Passage Evaluation of Radio-tagged Chinook and Sockeye salmon after Modifications at The Dalles and John Day Dams, 2013

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Report of research by

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Executive Summary

At ***The Dalles Dam***, construction of a ~145-m spill wall was completed in April 2010 and was designed to improve the survival of spillway-passed juvenile salmonids by directing them toward deep water with fewer predators. We evaluated how behavior and passage time of radio-tagged adult and jack spring-summer Chinook salmon *Oncorhynchus tshawytscha* and sockeye salmon *O. nerka* in 2013 were affected by three factors: 1) a new spill wall, 2) changing spill volumes, and 3) a spill pattern that directs most water though the northern-most spillbays. We focused analyses on fish size and use of the north fishway.

Radio-tagged salmon used the north side of the river less frequently than the south side; this trend intensified as fish migrated from the tailrace to the base of The Dalles Dam. In 2010, a majority of tagged adults swimming up the north shore crossed the river to the south before approaching a powerhouse fishway opening, particularly during periods of higher spill. In 2013, we did not estimate how far fish migrated on the north shore prior to switching sides, but over 85% of salmon that were on the north shore switched to the east fishway prior to approaching the dam. Our results indicated that fish size is related to use of the north ladder, as is spill and temperature. However, we did not find an interaction between fish size and spill. Unlike Jepson et al. (2011), who found low entrance efficiency at the north fishway opening, entrance efficiency in 2013 was high for all groups at both fishways.

The new spill wall and the 2013 spill pattern did not appear to impede the ability of tagged salmon to seek and find alternate passage routes, even when approaches at the north fishway did not result in a fishway entry. Salmon recorded on the north shore that subsequently switched sides had median fishway entry times similar to those of fish that did not switch (adult Chinook salmon that switched entered 1 h faster while sockeye salmon that switched were 0.6 h slower than those that did not switch). Dam passage times for radio-tagged Chinook salmon in 2013 (median = 12.1 h, n = 285) were about average relative to those in the 11 years for which comparison data are available. When data were separated by month, fish passing in June were the slowest among the 11 years, while fish passing in July were the fastest (on median).

At ***John Day Dam***, several structural modifications were made to the north fishway entrance in winters 2012 and 2013 in order to improve passage of adult salmonids and Pacific lamprey *Entosphenus tridentatus*. These modifications included the removal of lower fishway weirs; closure of one of two entrance slots; and installations of a variable-width entrance weir, a bollard field, and a lamprey passage system (LPS).

Structural modifications were also made to the upper north ladder in 2010 that included the removal of concrete weirs; replacement of a bulkhead, crowder, light box, and picket leads near the count window; and the installation of a window washer on the count window. We evaluated how these modifications may have affected behaviors and passage times of radio-tagged adult and jack spring-summer Chinook salmon by comparing behavior and passage time data from 2013 to those collected in pre-modification years 1997-1998 and 2000-2006.

Use of the John Day north fishway by spring and summer Chinook salmon in 2013 was consistent with patterns of use observed in pre-modification years. Entrance efficiencies and fishway passage efficiencies in 2013 were either within the range of pre-modification values or were higher. Fishway exit ratios (i.e., exit to the tailrace) for 2013 adult Chinook salmon were similar to exit ratios in prior years; jack Chinook salmon had considerably lower exit ratios than adults. We also found that salmon passage times were similar to or faster than those estimated prior to the north fishway modifications. Approach-to-entrance times were significantly faster in 2013 than in most pre-modification years, while entrance-to-ladder base times were similar to previous results. The percentage of Chinook salmon that required more than 1 h to complete these passage segments was much lower in 2013 than in most pre-modification years.

Salmon passage up the north ladder (from the base to the ladder exit) was significantly shorter for adult spring Chinook salmon in 2013 than in previous years; ladder passage times for adult summer Chinook salmon in 2013 were similar to pre-modification ladder times. Jacks passed the ladder more slowly than adults in both spring and summer. All of the passage metric results suggest that the recent north fishway modifications had no adverse effect on the passage behavior of Chinook salmon.

Contents

Introduction

Adult salmon and steelhead migrating to 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 and Conservation Council (NWPCC) and by NOAA Fisheries (NOAA). This study address priority research areas related to improving passage and survival of adult salmonids identified by the U.S. Army 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.

At The Dalles and John Day Dams, major and minor fishway modifications intended to improve passage of adult Pacific lamprey and/or adult salmonids have recently been completed, as well as structural and operational changes to improve juvenile salmonid survival. As with any significant changes, these modifications must be evaluated for effectiveness, including assessments to ensure that adult salmonid passage is not adversely affected.

The Dalles Dam

The construction of a ~145-m spill wall at the western base of The Dalles Dam was completed in April 2010. This wall was designed to improve the survival of spillway-passed juvenile salmonids by directing them toward deep water with fewer predators (Figure 1). In addition to installation of the spill wall, spillway discharge was to be directed through the northernmost spill bays. The new spill pattern raised concerns that migration of adult salmon and steelhead might be slowed because fish would have difficulty finding and/or using the north-shore fishway opening.

Post-modification behavior and passage metrics of adult Chinook salmon at The Dalles Dam was evaluated in spring and summer 2010 using radio-tagged adult spring-summer Chinook salmon (Jepson et al. 2011). Results from that study showed that adult Chinook salmon had low entrance efficiency at the north-shore fishway under high spill conditions. In fact, many salmon migrating along the north shoreline below The Dalles Dam crossed the river to the east fishway (located on the south side of the river) when spill was high (Jepson et al. 2011).

In 2011-2012, fish count data indicated very low proportions of adult passage at The Dalles Dam north fishway, particularly during high spill conditions and for smaller adult fish (i.e., jack Chinook salmon and sockeye salmon).

This report addresses concerns raised in 2010-2012 regarding the effects of fish size on behavior and passage time of radio-tagged adult spring-summer Chinook salmon. In addition to radio-tagging 599 adult spring-summer Chinook salmon for passage evaluation, we further evaluated size effects on passage by radio-tagging 301 jack Chinook salmon and 399 sockeye salmon for use in species and size comparisons. Specific objectives for these tagging studies at The Dalles Dam in 2013 included:

1. Evaluate adult passage-route selection based on water temperature, date, time of day, flow, spill volume, dissolved gas, and fish size.
2. Evaluate adult travel times based on environmental conditions and biological traits.
3. Estimate adult fishway entrance efficiency at both the north and east ladder entrances.

Figure 1. Photograph of spill walls at bays 6-7 (left) and 8-9 (right) at The Dalles Dam in 2010.

John Day Dam

Several recent modifications have been made to the north fishway at John Day Dam. The upper section of the north shore fish ladder at John Day Dam was reconstructed during winter 2009-2010. Specific modifications included:

1. Removal of existing concrete weirs in the fish ladder along with the existing sill gates and actuators
2. Construction of new concrete weirs
3. Modification of existing concrete baffles in the transition section located in the non-overflow portion of the fishway
4. Modifications to the floor, diffuser, and fish counting building within the fish ladder
5. Replacement of the existing bulkhead, picket leads, crowder, and light box and addition of a window washer for the fish counting building

In winter 2011-2012 and 2012-2013, additional north fishway modifications were conducted to facilitate the upstream passage of adult salmonids and adult Pacific lamprey *Entosphenus tridentatus*. These modifications included:

1. Installation of a variable width entrance weir
2. Closure of one of the two fishway entrance slots
3. Installation of velocity-reducing bollards on the fishway floor just inside the entrance
4. Installation of a lamprey passage structure (LPS) on the north wall just upstream from the entrance
5. Removal of the first two concrete overflow weirs from the fishway (Figure 2)

Our primary objectives at John Day Dam were to compare adult Chinook salmon passage times and behaviors at the north fishway in 2013 to those from pre-modification years while simultaneously considering interannual variation in environmental conditions. Specific objectives included:

1. Evaluate salmon passage time through the north fish ladder including passage by the modified count station.
2. Evaluate passage time at the north fishway opening and lower north fishway.
3. Estimate entrance efficiency and other passage metrics at the north ladder entrance.

Figure 2. Modifications to the John Day Dam north fishway entrance area; camera is facing upstream in all photos except A. From left to right, clockwise: A) downstream variable-width entrance weir, bollard field, and closed entrance slot (new concrete on left wall); B) lamprey passage structure (with bollard field in foreground); C) removal of concrete weirs; and D) completed fishway with concrete weirs removed.

Study Fish and Monitoring Systems

For studies at both dams, we collected and tagged 599 adult Chinook salmon and 301 jack Chinook salmon at Bonneville Dam from 2 May through 15 July 2013. Adult Chinook were defined as fish greater than 60 cm fork length, while fish 60 cm or less were considered jacks. We also tagged and released 399 sockeye salmon from 7 June through 13 July. All fish were trapped and gastrically tagged at the Adult Fish Facility and released approximately 9 km downstream from the dam at sites on both sides of the Columbia River.

A total of 134,588 adult and 55,567 jack Chinook salmon were counted passing Bonneville Dam during the tagging period for these fish. Radio-tagged Chinook salmon represented ~0.4% of the adult salmon and ~0.5% of the jack salmon counted at the dam during this period. During the sockeye salmon tagging period, a total of 172,140 adult sockeye salmon were counted passing Bonneville Dam; radio-tagged sockeye represented ~0.2% of this total.

A description of the fish collection and tagging methods we followed is presented in Keefer et al. (2004) and Jepson et al. (2011). Details specific to the 2013 sampling effort at Bonneville Dam include transmitter specifications, anesthesia, data collection, and data coding methods; these are described in a companion report (Johnson et al. *in review*).

We used an array of fixed-site radio receivers to monitor locations of tagged fish at The Dalles and John Day Dams. Receiver deployments were similar to those in previous years to facilitate comparison of estimated passage metrics among years. Tailraces were monitored with aerial antennas at sites on both sides of the river (Figures 3 and 4). At each dam, primary fishway openings were monitored inside and outside with underwater coaxial cable antennas. Additional underwater antennas were used to monitor collection channels, transition areas between collection channels and overflow weir sections of the ladders, and near top-of-ladder exits to the dam forebay.

One difference at The Dalles Dam in 2013 compared to some previous years was that we did not deploy aerial (Yagi) antennas just downstream from the north ladder entrance (see Jepson et al. 2011, Figure 3 for comparison). Other among-year differences in monitoring effort were minor, and an effort was made to standardize specific antenna sites used for all comparative analyses across years.

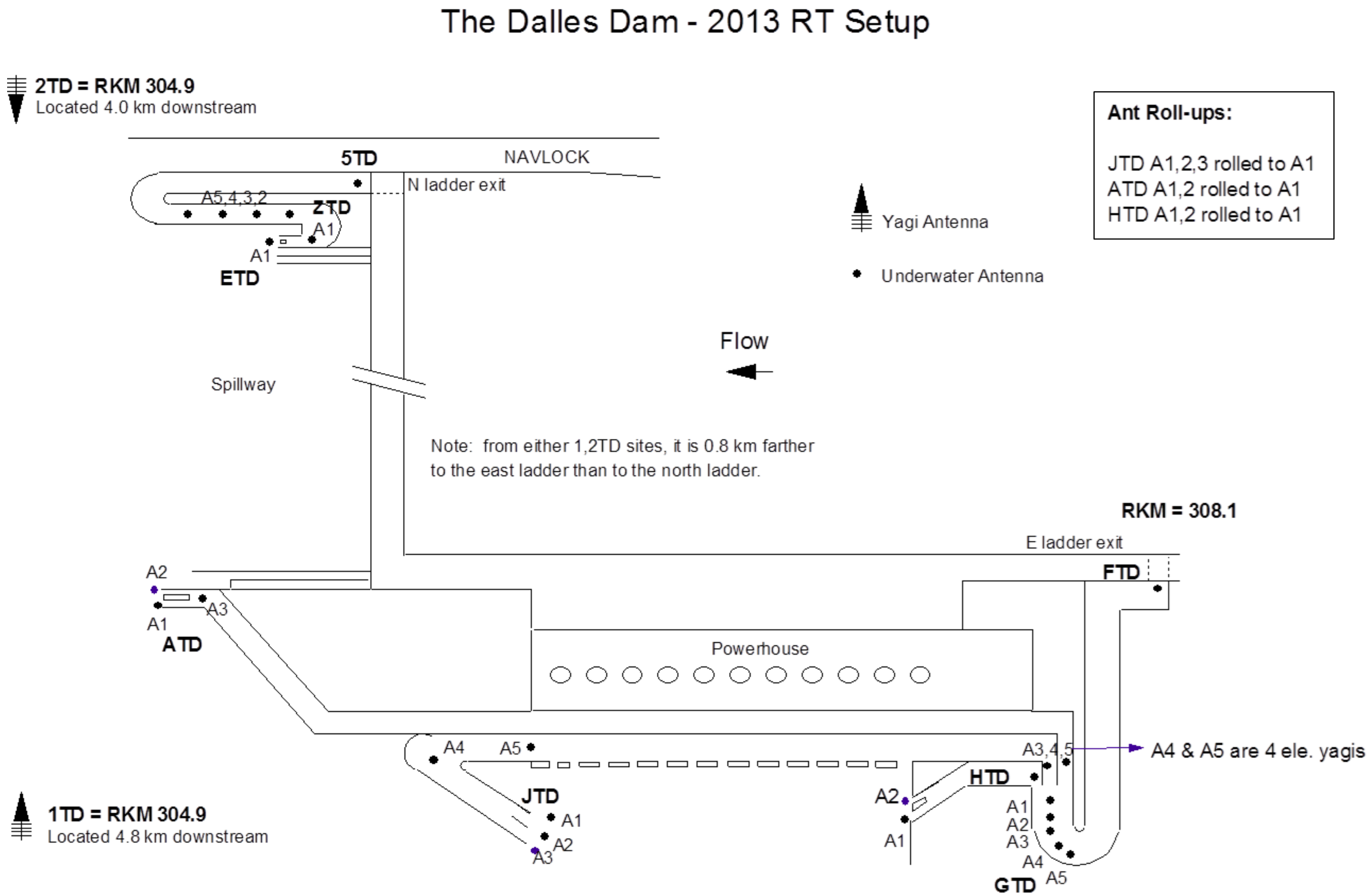

Figure 3. Plan view of radio antennas deployed at The Dalles Dam in 2013 (drawing not to scale).

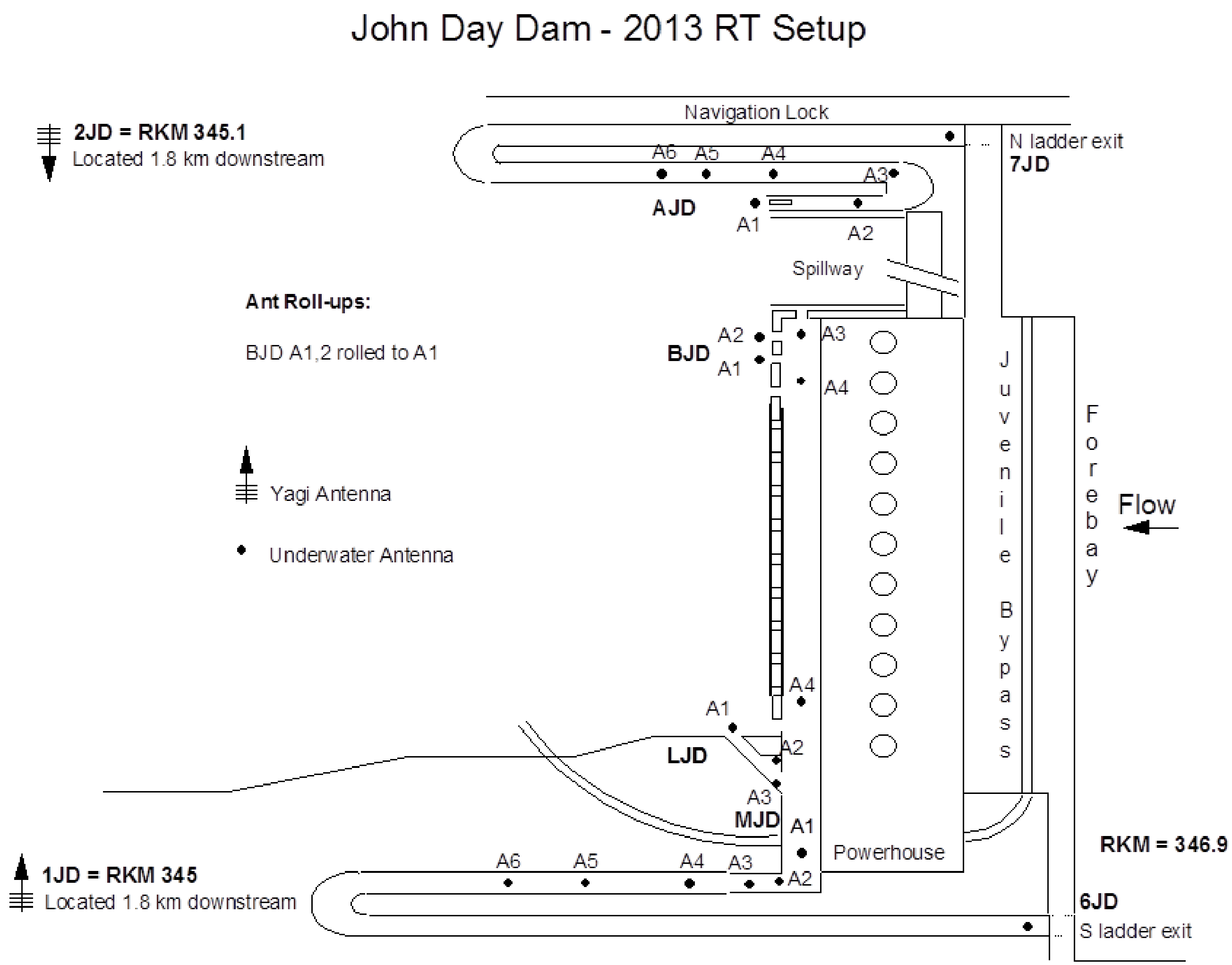

Figure 4. Plan view of radio antennas deployed at John Day Dam in 2013 (drawing not to scale).

The Dalles Dam

Methods

Route-Specific Time to Enter

For each fish, we calculated the time from first detection in the tailrace (F1) to first detection at a fishway entrance (E1) as a measure of tailrace travel time. If the new spillway wall had a deleterious effect on travel time, we might expect to see longer travel times for fish first entering the north vs. the east ladder. We also compared travel time between fish that switched sides (i.e., crossed the tailrace) and those that did not. Due to the importance of time in this analysis, we excluded any fish that had an uncertain time stamp for either the F1 or E1 record.

For all analyses, we used an accelerated failure time (AFT) model with parametric baseline hazards (Zabel et al. 2014). This approach is similar to Cox proportional hazard (CPH) models, but explicitly states a parametric baseline (in this case, we used a Weibull distribution). Using AFT models allowed us to quantify the effects of covariates on time-to-event data, such as the F1-to-E1 data. It also allowed for time-varying covariate data, so covariates such as spill or temperature that change during the time a fish is in the tailrace can be evaluated appropriately. Because the response among species may differ, we ran separate models for each group of fish (adult Chinook salmon, Chinook salmon jacks, and sockeye salmon).

By including the E1 fishway (i.e., north, east) as a covariate in the model, we were able to quantify the relative impact on travel time for fish entering the north ladder vs. the east ladder, after having taken into account all of the other environmental effects. We used Akaike's information criterion (AIC) to determine model fit and report results from the best fit model. Therefore, if AIC did not suggest clear support for a covariate, it was not kept in the model, and the parameter estimate was not reported in the results.

Proportional Ladder Use

Fish choice of one of the two ladders at The Dalles Dam was modeled as a binomial process (two potential outcomes). We therefore used logistic regression to characterize the probability of salmon using the north or east ladder. To maintain consistency among analyses, we also refer to the two sides of the river downstream of the dam (at the F1 antenna sites) as north or east. We report the proportion of fish using the north ladder and then use logistic regression to allow estimation of the effect of various covariates that may influence that proportion. For adult Chinook salmon, Chinook salmon jacks, and sockeye salmon, we tested for effects of day vs. night, fish fork length, date, spill, water temperature, dissolved gas (we used gas pressure in mmHg, as some of the percent saturation data were missing), and river discharge (sometimes referred to as flow; kcfs). We included in the analysis all fish that were known to first approach or enter a specific ladder, even if the exact time of the event was not known. Fish with an uncertain time stamp could influence the estimated impact of time of day on proportion of fish using the north side of the river because estimated time would be biased later (although we think this effect would be very small). This bias on all other covariate estimates should be minimal.

