

Technical Report 2006-9

**ADULT CHINOOK SALMON AND STEELHEAD PASSAGE TIMES AND BEHAVIORS IN THE
SOUTH-SHORE LADDER AT JOHN DAY DAM, WITH SPECIAL REFERENCE TO LADDER
MODIFICATIONS: 1996-1998 and 2000-2004**

by

M.L. Keefer, M.A. Jepson, and C.A. Peery
U.S. Geological Survey, Idaho Cooperative Fish and Wildlife Research Unit
University of Idaho, Moscow, Idaho 83844-1141

for

U.S. Army Corps of Engineers
Portland District
Portland, Oregon

and

Bonneville Power Administration
Portland, Oregon

2006

Preface

Managers of Columbia River basin anadromous salmonids *Oncorhynchus* spp. are interested in the circumstances of adult migrants that fail to pass dams, as well as why some fish experience passage delay, particularly if the delay can be linked to dam operations or fishway configurations. In this report, we present summary information on passage times and behaviors of radio-tagged adult spring–summer and fall Chinook salmon and steelhead through the south-shore ladder at John Day Dam from 1996-1998 and 2000-2004. The flow-control section of the upper ladder was modified in winter 2002-2003 to include slot and orifice weirs, and reporting emphasis is on the effects of these changes.

This and related reports from this research project can be downloaded from the website:
<http://www.cnr.uidaho.edu/uifer/>

Acknowledgements

Many people provided time and assistance during the course of this study. We especially acknowledge T. Bjornn and L. Stuehrenberg. K. Tolotti, R. Ringe, S. Lee, T. Clabough, G. Naughton, W. Daigle, M. Heinrich, C. Morat, D. Queampts, M. Morasch, T. Dick, M. Faulkender, D. Joosten, C. Nauman, and C. Williams helped with field operations and collection and processing of telemetry data at the University of Idaho. A. Matter, S. McCarthy, K. Frick, and T. Bohn, NOAA-Fisheries, helped with data management. The U.S. Army Corps of Engineers provided funding for this study; we thank D. Clugston, M. Zyndol, M. Shutters, R. Dach, M. Langeslay, K. Zelch, and T. Mackey, for their assistance.

Table of Contents

Executive summary	4
Introduction.....	5
Methods.....	5
Fish collection and radio-tagging	5
John Day Dam south ladder study area	5
Statistical analyses	6
Results	7
Migration timing of radio-tagged fish	7
Passage times: Diffuser to ladder top	9
Passage times: Transition pool top to ladder top.....	12
Passage times: Ladder bottom to ladder top	14
Passage times: Full dam.....	16
Ladder rejection and ladder backdown.....	17
Discussion	17
References	18
Appendix	20

Executive Summary

Adult salmon and steelhead historically displayed unusual passage behaviors in the south-shore ladder at John Day Dam, including jumping, stranding, and delaying. Various lines of evidence suggested that hydraulics in the original serpentine flow-control section of the upper ladder were unattractive or disorienting for some adult migrants. In response, the Corps of Engineers tested slot and submerged orifices in this portion of the ladder. Fish response was favorable to the tests, and the Corps subsequently rebuilt the upper south-shore ladder in winter 2002-2003.

Here, we used a multi-year, multi-species adult radiotelemetry dataset to evaluate the effects of the ladder modification on adult passage. Behaviors and passage times of radio-tagged spring–summer and fall Chinook salmon and steelhead were compared using 4-6 years of pre-modification data and two years of post-modification data for each run.

Results consistently indicated that the John Day ladder modification significantly reduced adult passage times for all runs through three ladder segments: 1) through the modified flow-control section, 2) from the top of the transition pool to the ladder top, and 3) from the bottom of the ladder to the ladder top. In addition, significantly fewer fish backed down the ladder after reaching the modified section in the post-modification years, and significantly fewer fish rejected the south-shore ladder in favor of other routes. Improved passage efficiency through the John Day south-shore ladder after modification was observed in almost all months for the studied runs and during all times of the day.

Introduction

Average fish passage times for adult salmon and steelhead at John Day Dam have historically been among the longest recorded at any lower Columbia or Snake River dam (Keefer et al. 2004). Unusually slow adult passage at John Day Dam has been attributed to a variety of factors, including high fishway exit rates (Keefer et al. *in review*), high-temperature barriers in fishways and ladders (Keefer et al. 2003, Caudill et al. 2006), and unusual jumping and ‘delay’ behaviors associated with hydraulics in the flow-control sections of ladders (Jonas et al. 2004 and citations therein). Jumping was most common for steelhead, some of which died when they jumped out of the ladder. Substantial delays were also common for steelhead, with ladder residence times of weeks and even months.

The original ladder design in the flow-control sections of John Day Dam ladders created serpentine flow patterns that were apparently disorienting or unattractive to some adult migrants. To address the problem, the Fisheries Field Unit tested a surface slot and a submerged orifice in the south ladder in 2000 and 2001, and both treatments resulted in reduced adult jumping (Jonas and Madson 2001). The Portland District Corps of Engineers subsequently redesigned the entire flow-control section of the south ladder, and the serpentine section was rebuilt with vertical slot and submerged orifices in winter of 2002–2003 (design details in Jonas et al. 2004). In a 2003 post-construction evaluation, no adult jumping was recorded in the rebuilt ladder over 214 h of observation (Jonas et al. 2004). This evaluation also found significantly reduced passage times through the flow-control and upper ladder sections for radio-tagged adult spring-summer Chinook salmon and steelhead in 2003 when compared to passage times for fish from 1993.

In this report, we examine the effects of the John Day ladder modification on both the flow-control section and full south-ladder passage times using a much larger radiotelemetry dataset that included two post-modification years (2003-2004) and six pre-modification years (1996-1998, 2000-2003). Our primary objectives were to validate and expand upon the findings of Jonas et al. (2004), to examine the effects of the modification on a broader set of passage time metrics and adult fish behaviors, and to assess diel and seasonal effects. Pre-modification radiotelemetry data included six years for spring–summer Chinook salmon (1996-1998, 2000-2002), four years for fall Chinook salmon (1998, 2000-2002), and five years for steelhead (1996-1997, 2000-2002).

Methods

Fish collection and radio-tagging. – All adult fish were collected and intragastrically radio-tagged in the Adult Fish Facility at Bonneville Dam. In general, selection of adults was broadly representative of each run in each migration year. Deviations from ‘unselective’ sampling mostly occurred to accommodate the many objectives of the adult passage project, including selection for known-origin (PIT-tagged) fish, sampling to ensure sample sizes for specific tests, and sampling interruptions due to water temperature or other restrictions. Details of collection and tagging methods for all runs are included in Bjornn et al. (2000), Jepson et al. (2005), and Keefer et al. (2004b, 2005).

John Day Dam south ladder study area. – The south ladder at John Day Dam was monitored with a variety of underwater radio antenna configurations over the study years (Figure 1). In all years, antennas were present near the bottom of the ladder and also at the ladder exit into the forebay. The flow-control section and upper ladder diffuser were monitored with a pair of antennas in 1996-1998 and again in the post-modification years of 2003-2004. A third antenna location, just upstream from the highest recorded tailwater elevations above the transition pool, was also monitored in multiple years (1997 and 2000-2004). Combinations of telemetry records at these antennas were used to calculate fish passage times and to estimate the proportions of fish that moved downstream in the ladder after being detected in the flow-control section.

