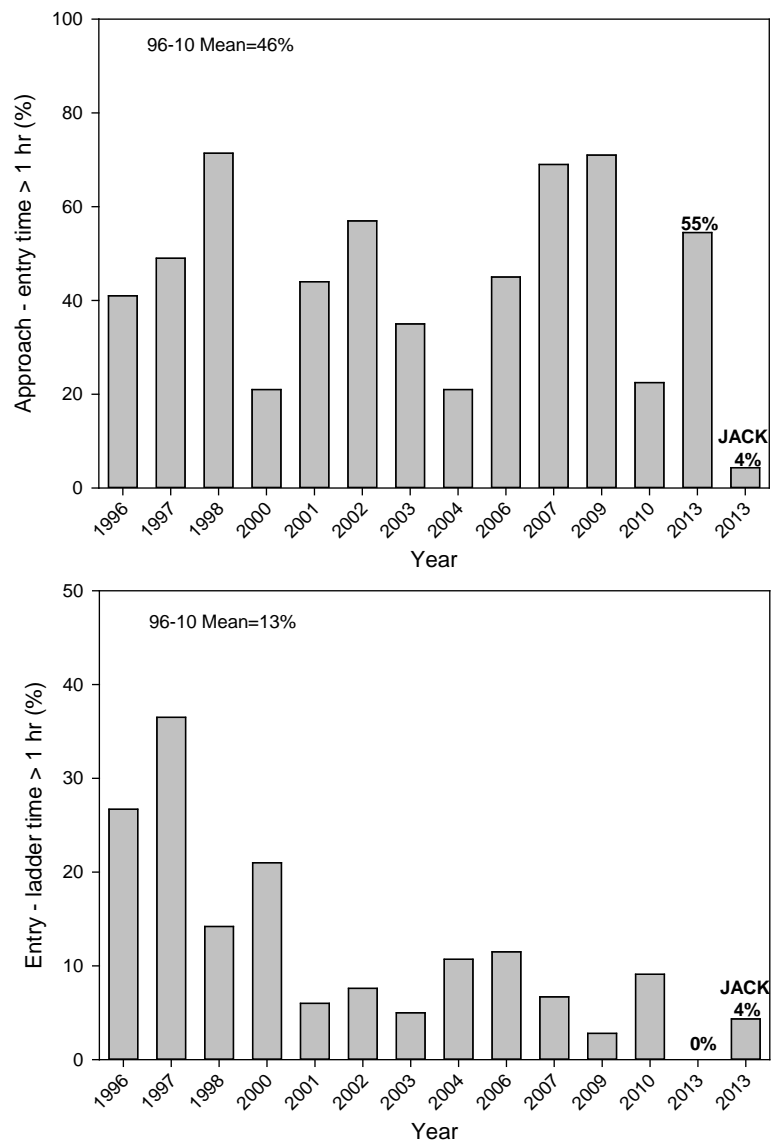
Figure 22. Percentages of radio-tagged spring Chinook salmon that took > 1 h to enter the north downstream fishway entrance (top panel) and the time to pass from the fishway opening to the base of the ladder (bottom panel). Note last bar on graph denotes spring jack Chinook.

24
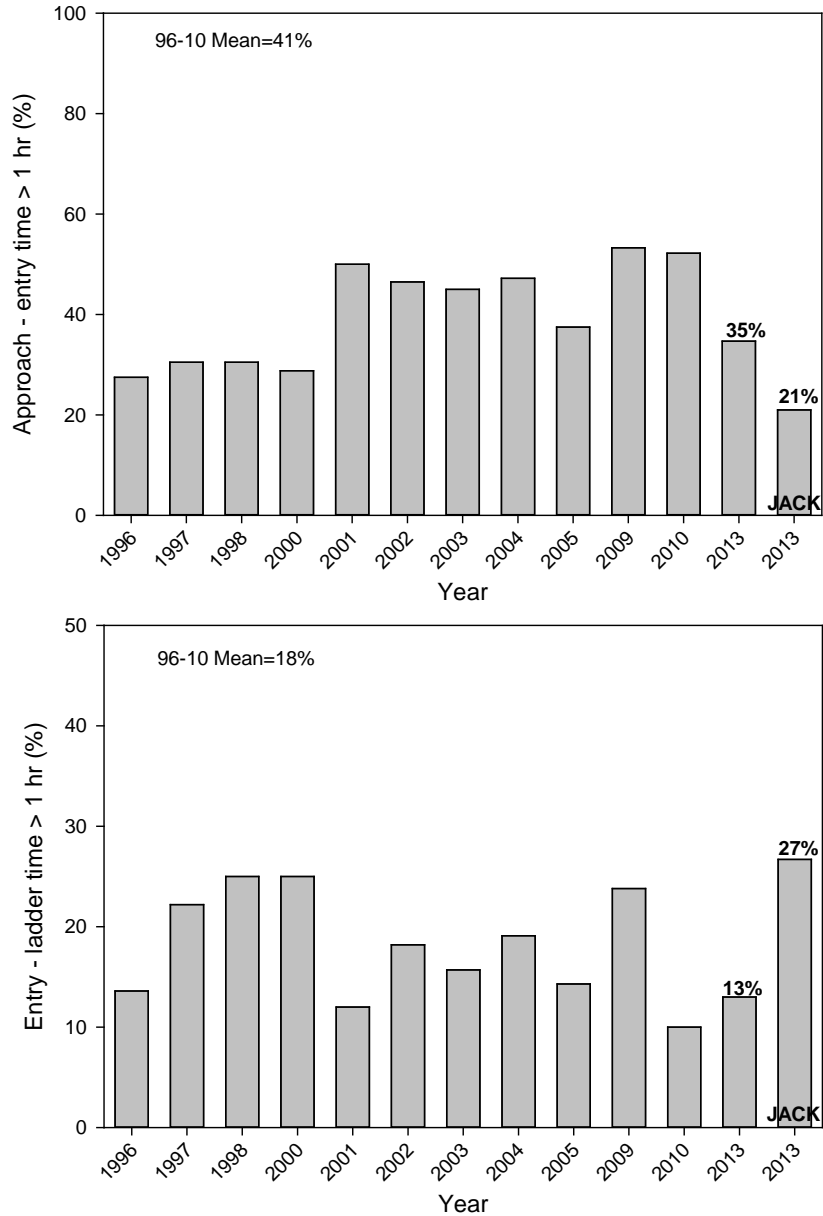
Figure 23. Percentages of radio-tagged summer Chinook salmon that took > 1 h to pass from the north downstream approach to fishway entrance and from opening to the base of the ladder. Note last bar on graph denotes summer jack Chinook.

In 2013, the percentage of tagged adult summer Chinook salmon with long approach-to-enter passage times (> 1 h) at NDE was 35% and the percentage of fish entering NDE taking longer that 1 hr to reach the first ladder antenna was 13% (Figure 23). The percentages for summer jack Chinook with longer approach-to-entry and base of ladder passage times was 21% and 27%, respectivley. Adult summer Chinook salmon percentages were both below the mean percentages of prior years (41% and 18%). Sockeye salmon with longer passage times through these segments were similar to adult summer Chinook at 18% and 10%, respectively.

25

Metric 6: PH2 entry locations of successful dam passages. In 2103, 27% of adult Chinook salmon that had LP records and used one of the four main PH2 fishway openings had entered via NDE and the other 73% entered at NUE, SDE or SUE (Figure 24). In previous years, this NDE metric ranged from 22-68% (*mean = 43%*). In 2013, 42% of jack spring Chinook entered NDE The adult Chinook results were at the low end of the range while the jack Chinook results were similar to the adult mean value.
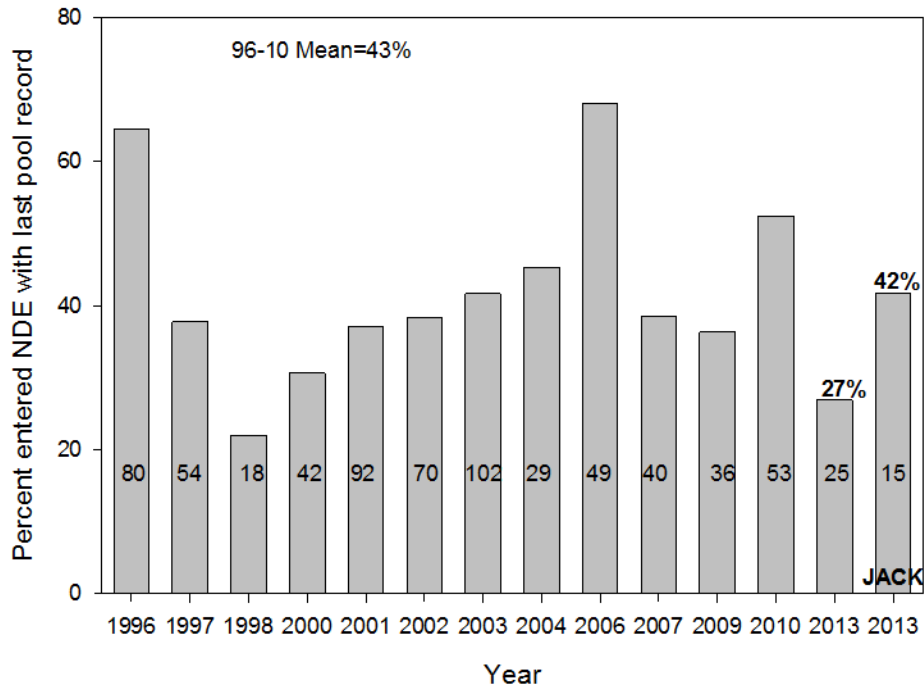
Figure 24. Percent of radio-tagged spring Chinook salmon that reached the upstream portion of the transition pool area (last pool) after entering NDE. Note last bar on graph denotes spring jack Chinook.