All environmental data were obtained from the Columbia River Data Access in Real Time database (CR DART 1996). Although there is the potential for interactions among environmental variables, we did not test for interaction effects. We also did not test two variables in a single model that were too highly correlated. For example, discharge and spill in the jack Chinook salmon dataset had a correlation coefficient (*r*) of 0.92, and were therefore not both included in the same model. We used AIC to determine the best set of covariates and reported results for only the best-fitting models.

Side Switching

If the presence of the new spill wall (or any other feature of a particular ladder) results in reduced guidance, attraction, or entry of salmon to the north ladder, salmon could switch sides of the river. We analyzed the propensity to switch sides of the river between the first downstream detection (F1) and the first fishway entrance (E1) as a function of environmental covariates. Just as ladder use can be modeled as a binomial process (north or east), so can switching (switched or not). We therefore used logistic regression to characterize switching behavior. Fish can either switch from the north side of the river to the south or from the south to the north, so we analyzed these two behaviors separately because they may be related to different environmental factors. For the side-switching analysis, we tested the same set of covariates as we used for proportional ladder use and included all fish known to first approach or enter a specific fishway, even if the exact time of the event was not known.

Entrance Efficiency

At each of the north and east fishways, we calculated the proportion of fish first approaching a fish ladder that also first entered that ladder to determine whether there were any issues related to entering a fishway. We ran these analyses at each ladder separately. Sample sizes for this analysis were too low to allow modeling of entrance efficiency as a function of environmental variables, particularly at the north ladder entrance. We included all fish that were known to first enter a specific ladder, even if the exact time of the entrance was not known.

Results

Environmental Data

Columbia River water temperature at The Dalles Dam increased steadily during the 2013 study period with a mean of 16.5°C (range 10.7-21.7°C, Figure 5). Spillway discharge averaged 90.1 kcfs (range 41-135 kcfs), and mean dissolved gas levels were 880.6 mmHg (range 833-915 mmHg; Figures 6-7).

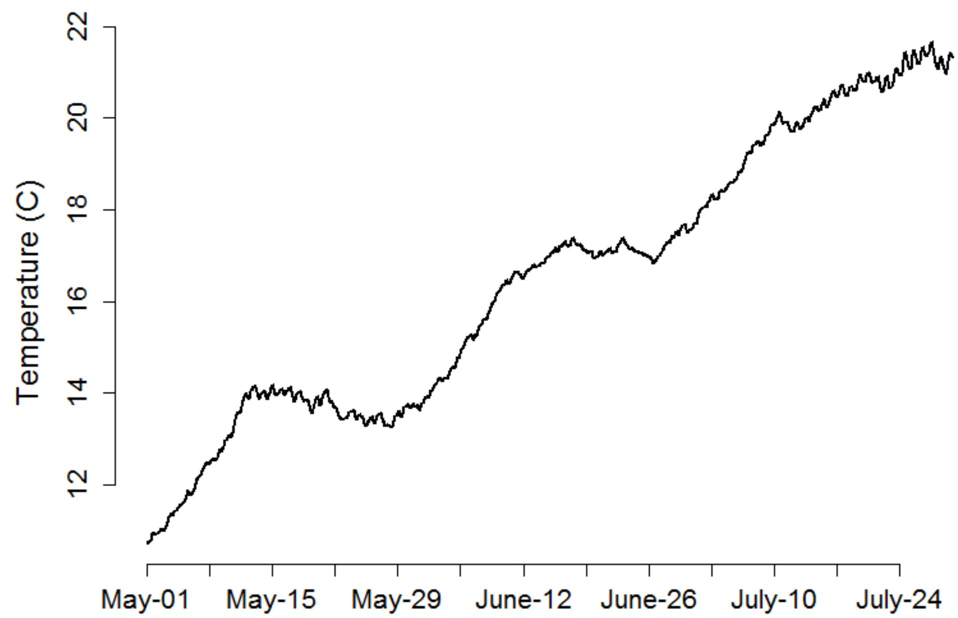

Figure 5. Hourly water temperature recorded at The Dalles Dam during May and July 2013 (CRDART 1996).

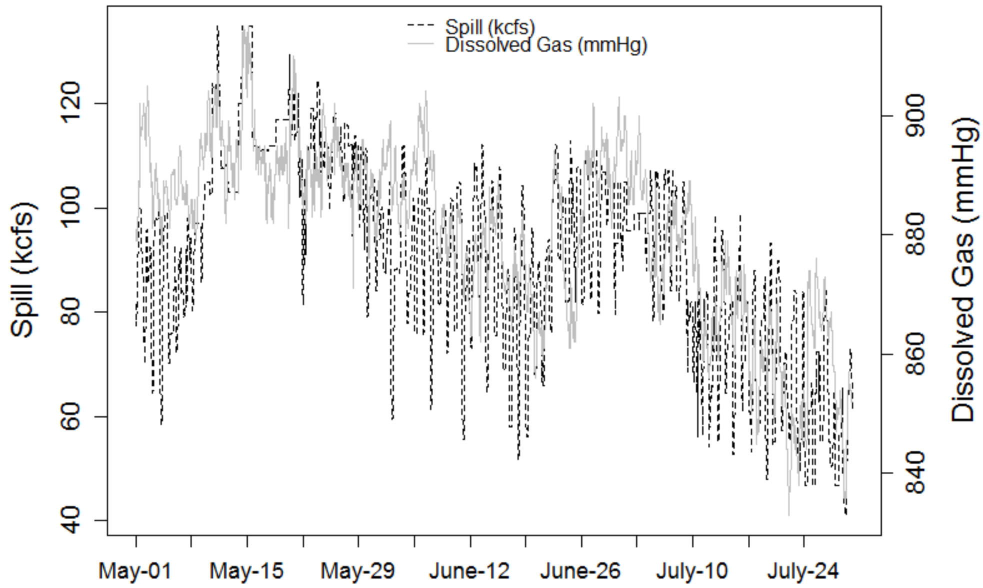

Figure 6. Spill and dissolved gas (in-water pressure, in mmHg) recorded at The Dalles Dam during May and July 2013 (CRDART 1996-).

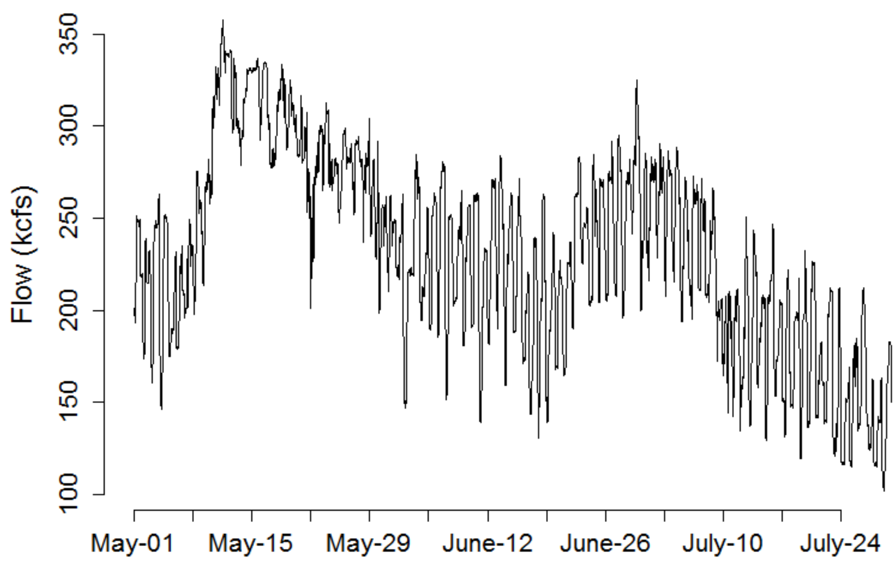

Figure 7. River discharge (outflow) recorded at The Dalles Dam from May through July 2013 (CRDART 1996-).

Summary of Detections at The Dalles Dam

We tagged fish from a wide range of sizes in 2013 (Figure 8), with sockeye salmon (mostly < 60 cm) overlapping Chinook salmon jacks, while adult Chinook salmon ranged from 60 to 100 cm. No salmon were tagged in April at Bonneville Dam due to delays in contracting and funding. Consequently, an early peak in Chinook salmon passage was not included in the radio-tagged samples. Of the 599 tagged adult Chinook salmon released downstream from Bonneville Dam, 521 (87%) were recorded at The Dalles Dam (Table 1). Similarly, of the 301 jack Chinook salmon tagged and released downstream of Bonneville Dam, 261 (87%) were recorded at the Dalles Dam. Initial detection dates at The Dalles Dam ranged from 4 May to 17 July for adult Chinook salmon and from 6 May to 16 July for jack Chinook salmon.

A total of 122,296 adult Chinook salmon were counted passing The Dalles Dam during the initial detection period for tagged salmon, which represented ~0.4% of those counted. During the time when tagged jack Chinook salmon were initially detected at

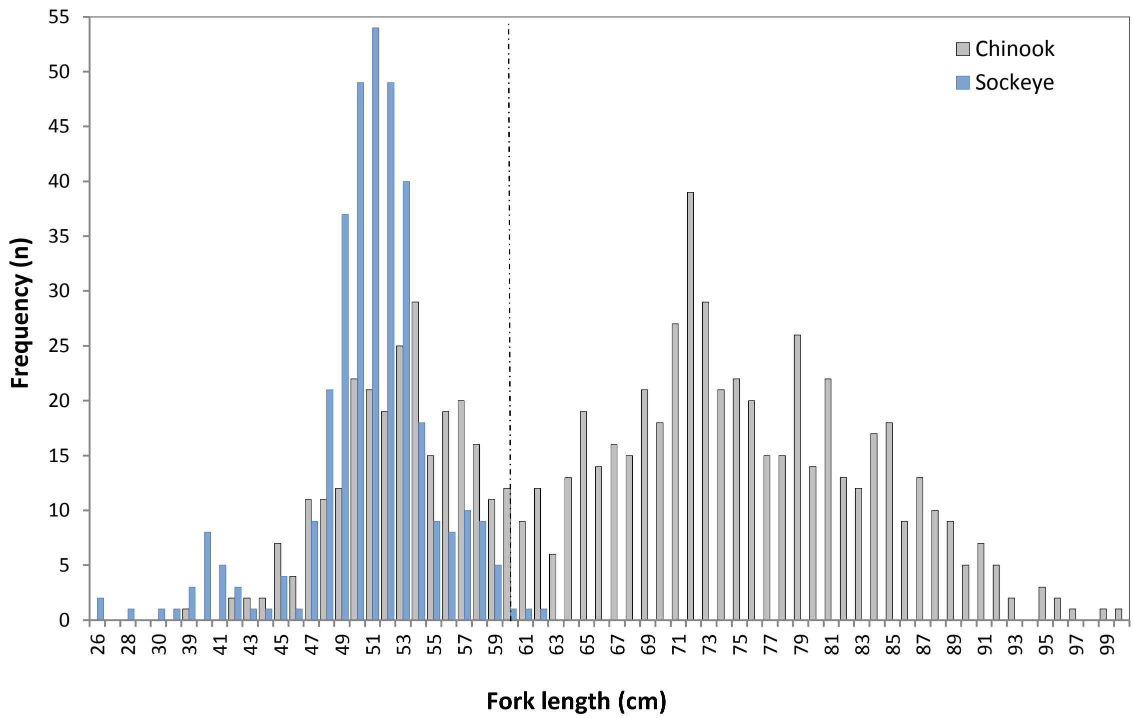

Figure 8. Distribution of fork lengths of radio-tagged spring-summer Chinook and sockeye salmon detected at The Dalles Dam in 2013. The dashed line represents the size cutoff (60 cm) applied to differentiate jack from adult Chinook salmon.

The Dalles Dam, a total of 45,649 jacks were counted passing the dam; tagged jack Chinook salmon represented ~0.6% of this total. Of the 399 sockeye salmon released below Bonneville Dam in 2013, 353 (88%) were recorded at The Dalles Dam, with initial detection dates ranging from 9 June to 14 July. During this period, a total of 149,140 sockeye salmon were counted passing the dam; tagged sockeye salmon represented ~0.2% of this total.

Table 1. Number and percent of radio-tagged jack and adult Chinook salmon and sockeye salmon at The Dalles Dam that were recorded, known to pass the dam, recorded on first passage of the tailrace, first approach at a fishway opening, and first fishway entry, as well as the number recorded passing the ladder tops.

	Radio-tag detections at The Dalles Dam	Frequency (n)	Percent
Jack Chinook salmon	Recorded at dam	261	100
	Known to pass dam	257	98.5
	Recorded first tailrace passage	179	68.6
	Recorded first (known) fishway approach	179	68.6
	Recorded first (known) fishway entrance	118	45.2
	Recorded ladder exit	255	97.7
Adult Chinook salmon	Recorded at dam	521	100
	Known to pass dam	501	96.2
	Recorded first tailrace passage	368	70.6
	Recorded first (known) fishway approach	394	75.6
	Recorded first (known) fishway entrance	250	48.0
	Recorded ladder exit	500	96.0
Sockeye salmon	Recorded at dam	353	100
	Known to pass dam	345	97.8
	Recorded first tailrace passage	311	88.1
	Recorded first (known) fishway approach	188	53.2
	Recorded first (known) fishway entrance	114	32.3
	Recorded ladder exit	342	96.9

Proportional Ladder Use

Adult and jack Chinook salmon**—**With few exceptions, the daily count of adult Chinook passing the dam via the east ladder exceeded the count of adults passing via the north ladder (Figure 9). For Chinook jacks there were no exceptions to this passage pattern during the spring-summer migration season (Figure 10). Of the 521 adult radio-tagged Chinook salmon recorded at The Dalles Dam, 501 passed the dam (Table 1); 138 of the 501 (~28%) were detected passing via the north ladder and 363 (72%) via the east ladder. Of the 261 radio-tagged Chinook jacks recorded at The Dalles Dam, 257 passed the dam; 24 of these 257 (9%) were detected passing via the north ladder and 232 (90%) via the east ladder.

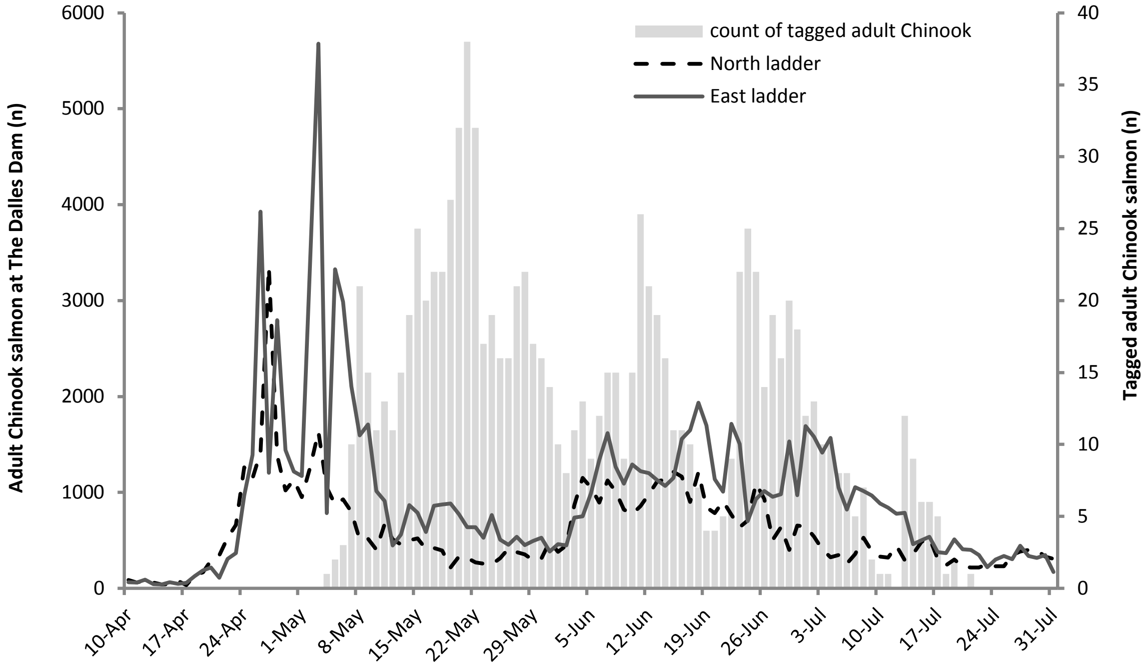

Figure 9. Count of radio-tagged adult Chinook salmon at The Dalles Dam in 2013 relative to overall adult Chinook salmon passage counts by ladder.

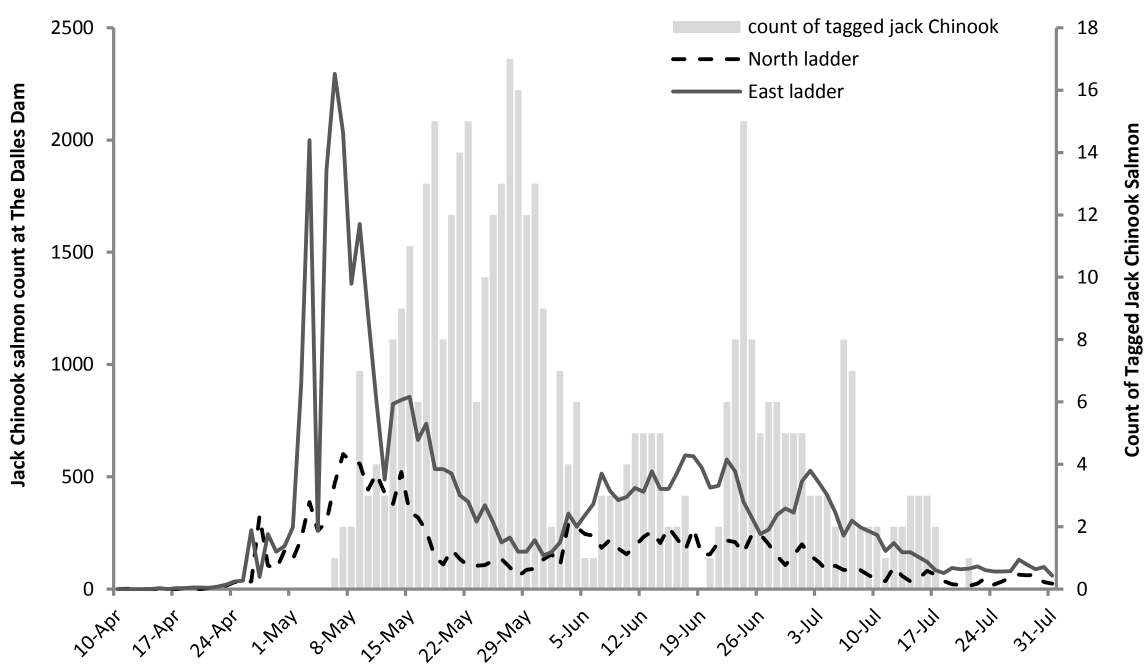

Figure 10. Count of radio-tagged Chinook jacks at The Dalles Dam in 2013 relative to overall Chinook jack passage counts by ladder.

Detection efficiencies of behavioral events were high for most metrics (Table 1), though first entrance detections were consistently less than 50%, particularly at the east fishway opening. A total of 49 fallback events were recorded for 42 unique radio-tagged adult Chinook salmon (fallback percentage = 8.4%), while 16 fallback events were recorded for 14 unique radio-tagged jack Chinook salmon (fallback percentage = 5.4%). For adult Chinook salmon, 29 first-fallback events were preceded by dam passage via the east ladder (8.0% of first-passage events resulted in fallback) and 11 were preceded by dam-passage events via the north ladder (8.0%). Among first fallbacks observed for jack Chinook salmon, one followed dam passage via the north ladder (4.2%) and 13 followed dam passage via the east ladder (5.6%). No post-fallback data were evaluated as part of this report.

***Sockeye salmon*—**Sockeye salmon passed The Dalles Dam primarily using the east ladder (Figure 11), with only a single day exception. Of the 353 adult radio-tagged sockeye salmon recorded at The Dalles Dam, 345 passed the dam (Table 1). Of these 345, 35 (10%) passed via the north ladder and 308 (89%) passed via the east ladder; 2 adult sockeye passed undetected. Detection efficiency at fishway entrances was especially low (32.3%) for tagged sockeye salmon, though a high percentage of behaviors such as tailrace entrance and ladder passage was detected for these fish (Table 1).