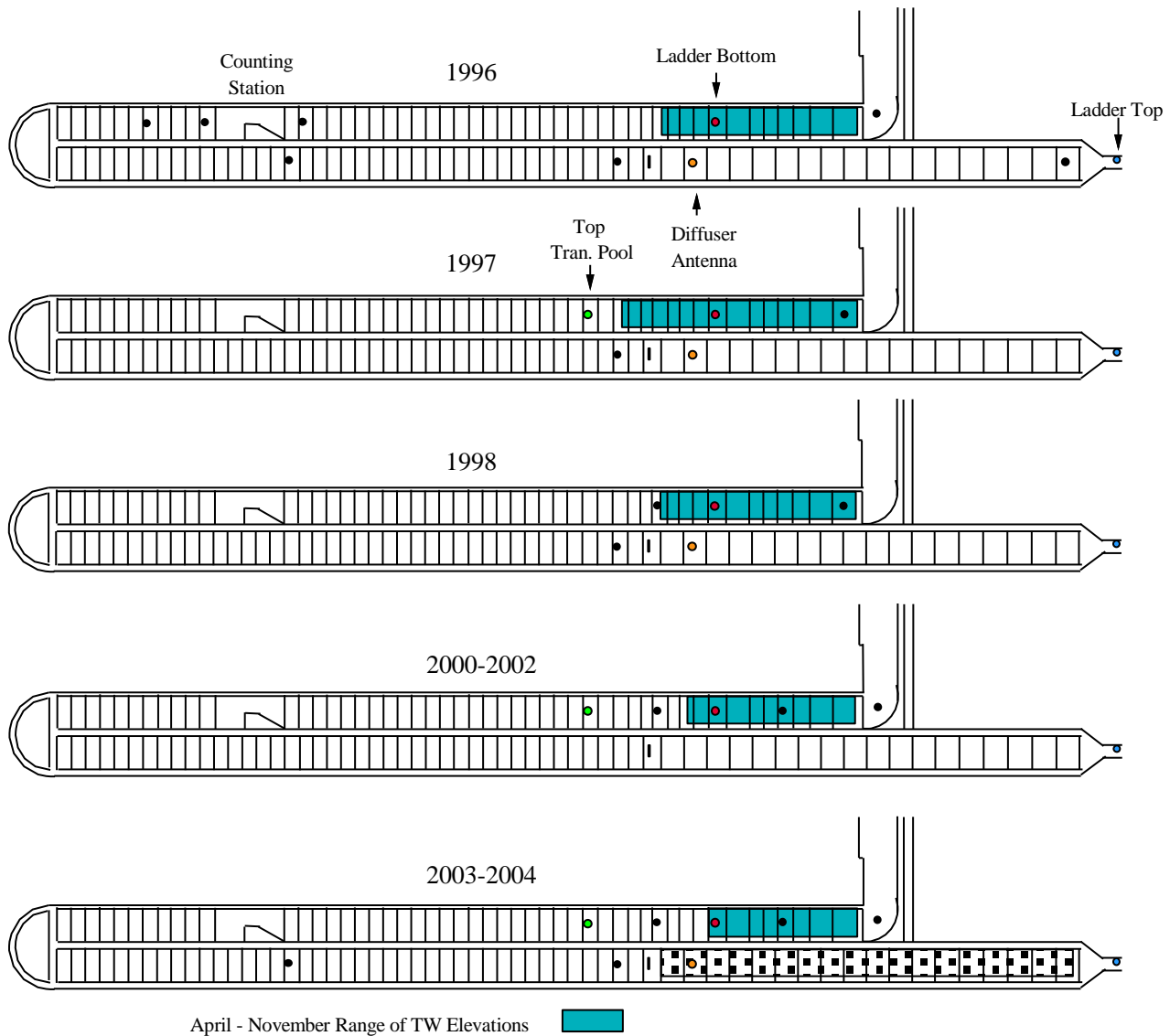


Figure 1. Locations of underwater antennas used to monitor adult Chinook salmon and steelhead passage times and behaviors at the south-shore ladder at John Day Dam from 1996-1998 and 2000-2004. Red antennas mark the approximate bottom of the ladder in all years; green antennas mark the lower ladder upstream from the top of the transition pool (1997 and 2000-2004); orange antennas mark the lower end of the flow-control section of the upper ladder (1996-1998 and 2003-2004); blue antennas mark the ladder exit. Blue-shaded areas in the lower ladder show the range of tailwater elevations recorded during April-November during each study period. The gray-shaded area in the upper ladder is the flow-control section modified in the winter of 2002-2003 to include slot and orifice weirs.

Statistical analyses. – A challenge inherent to this type of retrospective analysis is that the effects of the treatment (in this case, ladder modification) can be confounded by a variety of peripheral factors. For example, inter-annual differences in environmental conditions or fish migration timing can potentially mask or exaggerate apparent differences between treatments. In tailraces and inside fishways, seasonal temperature and flow (e.g., tailwater elevation) effects on adult passage behaviors can be substantial at John Day Dam (e.g., Keefer et al. 2003 and *in review a*), and therefore we stratified analyses where possible to account for seasonality. Time of day also influences both adult passage times and behaviors (e.g., Naughton et al. 2005; Keefer et al. *in review b*), as many fish are

hesitant to move inside fishways and ladders at night. Differences in the timing of fish arrival in each passage segment are therefore potentially important, and we accounted for this by stratifying analyses by time of day in some cases.

For this summary, we focused passage time analyses on three ladder segments: (1) from the antenna just upstream from the ladder diffuser to top-of-ladder exit; (2) from the antenna just upstream of the transition pool to top-of-ladder exit; and (3) from the antenna near the bottom of the ladder to top-of-ladder exit. Of these, we expected the first metric to be most sensitive to the ladder modification and the third to be least sensitive because of the effects of transition pool behaviors. All passage time calculations were from the first telemetry record at the downstream antenna to the last record at the top-of-ladder antenna.

Passage time distributions for all three metrics were right-skewed in all years and for all runs. This is typical of adult passage times at Columbia and Snake River dams, and reflects the effects of overnight behaviors, ladder exits to the tailrace, and the tendency for a small number of fish to take much longer to pass through almost all environments we have monitored (Keefer et al. 2004a). In some cases, right-skewing greatly inflated mean estimates (some steelhead, for example, took several months to pass the ladder), and so we have focused here on median times and used nonparametric Kruskal-Wallis tests to compare passage time distributions. However, because fish with long passage times were of particular interest in this evaluation, we also compared the percentages of fish that spent one or more nights passing through each ladder segment. This biologically-based metric captured the right-tail end of the passage distributions and was useful for simply identifying the group of fish with the longest passage times. Overnight behavior was identified by telemetry detections at the upper site that occurred on one or more dates after detection at the lower site in each passage segment. In a small number of cases, fish identified as ‘overnighting’ passed the upper site between midnight and sunrise. However, this behavior was not associated with ladder configurations and substituting a passage time cutoff of 12 h or 24 h in place of the overnight metric produced qualitatively very similar results. Overnight percentages were compared using Pearson χ^2 tests.