In comparison to spring Chinook, more summer Chinook adult (56%) and jack summer Chinook (53%) had an LP record after entering NDE versus other main PH2 fishway openings (Figure 25). These estimates were also higher than the pre-modification mean for adult summer Chinook of 35%. The percentage of sockeye salmon reaching the transition pool after entering NDE (39%) was similar to the pre-modification mean for adult summer Chinook.

80

96-10 Mean=35%

60

56%   53%

Percent entered NDE with last pool record

40

20

16 18 42 15 33 34 42 25   3   13 14 20   9

JACK

0

1996 1997 1998 2000 2001 2002 2003 2004 2005 2009 2010 2013 2013

Year
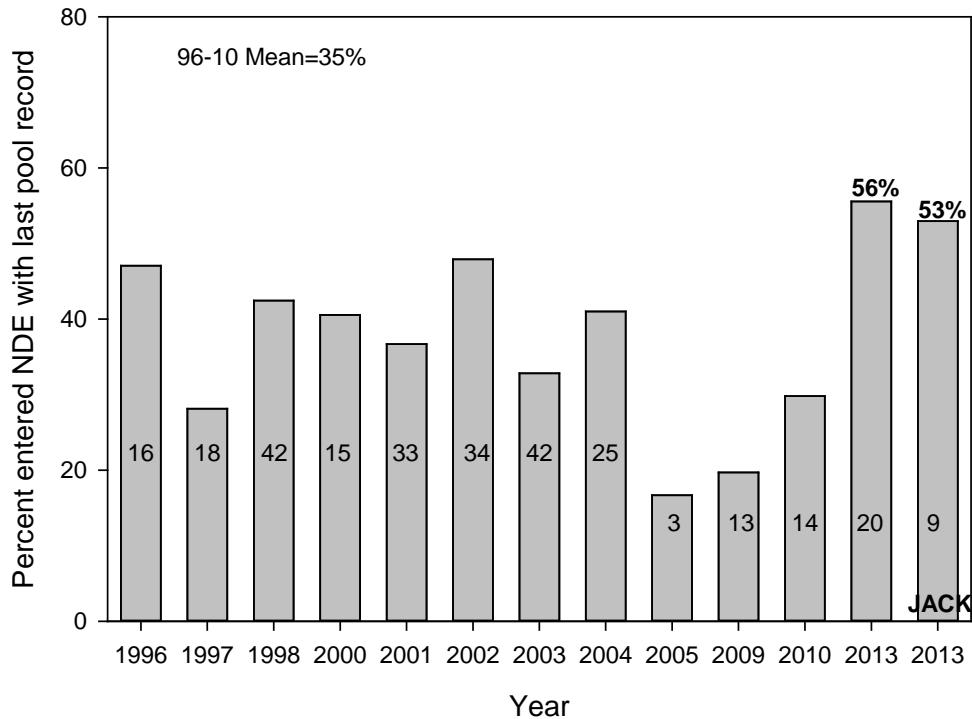
Figure 25. Percent of radio-tagged summer Chinook salmon that reached the upstream portion of the transition pool area (last pool) after entering NDE. Note last bar on graph denotes summer jack Chinook.

Metric 7: Ratio of PH2 NDE and PH2 SDE approaches and entries. The ratio of spring Chinook salmon that entered and approached NDE and SDE (NDE/SDE) was fairly constant among pre-modification years (NDE/SDE approach ratio ranged from 0.42-1.78; NDE/SDE entry ratio ranged from 0.32-4.50) except in 1996 and 2006 where the number of fish approaching and entering NDE was much higher than SDE (Figure 26). The NDE/SDE approach ratio in 2013 for adult Chinook was 1.38 and the NDE/SDE entry ratio was 1.32. The NDE/SDE approach and entry ratios for jack spring Chinook salmon were 0.51 and 0.96, respectively. These results reported for spring Chinook salmon were well within the range of prior years. In contrast, the 2013 adult summer Chinook salmon ratios (NDE/SDE approach ratio = 4.35; NDE/SDE entry ratio = 5.09) were considerably higher than in prior years (range of NDE/SDE approaches 0.75-1.5) and NDE/SDE entries 0.48-2.4). Summer jack Chinook were closer to prior year approach (1.46) and entry (2.22) ratios for adults and sockeye salmon ratios were similar to summer Chinook in 2013 (approach=1.83; entry=3.31).
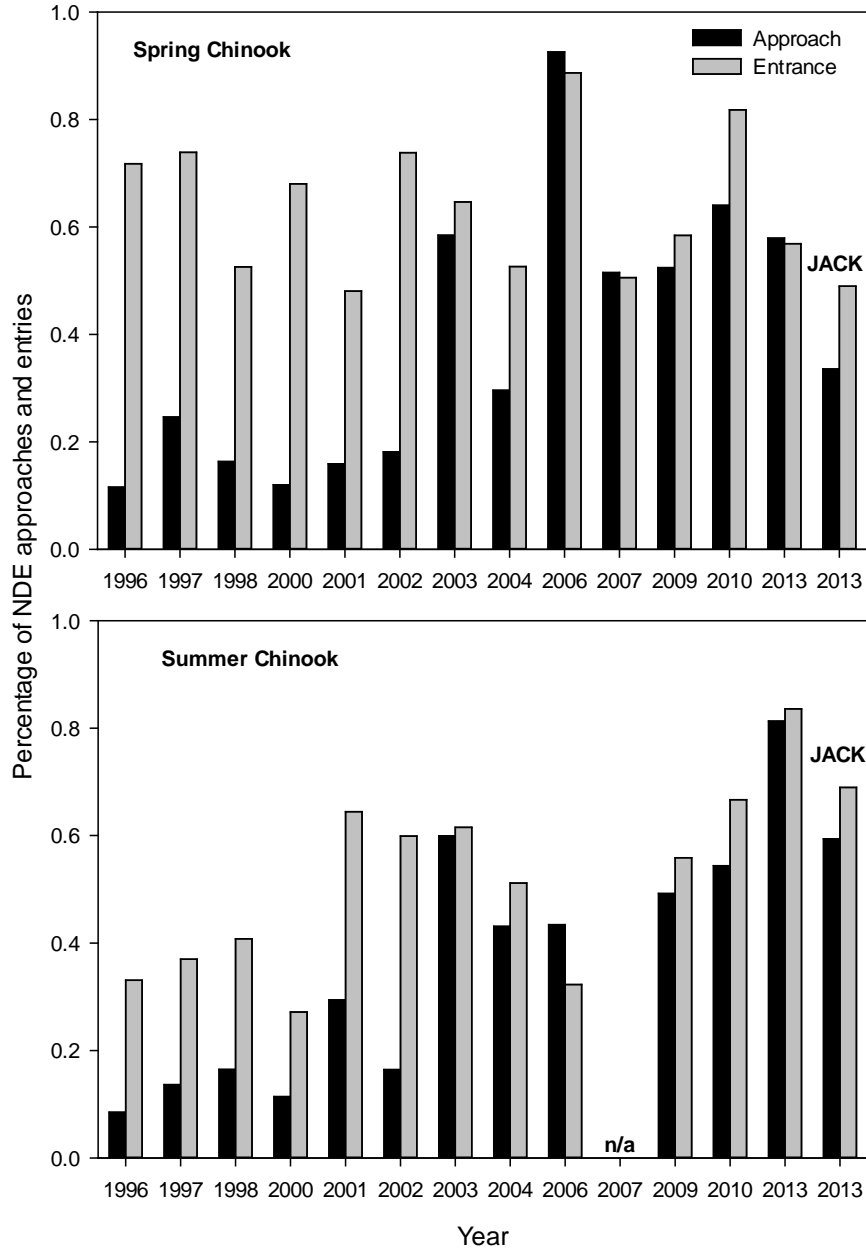
Figure 26. Percentage of NDE approaches and entries of radio-tagged spring (top panel) and summer (bottom panel) Chinook salmon in 2013. Percent = NDE/(NDE+SDE).

Cascades Island Results

Of the adult spring Chinook salmon tagged through 31 May 2013, 70 (21%) were recorded approaching and 14% were recorded entering the CI fishway opening (Figure 27). 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 28), though the relationship was driven by two extreme years. The 2009-13 rates were in line with rates post-modification given river conditions.
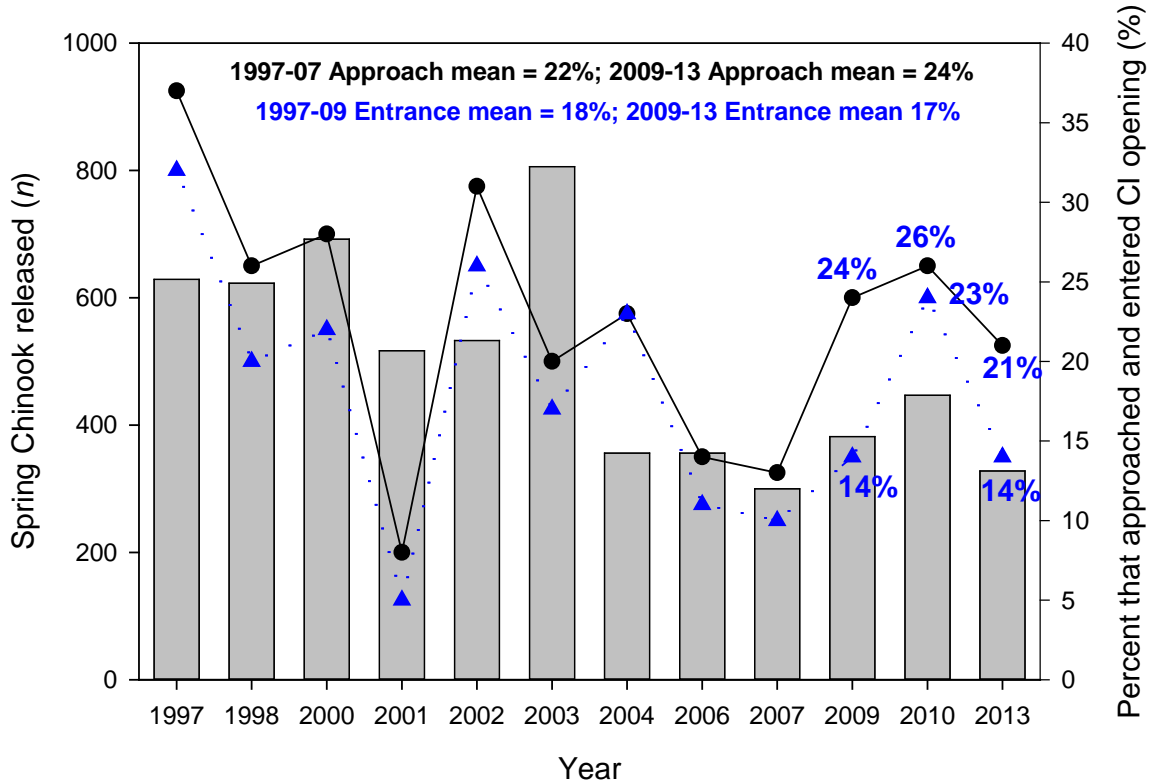
Figure 27. Number of adult spring Chinook salmon radio-tagged (bars) and the percentages that were recorded approaching (circles and solid line) and entering (triangles and dashed line) the Cascades Island fishway.