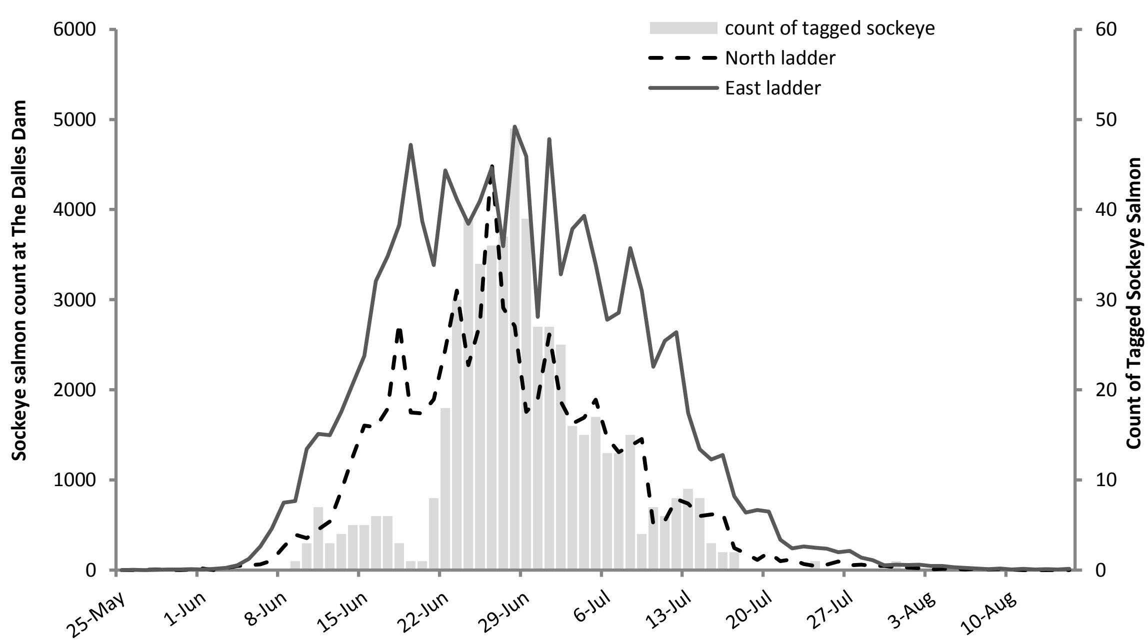

Figure 11. Count of radio-tagged sockeye salmon at The Dalles Dam in 2013 relative to overall sockeye passage counts by ladder.

A total of 10 fallback events were recorded for radio-tagged salmon, with no individuals falling back more than once (fallback percentage = 2.9%). All fallback events by sockeye salmon were recorded after fish passed via the east ladder and after 3.2% of first-passage events from this fishway. No post-fallback data for sockeye salmon were evaluated as part of this report.

Passage Time and Environmental Predictors

For adult Chinook salmon, median time from first tailrace detection to first detection on a fishway approach was 3.8 h (n = 138) in May, 3.6 h in June (n = 114), and 2.9 h (n = 31) in July 2013 (Table 2). These median times were near the averages over the 11 study years. In 2013, median time for adult Chinook salmon to pass The Dalles Dam (first tailrace detection to ladder top) was the longest of all years in June, but the shortest of all years in July.

For Chinook salmon jacks and sockeye salmon, passage times through the various segments tended to fall within the range of values for adult Chinook salmon. Note that there were no comparison data from previous years for jack Chinook salmon, and only a single year of comparison data for sockeye salmon (1997, a year with exceptionally high river discharge and spill).

Passage times from tailrace to first fishway entrance were associated with the time of day during which salmon were first detected in the tailrace, as shown in Figure 12 for adult Chinook, Chinook jacks, and adult sockeye salmon. For all study groups, median time between first detection in the tailrace and first detection in a fishway entrance was shorter for fish detected in the tailrace before 1600 than for those detected after 1600. A higher proportion of fish entered the tailrace before 1600 in all study groups as well.

For adult Chinook salmon first detected in the tailrace before 1600, median time from tailrace to first entrance was 4.4 h (n = 138) vs. 12.2 h (n = 42) for those first detected after 1600 h. For jack Chinook salmon detected on tailrace monitors before 1600, median time to first approach was 4.2 h (n = 59) compared with 12.7 h for those first detected after 1600 (n = 17). Likewise, sockeye salmon first detected in the tailrace before 1600 had a median time to entry of 4.2 h (n = 68), while those with first detections in the tailrace after 1600 had a median time to entry of 10.2 h (n = 30).

Table 2. Median time for adult radio-tagged spring/summer Chinook salmon from first detection in the tailrace to first detection on a fishway approach, fishway entrance, or ladder exit (indicating passage at The Dalles Dam). Time from first detection at a fishway approach to first detection at a fishway entrance is also shown by month during spring/summer migration period. Rank among years is shown at right for 2013 values, with 1 being the shortest time and 11 being longest.

	Median time for adult spring/summer Chinook salmon passing The Dalles Dam (h)																						
	1997		1998		2000		2001		2002		2003		2004		2007		2009		2010		2013		
	N	Med	N	Med	N	Med	N	Med	N	Med	N	Med	N	Med	N	Med	N	Med	N	Med	N	Med	Rank
Tailrace to first approach																							
April	125	11.6	147	5.2	199	7.1	295	4.2	147	9	179	4.7	56	3	2	8.2	1	12	51	2.9			
May	242	6.2	229	3.1	210	4.3	238	3.7	311	4.1	158	3.4	121	3.1	66	4.7	212	4.8	122	3.3	**138**	**3.8**	**6**
June	87	3.6	100	3.7	96	3.4	136	2.8	155	3.6	135	3.4	92	3.3	115	3.8	170	4	93	5	**114**	**3.6**	**4.3**
July	118	2.6	67	2.5	54	3.2	114	2.7	94	3.5	136	3.1	53	2.8	3	2.9	7	4.5	5	3.5	**31**	**2.9**	**4.5**
Tailrace to first entry																							
April	101	71.1	132	20	172	22.8	271	13.8	140	27	165	11.2	48	4.1	2	11.6	1	17.1	45	3.6			
May	186	33.8	203	10.1	200	12.1	186	6.8	300	12	156	5.3	112	4	62	5.5	221	9.3	99	4.2	**82**	**5.8**	**5**
June	68	5.5	72	8.8	94	5.2	136	4.1	149	5.8	132	4.3	88	5.7	96	4.2	172	5.7	81	7.6	**77**	**6.0**	**9**
July	100	3.1	58	4.1	53	5.3	114	3.6	92	6	135	4.2	52	3.1	3	5.8	9	6.2	5	5.8	**21**	**3.8**	**4**
Tailrace to ladder exit																							
April	118	98.2	141	47.1	198	34.1	290	24.7	144	41.1	182	17.4	56	9.4	9	8.8	1	28.5	45	8.5			
May	221	53.1	222	22	205	22.3	238	19.7	304	19.8	160	13.5	121	13	100	14.6	223	15.6	127	11.3	**171**	**19.3**	**6**
June	83	18.1	98	20.3	96	12.8	138	15.1	154	20.6	136	18.1	92	20.5	112	19.8	177	15.7	107	13.8	**139**	**20.7**	**11**
July	133	12.7	69	14.3	55	15.2	111	14.6	95	17.6	139	13.4	53	11.6	2	29.7	17	13.6	6	11.7	**40**	**9.4**	**1**
First approach to first entry																							
April	101	41.2	133	8.6	172	11.4	271	4.1	140	14.8	218	3	60	0.2	8	< 0.1	1	5.1	72	0.2			
May	186	21	203	3.6	200	5.6	186	1.6	300	3.7	224	0.9	127	0.5	105	0.1	230	1.2	142	0.2	**110**	**0.9**	**3.5**
June	68	0.5	72	0.2	94	0.5	136	0.2	149	0.6	192	0.3	99	0.7	155	< 0.1	183	0.3	98	<0.1	**103**	**0.6**	**8.5**
July	99	0.2	58	<0.1	53	0.4	114	0.3	92	1.2	170	0.2	54	0.2	3	2.9	10	0.1	7	0.1	**37**	**0.1**	**1.3**

* Data for 1997-1998 and 2000-2001 from Keefer et al. (2007); for 2002 from Wilson et al. *unpublished data*; for 2003 from Boggs et al. *unpublished data*; for 2004, 2007, and 2009-2012 from Jepson et al. (2011).

Table 3. Median time (h) from first detection in the tailrace to first detection on a fishway approach, fishway entrance, or ladder exit (indicating passage) at The Dalles Dam for sockeye salmon and Chinook salmon jacks. Also shown is time from first detection on a fishway approach to first fishway entry by month of first detection at the Dalles Dam in 2013 vs. 1997.

	Sockeye salmon					
	1997*		2013		Chinook jacks	
	N	Median	N	Median	N	Median
Tailrace to first approach						
May					62	4.1
June	120	2.4	110	4.1	45	3.8
July	211	2.7	55	4	14	6.1
Tailrace to first ladder entry						
May					41	5.4
June	104	2.4	65	5	27	4.7
July	181	2.7	33	3.5	8	6.6
Tailrace to ladder exit						
May					92	17.1
June	152	9.3	200	11.9	61	13
July	258	7.3	100	10.6	22	12.2
First approach to first entry						
May					68	0.4
June			74	0.4	37	1.1
July			40	<0.1	13	0.1

* 1997 data from Keefer et al. (2005)

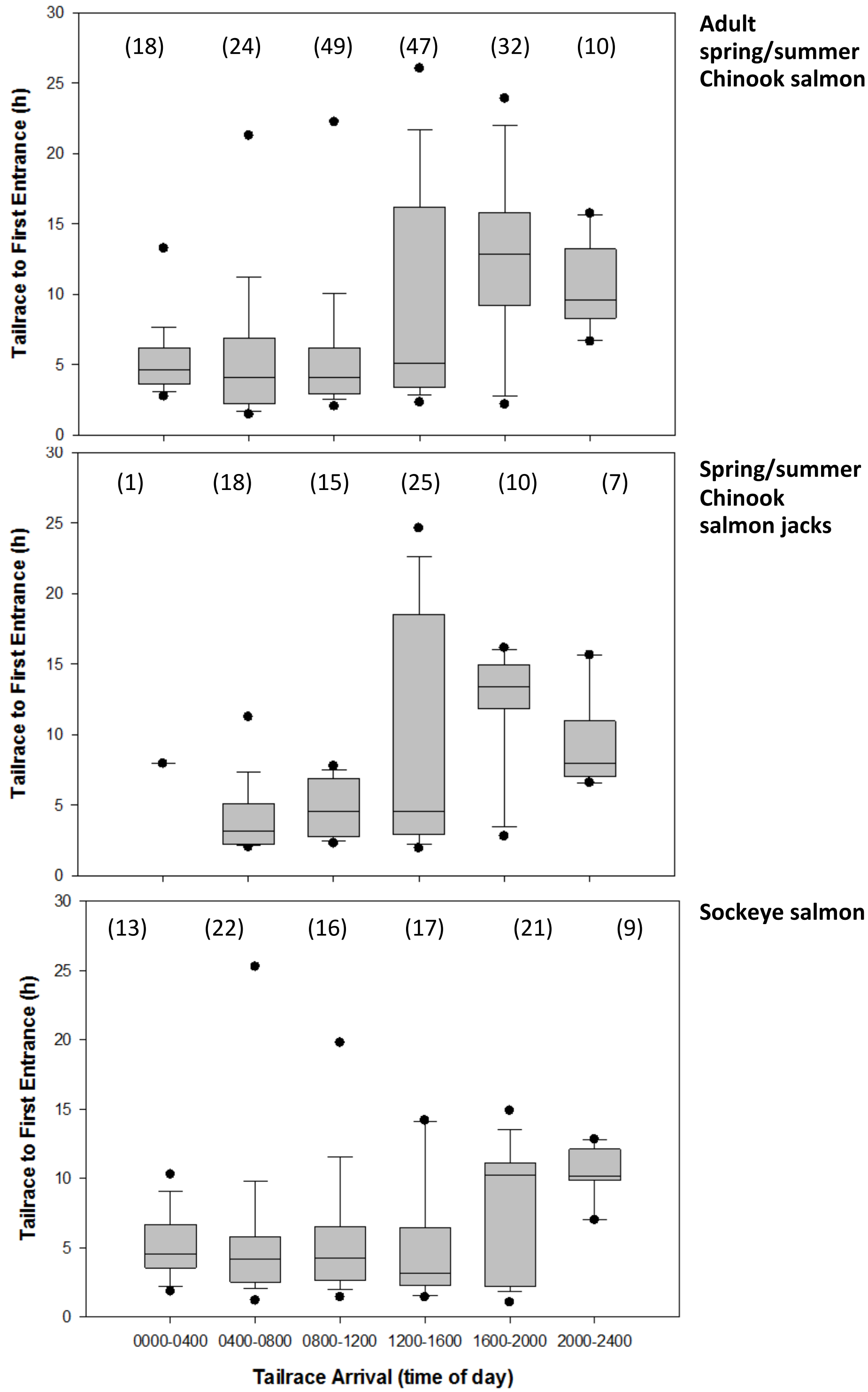

Figure 12. Passage time (h) as a function of time of day from entry in the tailrace to first detection in a fishway at The Dalles Dam, 2013. Boxes indicate quartiles, lines indicate median, whiskers indicate 10^{th} and 90^{th} percentiles, and dots (•) indicate 5^{th} and 95^{th} percentiles. Sample sizes are shown above boxes for adult Chinook (top), Chinook jacks (middle), and sockeye salmon (bottom).

Route-Specific Time to Enter

The distance between the tailrace antenna on the north shore and the north fishway opening (about 3.1 km) differed from the distance between the tailrace antenna on the south shore and the east fishway opening (about 5.6 km). Therefore, we expected travel times from F1 to E1 to be longer for fish moving along the south shore. In all three groups analyzed, travel times were indeed longer on the south side of the river (Figure 13, Table 4). Travel times were about twice as long for adult Chinook on the south side relative to the north side, all else being equal. But for Chinook jacks and sockeye, fish traveling on the south side took about five times as long as fish traveling on the north side.

Among all groups, travel time was longer for those that entered the tailrace at night (Table 4). Adult Chinook and sockeye salmon passage time were both associated with dissolved gas concentration, but in opposite ways (adult Chinook were slightly faster at higher dissolved gas levels, while sockeye salmon were slower). There was also a seasonal effect for adult Chinook, with fish that arrived late traveling slightly faster than those that arrived early in the run.

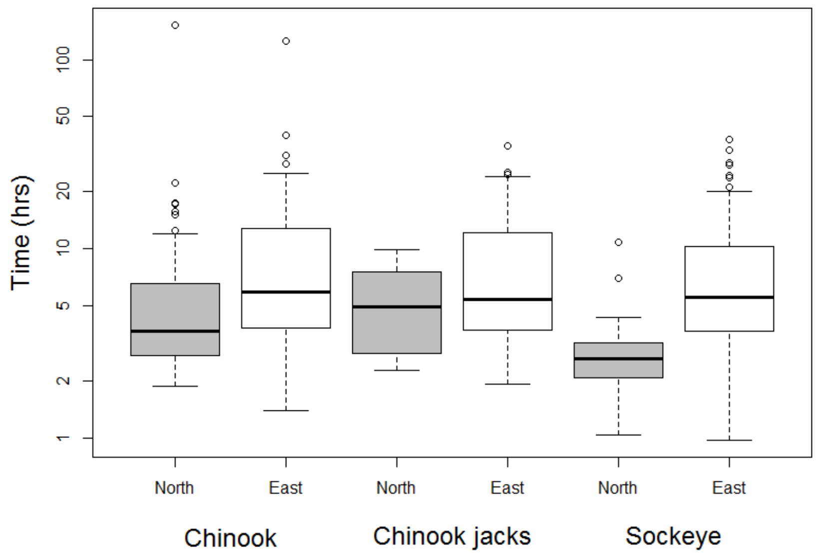

Figure 13. Travel time between first detection on a tailrace entry monitor and first detection on a fishway entrance for fish that entered the north vs. east ladder at The Dalles Dam, 2013. Note that most fish traveled along the south shoreline before entering the east fishway.

Table 4. Covariate parameter estimates from AFT models of travel time from first detection downstream of the dam (F1) and first fishway entrance (E1). *Time ratio* is the proportional change in travel time for a given unit change in the covariate value (e.g., adult Chinook salmon used 99% of time to travel from F1 to E1 as those entering the previous day and entry time in the north ladder was about 51% of entry time in the east ladder). Only covariates that were in the best model (i.e., the model with the lowest AIC) are shown.

	Adult Chinook (N = 349)			Chinook jacks (N = 174)			Sockeye (N = 304)		
	Estimate	SE	Time ratio	Estimate	SE	Time Ratio	Estimate	SE	Time ratio
Date	-0.01	0.00	0.99						
Night	1.04	0.15	2.83	1.51	0.29	4.51	1.09	0.20	2.98
North fishway	-0.67	0.14	0.51	-1.30	0.26	0.27	-1.69	0.18	0.19
Switched				0.32	0.20	1.38			
Length									
Temperature									
Spill									
Dissolved gas	-0.01	0.01	0.99				0.01	0.01	1.01

Proportional Use of the North Fishway

The percentage of tagged Chinook salmon detected at the north fishway averaged 52% during 1997-2004 (range 43-67%, Figure 14). In contrast, relatively small percentages (14-18%) were detected at the north fishway in 2007 and 2009, and an intermediate percentage (34%) was detected there in 2010. Passage via the north fishway in 2013 was also intermediate for tagged adult Chinook salmon, which used this route 30% of the time. Use of the north fishway by jack Chinook and sockeye salmon was low/minimal (11% each; Figure 14).

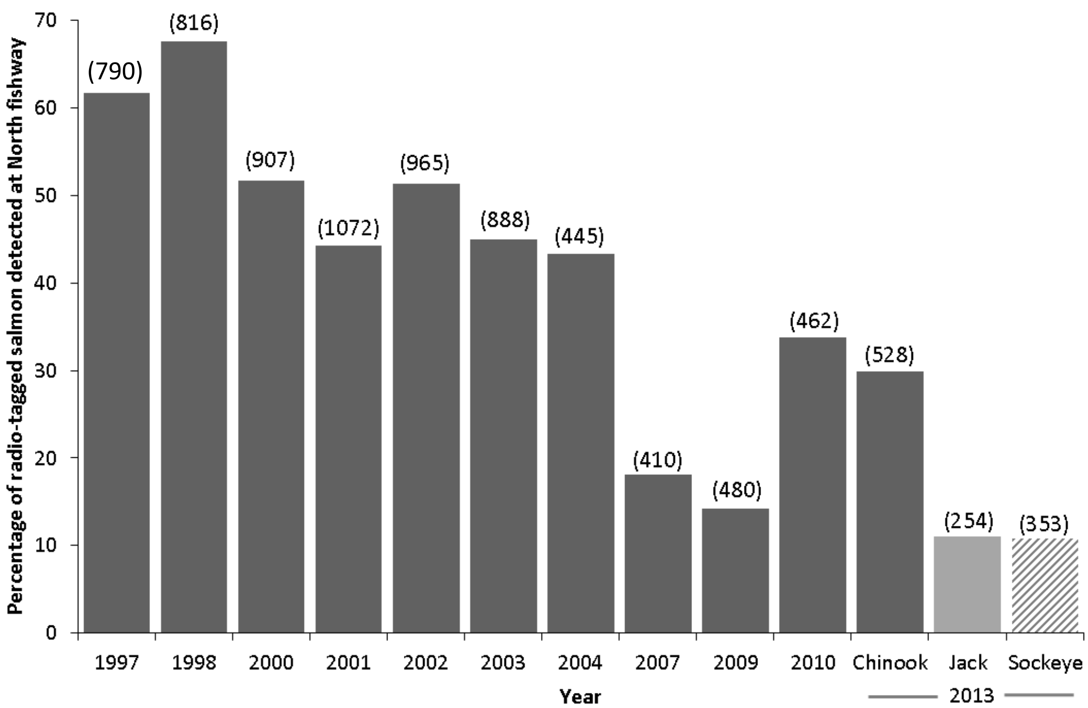

Figure 14. Percentage of radio-tagged adult spring-summer Chinook detected at The Dalles Dam north fishway in 2013 vs. 10 previous study years. Data for Chinook jacks and sockeye salmon in 2013 are also shown. Total sample sizes detected at the dam are in parentheses above each bar.