We also calculated the percentages of fish that moved down the south ladder after being recorded at the antenna above the diffuser. This behavior was termed ‘backdown’ and was identified by fish detection at the upstream site followed by detection at an antenna in the lower ladder or transition pool. The majority of fish that backed down the ladder eventually passed the dam via the south ladder (see Results), but a portion backed down, exited the fishway, and the passed the dam via another route or failed to pass. Backdown followed by non-passage or passage via an alternate route was termed ‘ladder rejection.’

Results

Migration timing of radio-tagged fish. – Migration timing of spring–summer Chinook salmon at John Day Dam varied among years (Figure 2). In general, more spring than summer Chinook were tagged and subsequently detected at John Day Dam, and passage distributions were bimodal. Overall study objectives changed in 2003-2004 so that tagging occurred more evenly throughout the spring and summer. This resulted in flatter passage distributions at John Day Dam and later median migration dates in 2003-2004 as compared to earlier years. Later timing suggests that fish in the post-modification years were more likely to encounter warmer temperatures in these years, and this has typically been associated with faster passage.

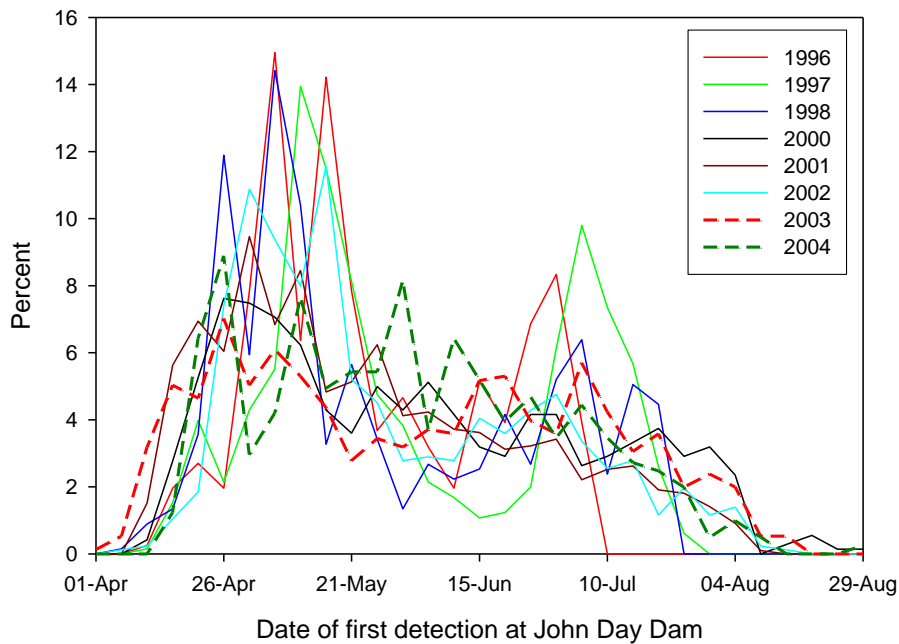


Figure 2. Annual migration timing distributions for radio-tagged spring-summer Chinook salmon at John Day Dam based on date of first detection. Median dates were 15-20 May in 1996, 1997, 1998, 2001, and 2002 and were 27-30 May in 2000, 2003, and 2004.

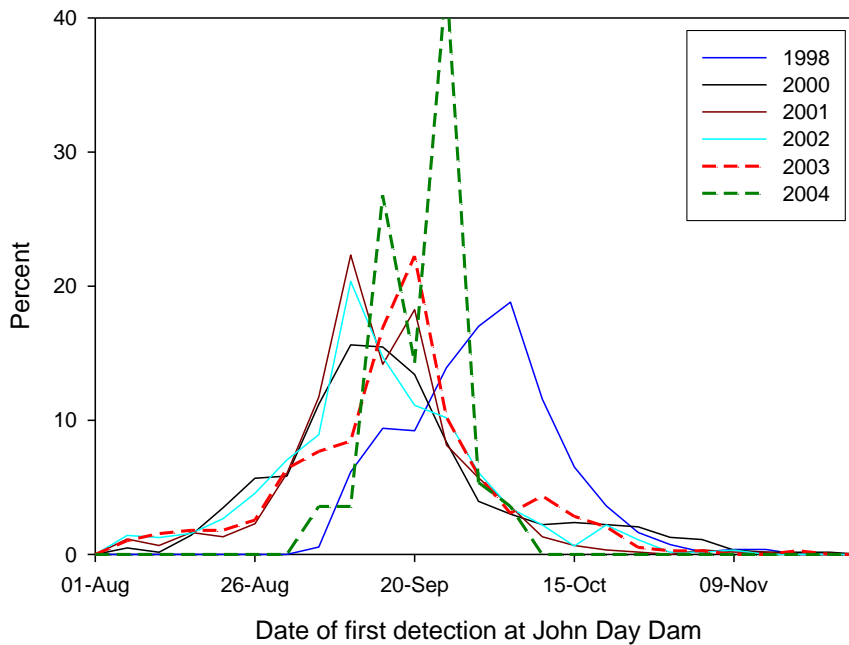


Figure 3. Annual migration timing distributions for radio-tagged fall Chinook salmon at John Day Dam based on date of first detection. Median dates were 29 September in 1998 (no fish were tagged in August) and 12-19 September in 2000-2004.

Timing distributions for fall Chinook salmon at John Day Dam were unimodal and generally normally distributed (Figure 3). Median dates were similar for all years, except for 1998 when no fall

Chinook salmon were tagged at Bonneville Dam in August. The 2004 sample was also somewhat unusual in that the distribution at John Day Dam was more compressed than in other years.

Steelhead distributions showed variable passage at John Day Dam during summer, followed by peaks in mid-September to early October (Figure 4). Median dates were similar in all years except 2004, when more steelhead passed in June and late August through early September. Temperature exposures for steelhead in 2004 were probably higher on average than in other years. This could have had mixed effects on passage times at the dam, as faster passage typically occurs at higher temperatures, but fish are also likely to exit the fishways at higher rates at the dam during warm periods.

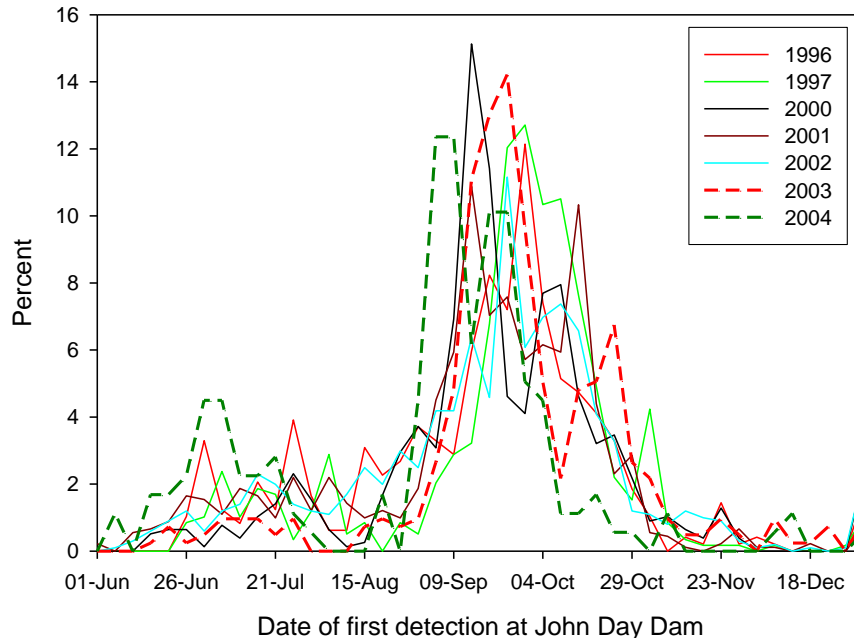


Figure 4. Annual migration timing distributions for radio-tagged steelhead at John Day Dam based on date of first detection. Median dates were 18-27 September in 1996-2003 and 6 September in 2004.