Of the 272 summer Chinook salmon tagged in 2013, 87 (32%) were recorded approaching and 41 (15%) were recorded entering the CI fishway opening. Approach percentages in 2013 were similar to 2002-2004 (pre-modification), when 30-32% approached the CI fishway. The percentage of tagged summer Chinook salmon entering the CI fishway was lower in 2013 (15%) compared to pre-modification years (range 22-28%), but were similar to the number of tagged fish entering the CI fishway opening in 2009 (14%) and in 2010 (18%).
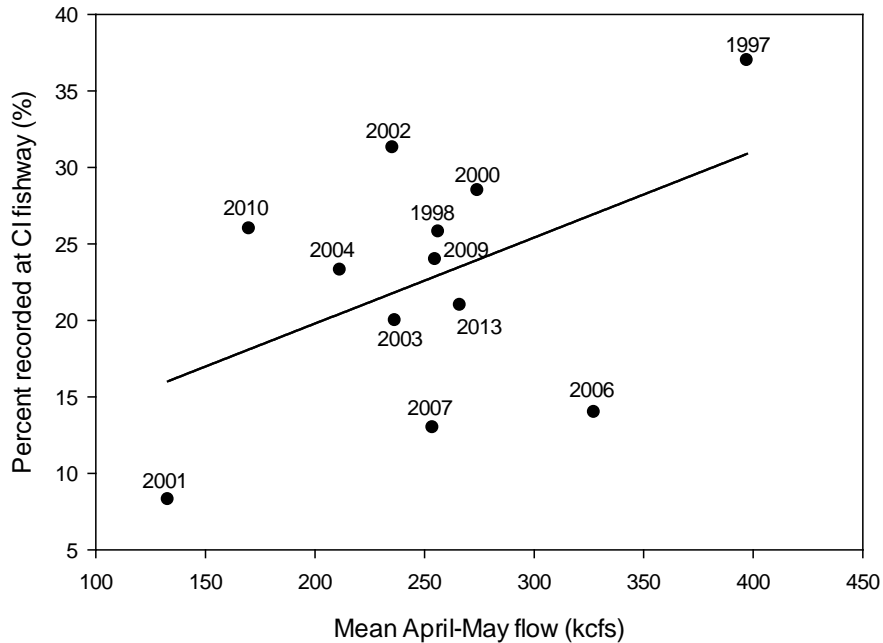
Figure 28. Linear relationship between mean April-May discharge at Bonneville Dam and the percentage of spring Chinook salmon recorded at the Cascades Island fishway ($r^2 = 0.22$).

Metric 1: Entrance efficiency. 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 29), with the lowest estimate in 2001 when river flow and spill were low and few fish used the CI fishway. The mean entrance efficiency post-modification was 0.72. 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) while the entrance efficiency in 2013 (0.67) was closer to the pre-modification mean (0.79). Entrance efficiency for jack spring Chinook salmon in 2013 was 0.74.

For radio-tagged summer Chinook salmon, the CI entrance efficiency estimates prior to entrance modifications ranged from 0.72–0.89 (*mean* = 0.83; Figure 30). The entrance efficiency post modification ranged from 0.47-0.71 (*mean* = 0.63). Entrance efficiency estimates in 2013 (0.47) were the lowest of the past 6 years, pre- or post-modification. Entrance efficiency for jack summer Chinook salmon in 2013 was 0.77.

Limited data exists to make comparisons for sockeye salmon entrance efficiency comparisons prior to CI entrance modifications. Entrance efficiencies at CI in 2013 for sockeye was 0.61, slightly lower than those of similar size jack spring and summer Chinook salmon.
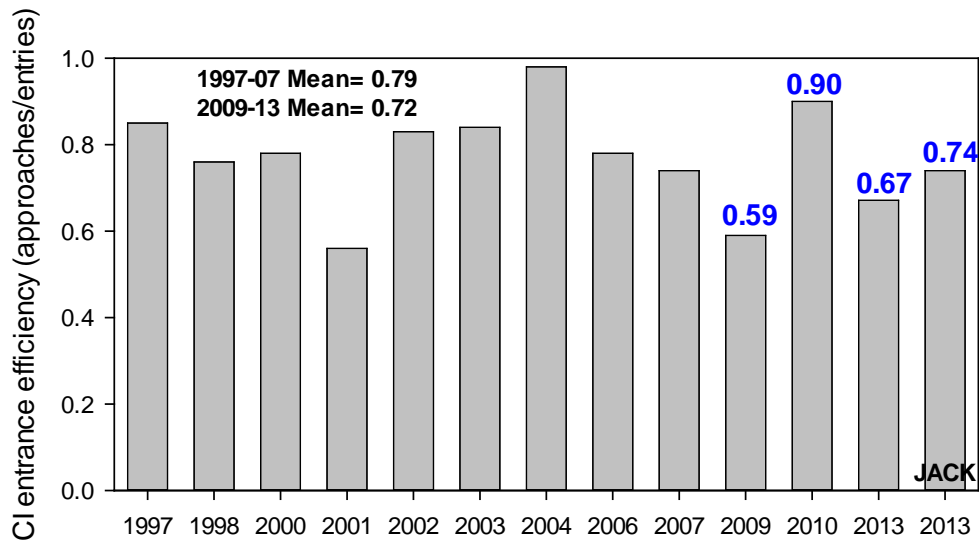
Figure 29. Cascades Island entrance efficiency (unique entrances/unique approaches) for radio-tagged spring Chinook salmon. Modifications occurred prior to the 2009 migration.
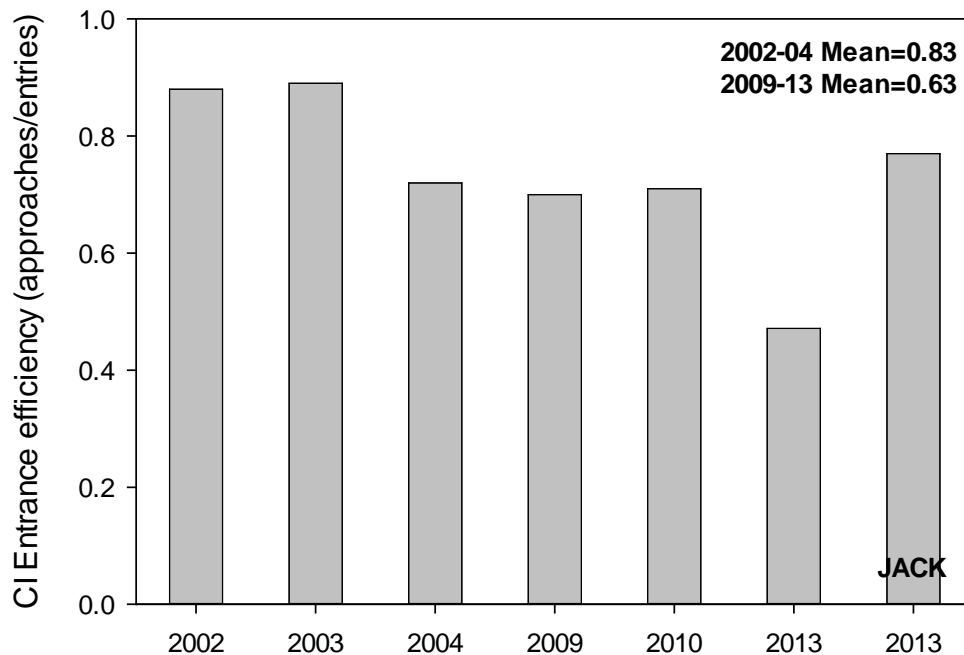
Figure 30. Cascades Island entrance efficiency (unique entrances/unique approaches) for radio-tagged summer Chinook salmon. Modifications occurred prior to the 2009 migration.