Route-Specific Approaches and Entrances

The proportion of fish using the north side of the river downstream from the dam (at the F1 sites) varied by species and age class. About 15% of adult Chinook salmon and 19% of Chinook jacks used the north side, while over half of the sockeye salmon used the north side of the river at the time of their first F1 detection (Table 5). For adult Chinook salmon, the proportion on the north side dropped only slightly as fish progressed up to the dam and entered the fishway. However, for Chinook jacks and sockeye salmon, there was a larger drop in the proportion of the fish on the north side for approaches and entrances into a fishway.

Table 5. Proportions of fish first detected on the north tailrace antenna (F1), at the north fishway opening during their first fishway approach (A1), and at the north fishway on their first fishway entrance (E1).

	Proportion detected (%)		
North fishway	Chinook	Chinook jack	Sockeye
First tailrace detection F1	0.15	0.19	0.53
First detection at fishway opening A1	0.10	0.04	0.06
First detection at fishway entrance E1	0.12	0.04	0.06

Several environmental covariates were associated with the proportion of fish that entered the tailrace on the north side of the river and first approached and entered the north fishway. For adult Chinook and sockeye salmon, fork length was consistently important in the models, with larger fish more likely to use the north side (Figure 15, Table 6). However, length was not important for Chinook salmon jacks, perhaps because there was not enough variability in length among jacks to detect an effect.

For all three groups, more fish were first detected on the north downstream antenna (F1) as the season progressed, but date did not influence the side of the river once fish approached or entered the fishways. Spill was consistently related to lower use of the north side for first fishway approaches (A1) for all three groups (Figure 16). Although spill dropped out of the model for first fishway entrances (E1), higher dissolved gas (which was correlated with spill) was associated with lower use of the north fishway for jack Chinook salmon. Temperature was important in some models, but there was not a consistent response among species or activities (see Figure 17 for effect of temperature for adult Chinook salmon).

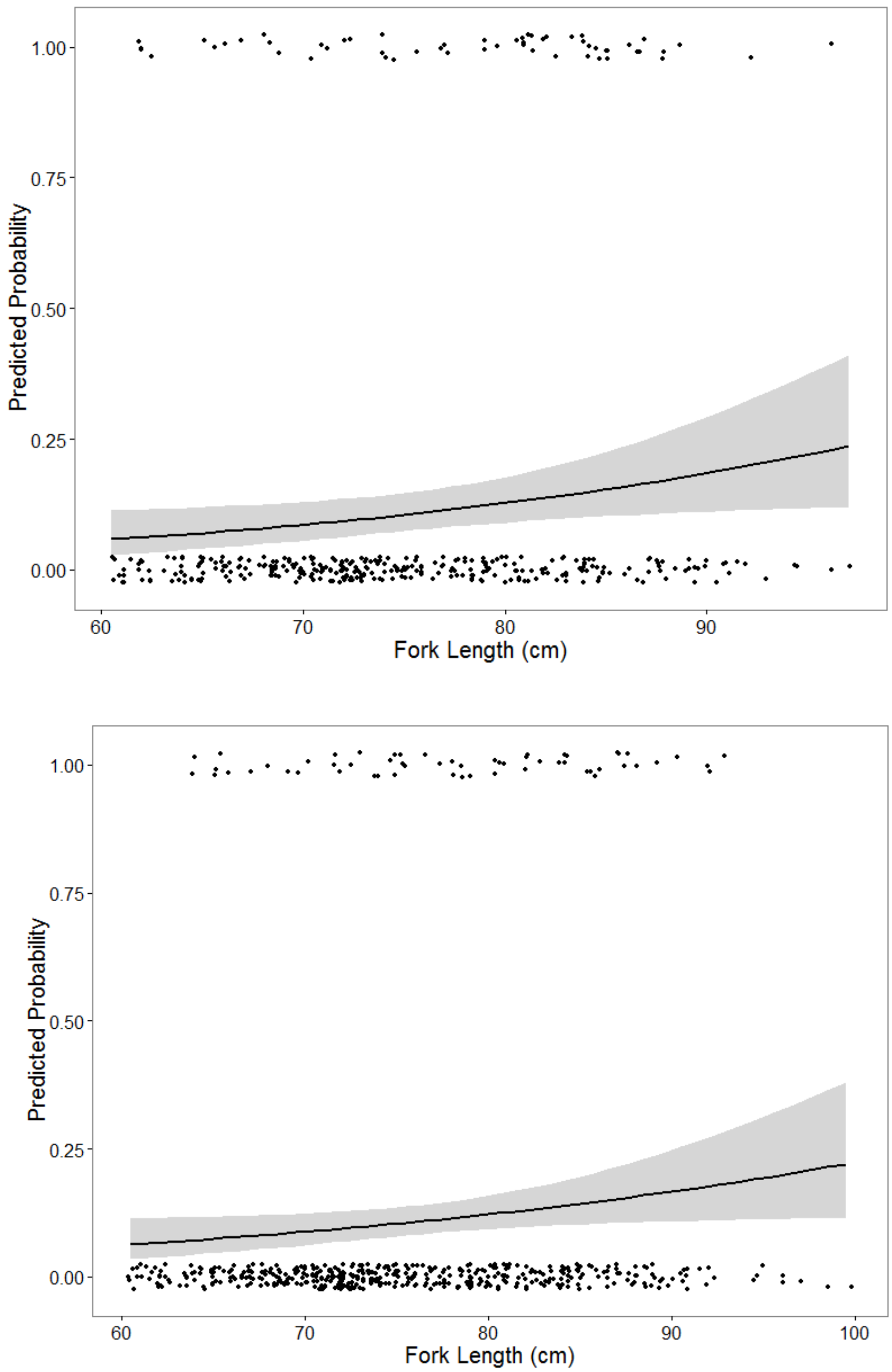

Figure 15. Predicted probability that adult Chinook salmon would first be detected at the tailrace site on the north side of the river (F1; top panel) and would first enter the north fishway (E1; bottom panel. Black dots represent individual fish that were first detected on the north side (jittered around 1 on the Y axis) and fish that were first detected on the east side (jittered around 0). Grey area represents ±1 standard error. Black line is the mean predicted probability.

Estimated covariate values (Table 6) represent the expected change in proportion of fish using the north side per unit increase in the covariate value. Therefore, these estimates cannot be compared across covariates. Most passage metrics were measured within a temperature range of 1-2°C, so the estimated parameter per unit (°C) was fairly large. For example, there was a 54% drop in the proportion of adult Chinook using the north side per 1-degree increase in temperature. In contrast, differences in fish length spanned over 30 cm, so individual increments had a seemingly smaller impact. For example, a there was a 4% increase in the proportion of adult Chinook using the north side per 1-cm increase in fish length.

We did not analyze the data in a way that would have standardized effect size across covariates because we wanted to keep measures of impact in the same units as the covariates themselves. Each value listed in Table 6 contributed significantly to model fit based on AIC—variables that did not improve AIC ranking (i.e., were not important in the model fit) were left blank.

Table 6. Covariate parameter estimates from logistic regression models of the likelihood of first detections at the north tailrace (F1) or north fishway approach (A1) and of first entrances at the north fishway (E1). Each estimate is the expected change in probability of using the north side per unit change in the parameter. Only covariates fits from the best model are shown.

	Adult Chinook		Chinook jack		Sockeye	
North fishway	Estimate	SE	Estimate	SE	Estimate	SE
First detection at north tailrace (F1)						
Sample size	n = 367		n = 179		n = 311	
Length	0.04	0.02			0.08	0.03
Night						
Date	0.12	0.03	0.03	0.01	-0.08	0.04
Temperature	-0.54	0.28			1.00	0.33
Flow	0.02	0.01			0.03	0.00
Spill						
Dissolved gas						
First detection at north fishway approach (A1)						
Sample size	n = 504		n = 257		n = 346	
Length	0.04	0.02			0.19	0.07
Night						
Date						
Temperature						
Flow						
Spill	-0.02	0.01	-0.06	0.02	-0.09	0.02
Dissolved gas						
First entrance at north fishway (E1)						
Sample size	n = 500		n = 256		n = 346	
Length	0.04	0.02			0.18	0.07
Night						
Date						
Temperature	0.18	0.06				
Flow					-0.03	0.01
Spill						
Dissolved gas			-0.07	0.02		

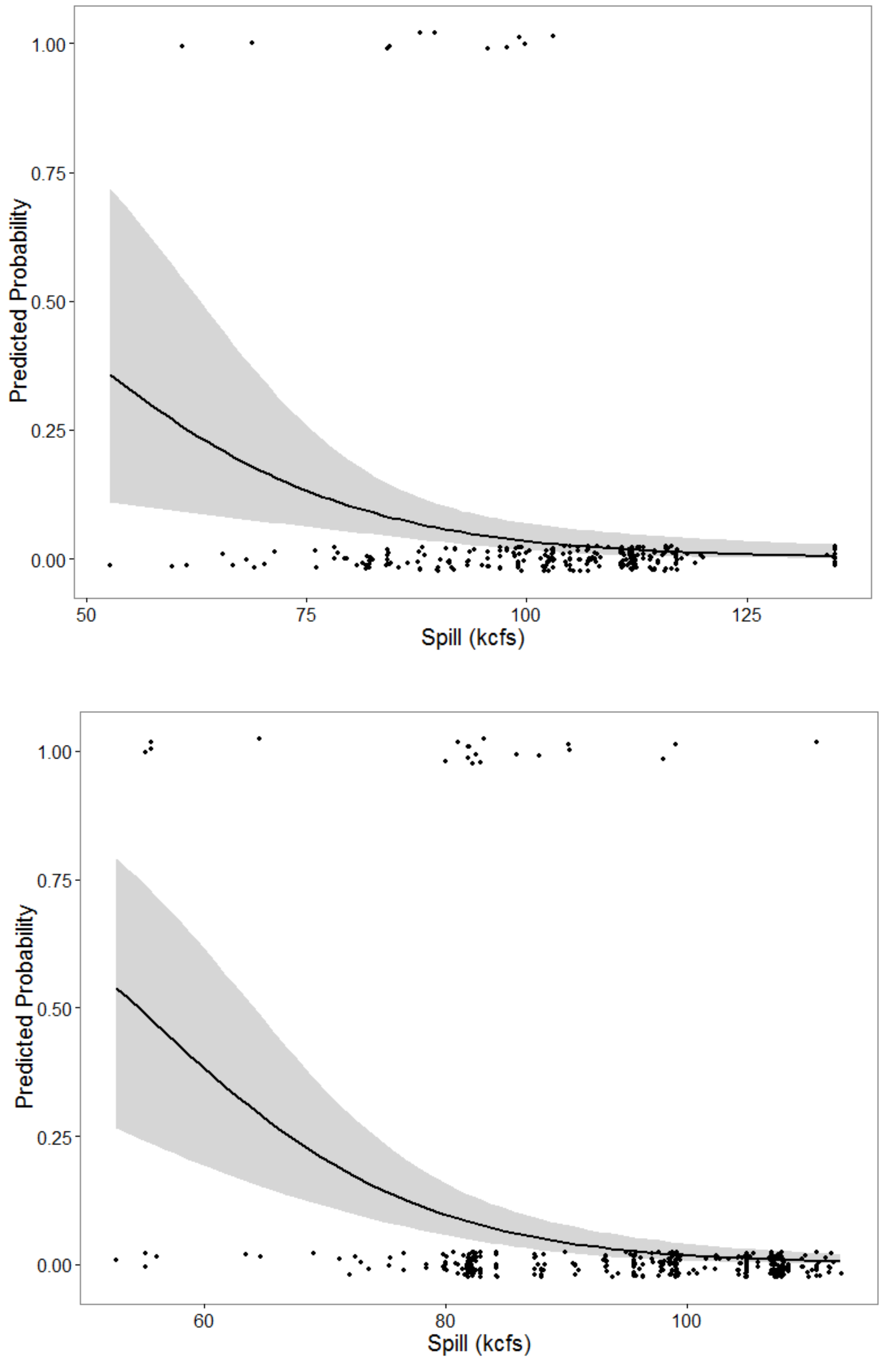

Figure 16. Predicted probability that Chinook salmon jacks (top) and sockeye salmon (bottom) would first approach The Dalles north fishway (A1) as a function of discharge. Black dots represent individual fish that were first detected on the north side (jittered around 1 on the Y axis) and fish that were first detected on the east side (jittered around 0). Grey area represents ±1 standard error. Black line is the mean predicted probability.

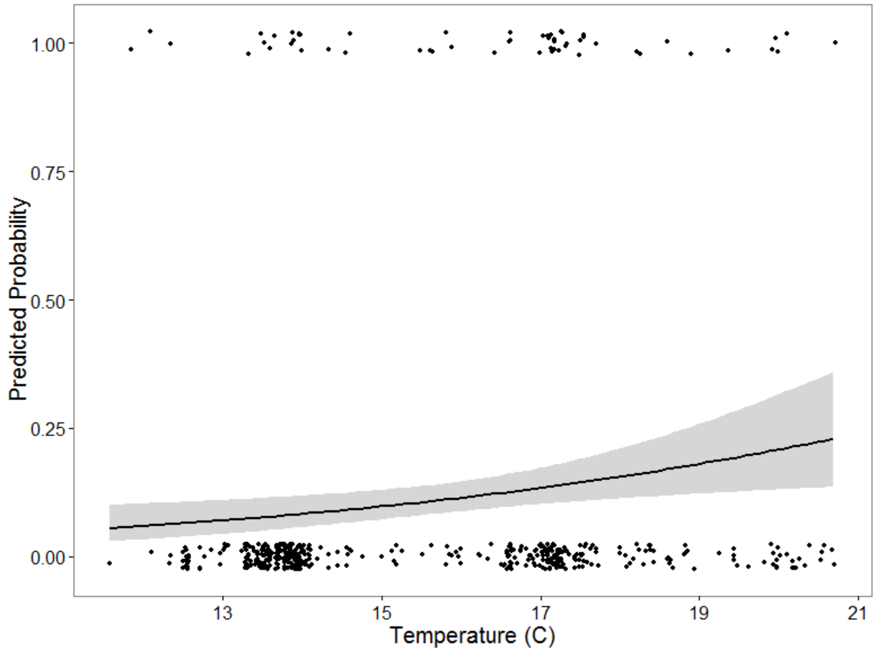

Figure 17. Predicted probability that adult Chinook salmon would first enter The Dalles north fishway (E1) as a function of water temperature. Black dots represent individual fish that were first detected on the north side (jittered around 1 on the Y axis) and fish that were first detected on the east side (jittered around 0). Grey area represents ±1 standard error. Black line is the mean predicted probability.

Side Switching

The vast majority (85-93%) of fish that entered the tailrace on the north side of the river switched sides in order to make their first entry at the east fishway (Table 7). Conversely, fish first detected on the east side were much less likely to switch sides before entering a fishway, particularly for jack Chinook and sockeye salmon.

Table 7. Proportion of fish that switched sides of the river between tailrace entry (F1) and first fishway entry (E1).

	Adult Chinook	Chinook jack	Sockeye
From north to east	0.86	0.85	0.93
From east to north	0.15	0.05	0.07

Several covariates were associated with side switching. For adult Chinook and sockeye salmon, larger fish were less likely to switch from north to east sides, but length was not associated with switching for Chinook salmon jacks. Fish length was not associated with switching from east to north sides for any fish group (Table 8).

Higher spill was associated with increased switching from north to east sides and with decreased switching from east to north sides (Figure 18). Flow and spill were too highly correlated with one another to test in the same model, but increased flow was related with increased switching of sockeye salmon from east to north, just as spill was related with east-to-north switching by Chinook salmon. We did not find any significant interactions between fish size and spill. Interestingly, Chinook salmon jacks switched from east to north more often at night than during the day, all else being equal.

Table 8. Covariate parameter estimates from logistic regression models of the likelihood that salmon would switch the side of the river used between first detection downstream of the dam (F1) and first fishway entrance (E1). Each estimate is the expected change in the probability of switching for a unit change in the parameter (e.g., adult Chinook salmon were 9% less likely to switch sides from the north to the east for each 1-cm increase in fish size). Only covariates that were in the best model (according to AIC) are shown. Sample size (*n*) is shown as the first value.

	Adult Chinook		Chinook jack		Sockeye	
	Estimate	SE	Estimate	SE	Estimate	SE
From north to east	n = 56		n = 34		n = 165	
Length (cm)	-0.09	0.06			-0.33	0.11
Night[a]						
Date[b]						
Temperature (°C)						
Flow (kcfs)						
Spill (kcfs)	0.07	0.04	0.09	0.04		
Dissolved gas (mmHg)	-0.09	0.05			0.07	0.03
From east to north	n = 311		n = 145		n = 146	
Length (cm)						
Night[a]			1.43	0.87		
Date[b]						
Temperature (°C)						
Flow (kcfs)					-0.04	0.01
Spill (kcfs)	-0.02	0.01	-0.07	0.03		
Dissolved gas (mmHg)						

[a] Daytime passages were those detected between 0500 and 1700 PDT; nighttime passages were between 1700 and 0500 the following day.

[b] Adult and jack Chinook were tagged 2 May-15 July 2013. Sockeye were tagged 7 June-13 July.

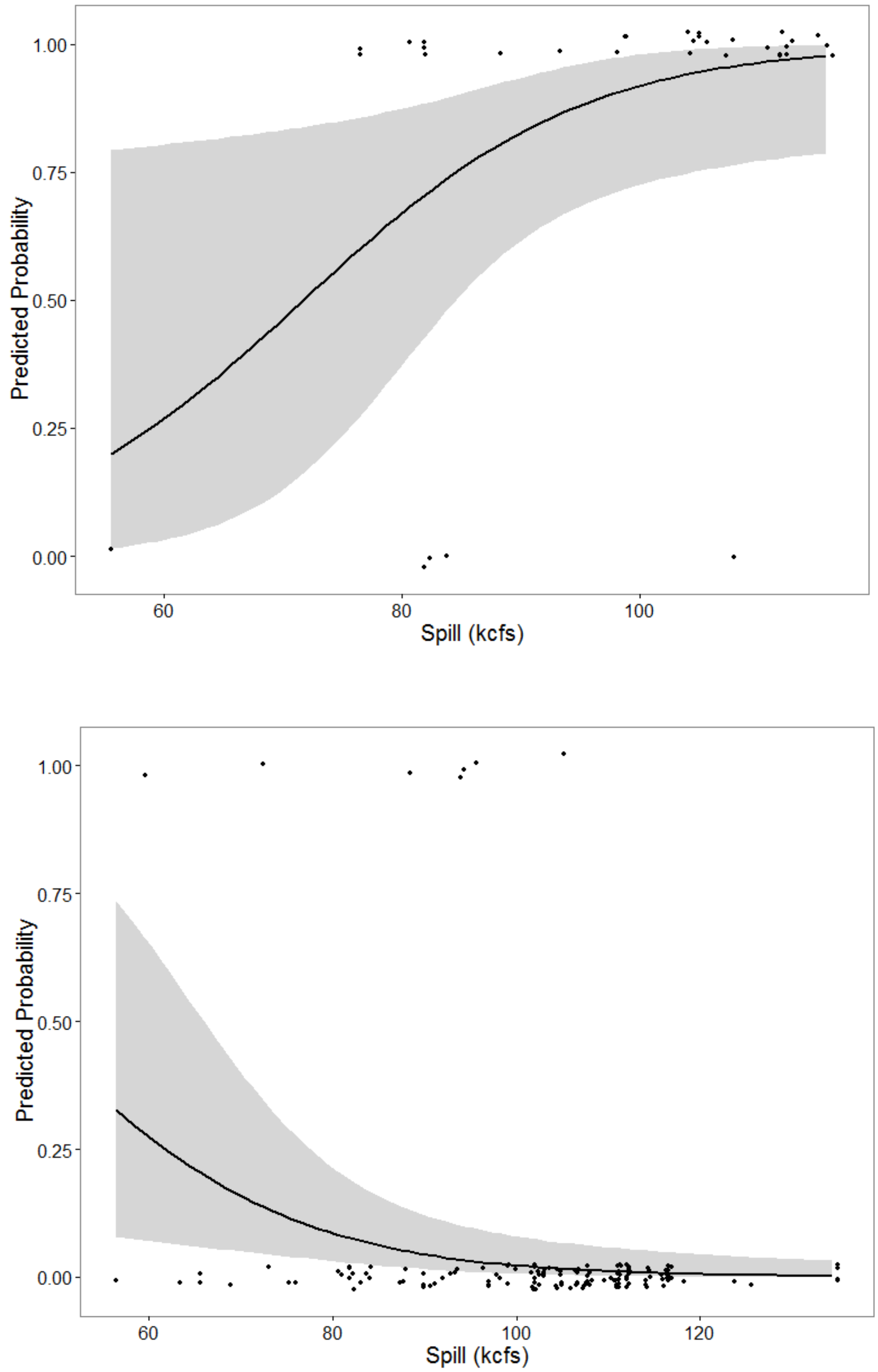

Figure 18. Predicted probability that Chinook salmon jacks would switch sides from north to east (top) vs. from east to north (bottom) as a function of spill. Black dots represent individual fish that switched sides (jittered around 1 on the Y-axis) and fish that did not switch (jittered around 0). Grey area represents ±1 standard error. Black line is the mean predicted probability.