Passage times: Diffuser to ladder top. – Most radio-tagged fish from all runs passed through this section quickly, with median times of less than 1 h (Table 1, Figure 5). However, all data were right-skewed, especially for steelhead in 1996 and 1997. With all years combined within the pre- and post-modification periods, median passage times were significantly shorter after modification for all runs (Kruskal-Wallis tests: spring–summer Chinook salmon $\chi^2 = 158.0$, $P < 0.0001$; fall Chinook salmon $\chi^2 = 59.6$, $P < 0.0001$; steelhead $\chi^2 = 386.5$, $P < 0.0001$). By percentage, reductions in medians were greatest for spring–summer Chinook salmon (0.36 h, 54%), followed by steelhead (0.39 h, 47%) and fall Chinook salmon (0.09 h, 14%) (Table 1). Reductions in means were more substantial at between 3.5 and 4 h (75-80%) for spring–summer and fall Chinook salmon and 37.9 h (92%) for steelhead. This pattern for means indicates that fish (especially steelhead) were much less likely to have very long passage times in years after the modification.

Patterns were similar when we stratified by month (Figure 6). Median passage times were significantly ($P < 0.05$) lower after ladder modification in almost all months for all runs, with the greatest reductions occurring for steelhead. Overnight percentages also tended to be lower after modification, with the most dramatic differences for steelhead and for spring–summer Chinook salmon in April and May (Figure 6).

The likelihood that fish spent a night or more in the ladder was strongly related to the time fish were first detected at the diffuser antenna, with late-arriving fish much more likely to overnight (Figure 7). There was a tendency, especially among spring–summer Chinook salmon, for earlier arrival at the diffuser antenna in the years after the ladder modification (Appendix 1). This shift towards earlier timing would, in itself, tend to reduce overnight percentages for the later years. However, the significant ($P < 0.05$) reductions in overnight percentages across most times of the day (Figure 7) clearly indicate that the ladder modification was more influential (Figure 7).

Table 1. Mean and median passage times (h) for radio-tagged adult spring–summer and fall Chinook salmon and steelhead through sections of the south-shore ladder at John Day Dam. ‘Pre-mod’ and ‘post-mod’ refer to years before and after the south-shore ladder was modified in winter 2002-2003.

	Diffuser to ladder top			Transition pool to ladder top			Ladder bottom to ladder top		
	<i>n</i>	Median	Mean	<i>n</i>	Median	Mean	<i>n</i>	Median	Mean
Spring-Summer Chinook salmon									
1996	279	0.73	6.56	--	--	--	278	4.12	26.41
1997	461	0.69	5.65	474	2.99	16.95	467	3.69	25.85
1998	426	0.62	3.80	--	--	--	413	3.05	11.18
2000	--	--	--	333	2.69	5.63	331	2.92	8.93
2001	--	--	--	564	2.85	6.56	550	2.99	7.31
2002	--	--	--	495	2.78	5.42	496	3.06	13.12
2003	495	0.56	1.51	520	2.94	5.12	522	3.28	13.86
2004	252	0.42	0.95	250	2.31	3.51	252	2.67	8.56
Pre-mod	1,163	0.67	5.20	1,866	2.85	8.73	2,535	3.18	14.80
Post-mod	747	0.31	1.32	770	2.73	4.60	774	3.12	12.13
Fall Chinook salmon									
1998	281	0.63	4.46	--	--	--	246	2.79	8.70
2000	--	--	--	322	2.84	7.57	307	2.92	7.80
2001	--	--	--	484	3.12	6.50	468	3.43	8.39
2002	--	--	--	403	3.08	6.75	384	3.22	8.41
2003	290	0.60	0.99	285	2.91	4.61	277	3.12	6.11
2004	316	0.49	0.84	305	2.58	3.34	303	2.69	4.10
Pre-mod	281	0.63	4.46	1,209	3.04	6.87	1,405	3.14	8.32
Post-mod	606	0.54	0.91	590	2.74	3.95	580	2.88	5.06
Steelhead									
1996	348	0.81	31.69	--	--	--	310	2.89	56.86
1997	377	0.89	49.52	382	2.91	54.15	367	3.07	56.93
2000	--	--	--	413	2.39	36.48	392	2.54	38.32
2001	--	--	--	655	2.74	39.25	639	2.99	45.46
2002	--	--	--	537	2.57	30.35	500	2.77	35.48
2003	273	0.44	4.15	273	2.32	6.70	271	2.49	7.52
2004	125	0.44	0.82	124	2.24	2.96	121	2.43	3.19
Pre-mod	725	0.83	40.96	1,987	2.65	39.14	2,208	2.87	45.44
Post-mod	398	0.44	3.11	397	2.30	5.53	392	2.47	6.18

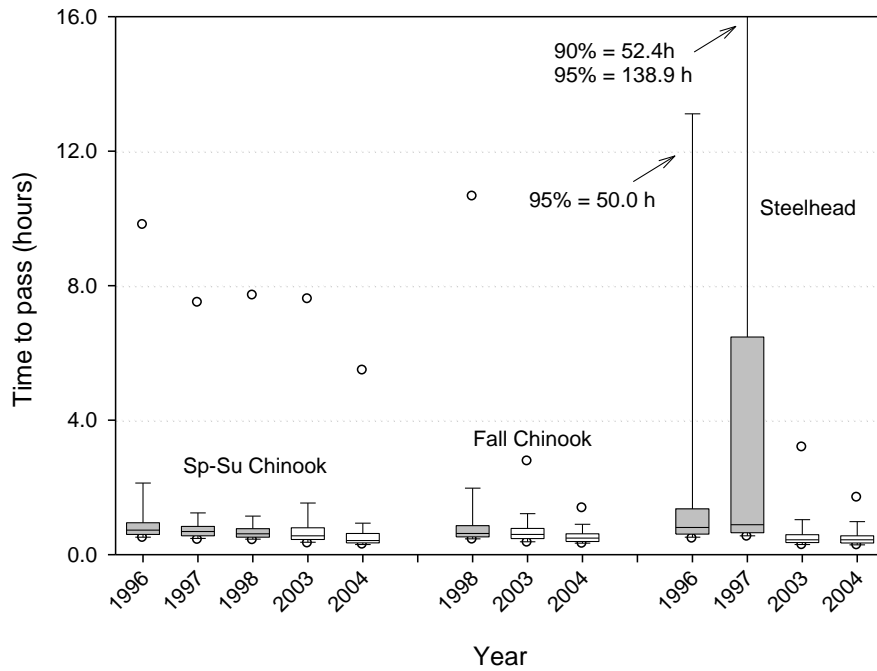


Figure 5. Median, quartile, 5th, 10th, 90th, and 95th percentiles of adult Chinook salmon and steelhead passage times between their first record above the diffuser grating in the upper south-shore ladder at John Day Dam and exit from the top of the ladder, by year.