Metric 2: Exit Ratio. Exit ratios for radio-tagged spring Chinook salmon prior to modifications at the CI entrance were variable, ranging from 0.00–0.46 (*mean* = 0.24; Figure 31). Post-modification exit ratios were lower and less variable, ranging from 0.00-0.13 (*mean* = 0.06). Exit ratio estimates in 2013 (0.13) were slightly higher than the two previous year's estimates post- modification but were still at the low end of the range across all study years. Exit ratios for jack spring Chinook salmon were lower (0.06) than those recorded for adult spring Chinook salmon but consistent with the post-modification average.
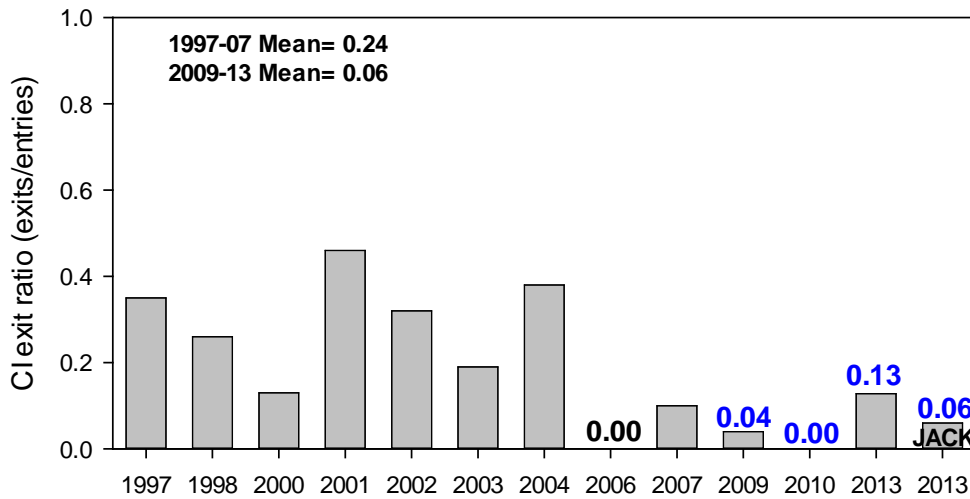
Figure 31. Cascades Island exit ratios (unique salmon that exited/unique salmon that entered) for radio-tagged spring Chinook salmon.

For tagged summer Chinook salmon, exit ratios were more variable and generally higher than those for adult spring Chinook salmon but followed the same general trend of fewer exits post modifications (Figure 32). Exit ratios prior to entrance modifications at CI ranged from 0.35–0.77 (*mean* = 0.62). Post-modification exit ratios ranged from 0.19-0.62 (*mean* = 0.36). Exit ratios in 2010 (0.26) and 2013 (0.19) were the lowest among the six study years. Jack summer Chinook exit ratios were slightly lower (0.13). Exit ratios for adult sockeye were higher (0.23) than those for either spring or summer Chinook salmon (including jacks) in 2013.
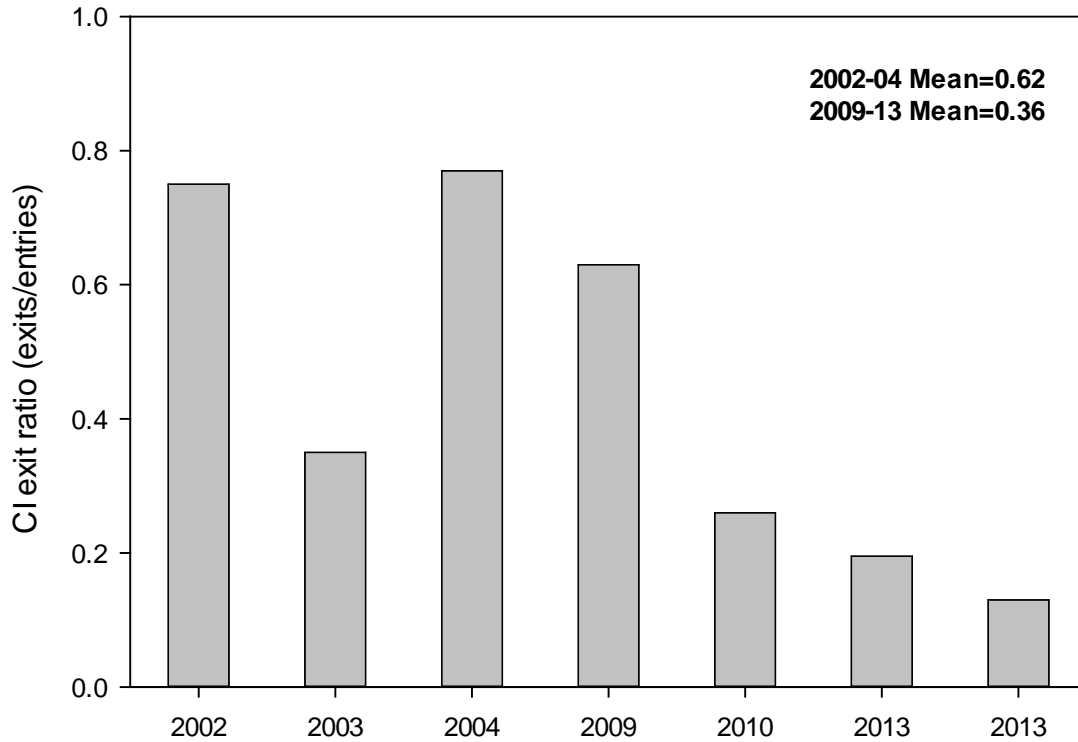
Figure 32. Cascades Island exit ratios (unique salmon that exited/unique salmon that entered) for radio-tagged summer Chinook salmon.

Metric 3: Entrance time. 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 for samples that included or excluded adults tagged in April (Figure 33). 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 adult spring Chinook salmon, annual median approach-entrance times ranged from a couple minutes to 46 minutes in years prior to fishway entrance modifications, with tagged salmon in the small 2007 sample ($n = 20$) having the longest median passage time (46 min). Post-modification, the median was 59 minutes in 2009, 42 minutes in 2010, and 21 minutes in 2013. The 2013 median passage time for jack spring Chinook salmon was 12 minutes. ANOVA results for log-transformed passage times indicated significant among-year differences in annual means ($df = 11$, F = 18.1, $P < 0.0001$). In pairwise comparisons, the 2009 mean was significantly higher than means in 5 of the 9 pre-modification years (1997, 1998, 2000, 2004, and 2006) using the Tukey Test (Zar 1999). The 2010 mean was significantly longer than the mean in the same 5 of 9 pre- modification years, while the 2013 mean was only significantly longer than the 1997 and 1998 means.

No salmon were tagged in April 2013, and exclusion of April-tagged adults from prior years produced similar results (Figure 33). ANOVA results for log-transformed passage times (excluding April passage times) indicated significant among-year differences in means ($df = 11$, F = 15.8, $P < 0.0001$). In pairwise comparisons, the 2009 mean was significantly higher than

means in 6 of the 9 pre-modification years (1997, 1998, 2000, 2003, 2004, and 2006) using the Tukey Test (Zar 1999). The 2010 mean was significantly longer than the mean in 4 of 9 pre-modification years (1997, 1998, 2000, and 2006), while the 2013 mean was significantly longer than the 1997 and 1998 means.

Figure 33. 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; light gray boxes include April passage times and white boxes do not.

Median CI approach-entrance times for summer Chinook salmon in pre-modification years were 6–12 min (*mean* = 8 min; Figure 33). The median in 2009 was 16 min, < 1 min in 2010, and 27 min in 2013. ANOVA results for log-transformed passage times indicated significant among-year differences in means (*df* = 5, F = 6.5, *P* < 0.0001). The 2013 mean was significantly longer than the 2010 mean (post-modification) and the 2002 and 2003 means. In an ANOVA of post-modification years, there was a significant difference among years with 2010 being significantly faster than 2009 or 2013. The median approach-entry time for jack summer Chinook salmon in 2013 was 22 minutes.