Entrance Efficiency

Forty-eight adult Chinook salmon were recorded first approaching the north fishway, and 46 of these fish first entered the north fishway (entrance efficiency 95.8%, Table 9). Similarly, 10 of 11 Chinook salmon jacks that first approached the north fishway also first entered there (efficiency 90.9%). Entrance efficiency was near 100% at the east fishway for both Chinook salmon groups and was 100% at both fishways for sockeye salmon (Table 9).

High entrance efficiencies at both fishways for all groups prevented any analyses relative to environmental covariates. However, results suggest that tagged salmon had little or no difficulty entering the north fishway after they had approached the fishway entrance.

Table 9. Entrance efficiency (first site entered/first site approached) for each fishway.

		Number first approaching	Entrance efficiency (%)
North side	Adult Chinook	48	95.8
	Chinook jack	11	90.9
	Sockeye	21	100.0
East side	Adult Chinook	456	97.1
	Chinook jack	246	99.2
	Sockeye	325	100.0

Discussion

The results of these evaluations were broadly consistent with the hypothesis that high spill volumes at The Dalles Dam reduce use of the north fishway by Chinook and sockeye salmon. However, use of the north side of the river was low, even at the tailrace monitoring site, which was several kilometers downstream from the dam. Furthermore, even among the relatively small number of fish using the north side of the river, many switched to the east side, and this behavior was associated with spill and dissolved gas levels.

However, as Jepson et al. (2011) reported, differences in fishway selection appeared to have relatively limited effects on overall fishway entrance efficiency or on overall dam passage time. In previous studies, high spill volume (Boggs et al. 2004; Keefer et al. 2004; Caudill et al. 2006) and some spill patterns (Jepson et al. 2009) have slowed adult Chinook salmon passage at Columbia and Snake River dams.

Radio-tagged salmon used the north fishway less frequently in 2013, but they did not appear to spend undue amounts of time seeking and finding alternate passage routes, a finding which was consistent with that of Jepson et al. (2011). Dam passage times for radio-tagged Chinook and sockeye salmon at The Dalles Dam in 2013 were about average relative to results from previous study years.

Over 85% of salmon detected on the north side of the river downstream from The Dalles Dam eventually switched sides and entered the east fishway. However, the new spill wall did not appear to excessively impede the ability of salmon to find alternate passage routes, even when spill volumes were high. Salmon that were recorded on the north shore at F1 tailrace sites and that subsequently switched sides had median fishway entry times (F1 to E1) similar to those of fish that did not switch. For example, adult Chinook salmon that switched sides entered a fishway 1 h sooner than those that did not switch, while sockeye salmon that switched sides entered a fishway 0.6 h later than those that did not switch.

Our findings support the observation from count data that smaller-bodied adults are less likely to use the north fishway. Model results indicated length was a predictive covariate of side-switching for adult Chinook and sockeye salmon, but not for Chinook jacks. However, had we modeled adult Chinook salmon and the smaller Chinook jacks and sockeye salmon together, the size effect likely would have been more pronounced for Chinook jacks.

Spill tended to have a more consistent effect on side switching for all three groups, with switching increasingly likely as spill increased. Reduced use of the north fishway is of concern to managers for small-bodied fish because approaches to the north fishway could be associated with delay or passage failure if smaller adults must search for an upstream passage route after not finding or rejecting the north fishway entrance. However, we found little evidence that side-switching was associated with additional passage time or energetic expenditure. While passage times to the east ladder were slightly longer, this was likely an effect of the longer distance traveled from the tailrace receivers to entrances at the east ladder.

In a previous analysis (e.g., Bjornn et al. 2000), 9.2% of the north-ladder migrants fell back over the dam compared to 2.3% of the east ladder migrants. In general, we did not see this difference in fallback rates between fishways in 2013. Adult Chinook salmon fallback rates were ~8% at both fishways, whereas those for Chinook jacks were ~4% at the north and ~6% at the east fishway. No sockeye salmon fell back after passing the north ladder, while ~3% of sockeye that passed the east ladder fell back.

John Day Dam

Methods

North Fishway Passage Performance Metrics

Chinook salmon passage times, entrance and passage efficiencies, and behaviors at the John Day north fishway opening in 2013 were compared to similar metrics from radio-tagged adult Chinook salmon data collected in 1997-1998 and 2000-2006. Variability in passage times among these study years was evaluated to provide context for more specific evaluations of the lower north fishway. Reporting in each year was separated into spring and early summer components. We used 5 June as the last date of the spring Chinook run, since 5 June is the established spring-summer run separation date at John Day Dam. **Note:** this method differed from that used for evaluations at The Dalles Dam, where we used tag date at Bonneville Dam to assign fish as either spring- or summer-run.

We considered eight metrics, with three designed to evaluate passage efficiency and four to evaluate passage time. These were used to assess potential effects on adult and jack spring/summer Chinook salmon behavior from modifications to the John Day north fishway entrance:

Passage efficiency metrics

Entrance efficiency	Ratio of unique fish recorded entering the north fishway to number of unique fish that approached the north fishway (entrances/approaches).
Exit ratio	Ratio of unique fish recorded exiting the north fishway to the tailrace to number that entered the north fishway (exits/entrances).
Collection channel efficiency	Ratios of unique fish recorded at the three lower fishway antennas to number of unique fish that entered the north fishway (unique salmon detected at antennas AJD-3, 4, or 5/JD-N entrances).
Lower fishway passage efficiency	Ratios of unique fish recorded passing the dam to number of unique fish that entered the north fishway (passes/entrances).

Passage time metrics

Entrance time	Passage time from first approach of the north fishway to first north fishway entrance.
Entrance to ladder base	Passage time from first north fishway entrance (at AJD-2) to first detection on the antenna in the transition pool at the base of the ladder.
Extended passage time percentages	We calculated the percentage of fish that required more than 1 h to swim through the two passage segments.
Ladder passage time	Passage time from the transition area (antenna AJD-5) to exit from the top of the fishway. (Note: the AJD-5 antenna was in the same position in all study years compared.)

Data Analyses

To compare passage time metrics among years, we calculated median passage times. We used analysis of variance (ANOVA) tests of log-transformed passage times to determine if differences existed among years for either spring or summer runs of Chinook salmon. If ANOVA tests indicated a difference ($P < 0.05$), pairwise Tukey tests were conducted to determine which years differed. We focused on differences between pre-modification years (1997-1998 and 2000-2006) and the post-modification year of 2013. We also ran pairwise comparisons of 2013 adult and jack Chinook runs to assess whether age/body size affected passage times.

We used correlation techniques to evaluate the degree of association between approach-to-entry time at the JD-N ladder and four environmental factors: total discharge or flow (kcfs), spillway discharge or spill (kcfs), water temperature (°C), and tailwater elevation (ft msl). We additionally evaluated the degree of association between approach-to-entry time at the JD-N ladder and date.

Results

Environmental Data

Flow, spillway discharge, tailwater elevation, and water temperature in the John Day Dam tailrace varied considerably during the spring and summer Chinook salmon runs over the 10 study years (Figure 19). This contributed to the large interannual variation in Chinook salmon passage behaviors. For example, total river discharge (flow) ranged from near-record low levels in 2001 (mostly < 200 kcfs) to ~500 kcfs in 1997.

During the 2013 spring Chinook salmon run, environmental conditions at John Day Dam were characterized by near-average conditions: mean spring tailwater elevation was 163.1 ft msl in 2013 vs. 162.4 ft msl in 1997-2006; mean spring temperature was 11.37 °C in 2013 vs. 11.46 °C in 1997-2006. Mean spill levels were moderately higher than average in spring 2013 vs. spring 1997-2006, at 83.4 vs 64.8 kcfs. Likewise, mean spring flows were moderately higher in 2013 than in 1997-2006, at 259.7 vs. 245.7 kcfs.

Environmental conditions after 5 June 2013 were characterized by modestly higher-than-average total river discharge, with summer mean flows of 223.3 kcfs in 2013 vs. 215.6 kcfs in 1997-2006 and summer mean spill volumes of 77.1 kcfs in 2013 vs. 61.8 kcfs in 1997-2006 (Figure 19). Summer mean water temperatures (June to mid-July) were lower in 2013 than in 1997-2006, at 16.59 vs. 18.32°C, while tailwater elevations were near average in 2013 relative to 1997-2006, at 162.5 vs. 161.5 ft msl.

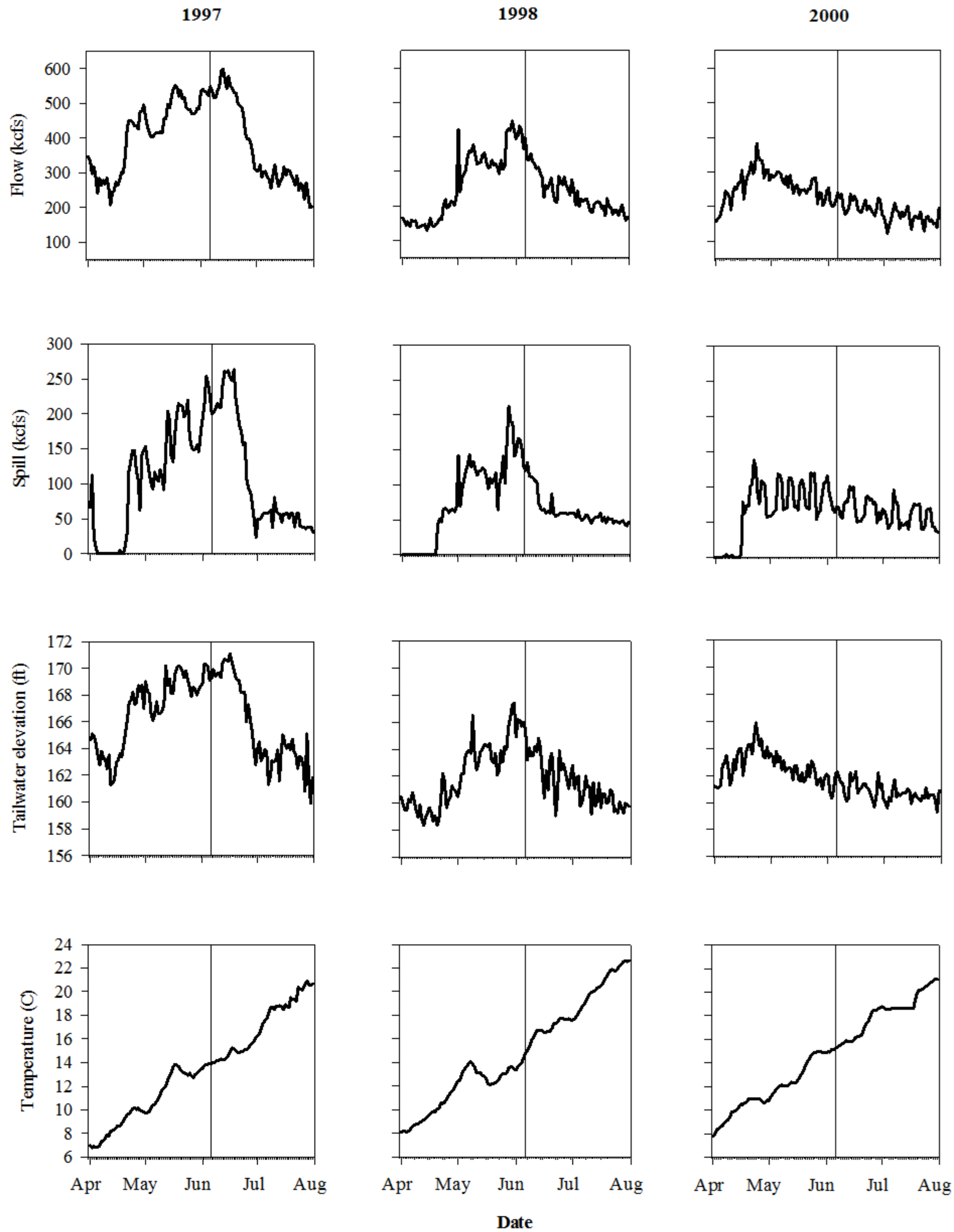

Figure 19. Mean daily flow, spillway discharge, and tailwater elevation and temperature at John Day Dam during the Chinook salmon run (April-Aug) 1997-1998, 2000-2006, and 2013. Vertical line indicates the separation between spring and summer runs.

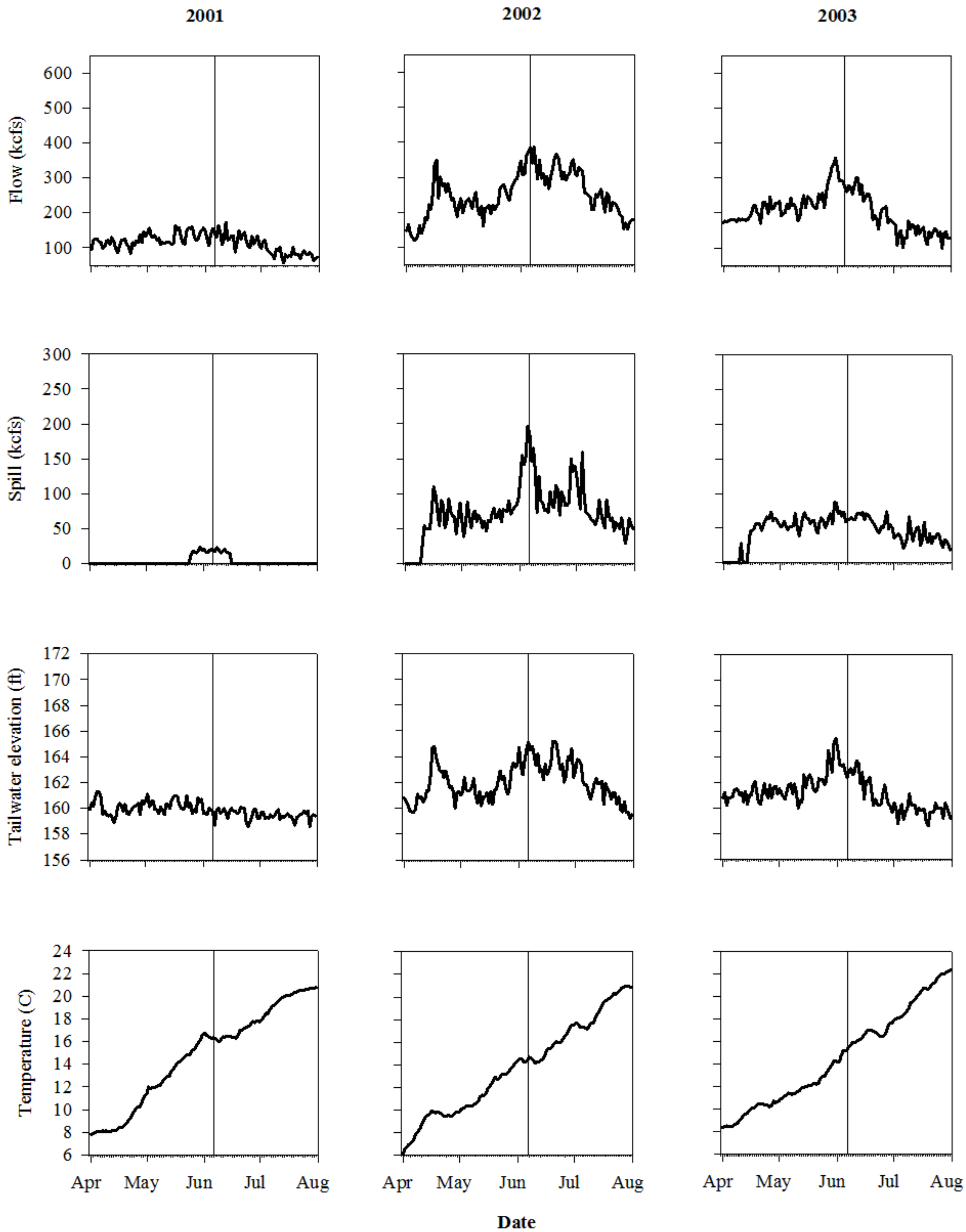

Figure 19. Continued.

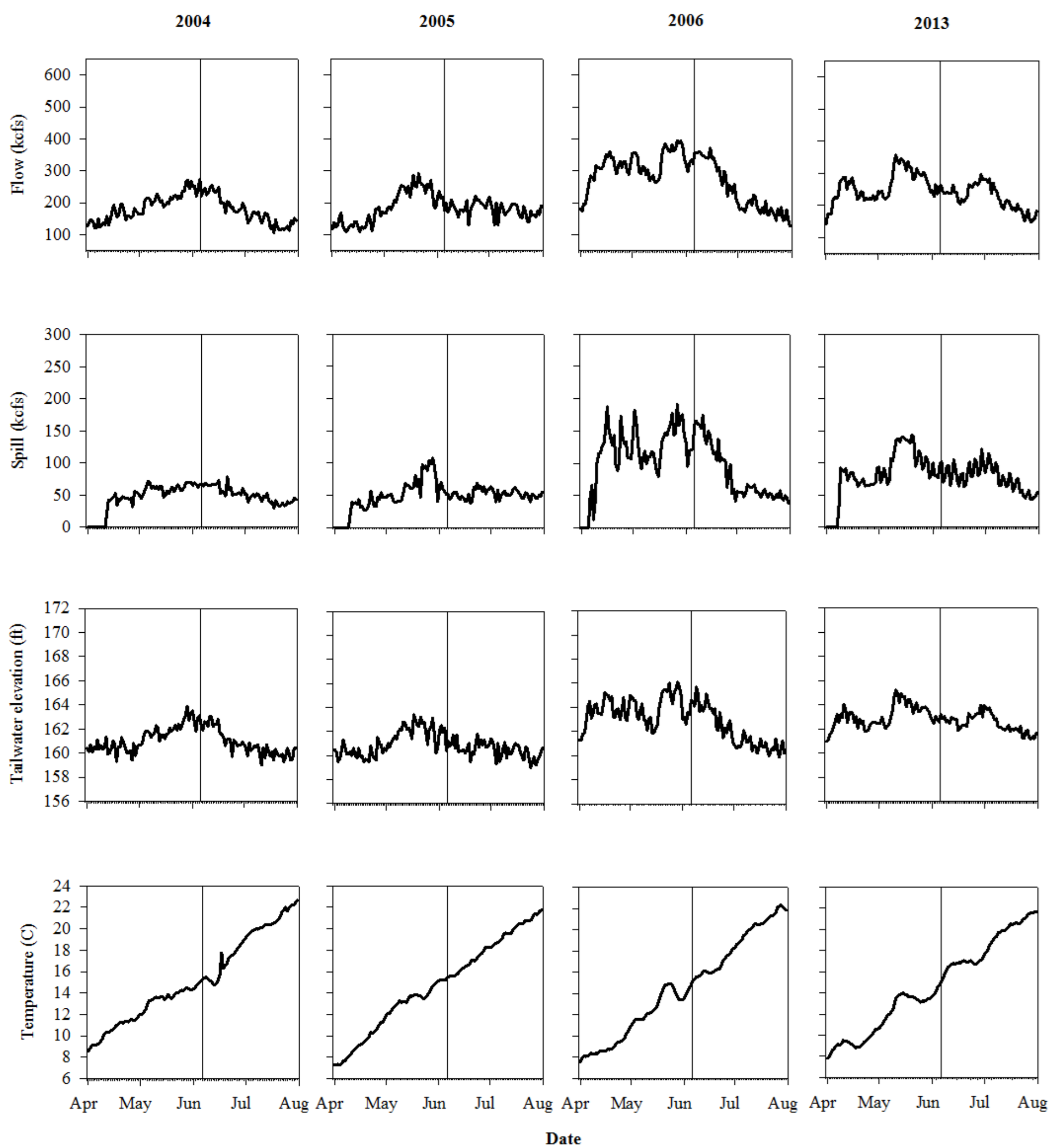

Figure 19. Continued.