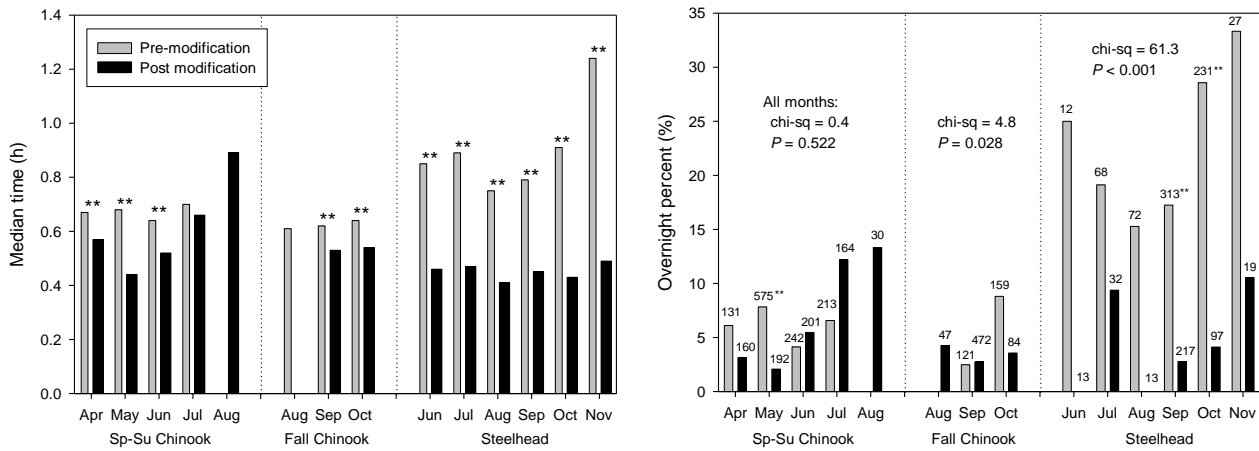


Figure 6. Median passage times (left panel) and percent (right panel) of radio-tagged adult Chinook salmon and steelhead that were recorded on more than one date (i.e., over night) between first record above the diffuser grating in the upper south-shore ladder at John Day Dam and exit from the top of the ladder, by month. Pearson χ^2 tests compared percentages and Kruskal-Wallis tests compared medians for years before the upper ladder modification (1996-1998, 2000-2002) and years after modification (2003-2004). * $P < 0.05$, ** $P < 0.005$.

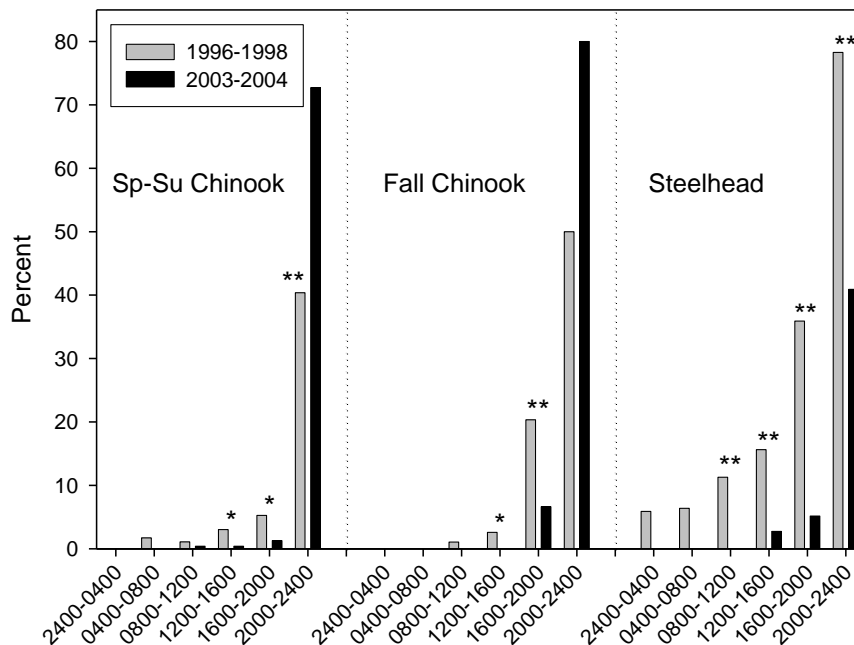


Figure 7. Percent of radio-tagged adult Chinook salmon and steelhead that were recorded on more than one date (i.e., over night) between their first record above the diffuser grating in the upper south-shore ladder at John Day Dam and exit from the top of the ladder, by time of first detection. Pearson χ^2 tests of percentages compared years before the upper ladder modification (1996-1998, 2000-2002) with years after modification (2003-2004). Pearson χ^2 tests, * $P < 0.05$, ** $P < 0.005$.

Passage times: Transition pool top to ladder top. – Median passage times for this segment were quite consistent between years and runs, at between 2.2 and 3.1 h (Table 1, Figure 8). Right-skewing was greatest for steelhead and spring–summer Chinook salmon in 1997. As with the shorter diffuser-to-ladder-top segment, median passage times were significantly shorter after the ladder modification for all runs (Kruskal-Wallis tests: spring–summer Chinook salmon $\chi^2 = 13.0$, $P = 0.0003$; fall Chinook salmon $\chi^2 = 36.4$, $P < 0.0001$; steelhead $\chi^2 = 73.7$, $P < 0.0001$). By percentage, reductions in medians ranged from 10-14% (0.12-0.35 h), while reductions in means were 43-47% (3-4 h) for the Chinook salmon runs and 86% (33.6 h) for steelhead (Table 1).

Again, patterns were similar when stratified by month (Figure 9). Median passage times were significantly ($P < 0.05$) lower after ladder modification in almost all months for all runs, and overnight proportions were also reduced in most months. The greatest passage time reductions were in late fall for steelhead and in April-May for spring–summer Chinook salmon.

Overnight percentages were higher for this passage segment than for the diffuser-ladder top segment. Between 20-50% of fish from all runs that were first detected at the lower antenna during the hours of 1600-2000 h spent the night in the ladder, as did nearly 100% of those detected after 2000 h. For the most part, fish from all runs that arrived during daylight hours were significantly ($P < 0.05$) more likely to overnight in the years prior to ladder modification (Figure 10).