Passage times for tagged sockeye salmon from first CI approach to first CI entry were strongly right-skewed. The median approach-entry time for adult sockeye in 2013 was 13 min (*n* = 47, *mean* = 66 min, *std* = 182 min).
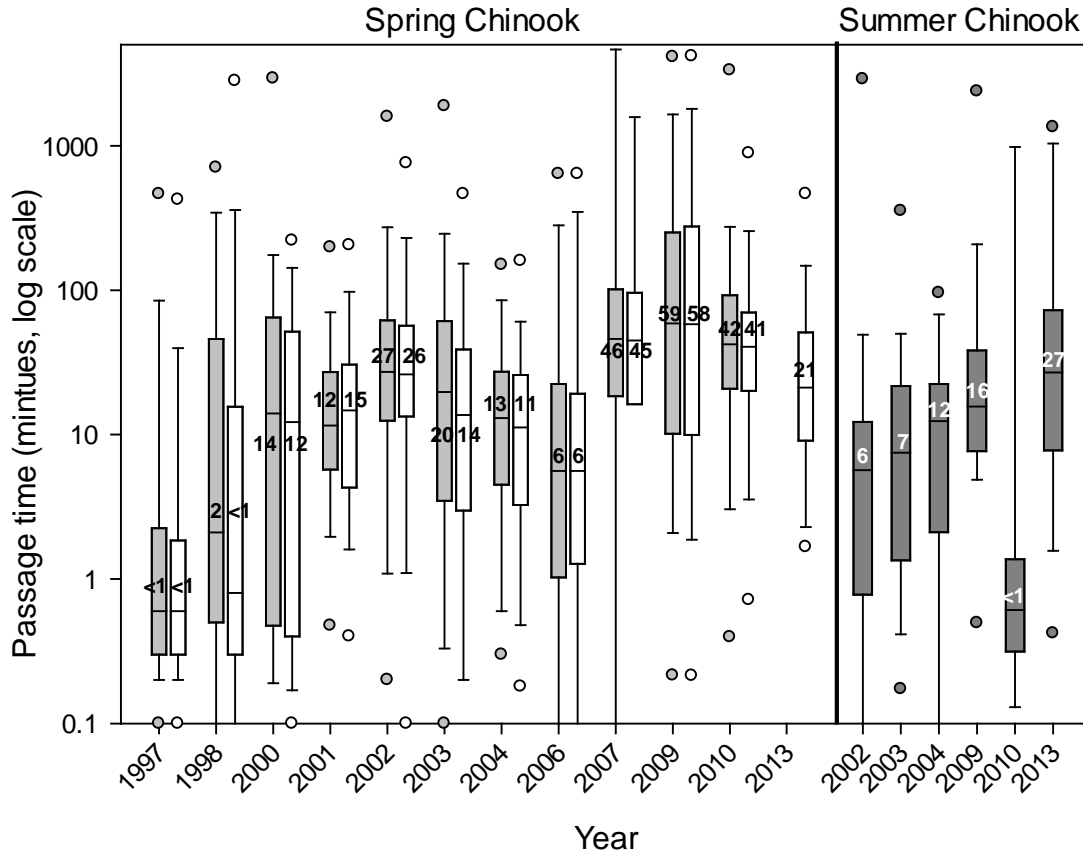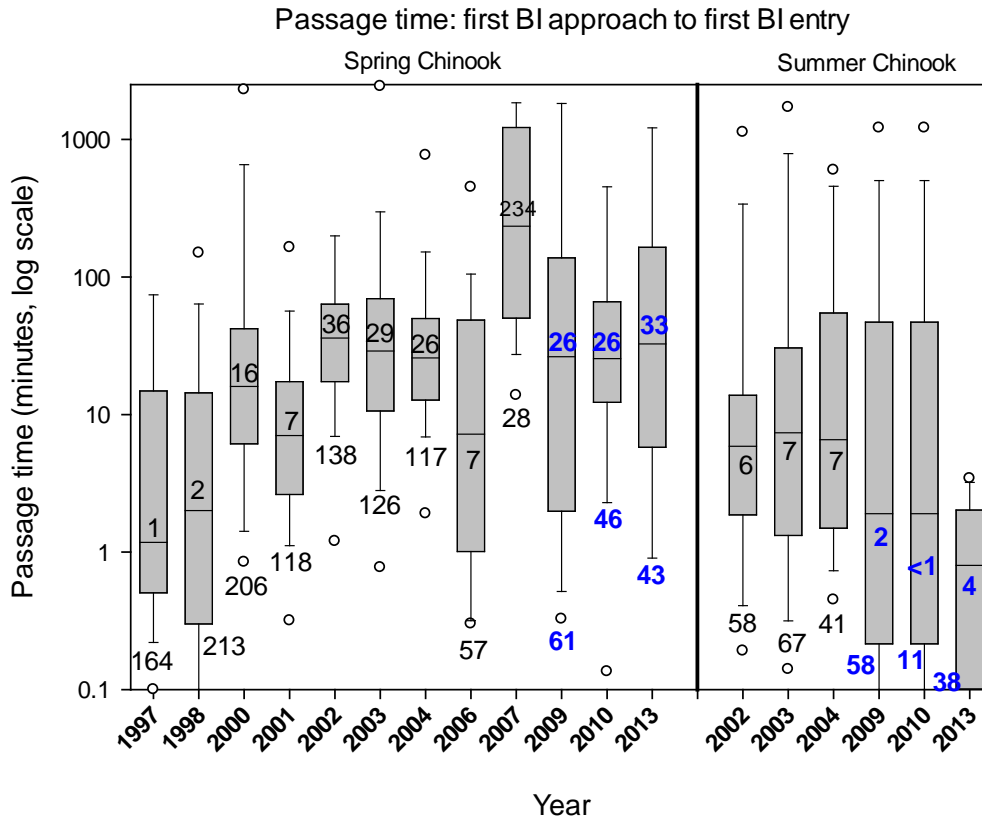

Figure 34. Spring and summer Chinook salmon passage time distributions (plotted on log scale) from approach to entry at the Bradford Island fishway. Values inside boxes are median times. Distributions show 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles; sample sizes are listed at bottom.

Similar to the comparisions between NDE and SDE, we compared passage times between CI and the Bradford Island Fishway entrance (BI) on the opposite side of the spillway channel. Prior to 2009, spring Chinook salmon had median approach to entry times at the BI fishway opening that were higher than or equal to those at the CI fishway opening in all years except 2001 (Figures 33 and 34). In contrast, the 2009 CI median approach to entry time for spring Chinook salmon was more 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). However, in 2013 the median approach-entry passage time at CI was lower than at BI, a trend more in line with pre-modification years. 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- entry time in 2004. In 2009, the median approach- entry time at the CI fishway opening was eight times higher than at the BI fishway opening, whereas the 2010 CI and BI approach-entry times were each < 1 min. Approach-entry times in 2013 for summer Chinook salmon were similar to 2009 in that CI entry

times were seven times higher at CI than at BI fishway openings (Figure 34). In comparison, median passage time for tagged sockeye salmon from first BI approach to first BI entry was 6 min ($n = 43$, *mean* = 50 min, *std* = 202 min).

For tagged adult spring Chinook salmon, the median CI approach-to-entry time in 2009 and 2010 was unexpectedly long compared to past approach-to-entry times at CI and at the Bradford Island fishway opening (Figure 35). In contrast, the relationship between CI and Bradford Island entry times for spring Chinook salmon was relatively close to 1:1 in 2013 and in 1997-2006. 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 adult summer Chinook salmon, the median CI approach-to-entry time in 2009 and 2013 was high compared to past approach-to-entry times at CI and the Bradford Island fishway opening whereas in 2010, both times were equally low (Figure 35).
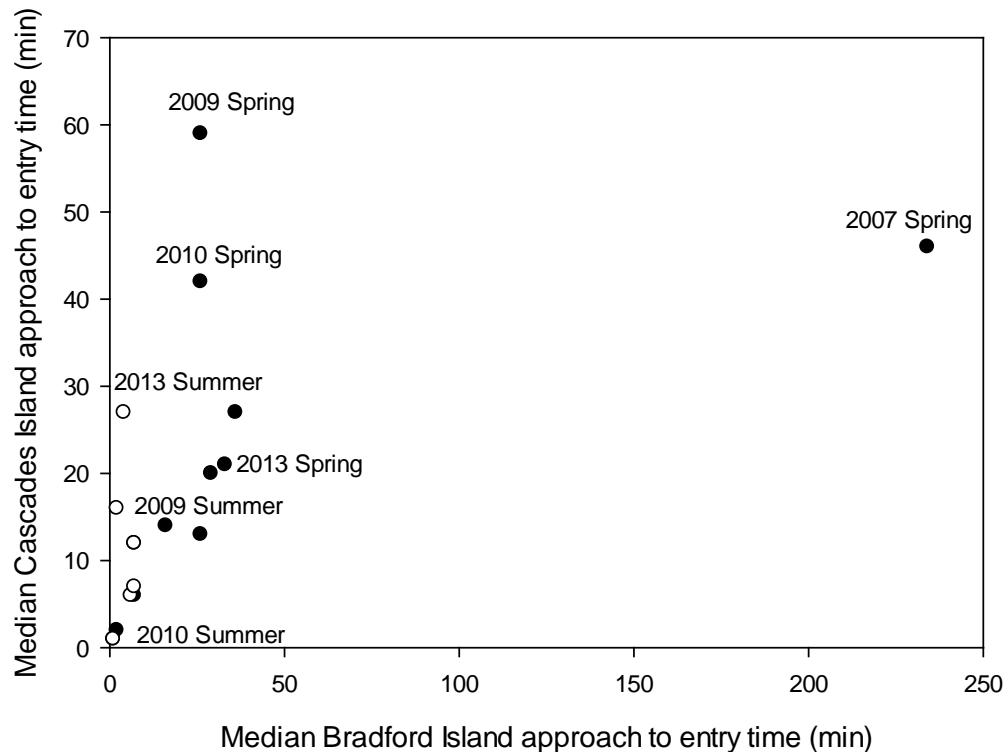
Figure 35. Scatterplot of annual median first approach to first entry times (min) at the Bradford Island and Cascades Island fishway entrances for radio-tagged spring (solid circles) and summer (open circles) Chinook salmon.

Compared to pre-modification years, there tended to be stronger correlations between spring Chinook CI approach-to-entry times and environmental conditions in 2009 than in 2010 and 2013 (Table 3). Negative correlation coefficients indicated faster approach-entry times when

tailwater elevation and flow were relatively high in 2013. Flow and tailwater elevations were lower when tagged salmon first approached the CI opening in 2010 compared to 2009 and 2013 (Figure 36). Tailwater elevation, flow, and water temperatures were slightly higher in 2013 compared to in the two other post-modification years. Overall, river environmental conditions in post-modification year (2009-2013) included the range of conditions fish have encountered in the pre-modification years excluding 1997, a year of near-record spring runoff. River environment parameters that were consistently correlated to passage times were tailwater elevation, flow, and temperature levels, which have been associated with longer salmon passage.

Table 3. 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. April passage times were removed in 1997-2010. Bold font indicates $P < 0.05$.