Summary of Detections at John Day Dam

In 2013, 707 radio-tagged Chinook salmon were detected at John Day Dam, including 458 adults and 249 jacks (Figures 20 and 21). Spring and summer runs of adult Chinook salmon were split nearly evenly, with 228 radio-tagged adults in the nominal spring run and 230 in the summer run, based on detection date at John Day Dam. Of the 249 Chinook jacks detected at John Day Dam, 152 were spring-run and 97 were summer-run.

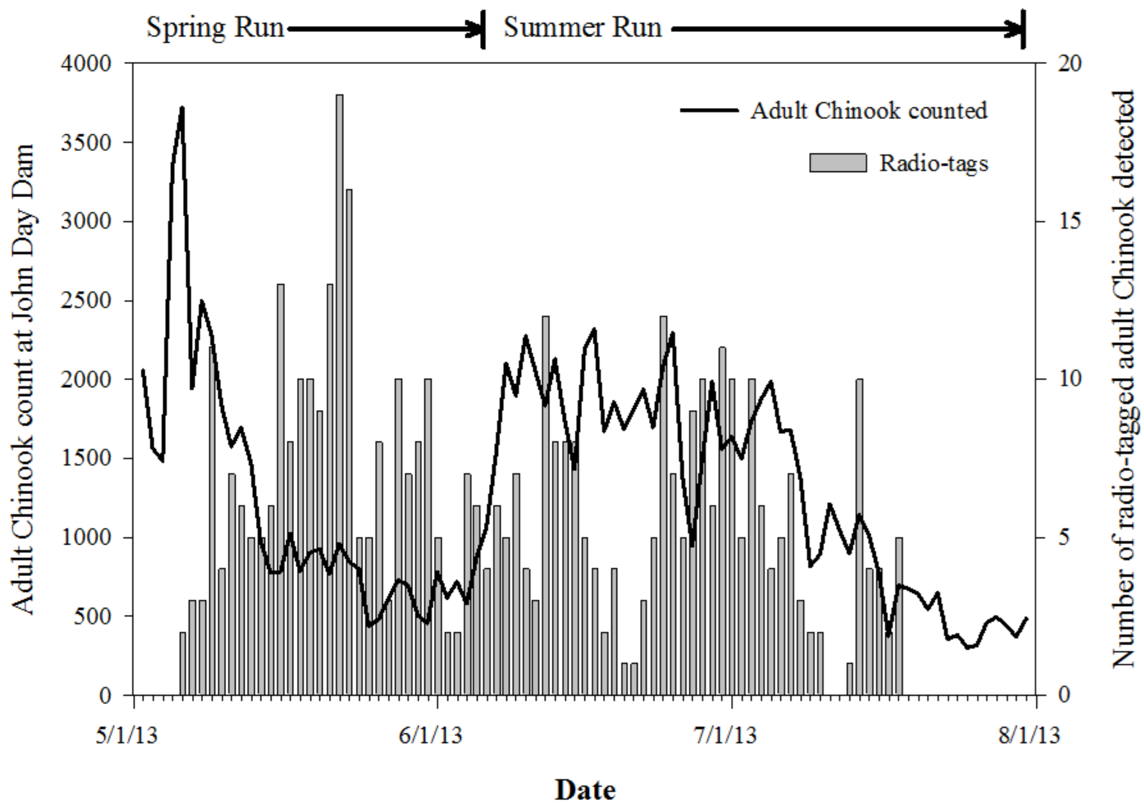

Figure 20. The number of first detections of radio-tagged adult Chinook salmon at John Day Dam, and the total count of adult Chinook salmon counted at John Day Dam from 1 May through 31 July 2013.

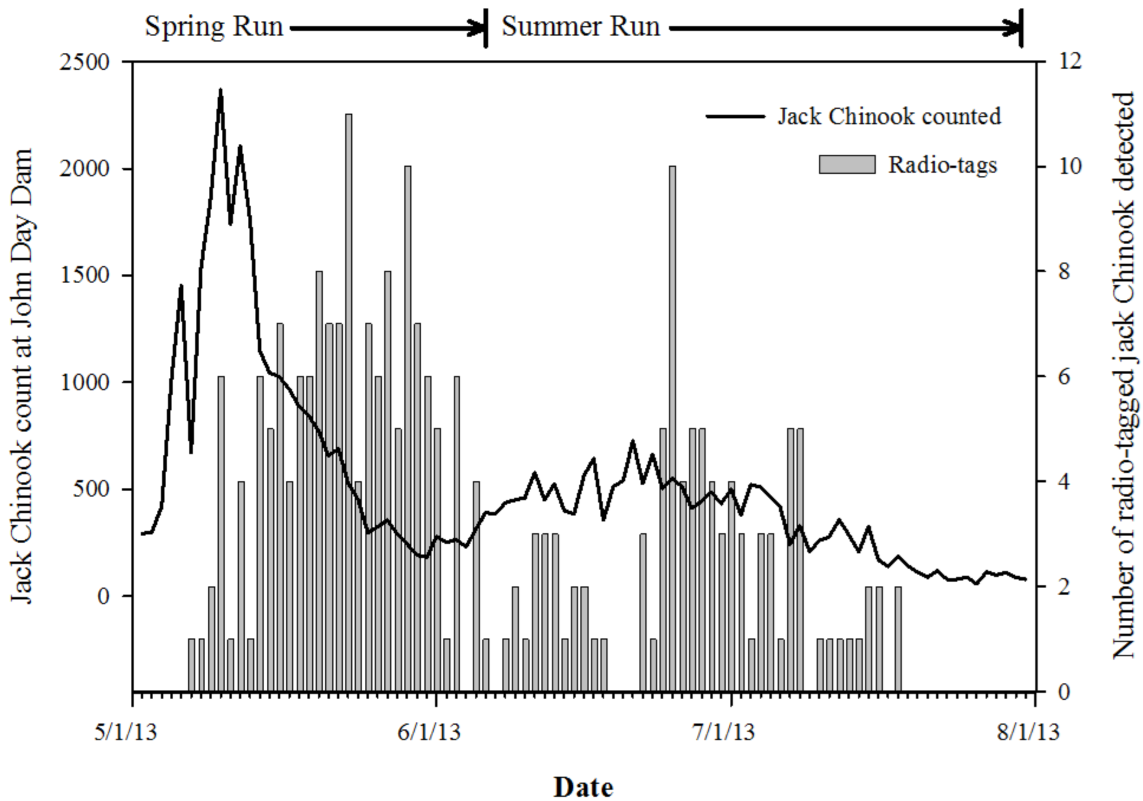

Figure 21. The number of first detections of radio-tagged jack Chinook salmon at John Day Dam, and the total count of jack Chinook salmon counted at John Day Dam from 01 May through 31 July 2013.

In 1997-1998 and 2000-2006, the number of adult radio-tagged Chinook salmon detected at John Day Dam ranged 130-989 (mean 595). During these years, as few as 20 and as many as 685 adult spring-run Chinook salmon (mean 370) have been detected approaching the dam (Table 10). For radio-tagged summer-run adult Chinook, detections at John Day have ranged 29-344 during these years (mean 225, Table 11). Chinook salmon jacks have not been tagged in study years prior to 2013.

Table 10. Spring Chinook passage results at John Day Dam from radio tagging studies in 1997-1998, 2000-2006, and 2013. Shown are numbers of radio-tagged fish that approached, entered, and exited the fishways; numbers that passed the dam; and estimated fishway-entrance, fishway-passage, and dam-passage efficiencies.

	Dam-wide passage for adult spring Chinook salmon at John Day Dam										
										2013	
	1997	1998	2000	2001	2002	2003	2004	2005	2006	Adult	Jacks
Unique passage events (n)											
Approached	398	427	417	685	564	403	234	20	184	228	152
Entered	386	418	409	681	562	397	233	20	182	227	151
Exited to TR	165	304	243	528	293	249	177	16	94	158	72
Passed dam	384	409	404	674	555	395	231	19	181	221	151
Entrance efficiency (entered/approached)											
	0.97	0.98	0.98	0.99	0.99	0.99	0.99	1.00	0.99	0.99	0.99
Fishway passage efficiency (passed/entered)											
	0.99	0.98	0.99	0.99	0.99	0.99	0.99	0.95	0.99	0.97	1.00
Dam passage efficiency (passed/approached)											
	0.97	0.96	0.97	0.98	0.98	0.98	0.99	0.95	0.98	0.97	0.99

Table 11. Summer Chinook passage results at John Day Dam from radio tagging studies in 1997-1998, 2000-2006, and 2013. Shown are numbers of radio-tagged fish that approached, entered, and exited the fishways; numbers that passed the dam; and estimated efficiencies of fishway entrance, fishway passage, and dam passage.

	Dam-wide passage for adult summer Chinook salmon at John Day Dam										
										2013	
	1997	1998	2000	2001	2002	2003	2004	2005	2006	Adult	Jacks
Unique passage events (n)											
Approached	251	229	296	304	294	344	166	110	29	230	97
Entered	248	227	294	302	291	342	166	110	28	228	96
Exited to TR	200	203	272	289	254	315	159	100	17	179	55
Passed dam	244	218	273	295	281	320	149	108	28	219	95
Entrance efficiency											
Ent/App	0.99	0.99	0.99	0.93	0.99	0.99	1.00	1.00	0.97	0.99	0.99
Fishway passage efficiency											
Pass/Ent	0.98	0.96	0.93	0.98	0.97	0.94	0.90	0.98	1.00	0.96	0.99
Dam passage efficiency											
Pass/App	0.97	0.95	0.92	0.97	0.96	0.93	0.90	0.98	0.97	0.95	0.98

Chinook Salmon Use of the North Fishway

Of the 228 adult spring Chinook salmon that approached the dam in 2013, 120 (53%) were recorded approaching, and 105 (46%) were recorded entering the north fishway at least once (Table 12). These percentages were within the range of values from pre-modification years, when 42-83% (mean 66%) were detected approaching the north fishway one or more times and 25-67% (mean 54%) were recorded entering the north fishway.

Of the jack Chinook salmon that approached John Day Dam in spring 2013, 68 (45%) were recorded approaching and 64 (42%) were recorded entering the north fishway (Table 12). Of the 230 adult Chinook salmon that approached John Day Dam in summer 2013, 175 (76%) approached and 159 (70%) entered the north fishway at least once (Table 13). These percentages were within the range of values from pre-modification years, when 71-86% (mean 80%) were detected approaching the north fishway one or more times and 46-81% (mean 64%) were recorded entering the north fishway. Of the 97 summer Chinook jacks that approached the dam, 48 (50%) approached and 44 (46%) entered the north fishway at least once (Table 13).

Table 12. Numbers and proportions of radio-tagged spring Chinook salmon that approached and entered the north fishway vs. those that passed via the north fishway at John Day Dam in 2013 and in 9 prior study years.

	Spring Chinook north fishway passage at John Day Dam										
										2013	
	1997	1998	2000	2001	2002	2003	2004	2005	2006	Adult	Jacks
Unique passage events at John Day north fishway (n)											
Approached	166	288	280	565	374	243	179	13	120	120	68
Entered	98	227	228	458	303	188	152	12	99	105	64
Passed	67	127	159	307	234	101	82	5	79	62	57
Proportion of dam-wide passage at north fishway (%)											
Approached	0.42	0.67	0.67	0.83	0.66	0.60	0.77	0.65	0.65	0.53	0.45
Entered	0.25	0.54	0.56	0.67	0.54	0.47	0.65	0.60	0.54	0.46	0.42
Passed	0.17	0.31	0.39	0.46	0.42	0.26	0.36	0.26	0.44	0.28	0.38

Table 13. Numbers and proportions of radio-tagged summer Chinook salmon that approached and entered the north fishway vs. those that passed via the north fishway at John Day Dam in 2013 and in 9 prior study years.

	Summer Chinook north fishway passage at John Day Dam										
										2013	
	1997	1998	2000	2001	2002	2003	2004	2005	2006	Adult	Jacks
Unique passage events at John Day north fishway (n)											
Approached	178	182	253	254	252	275	133	82	23	175	48
Entered	160	154	238	202	207	215	104	60	13	159	44
Passed	70	57	136	60	92	68	39	25	9	106	33
Proportion of dam-wide passage at north fishway (%)											
Approached	0.71	0.80	0.86	0.84	0.86	0.80	0.80	0.75	0.79	0.76	0.50
Entered	0.65	0.68	0.81	0.67	0.71	0.63	0.63	0.55	0.46	0.70	0.46
Passed	0.29	0.26	0.50	0.20	0.33	0.21	0.26	0.23	0.32	0.48	0.35

Dam-Wide Efficiency Metrics

Estimated dam-wide entrance efficiency (entrances/approaches) was 0.99 for adult spring Chinook salmon (Table 10). Fishway passage efficiency for adults that entered a fishway was 0.97, as was dam passage efficiency for those that approached the dam. These values were consistent with the ranges of dam-wide efficiency values observed for adult spring Chinook salmon in pre-modification years wherein entrance efficiency has ranged 0.97-1.00 (mean 0.99), fishway passage efficiency ranged 0.95-1.00 (mean 0.99), and the range of dam passage efficiency values was 0.95-0.99 (mean 0.97).

Dam-wide entrance efficiency for spring Chinook jacks was 0.99. For jacks that entered a fishway, fishway passage efficiency was 1.00, compared with dam passage efficiency of 0.99 for jacks that approached the dam (Table 10). For adult summer Chinook, dam-wide entrance efficiency was 0.99, and fishway passage efficiency for those that entered a fishway was 0.96 (Table 11). Dam passage efficiency for adult Chinook salmon that approached the dam was 0.95. These values fell within the ranges of corresponding dam-wide efficiency values observed for adult summer Chinook salmon in pre-modification years, when entrance efficiency ranged 0.93-1.00 (mean 0.98), fishway passage efficiency ranged 0.90-1.00 (mean 0.96), and dam passage efficiency ranged 0.90-0.97 (mean 0.95).

For summer Chinook jacks, dam-wide entrance efficiency was 0.990, fishway passage efficiency was 0.99, and dam passage efficiency was 0.98 (Table 11).

North Fishway Passage Efficiency

Entrance efficiency—For radio-tagged adult spring Chinook salmon passing via the north fishway at John Day dam (JD-N), entrance efficiency estimates in pre-modification years ranged 0.59-0.92 (mean 0.80, Table 14, Figure 22). The lowest estimate was in 1997, when average river flow, spill, and tailwater elevation were at their highest levels of the 10 study years. The highest pre-modification estimate occurred in 2005. In 2013, entrance efficiency for adult spring Chinook salmon was estimated at 0.88, near the high end of the range from previous years. Entrance efficiency for spring Chinook jacks was also high (0.94) in 2013; there were no previous jack study years for comparison.

For radio-tagged adult summer Chinook salmon, estimated entrance efficiency at the John Day north ladder has ranged from 0.57 in 2006 to 0.94 in 2000 (overall mean 0.80; Table 15, Figure 22). Estimated entrance efficiency for adult summer Chinook salmon in 2013 was 0.91, at the high end of the range from previous years. Estimated entrance efficiency for summer Chinook jacks in 2013 was 0.92.

These results indicate that recent modifications to the north fishway opening did not have adverse effects on spring and summer Chinook salmon entrance efficiency.

Exit ratio—For radio-tagged adult spring Chinook salmon, exit ratios have ranged 0.42-0.83 in previous years (mean 0.58; Table 14, Figure 22). In 2013, the estimated exit ratio was near the middle of this range (0.66) for spring Chinook adults but relatively low for spring Chinook jacks (0.38). Of the 105 adult spring Chinook that entered the north fishway in 2013, 69 exited back into the tailrace; of these 69 fish, 26 (38%) re-ascended and ultimately passed John Day Dam via the north fishway. Of the 64 spring Chinook jacks that entered the north fishway in 2013, 24 exited back into the tailrace; 17 of these 24 fish (71%) re-entered and passed the dam via the north fishway.

In radio-tag studies from previous years, adult exit ratios have generally been higher for summer than for spring Chinook salmon, ranging 0.62-0.87 (mean 0.78). In 2013, the estimated exit ratio was slightly below this range for adult summer Chinook (0.60) and considerably below it for summer Chinook jacks (0.36). Of the 159 adult summer Chinook that entered the north fishway in 2013, 95 exited back into the tailrace; 42 of these 95 fish (44%) re-ascended and ultimately passed via the John Day Dam north fishway. Of the 44 summer Chinook jacks that entered the north fishway in 2013, 16 exited back into the tailrace; 5 of these 16 (31%) passed via the north fishway.

Table 14. Numbers of unique ($_U$) spring Chinook salmon that approached (App) and entered (Ent) the John Day north fishway, exited to the tailrace (Exit), were detected at antennas 3, 4, and 5 inside the north ladder, and that passed the dam (Pass) via the north fishway in 1997-1998, 2000-2006, and 2013. See Figure 3 for antenna locations.

										2013	
	1997	1998	2000	2001	2002	2003	2004	2005	2006	Adult	Jack
Unique fish											
App_U	166	288	280	565	374	243	179	13	120	120	68
Ent_U	98	227	228	458	303	192	152	12	99	105	64
$Exit_U$	44	149	118	261	150	124	100	10	42	69	24
$Ladder3_U$	85	214	223	424	300	186	145	11	99	104	64
$Ladder4_U$	81	209	219	411	294	180	142	11	97	99	61
$Ladder5_U$	79	145	170	318	244	117	110	8	88	88	58
$Pass_U$	67	127	159	307	234	104	82	5	79	62	57
Total events											
App_{Tot}	301	780	631	1461	1132	609	402	34	260	372	113
Ent_{Tot}	121	368	366	718	486	328	286	24	145	227	97
$Exit_{Tot}$	57	238	205	414	266	226	204	19	72	167	41
Entrance efficiency											
Ent_U/App_U	0.59	0.79	0.81	0.81	0.81	0.79	0.85	0.92	0.83	0.88	0.94
Ent_{Tot}/App_{Tot}	0.40	0.47	0.58	0.49	0.43	0.54	0.71	0.71	0.56	0.61	0.86
Exit ratio											
$Exit_U/Ent_U$	0.45	0.66	0.52	0.57	0.50	0.65	0.66	0.83	0.42	0.66	0.38
$Exit_{Tot}/Ent_{Tot}$	0.47	0.65	0.56	0.58	0.55	0.69	0.71	0.79	0.50	0.74	0.42
Collection channel efficiency											
$Ladder3_U/Ent_U$	0.87	0.94	0.98	0.93	0.99	0.97	0.95	0.92	1.00	0.99	1.00
$Ladder4_U/Ent_U$	0.83	0.92	0.96	0.90	0.97	0.94	0.93	0.92	0.98	0.94	0.95
$Ladder5_U/Ent_U$	0.81	0.64	0.75	0.69	0.81	0.61	0.72	0.67	0.89	0.84	0.91
Lower fishway passage efficiency											
$Pass_U/Ent_U$	0.68	0.56	0.70	0.67	0.77	0.54	0.54	0.42	0.80	0.59	0.89

These lower exit ratios at the north fishway in 2013 suggest that the modified opening, new bollard field, and lamprey passage structure (LPS) inside the fishway opening did not result in increased turn-around behavior. Instead, it appears that these modifications may be associated with reduced fishway fallout for adult Chinook salmon. This is potentially due to the removal of the two lower weirs, but we did not specifically test to evaluate the mechanism for reduced fallback.

Table 15. Numbers of unique ($_U$) summer Chinook salmon that approached (App) and entered (Ent) the John Day north fishway, exited to the tailrace (Exit), were detected at antennas 3, 4, and 5 inside the north ladder, and that passed the dam (Pass) via the north fishway in 1997-1998, 2000-2006, and 2013. See Figure 3 for antenna locations.