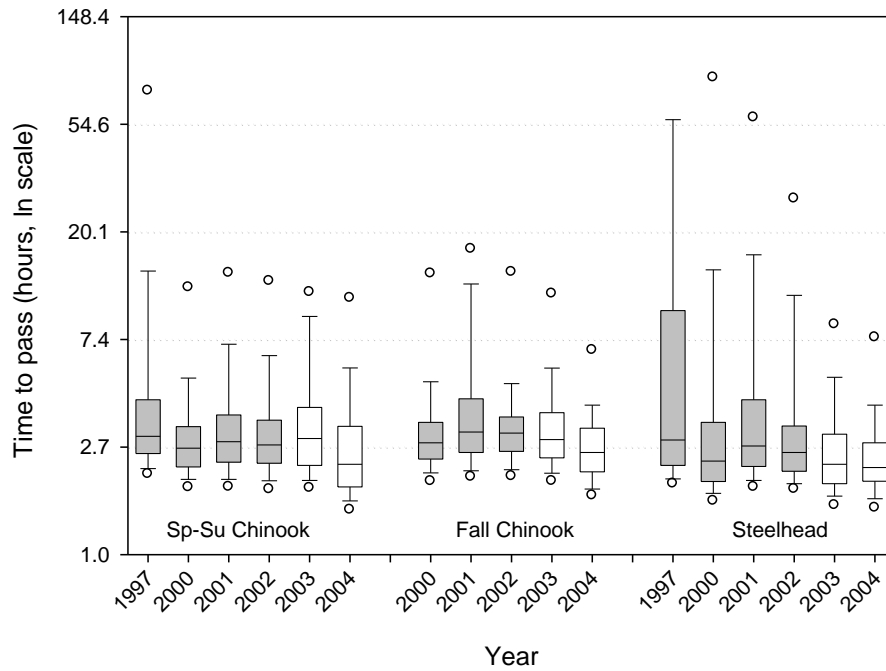


Figure 8. Median, quartile, 5th, 10th, 90th, and 95th percentiles of adult Chinook salmon and steelhead passage times between their first record at antenna near the top of the south-shore transition pool at John Day Dam and exit from the top of the ladder, by year. Note ln scale to accommodate right-skewed data.

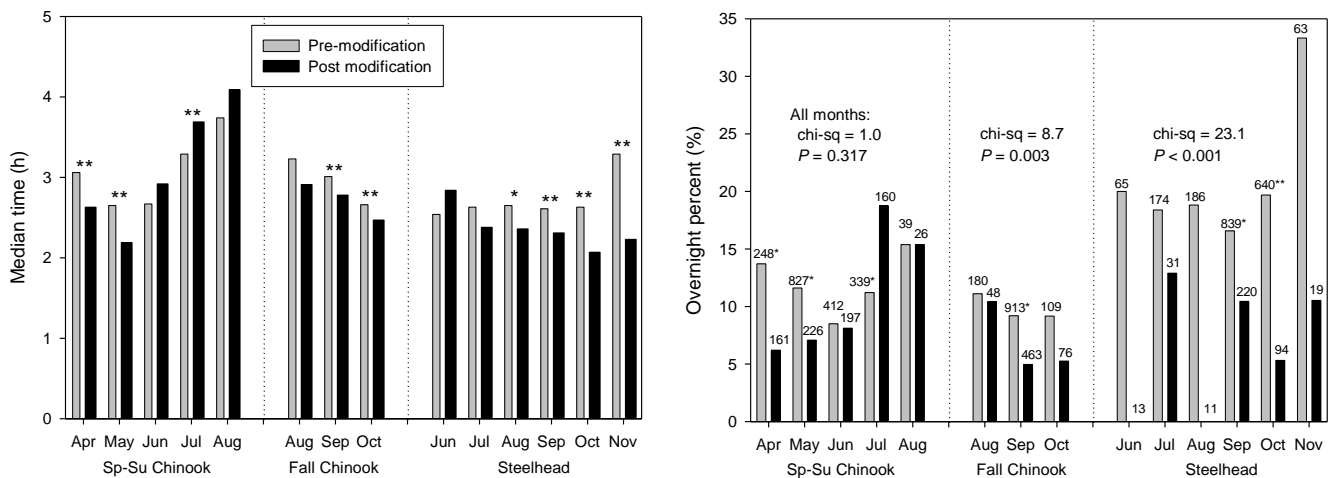


Figure 9. Median passage times (left panel) and percent (right panel) of radio-tagged adult Chinook salmon and steelhead that were recorded on more than one date (i.e., over night) between their first record at antenna near the top of the south-shore transition pool at John Day Dam and exit from the top of the ladder, by month. Pearson χ^2 tests compared percentages and Kruskal-Wallis tests compared medians for years before the upper ladder modification (1997 and 2000-2002) and years after modification (2003-2004). * $P < 0.05$, ** $P < 0.005$.

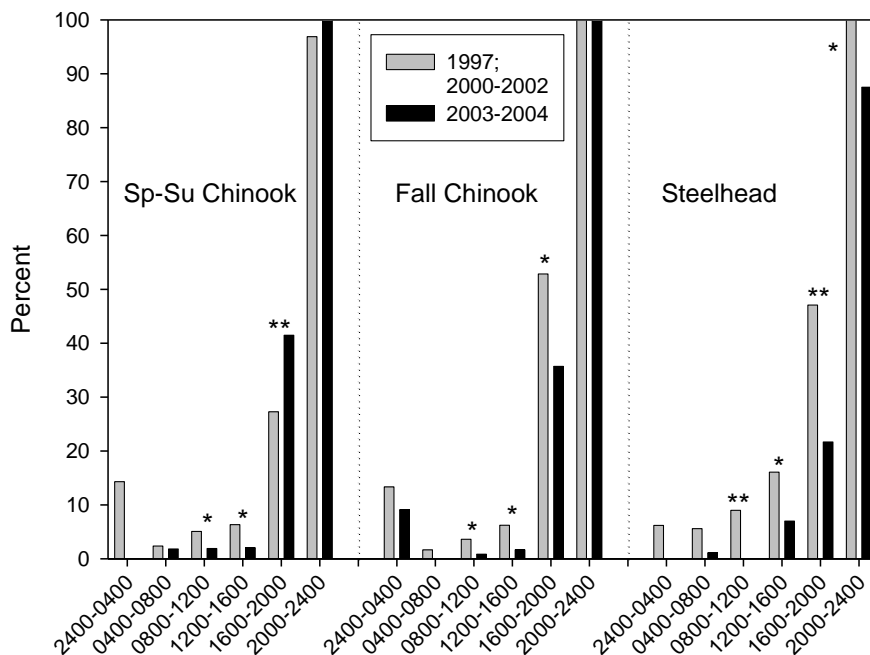


Figure 10. Percent of radio-tagged adult Chinook salmon and steelhead that were recorded on more than one date (i.e., over night) between their first record at antenna near the top of the south-shore transition pool at John Day Dam and exit from the top of the ladder, by time of first detection. Pearson χ^2 tests of percentages compared years before the upper ladder modification (1997 and 2000-2002) with years after modification (2003-2004). * $P < 0.05$, ** $P < 0.005$.