Year	Flow	Spill	Temp	Tailwater elev.	Date
1997	0.15	0.16	0.09	0.15	0.13
1998	-0.21	-0.12	-0.09	-0.22	-0.18
2000	**0.29**	0.15	**-0.39**	**0.30**	**-0.34**
2001	-0.17	0.39	**0.51**	-0.22	**0.49**
2002	-0.14	-0.15	-0.18	-0.15	-0.16
2003	**-0.25**	-0.01	-0.22	**-0.26**	-0.19
2004	0.05	-0.02	0.06	0.03	0.03
2006	-0.25	-0.27	-0.25	-0.27	-0.21
2007	0.07	0.33	0.36	0.01	0.36
2009	**-0.51**	**-0.38**	**-0.39**	**-0.51**	**-0.43**
2010	**-0.27**	-0.03	**-0.28**	-0.23	**-0.30**
2013	**-0.31**	-0.03	-0.08	**-0.35**	-0.16

Compared to pre-modification years, correlations between CI approach-to-entry times for tagged summer Chinook salmon and environmental conditions in 2009 and 2010 were generally no statistically significant (*P* > 0.05; Table 4). Spill, water temperature, and the date fish approached the CI fishway were weakly associated in 2013. Negative correlation coefficients indicated faster approach-entry times when temperatures were relatively high in 2013. Significant positive correlations in 2009 and 2013 indicated slower entry times with increased spill. Summer Chinook salmon experienced lower temperatures, higher spill volumes and higher tailwater elevations in 2010 compared to in 2009 and 2013 (Figure 37).
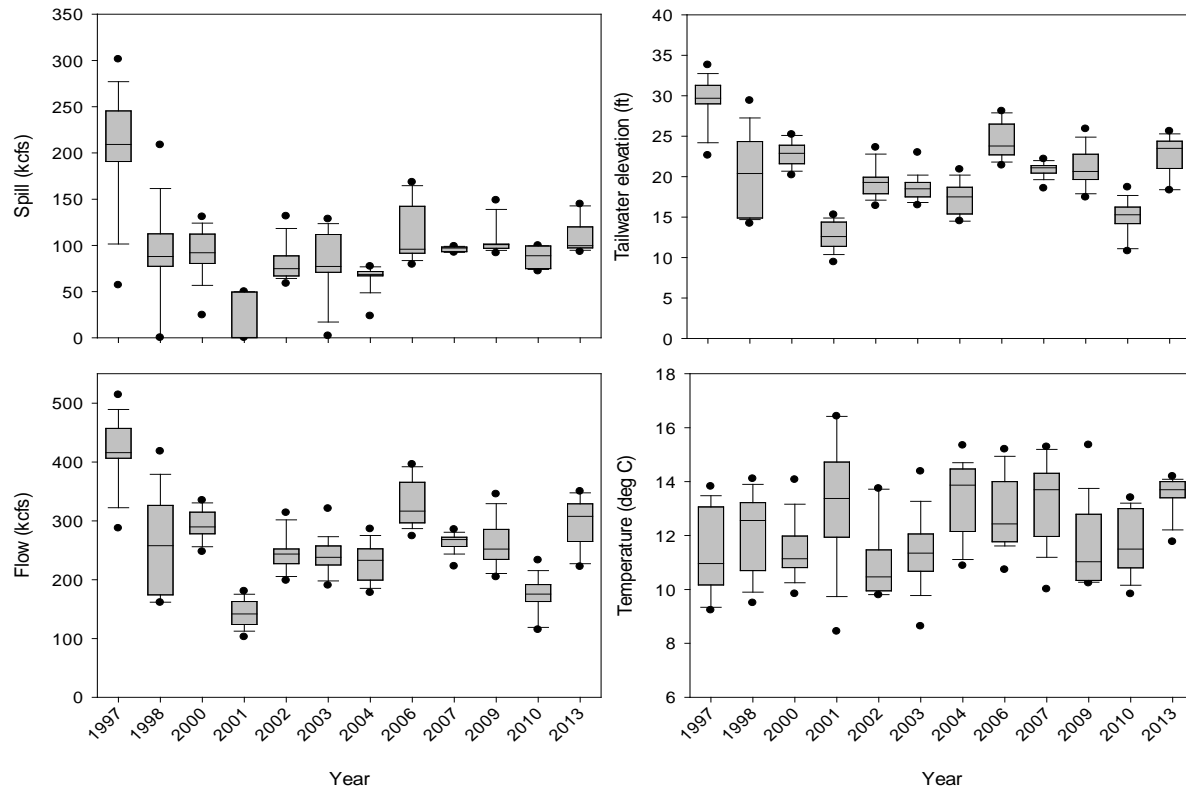
Figure 36. Box plots of the total discharge ('flow'), spill, tailwater elevation, and temperature on the days that radio-tagged spring Chinook salmon first approached the Cascades Island fishway opening. Distributions show 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles.

Table 4. Correlation coefficients (*r*) between environmental conditions tagged summer 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
2013	-0.10	**0.37**	**-0.36**	-0.10	**-0.38**
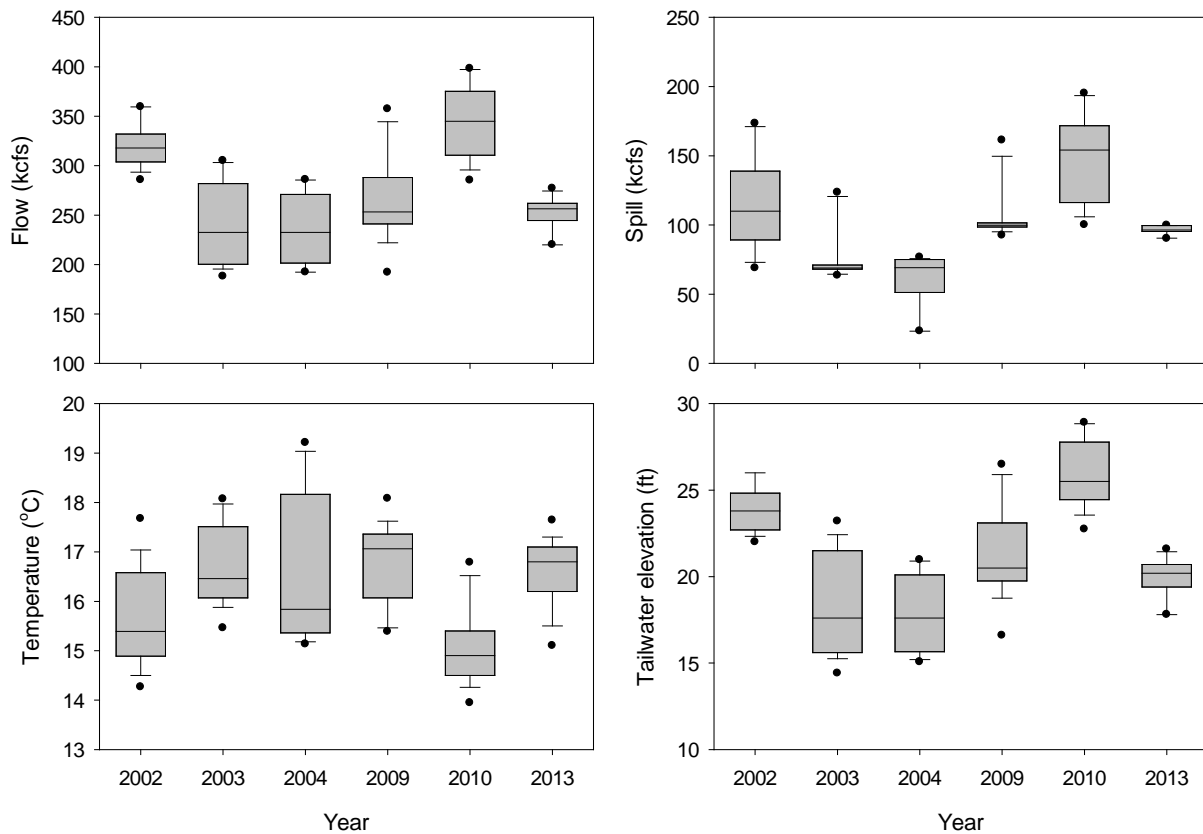
Figure 37. Box plots of the total discharge ('flow'), spill, water temperature, and tailwater elevation on the days that radio-tagged summer Chinook salmon first approached the Cascades Island fishway opening. Distributions show 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles.

Metric 4: Entrance to base of ladder time. After tagged spring Chinook salmon entered the CI fishway, the median time to reach the ladder base ranged from 7–16 min in pre-modification years. Both the 2009 and 2010 medians were 13 min and the 2013 median was 11 min. Median base-of-ladder passage times for jack Chinook salmon was 17 in 2013. The distributions were similar to pre-modification years (Figure 38). In some years, 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.

For tagged summer Chinook salmon, the median time to reach the ladder base ranged from 12–21 min prior to fishway modificatons. The medians in 2009 and 2010 were 17 and 20 min, respectively, and distributions were similar to those in earlier years (Figure 38). The median base-of-ladder passage time of 10 min in 2013 was the fastest of the 6 study years. Median base-of-ladder time for jack summer Chinook salmon was 11 min.

Sockeye salmon tagged in 2013 had the fastest base-of-ladder passage times (*median* = 6 min) compared to both Chinook runs (including jacks).
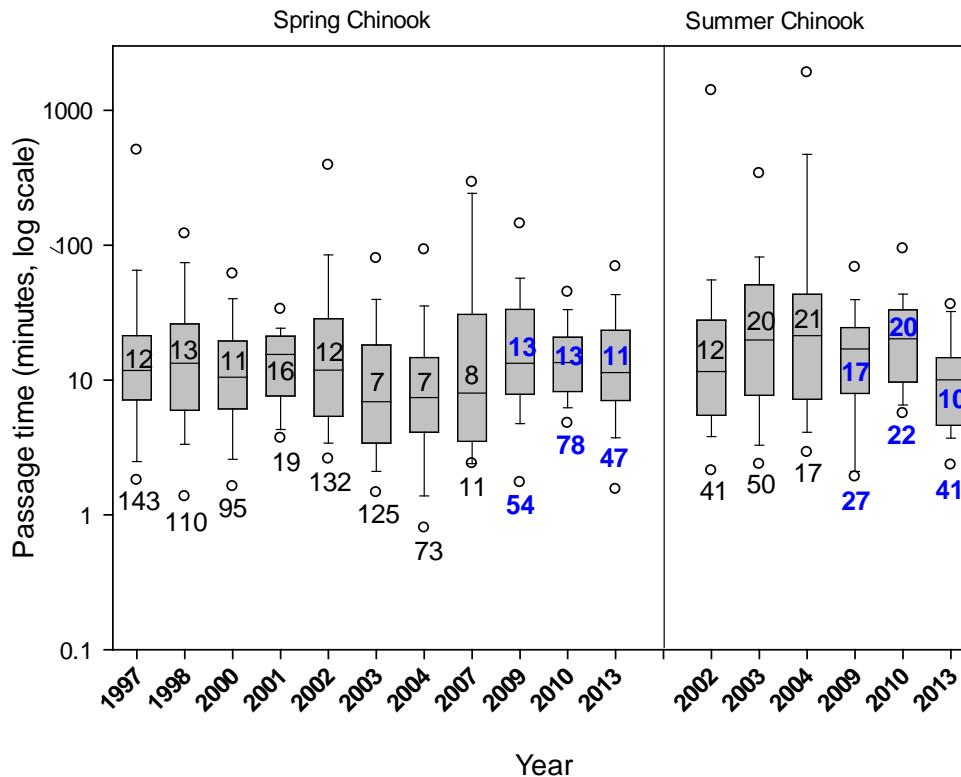
Figure 38. Spring and summer Chinook salmon passage time distributions (plotted on log-scale) from Cascades Island fishway entry to the antenna at the base of the ladder (not monitored in 2006). Numbers inside boxes are median times. Distributions show 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles; sample sizes are listed below boxes.