										2013	
	1997	1998	2000	2001	2002	2003	2004	2005	2006	Adult	Jack
Unique fish											
App_U	178	182	253	254	252	265	133	82	23	175	48
Ent_U	160	154	238	202	207	207	104	60	13	159	44
$Exit_U$	126	126	192	173	163	168	83	44	8	95	16
$Ladder3_U$	151	142	232	183	202	201	102	59	13	158	43
$Ladder4_U$	143	137	223	179	164	197	101	56	13	154	40
$Ladder5_U$	87	110	142	79	121	86	42	41	10	150	40
$Pass_U$	70	57	136	60	92	65	39	25	9	106	33
Total events											
App_{Tot}	957	568	1390	1019	1574	1331	992	355	195	632	84
Ent_{Tot}	555	344	926	608	685	575	281	124	46	367	61
$Exit_{Tot}$	478	282	792	569	594	507	242	98	38	253	27
Entrance efficiency											
Ent_U/App_U	0.90	0.85	0.94	0.80	0.82	0.78	0.78	0.73	0.57	0.91	0.92
Ent_{Tot}/App_{Tot}	0.58	0.61	0.67	0.60	0.44	0.43	0.28	0.35	0.24	0.58	0.73
Exit ratio											
$Exit_U/Ent_U$	0.79	0.82	0.81	0.86	0.79	0.81	0.80	0.73	0.62	0.60	0.36
$Exit_{Tot}/Ent_{Tot}$	0.86	0.82	0.86	0.94	0.87	0.88	0.86	0.79	0.83	0.69	0.44
Collection channel efficiency											
$Ladder3_U/Ent_U$	0.94	0.92	0.98	0.91	0.98	0.97	0.98	0.98	1.00	0.99	0.98
$Ladder4_U/Ent_U$	0.89	0.89	0.94	0.89	0.79	0.95	0.97	0.93	1.00	0.97	0.91
$Ladder5_U/Ent_U$	0.54	0.71	0.60	0.39	0.59	0.42	0.40	0.68	0.77	0.94	0.91
Lower fishway passage efficiency											
$Pass_U/Ent_U$	0.44	0.37	0.57	0.30	0.44	0.31	0.38	0.42	0.69	0.67	0.75

Collection channel efficiency—In 2013, collection channel efficiency was 0.99 for adult summer Chinook and 0.98 for summer Chinook jacks. Efficiency from fishway entry to antenna 4 ranged 0.79-1.00 (mean 0.92) in pre-modification years and was 0.97 for adults and 0.91 for jacks in 2013. Efficiency from entry to antenna 5 ranged 0.39-0.77 (mean 0.57) in pre-modification years and was 0.94 for adult summer Chinook and 0.91 for summer Chinook jacks in 2013.

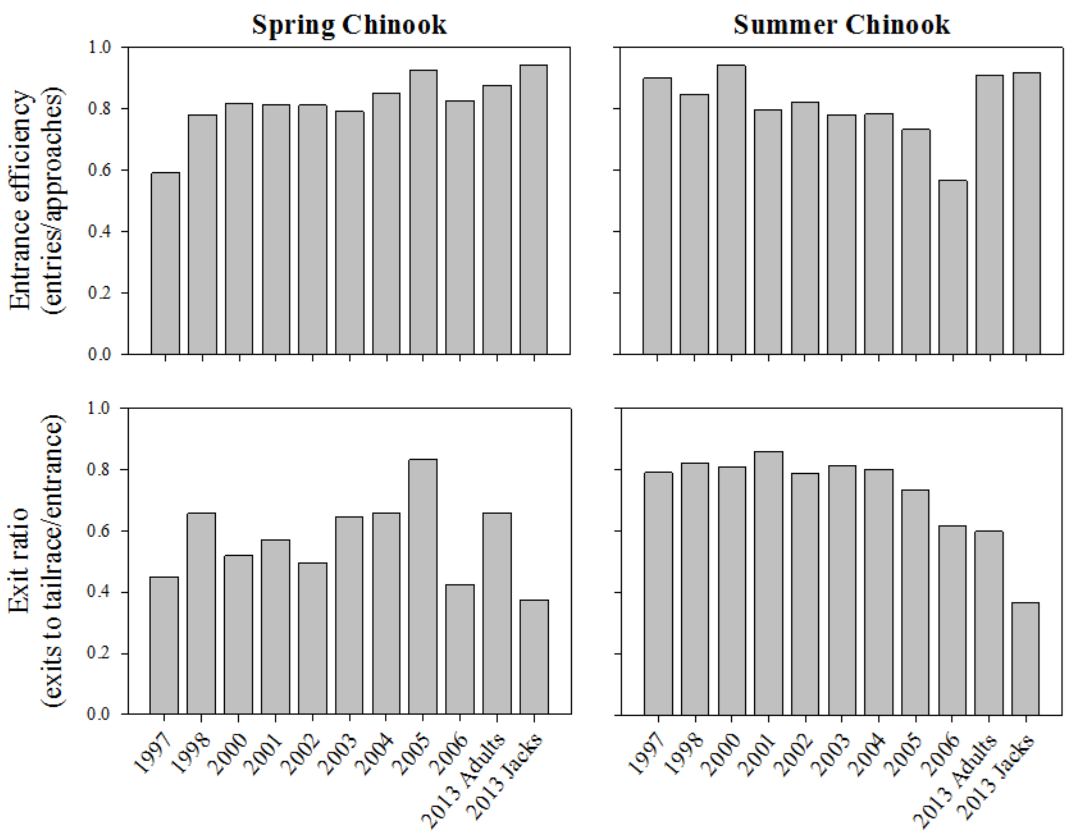

Figure 22. Unique fish entrance efficiencies (top panels) and exit ratios (bottom panels) for radio-tagged spring and summer Chinook salmon at the John Day north fishway in 1997-1998, 2000-2006, and 2013.

Lower fishway passage efficiency—To evaluate passage efficiency in the lower portion of the north fishway, we used detections at the series of additional antennas in the collection channel and transition area upstream from the overflow weir portion of the fishway (see Figure 3). Lower fishway passage efficiency was estimated by dividing the number of unique detections on antennas 3, 4, and 5 by the number of unique detections of fish entering the fishway (Table 14, Figure 23).

In pre-modification years, lower fishway passage efficiencies from entry (at antenna 2) to antenna 3 for adult spring Chinook salmon ranged 0.87-1.00 (mean 0.95). In 2013, lower fishway efficiency was 0.99 for spring Chinook adults and 1.00 for spring Chinook jacks. Efficiency from entry to antenna 4 ranged 0.83-0.98 (mean 0.93) in pre-modification years and was 0.94 for adults and 0.95 for jacks in 2013. Efficiency from entry to antenna 5 has ranged 0.61-0.89 (mean 0.73) in pre-modification years and was 0.84 for spring Chinook adults and 0.91 for spring Chinook jacks in 2013.

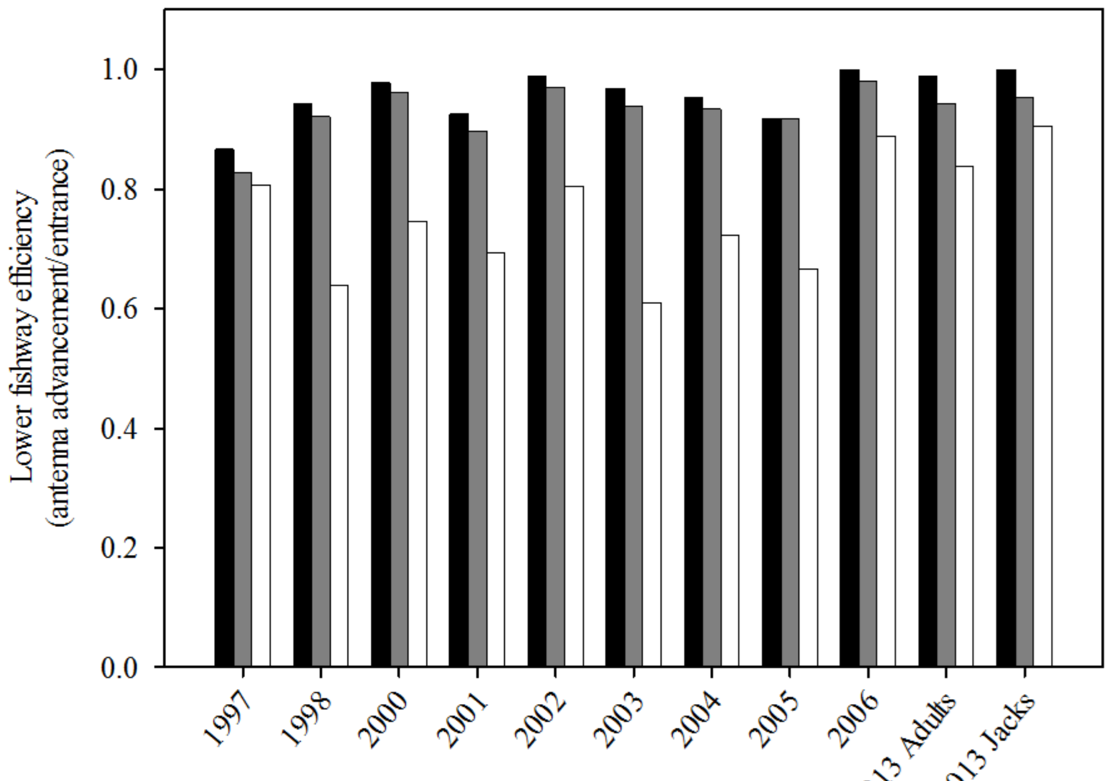

Figure 23. John Day north lower fishway efficiency for radio-tagged spring Chinook salmon. Black bars represent advancement to antenna 3 (transition pool), gray bars represent advancement to antenna 4, and white bars represent advancement to antenna 5.

In pre-modification years, lower fishway passage efficiencies from entry to antenna 3 (Figure 3) ranged 0.91-1.00 (mean 0.96) for adult summer Chinook (Table 15, Figure 24). In 2013, fishway efficiency in this segment was 0.99 for adult summer Chinook and 0.98 for summer Chinook jacks. Efficiency from fishway entry to antenna 4 ranged from 0.79-1.00 (mean 0.92) in pre-modification years and was 0.97 for adults and 0.91 for jacks in 2013. Efficiency from entry to antenna 5 ranged 0.04-0.77 (mean 0.57) in pre-modification years and was 0.94 for adult summer Chinook and 0.91 for summer Chinook jacks in 2013.

In all cases, the 2013 estimates were near the high end of the range from previous years, suggesting either a benefit or no adverse effects from modifications to the lower north fishway at John Day Dam.

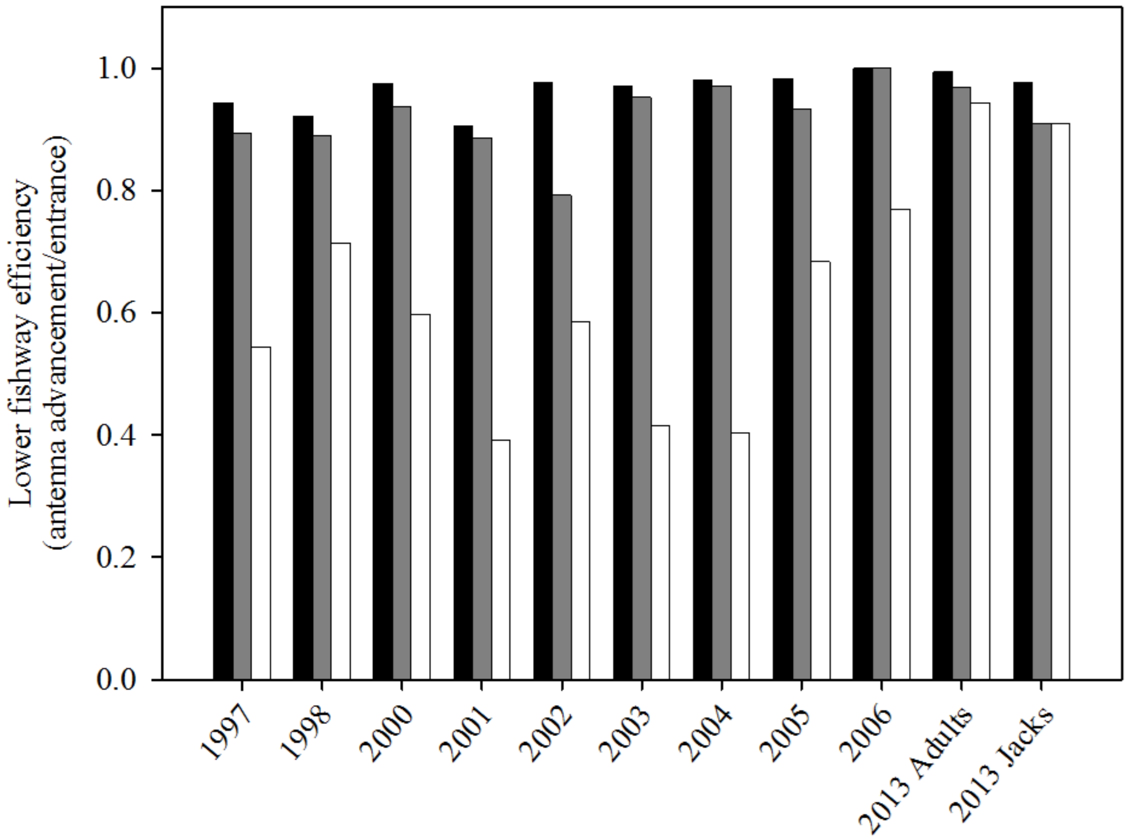

Figure 24. John Day north lower fishway efficiency for radio-tagged summer Chinook salmon. Black bars represent advancement to antenna 3 (transition pool), gray bars represent advancement to antenna 4, and white bars represent advancement to antenna 5.

North Fishway Passage Time

Entrance time—In previous study years, median entrance time at the John Day north fishway has ranged 8-47 minutes for adult spring Chinook (mean *of medians* 28 minutes; Figure 25). In 2013, median entrance time was 13 minutes for adult spring Chinook and 9 minutes for spring Chinook jacks. Results from ANOVA for log-transformed mean passage times indicated significant among-year differences ($df = 10$, $F = 9.408$, $P < 0.0001$). In pairwise comparisons using the Tukey test (Zar 1999), mean entrance time for adult spring Chinook was significantly lower in 2013 than in 5 of 9 pre-modification years. In an ANOVA restricted to 2013 passage times for adult and jack spring Chinook, we found no difference between age classes ($df = 1$, $F = 1.43$, $P = 0.234$).

In previous study years, median entrance time at the John Day north fishway has ranged 3-41 minutes (mean 21 minutes; Figure 25) for summer Chinook adults. In 2013, median entrance time was 5 minutes for summer Chinook adults and 2 minutes for summer Chinook jacks. Results from ANOVA indicated significant differences in mean entrance time among years (df = 10, F = 14.45, P < 0.0001). In pairwise comparisons using the Tukey test (Zar 1999), mean entrance time was significantly lower in 2013 than in all pre-modification years for summer adult Chinook. There was no significant difference in mean entrance time between jack and adult Chinook salmon in 2013 (df = 1, F = 2.156, P = 0.144). These results indicate that modifications to the John Day north fishway did not result in passage delays for adult Chinook salmon in the entrance area.

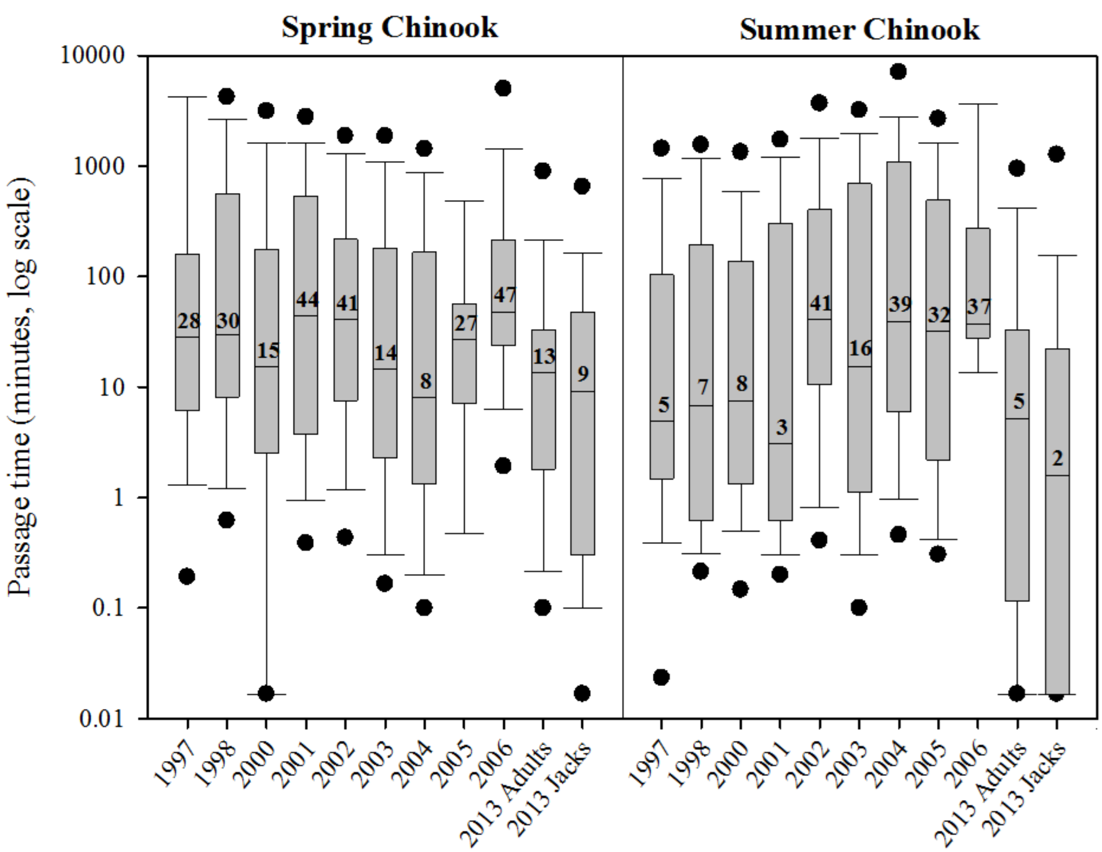

Figure 25. Spring and summer Chinook salmon passage time distributions (plotted on log scale) from approach to entry of the John Day north fishway in 1997-1998, 2000-2006 and 2013. Distributions show 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles. Numbers inside bars are median time in minutes.

Correlations between environmental conditions and entrance time for spring Chinook salmon at the John Day north fishway were weak, both during pre-modification years and in 2013 (Table 16). An exception was in 2001, when extremely low river flows and limited spill may have affected results. In 2013, warmer water temperature was negatively correlated with entrance time for adult spring Chinook but not for spring Chinook jacks. For jacks, there were modest negative correlations in 2013 between passage timing and river discharge, spill, and tailwater elevation; these correlations were not statistically significant (*P* > 0.05).

Table 16. Correlation coefficients (*r*) between environmental conditions spring Chinook salmon encountered when they first approached the John Day north fishway and log transformed approach-to-entry times, by year. Shaded cells with bold typeface indicate *P* < 0.05.

Year	Flow	Spill	Tailwater elevation	Temperature	Date
1997	-0.03	-0.03	-0.04	0.01	-0.02
1998	-0.06	-0.02	-0.08	0.01	-0.06
2000	-0.08	-0.04	-0.12	**0.14**	**0.23**
2001	**-0.11**	**-0.16**	**-0.12**	**-0.26**	**-0.25**
2002	0.05	0.09	0.02	-0.10	-0.07
2003	-0.02	-0.11	<0.01	0.02	<0.01
2004	0.08	0.07	0.06	0.13	**0.17**
2005	-0.03	0.36	-0.25	-0.29	-0.41
2006	0.05	0.06	-0.01	0.13	**0.26**
2013					
Adults	-0.04	0.02	-0.01	**-0.33**	-0.03
Jacks	-0.22	-0.15	-0.20	0.04	0.09
All years	-0.03	-0.03	**-0.05**	**-0.10**	**-0.14**

Much like the relationships observed for spring Chinook salmon, correlations between entrance time and environmental conditions were weak for radio-tagged summer Chinook salmon in all study years (Table 17). In 2013, water temperature and calendar date were negatively correlated with entrance time for adult summer Chinook salmon. The same pattern was observed for summer Chinook jacks, but correlations were not significant (*P* > 0.05).