Passage times: Ladder bottom to ladder top. – We expected passage times for this full-ladder segment to be more variable than for the upstream segments. Many fish from all runs make multiple attempts to pass through the transition pool, adding to passage times. This variability is reflected in longer mean passage times and to a lesser extent in median times (Table 1). Wider distributions and longer tails were typical in most run-years, and particularly in 1996 and 1997 when discharge, turbidity, and tailwater elevation were much higher than average (Figure 11). Median passage times ranged from 2.4 h (2004 steelhead) to 4.1 h (1996 spring–summer Chinook salmon) (Table 1). As with the other segments, median passage times were significantly shorter after the ladder modification for all runs (Kruskal-Wallis tests: spring–summer Chinook salmon $\chi^2 = 9.1$, $P = 0.0025$; fall Chinook salmon $\chi^2 = 23.0$, $P < 0.0001$; steelhead $\chi^2 = 71.4$, $P < 0.0001$). By percentage, reductions in medians were more modest, ranging from 2% (0.06 h) for spring–summer Chinook salmon to 14% (0.40 h) for steelhead. Reductions in means were 18% (2.7 h) for spring–summer Chinook salmon, 39% (3.3 h) for fall Chinook salmon, and 86% (39.3 h) for steelhead (Table 1).

Monthly median passage times were significantly ($P < 0.05$) shorter in September–November for steelhead, September–October for fall Chinook salmon, and April–May for spring–summer Chinook salmon (Figure 12). The opposite pattern was observed in June–July for spring–summer Chinook salmon, with longer medians after the ladder modification. Water temperatures were higher than average during these months in 2003–2004, and this may have led to relatively higher transition pool exit rates and consequently longer passage times for this segment in the post-modification years. The result was not likely related to the ladder modification. Monthly and time-of-day overnight percentages followed similar patterns as for the other segments, with fewer fish spending a night in the ladder in the later years (Figures 12 and 13).

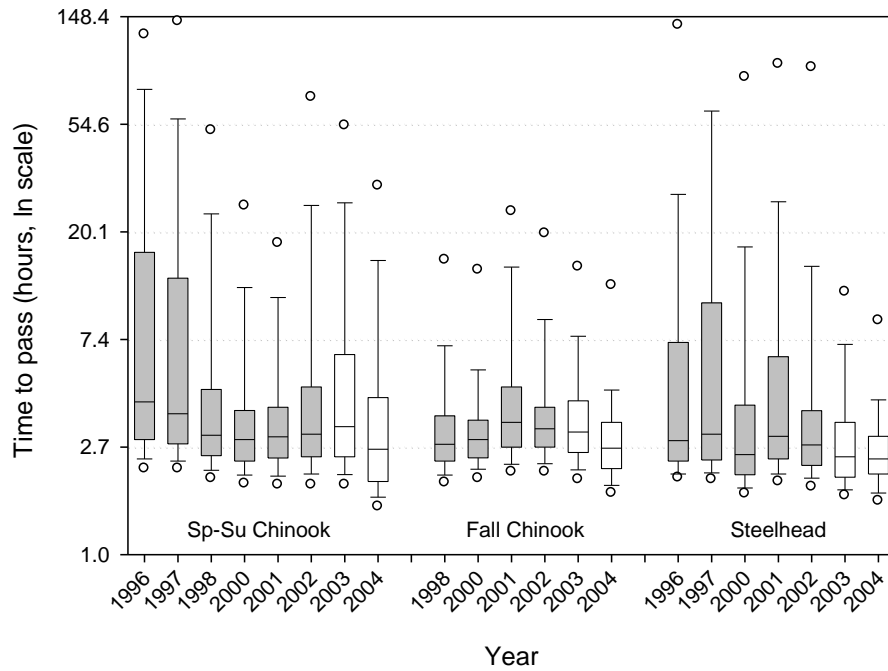


Figure 11. Median, quartile, 5th, 10th, 90th, and 95th percentiles of adult Chinook salmon and steelhead passage times between their first record near the bottom of the south-shore ladder at John Day Dam and exit from the top of the ladder, by year. Note In scale to accommodate right-skewed data.

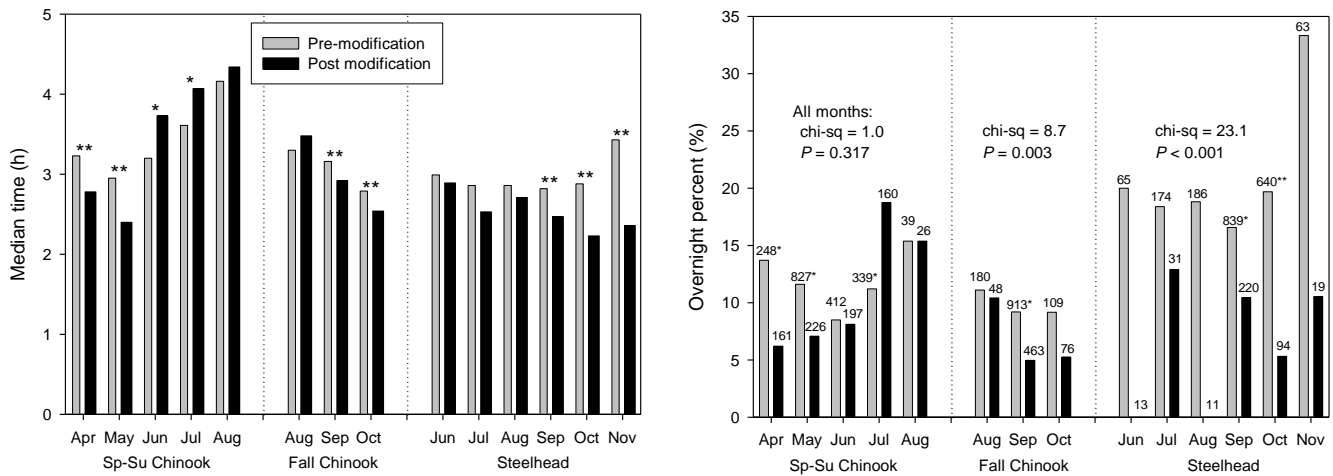


Figure 12. Median passage times (left panel) and percent (right panel) of radio-tagged adult Chinook salmon and steelhead that were recorded on more than one date (i.e., overnight) between their first record near the bottom of the south-shore ladder at John Day Dam and exit from the top of the ladder, by month. Pearson χ^2 tests compared percentages and Kruskal-Wallis tests compared medians for years before the upper ladder modification (1996-1998, 2000-2002) and years after modification (2003-2004). * $P < 0.05$, ** $P < 0.005$.