Metric 5: Extended passage times. During years prior to modification, 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 39). The mean approach-to-entry percent in 2013 (19%) was lower than in the pre-modification years (*mean* = 22%) and was lower than in 2009-2010. The percentage of spring Chinook with >1 h entry-base of ladder times was lower after the fishway was modified and (ranged from 1% in 2010 to 7% in 2009) compared to the pre-modification mean (8%). Spring jack Chinook salmon with longer passage times through both passage segments were similar to or less than the pre-modification means (approach-entry >1 h = 23%) and (entry-ladder > 1 h = 0%).

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 39). Percentages of adult summer Chinook salmon with approach-entry times (> 1 h) were higher in 2009 (17%) and 2013 (27%) compared to the pre-modification mean (9%). In contrast, the post-modification mean (4%) for entry to base of ladder (> 1 h) was less than the pre-modification mean (13%).

40

The percentage of jack summer Chinook taking > 1 h from approach to entry (25%) was similar to adult summer Chinook salmon; the percent of sockeye salmon was lower (17%).

Figure 39. Percentages of radio-tagged spring and summer Chinook salmon that took > 1 h to enter the Cascades Island fishway (top panel) and to pass from the fishway opening to the base of the ladder (bottom panel).

Discussion

General summary

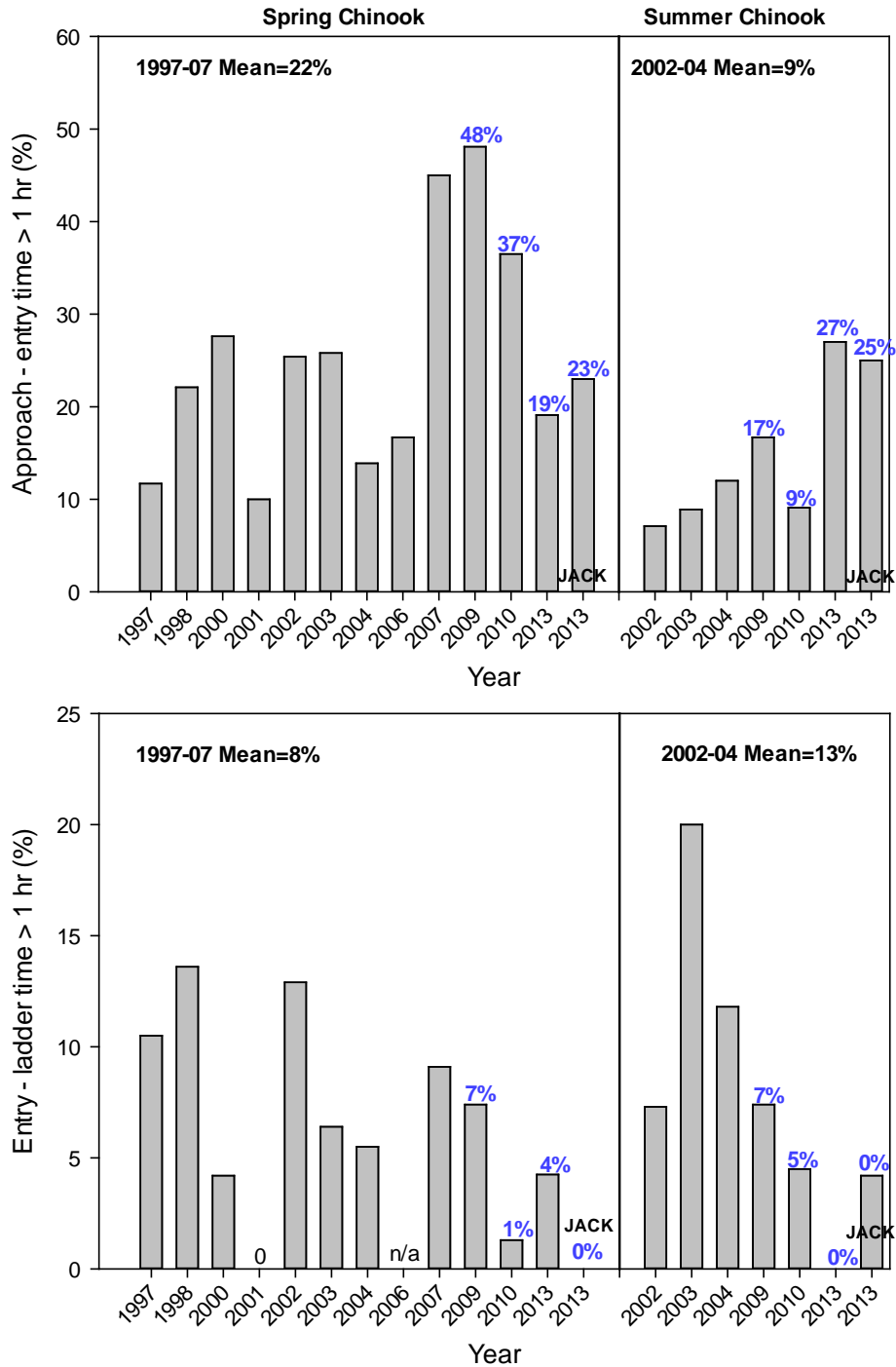Developing an optimal fish passage structure is challenging, particularly in altered river corridors that support fish communities with diverse fish behaviors and swimming capabilities (Haro et al. 2004; Keefer et al. 2013). Efforts have recently been made to facilitate adult Pacific lamprey passage at lower Columbia and Snake River dams by modifying fishway structures (e.g., Moser et al. 2011) and adjusting fishway operations (e.g., Johnson et al. 2012). The primary objective of this study was to evaluate whether the structural modifications made to the PH2 NDE in 2013 and the CI fishway in 2009 were associated with increased passage times or the avoidance or decreased use of the modified fishways by adult salmon. Adult spring Chinook salmon were of primary concern because delayed passage could result in increased predation by sea lions in the Bonneville tailrace (Stansell et al. 2009; Keefer et al. 2012).

Our multi-metric approach attempted to evaluate important elements of salmon passage behavior at the modified fishways, including entrance attraction and selection, success and duration of entrance attempts, and behavior in the lower fishway and fishway exits to the tailrace. Results for individual metrics indicated that the modifications had a mix of negative, neutral or positive effects on passage behavior and success (Tables 5 and 6).

Table 5. Qualitative classification of each 2013 passage metric compared to values from pre-modification years at the north downstream entrance (NDE) at Powerhouse 2. Green indicates better post-modification performance, white indicates no change, yellow indicates somewhat reduced performance, and red indicates substantially lower post-modification performance.

Metric	Spring Chinook Adult	Spring Chinook Jack	Summer Chinook Adult	Summer Chinook Jack
1) Entrance efficiency	Low	High	High	High
2) Exit ratio	Low	Low	Near average	Near average
3) Approach-Entry time	Near average	Fast	Fast	Fast
4) Entry-Ladder base time	Fast	Fast	Fast	Near average
5) Approach-Entry > 1 h[1]	Slightly high	Low	Low	Slightly high
5) Entry-Ladder base > 1 h	Low	Near average	Low	Low
6) Entry-Transition area	Low	Near average	Slightly high	Slightly high
7) NDE:SDE use	Near average	Near average	High	Near average

[1] Some estimates in 2013 were potentially longer due to use of aerial Yagi antennas

Averaging across all metrics, the weight of evidence in the 2013 results suggests the following:

● there was no evidence for dramatic passage delays or sharply reduced efficiency metrics at NDE for adult Chinook salmon in 2013 relative to previous years;

● there appeared be no net change in passage for adult spring Chinook salmon at NDE compared to prior years, with some metrics improving, some remaining neutral, and some declining slightly compared to results in the past;

42

● data from spring jack Chinook salmon at NDE suggest good performance by jacks in 2013 compared to adults in 2013 and compared to adults in prior years, either because the overall passage performance of jacks is higher than adults (and was higher in past years) or conditions at NDE were more favorable for jacks than adults post-modification;

Table 6. Qualitative classification of each 2013 passage metric compared to values from pre-modification years at the north downstream entrance (NDE) at Powerhouse 2. Green indicates better post-modification performance, white indicates no change, yellow indicates somewhat reduced performance, and red indicates substantially lower post-modification performance.