Table 17. Correlation coefficients (*r*) between environmental conditions encountered by summer Chinook salmon when they first approached the John Day north fishway and log-transformed entrance time, by year. Shaded cells with bold typeface indicate *P* < 0.05.

Year	Flow	Spill	Tailwater elevation	Temperature	Date
1997	<0.01	<0.01	-0.02	-0.03	-0.01
1998	0.02	0.04	0.02	-0.03	-0.04
2000	0.04	-0.07	0.06	-0.06	-0.01
2001	**0.19**	**0.15**	0.06	**-0.16**	**-0.17**
2002	0.07	0.03	0.10	0.01	<0.01
2003	0.07	0.10	0.05	**-0.15**	-0.13
2004	0.05	0.10	0.04	-0.10	-0.13
2005	**0.28**	**0.31**	0.14	**0.41**	**0.41**
2006	-0.17	<0.01	-0.31	0.28	0.23
2013					
Adults	-0.04	0.09	-0.05	**-0.22**	**-0.27**
Jacks	0.09	-0.04	0.04	-0.28	-0.25
All years	0.03	0.03	-0.02	**-0.10**	**-0.11**

Entrance to ladder base—After radio-tagged spring Chinook salmon entered the north fishway, median time to reach the antenna near the ladder base (i.e., antenna no. 3) ranged 1-8 minutes in pre-modification years. Median entrance to base-of-ladder time was 2 minutes for both adult and jack spring Chinook in 2013, and the shapes of distributions were similar to those in pre-modification years (Figure 26). Sample sizes for entrance-to-ladder-base metrics were slightly smaller than those for fishway entrance time because some fish did not reach the ladder antenna.

For summer Chinook salmon in pre-modification years, median time for entrance to ladder base ranged 2-6 minutes. Median time in 2013 was 2 minutes for adults and 3 minutes for jacks, and distributions were similar to those in earlier years (Figure 26). These results suggest that passage to the ladder base through the modified area (i.e., past bollards and the LPS) was not slowed for adult and jack Chinook salmon.

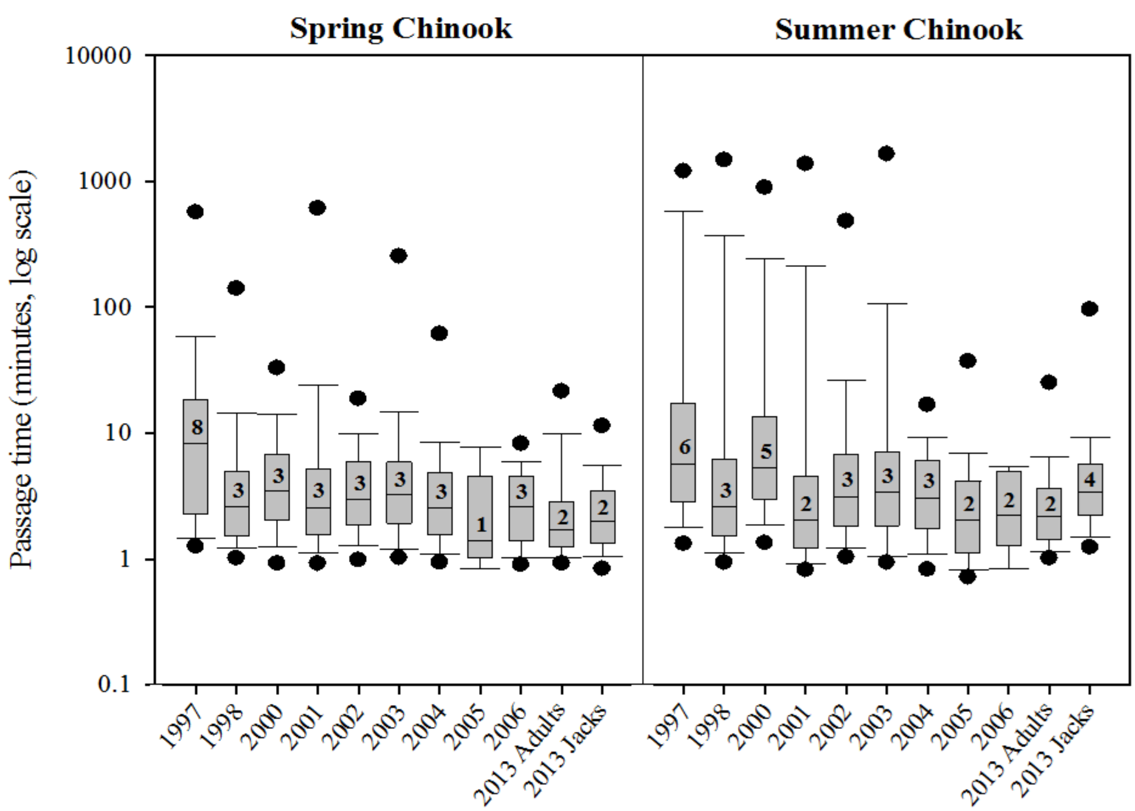

Figure 26. Spring and summer Chinook salmon passage time distributions (plotted on log scale) from entry to first transitional pool at the John Day north fishway. Distributions show 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles. Numbers inside bars are median time in minutes.

Extended passage time percentages—As in pre-modification years, extended passage time was defined as that requiring more than 1 h for either *entrance time* (first approach to first fishway entrance) or *entrance to ladder base* (first fishway entrance to first detection at the ladder base). We calculated the percentages of radio-tagged spring and summer Chinook salmon with extended passage timing through either of these segments.

Over 9 previous study years at the John Day north fishway, *entrance time* exceeded 1 h for 17-48% (mean 38%) of radio-tagged adult spring Chinook and *entrance to ladder base* exceeded 1 h for 0-10% (mean 5%) of these fish (Figure 27). In 2013, north fishway *entrance time* exceeded 1 h for 14% of radio-tagged adult spring Chinook and *entrance to ladder base* exceeded 1 h for 3%. Both percentages were below the mean for 9 pre-modification study years. For spring Chinook jacks in 2013, *entrance time* exceeded 1 h for 22% of fish, but no fish exceeded 1 h for *entrance to ladder base*.

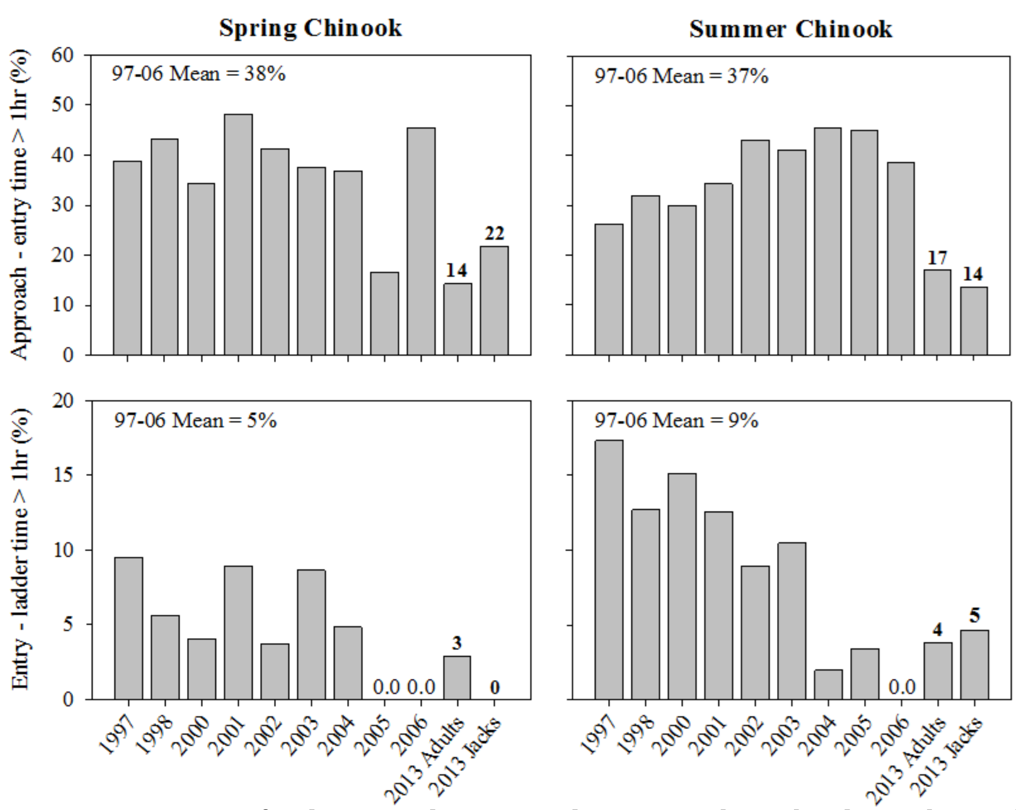

Figure 27. Percentages of radio-tagged spring and summer Chinook salmon that took over 1 h to pass from the John Day north fishway approach to fishway entrance (top) and from entrance to the base of ladder antenna (bottom).

For summer Chinook salmon in 9 pre-modification years, *entrance time* exceeded 1 h for 26-46% (mean 37%), while *entrance to ladder base* exceeded 1 h for 0-17% (mean 9%) of radio-tagged fish (Figure 27). In 2013, 17% of adult summer Chinook took over 1 h *entrance time* from approach to the north fishway entrance, and 4% took over 1 h for *entrance to ladder base* of the north fishway. Both of these values were below pre-modification means. In 2013, respective *entrance time* and *entrance to ladder base* time exceeded 1 h for 14 and 5% of summer Chinook jacks.

North ladder passage times**—**North fishway ladder passage time was calculated from first detection within the ladder (at AJD-5) to last detection at the ladder top (7JD-1). Median passage time ranged 133-193 minutes (mean 166 minutes; Figure 28) within this segment for adult spring Chinook over 9 previously assessed pre-modification years. In 2013, median north ladder passage time was 110 minutes for adult spring Chinook and 156 minutes for spring Chinook jacks.

Results from ANOVA of log-transformed passage times indicated significant among-year differences in mean north ladder passage time (df = 10, F = 14.48, P < 0.0001). In pairwise comparisons for adult spring Chinook salmon, north ladder passage times were significantly faster in 2013 than in 7 of the 9 pre-modification years. Results from ANOVA comparing north ladder passage time of adult vs. jack spring Chinook indicated that jacks took longer to pass than adults (df = 1, F = 18.02, P < 0.0001).

For summer Chinook salmon, median north ladder passage time ranged 127-222 minutes in pre-modification years (mean 191 minutes; Figure 28). In comparison, median ladder passage time in 2013 was 186 minutes for adults and 153 minutes for jacks. There were significant among-year differences in mean passage time for adults (df = 10, F = 8.982, P < 0.001), mostly associated with faster passage through the north ladder by summer Chinook salmon in 1998. Overall, we observed little difference between pre- and post-modification passage times at the north ladder: for adult summer Chinook, passage times in 2013 differed significantly from those in only two pre-modification years. In 2013, we found no significant difference between summer Chinook adult and jack passage times (df = 1, F = 0.966, P = 0.327).

These results suggest that recent modifications to the John Day north ladder have not adversely affected Chinook salmon passage times.

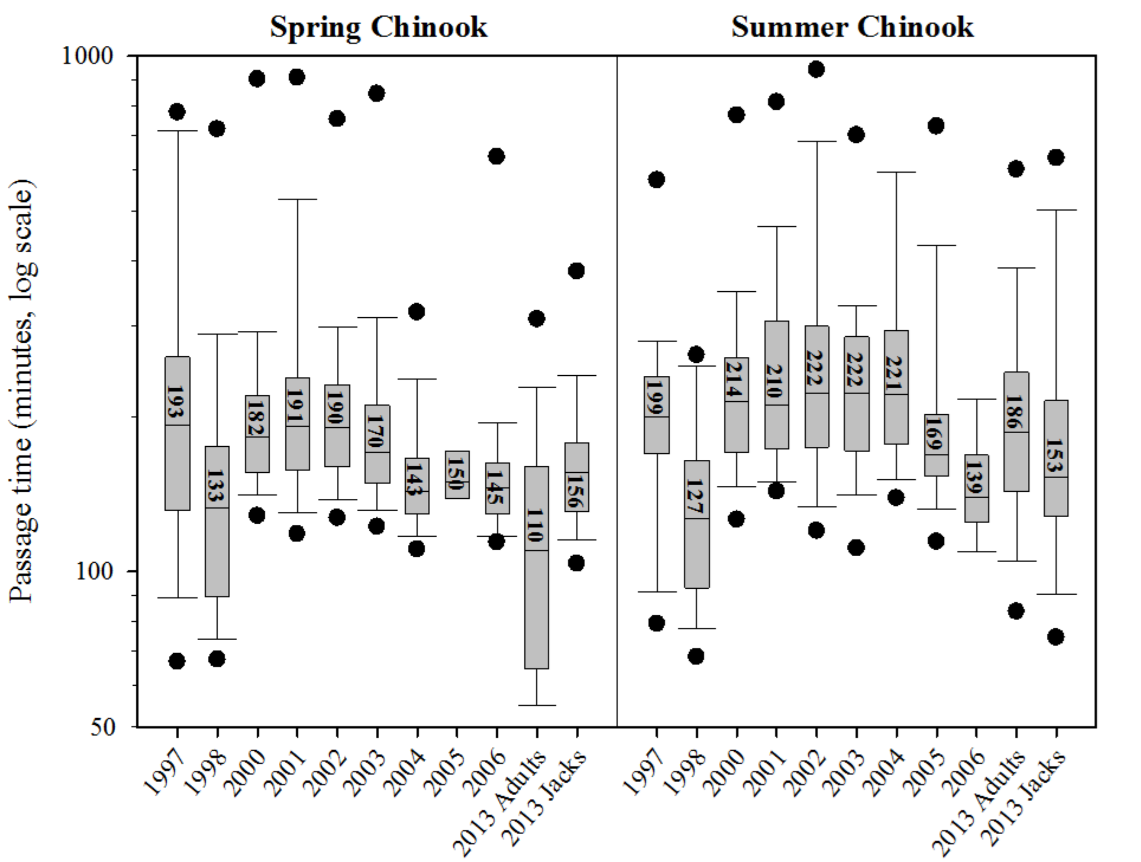

Figure 28. Spring and summer Chinook salmon passage time distributions (plotted on log scale) from antenna 5 to the top of the ladder at John Day north fishway in 1997-1998, 2000-2006 and 2013. Distributions show 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles. Numbers inside bars are median time in minutes.

Discussion

The primary objectives of this evaluation were to test for any negative effects on Chinook salmon passage behaviors from modifications for lamprey passage in and near the John Day north fishway opening and north ladder. Due to logistical constraints (e.g., winter dewatering schedules), several of the lower fishway modifications had been conducted simultaneously: the entrance weir was rebuilt, bollards were installed, two concrete weirs were removed in the transition area, and a new lamprey passage structure (LPS) was installed near the entrance.

Modifications near the north ladder entrance had the potential to affect salmonid behavior by changing the hydraulic and/or olfactory environment at the fishway opening or in the attraction plume outside the fishway opening. The variable-width weir had the highest potential to affect hydraulics outside the opening. Bollards had the potential to affect flow conditions outside the opening to a lesser degree, perhaps by decreasing mean velocity or increasing turbulence in the bottom portion of the attraction plume emanating from the fishway opening.

Inside the fishway entrance, bollards were designed to reduce near-bottom water velocity and increase turbulence for Pacific lamprey. However, installation of the LPS was not expected to substantially affect hydraulic conditions. In the transition area, removal of the two weirs was intended to improve attraction flow (e.g., Naughton et al. 2007).

Modifications within the upper section of the north ladder also had the potential to affect salmonid behavior and passage by altering flows and/or the olfactory environment. These modifications included the removal and construction of new concrete weirs, modifications to concrete baffles, and modifications around the count window (replacement of existing bulkhead, picket leads, crowder, and light box and addition of a window washer).

All modifications to the north fishway were non-experimental and could not be evaluated independently. Consequently, this evaluation relied on a post-hoc observational approach to assess the combined effects of all the modifications simultaneously by comparing passage metrics at the north fishway entrance to those during pre-modification years.

In 2013, entrance and lower fishway passage efficiencies for Chinook salmon indicated no adverse effects from modification to the north fishway at John Day Dam. Entrance efficiencies for 2013 adult Chinook in both the spring and summer runs were at the high end of the pre-modification range or above. These results indicate that introduction of the variable-width weir did not deter Chinook salmon from entering the north fishway. Indeed, installation of the new weir and closure of the northern fishway entrance to the north fishway may have improved attraction and guidance into the fishway compared to the pre-modification condition.

Exit ratios for 2013 adult Chinook (both spring and summer run) were also within the range of pre-modification values; 2013 spring and summer jack Chinook had high entrance efficiencies and very low exit ratios. Low exit ratios in 2013 suggests that the entrance weir, bollard field, and LPS had little or no negative effects on Chinook passage near the JD-N fishway entrance area.

Farther up the north ladder, lower fishway post-modification passage efficiencies were within pre-modification ranges or higher. For both spring and summer run Chinook (adult and jack), passage efficiencies to antennas 3 and 4 were comparable to previous years, and passage efficiencies to antenna 5 were higher. Removal of the concrete weirs within the John Day north lower fishway seems to have had no adverse effects on Chinook passage through these segments in 2013; rather, the data suggest potential benefits of improved hydraulics in the transition area (Naughton et al. 2007).

In the entrance area, both passage time metrics (approach-to-entrance and entrance-to-base-of-ladder) suggested no negative effects of the recent modifications to the JD-N entrance area. Entrance-to-base-of-ladder times remained consistent with times from pre-modification years. Furthermore, approach-to-entrance times were faster in 2013 than in prior years for both spring- and summer-run adults; these times were also fast for jack Chinook salmon, although we have no pre-modification comparison data.

The incidence of extended passage times (> 1 h) in 2013 were also below pre-modification means for both approach-to-entrance and entrance-to-ladder-base times. These findings further suggest that the variable-width weir, closure of the north opening, and any olfactory deterrence did not have a detrimental effect on the entrance of Chinook salmon into the JD-N fishway. Because of relatively little difference in entrance-to-base-of-ladder times across years, we also concluded that the hydraulic effects of the floor-mounted bollards and the new lamprey passage structure (LPS) inside the fishway had little or no effect on salmon passage behavior.

Modifications farther upstream in the John Day Dam north fishway also showed no evidence of slowing Chinook salmon passage. Fish ladder passage times (from antenna AJD-5 to top-of-ladder) were consistent with pre-modification times or faster. Adult spring Chinook ladder passage times were significantly faster in 2013 than pre-modification years, while those of adult summer Chinook (both adult and jack) were comparable to ladder passage times in pre-modification years. This indicates that the combined modifications to the upper north fishway had little or no negative effect on Chinook passage. These results support the findings of Jepson et al. (2011), which also showed that modifications around the JD-N count window had no adverse effects on spring and summer migrants.

We found some evidence for an age effect (adults vs. jacks) in the JD-N entrance area in 2013. For example, adult Chinook passage times were correlated with water temperature more than jack Chinook passage times, and a lower proportion of summer-run jacks than adults approached and entered JD-N. Exit ratios were also considerably lower for spring and summer jack Chinook salmon than for adults. No significant difference in entrance area passage times was observed between adult and jack Chinook salmon for either the spring or summer run in 2013. Ladder passage times (from lower ladder to top-of-ladder) were significantly faster for adult than for jack Chinook in spring 2013, but these ladder passage times were similar between adult and jack Chinook of the summer run.

Although nearly all results from this evaluation were encouraging, we caution against drawing conclusions based on one year of data, given the known large interannual variation in river conditions and operations. Additional years of monitoring may be necessary to fully evaluate the effects of modifications at the entrance of the John Day north fishway, and indeed, monitoring of the 2014 run has begun as a second year to this study. That said, based on the data collected in 2013, the bollards, the LPS, the variable-width weir, the lower fishway weir removals and the ladder modifications did not appear to appreciably impede salmon passage and they appear to offer some passage benefits (i.e., increased entrance efficiencies) for adult Pacific lamprey (Clabough et al. 2011; Kirk et al. *in review*).

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