Metric	Spring Chinook		Summer Chinook	
	Adult	Jack	Adult	Jack
1) Entrance efficiency	Slightly low	Near average	Low	Near average
2) Exit ratio	Low	Very low	Low	Very low
3) Approach-Entry time	Slightly high	Near average	High	High
4) Entry-Ladder base time	Near average	Slightly high	Low	Low
5) Approach-Entry > 1 h	Near average	Near average	Slightly high	High
5) Entry-Ladder base > 1 h	Near average	Low	Very low	Low

● the overall results for summer Chinook salmon at NDE indicated neutral or positive changes in passage for adults and possibly for jacks, though again there were no previous jack studies for direct comparison;

● results at CI were mixed for both runs, though two key metrics (entrance efficiency and passage time metrics) indicated passage conditions may have been less favorable in 2013 than in pre-modification years.

Below we discuss the magnitude of the differences among years for key metrics, identify potential mechanisms, implications and areas of concern for each run and location.

Powerhouse 2 NDE efficiencies

The structural modifications made at Bonneville Dam had the potential to affect adult salmonid behavior by changing hydraulic attributes and/or the olfactory environment at the NDE opening and/or in the attraction plume outside of the fishway opening. The LFS flume and water supply adjacent to the PH2 NDE also had the potential to affect hydraulics outside the opening or to change the environment by introducing underwater noise and/or low frequency vibration from water passing over the new structure. The introduction of odors or chemicals (e.g., human scent, unseasoned aluminum, and caulking) near the entrance might also slow or stop migration. Unfortunately from a research perspective, the modifications were installed simultaneously and could not be independently installed and removed in an experimental manner, as was the case for evaluations of structural modifications at Bonneville Dam in 2005 (e.g., sea lion exclusion devices, SLEDs) and at other locations (e.g., Naughton et al. 2007). Consequently, this evaluation relied on inter-annual comparisons and comparison to a reference site (SDE) to assess the combined effects of all the modifications simultaneously.

The proportion of radio-tagged salmon that approached and entered the PH2 NDE varied considerably year to year. The proportion of radio-tagged spring Chinook salmon that approached PH2 NDE in 2013 was 12% lower than the historic mean, but only ~ 5% lower than the mean after the shift to PH2 priority in 2001. In 2013, proportionately fewer radio-tagged salmon approached the PH2 NDE entrance and entrance efficiencies were somewhat lower than average. The number of radio-tagged spring Chinook that entered in 2013 was ~ 50% less than the historic mean, but entrance use at NDE has been generally declining since 2006. Despite the lower NDE entrance efficiencies in 2013, we have no reason to think the differences were related to the newly constructed lamprey flume system (LFS). Among-year differences in the ratio of fish approaching and entering the PH2 NDE compared to the PH2 SDE did not provide any indication of a shift away from use of NDE by radio-tagged spring Chinook salmon in 2013. In fact, proportionately more radio-tagged summer Chinook approached and entered the PH2 NDE relative the PH2 SDE compared to past years.

Inter-annual variation in entrance efficiencies are common, fluctuating 2-5 fold between years, and the entrance efficiency in 2013 was higher than or similar to four of the 12 study years. Moreover, entrance efficiencies were the highest observed for summer Chinook salmon, suggesting conditions at the PH2 NDE during the spring were related to other environmental or structural issues rather than the modifications. Jacks tagged during the same time as the larger adults had relatively high entrance efficiencies as well, which made it less plausible that factors related to the LFS (olfactory, noise, vibration, failed attempts to enter the lamprey specific openings, etc.) contributed to the lower entrance efficiencies for tagged adult spring Chinook salmon.

Other possibilities for the observed differences in NDE entrance use and entrance efficiency in 2013 may have been related to changes in the radiotelemetry array. The use of an aerial antenna at the PH2 NDE opening in 2013 may have inflated detection probabilities for fish migrating higher in the water column (i.e., fish may have been detected further from the entrance than historically using underwater antennas). In previous studies where we have had both underwater and aerial antennas at a single fishway opening, there have not been large differences in fish detection. Nonetheless, this methodological change (a result of the Bonneville fishway dewatering schedule) likely affected estimation of these metrics; we do not think that large behavioral differences were misidentified as a result of the change.

We observed little evidence of altered behavior after salmon entered at the PH2 NDE. Exit ratios indicated that there was no altered behavior related to recent modifications at the PH2 NDE for radio-tagged adult spring or summer Chinook salmon. The percentage of spring Chinook salmon that exited to the tailrace in 2013 was similar to the observed low exit ratio rates since 2006. Chinook salmon entrance-to-ladder times also provided no evidence of negative effects of the modifications on behavior inside the fishway. In contrast, the proportion of radio-tagged fish that reached the ladder (Metric 6) after entering the NDE was at the lower end of the historic range for adult spring Chinook. The opposite was true for adult summer Chinook salmon, with a majority of successful dam passages at the PH2 fishway originating from NDE.

It is not clear whether SLEDs or the presence of predators in the tailrace may have been responsible for the relatively low percentages of spring Chinook salmon exiting fishways in

2006-2007 and 2009-2013 compared to summer Chinook salmon. It is possible that some spring-run salmon that might otherwise have exited a fishway remained inside as a predator avoidance strategy. Observed inter-annual 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 (e.g., temperature, discharge; Keefer et al. 2003, 2013; Caudill et al. 2013) and sampling error.

Powerhouse 2 NDE passage times

For tagged spring Chinook salmon, the median NDE approach-to-entry time in 2013 suggested minimal differences compared to past approach-entry times. Spring Chinook salmon approach-entry times in 2013 were in the lower middle of the range in previous years and were faster than in 2 of the last 3 years. In 2013, over half the fish that eventually entered PH2 NDE took > 1 h to enter which was not unusual: 69% and 71% of spring Chinook salmon took >1 h to enter in 2007 and 2009, respectively. In contrast, the 2013 summer Chinook results suggested conditions near the fishway opening provided some of the best conditions observed across all study years. The median approach-entry time was one of the fastest observed and relatively fewer radio-tagged summer Chinook salmon were observed having extended (> 1 h) entry times.

Longer entry times for spring Chinook salmon in 2013 compared to 2010 at NDE could have been attributed to annual differences in flow and spill (e.g., Keefer et al. 2008). Correlation results suggested that environmental factors encountered in May 2013 were strongly related to the variability in adult salmon entrance times. Compared to 2010, flow and spill were elevated in 2013 and negatively correlated with adult passage time. Notably, the median NDE entry time for jack spring Chinook salmon was < 1 min, and entry times for summer Chinook were also relatively fast. The weight of evidence suggests that observed differences in passage times in 2013 spring adults were not directly related to structural or hydraulic changes associated with the LFS.

Cascades Island

The modified entrance weir at the Cascades Island entrance had the highest potential to affect hydraulics outside of the opening. The bollard field likely affected flow conditions outside the opening to a lesser degree, potentially by decreasing mean velocity and increasing turbulence in the bottom portion of the attraction plume from the opening. Inside the opening, the bollards altered near-bottom flows, and the CI LPS had limited potential to affect hydraulics. Importantly, the annual percentages of radio-tagged Chinook salmon that have approached and entered the CI fishway have changed little since the CI fishway modifications.

Collectively, the metrics used to assess adult Chinook salmon behavior at CI suggest the modifications have had neutral or perhaps slightly negative effects on passage efficiency (Table 6). Post-modification entrance efficiencies at CI have been quite variable and slightly lower – on average – for radio-tagged adult spring Chinook salmon. The lowest estimates were in 2009, and results from 2010 and 2013 suggest that unfavorable passage conditions associated with the

modifications in 2009 may have been ameliorated by 2010. The among-year differences also may be related to differences in tailwater elevations, total discharge and spill, all of which were considerably lower in 2010 than in 2009 and 2013. 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 (Jepson et al. 2010). Unexpectedly, CI entrance efficiencies for summer Chinook salmon in 2013 were the lowest ever despite near-average river conditions.

Conversely, exit ratios at CI were lower in 2013 for all groups, suggesting potentially improved retention. We have hypothesized that the risk of sea lion predation in the tailrace may act as a deterrent to fishway fallout, but this has not been tested directly and would require that sea lion observation data in the spillway tailrace be matched with the radiotelemetry data.

The multi-year results indicated longer entrance times for spring Chinook salmon at the CI fishway opening in 2009 relative to pre-modification years, but the 2010 and 2013 data were less different. Since the fishway entrance modifications at CI, there has also been a decrease in the number of fish with extended passage times. The slower CI approach-to-entry times in 2009 may have been produced by changes in hydraulic (AECOM, 2010 memorandum to Lois Loesch, U.S. Army Corps of Engineers) or olfactory conditions near 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 (e.g., Moser et al. 2011).

Summer Chinook salmon generally used less time than spring Chinook salmon to enter the CI fishway after approaching. Median entrance times for summer Chinook salmon were elevated in two of the three post-modification years but were still similar to or lower than those for spring Chinook salmon. It is unlikely that either result represents biologically significant increases in passage time given the annual variability in passage times (particularly post modification) these ranges do not provide conclusive evidence of degraded conditions at the CI fishway entrance. Furthermore, inter-annual variability in entry times (often times up to > 10 fold differences in median approach-entry times) is common at unaltered, but structurally similar fishways (see Figure 34). We did not examine the potential effects of spill patterns on these results. The 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 at CI in more recent years.

We also note that the PH2 NDE and CI approach-entry times encompassed the time and behaviors of tagged salmon that may have made multiple approaches at an opening before entering. As a consequence, the time tagged salmon used before re-approaching and subsequently entering are likely influenced by conditions elsewhere at the dam and not with any attributes of the opening *per se*. To this extent, we believe that entrance efficiency and fishway exit ratios may be a better overall index than passage times of the effects of the modifications made at the PH2 NDE and CI fishway openings.

In conclusion, the three years of data collected post modification at the CI entrance suggest there may have been some limited adverse effects near the opening, but that behaviors inside the fishway have not changed or have improved. Three post-modification years of data collected suggested that once salmon entered the CI opening, they did not have difficulty swimming past the modified area (i.e., past bollards and the LPS) to the base of the ladder.

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