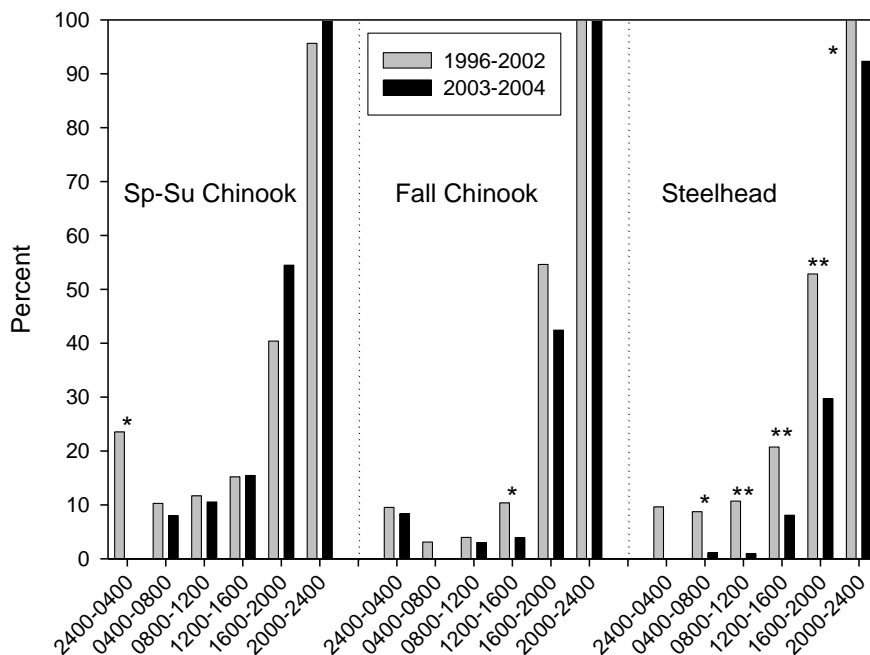


Figure 13. Percent of radio-tagged adult Chinook salmon and steelhead that were recorded on more than one date (i.e., over night) between their first record near the bottom of the south-shore ladder at John Day Dam and exit from the top of the ladder, by time of first detection. Pearson χ^2 tests of percentages compared years before the upper ladder modification (1996-1998, 2000-2002) with years after modification (2003-2004). Pearson χ^2 tests, * $P < 0.05$, ** $P < 0.005$.

Passage times: Full dam. – A full analysis of full-dam passage times was beyond the scope of this summary. Nonetheless, one might expect that the south-shore ladder modification and resulting reductions in ladder passage times would affect overall dam passage. In fact, median full-dam passage times for spring–summer and fall Chinook salmon were lower in 2003-2004 than in any years from 1996-2002 (Table 2). Full-dam passage times for steelhead in 2003-2004 were also among the lowest recorded. Reductions in full-dam passage times were greater than would be suggested by the reduced times recorded in the south-shore ladder, suggesting that factors other than the modification alone may have improved passage times in the later years.

Table 2. Full-dam passage times, from first tailrace record to last record at the top of a fish ladder, at John Day Dam for radio-tagged spring–summer and fall Chinook salmon and steelhead, 1996-2004. (Additional full-dam passage results in Keefer et al. *in review a* and Burke et al. 2005).

	Time to pass John Day Dam					
	Sp-Su Chinook		Fall Chinook		Steelhead	
	Median (h)	<i>n</i>	Median (h)	<i>n</i>	Median (h)	<i>n</i>
1996	30.2	307	--	--	20.4	393
1997	35.8	527	--	--	16.9	477
1998	31.2	505	23.1	299	--	--
2000	28.4	493	32.4	261	19.6	516
2001	26.1	690	21.4	284	20.3	509
2002	25.5	711	23.4	415	24.1	686
2003	24.1	640	19.1	214	15.7	333
2004	20.4	331	15.8	222	17.5	147

Ladder rejection and ladder backdown. – Small percentages (< 4%) of the radio-tagged Chinook salmon were recorded backing down the ladder from the diffuser antenna to antennas near the counting window or transition pool in 1996-1998 (Figure 13). Nonetheless, percentages were significantly lower ($P < 0.0001$, χ^2 tests) for both spring–summer and fall Chinook salmon in the post-modification years. Backdown percentages for steelhead were 11.3 and 18.5% in 1996 and 1997, respectively, and were reduced to < 1% in 2003-2004 ($P < 0.0001$) (Figure 13). Rejection of the south-shore ladder after detection at the diffuser antenna was typically less than half the backdown percentage for all runs during 1996-1998. This behavior was nearly non-existent in the 2003-2004 runs, and the treatment effect was significant ($P < 0.0001$) (Figure 13).

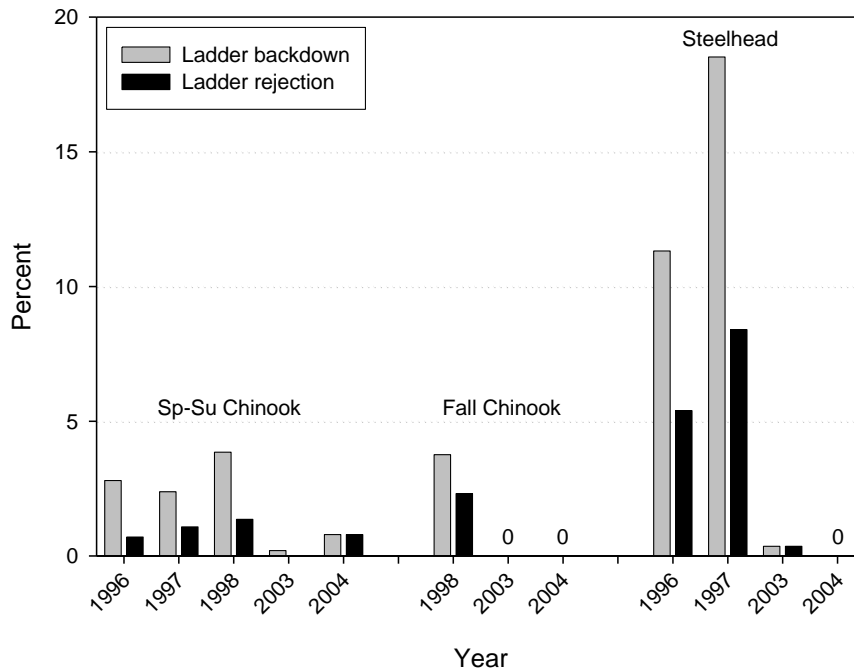


Figure 14. Percent of radio-tagged adult Chinook salmon and steelhead recorded at the antenna above the upper ladder diffuser that were subsequently recorded at an antenna near the counting station (1996 only) or transition pool (all years). Gray bars represent the percent that backed down the ladder but eventually passed the dam via the south-shore ladder; black bars represent the percent that backed down and either passed via the north-shore ladder or navigation lock, or did not pass the dam (ladder rejection).

Discussion

The results of this multi-year retrospective study of adult salmon and steelhead passage through the south-shore ladder at John Day Dam mostly confirm the findings of Jonas et al. (2004). Modification of the flow-control section of the upper ladder from serpentine weirs to a slot and orifice configuration appears to have reduced unfavorable behaviors—such as jumping, stranding, holding, ‘overnighting’, and ladder backdown—and also significantly reduced fish passage times for all of the studied runs.

The largest passage time reductions were for steelhead. In the early study years, steelhead passage time distributions were greatly skewed, with many fish taking weeks and even months to

pass the ladder. Anecdotal evidence and the collection of many fish during winter dewatering suggest that some steelhead historically overwintered in the ladder near the serpentine section. Following the ladder modification, the number of steelhead with extended ladder residence times was substantially reduced, most likely because fish moved straight through the upper section rather than hesitating or backtracking. Very few fish from any run took more than a day to pass through the diffuser-ladder top or transition pool-ladder top segments following modification. As would be expected, passage times from ladder bottom to ladder top were longer than the through the upper sections due to variability introduced by passage through the transition pool, but fish still had lower passage times through the full ladder after modification.

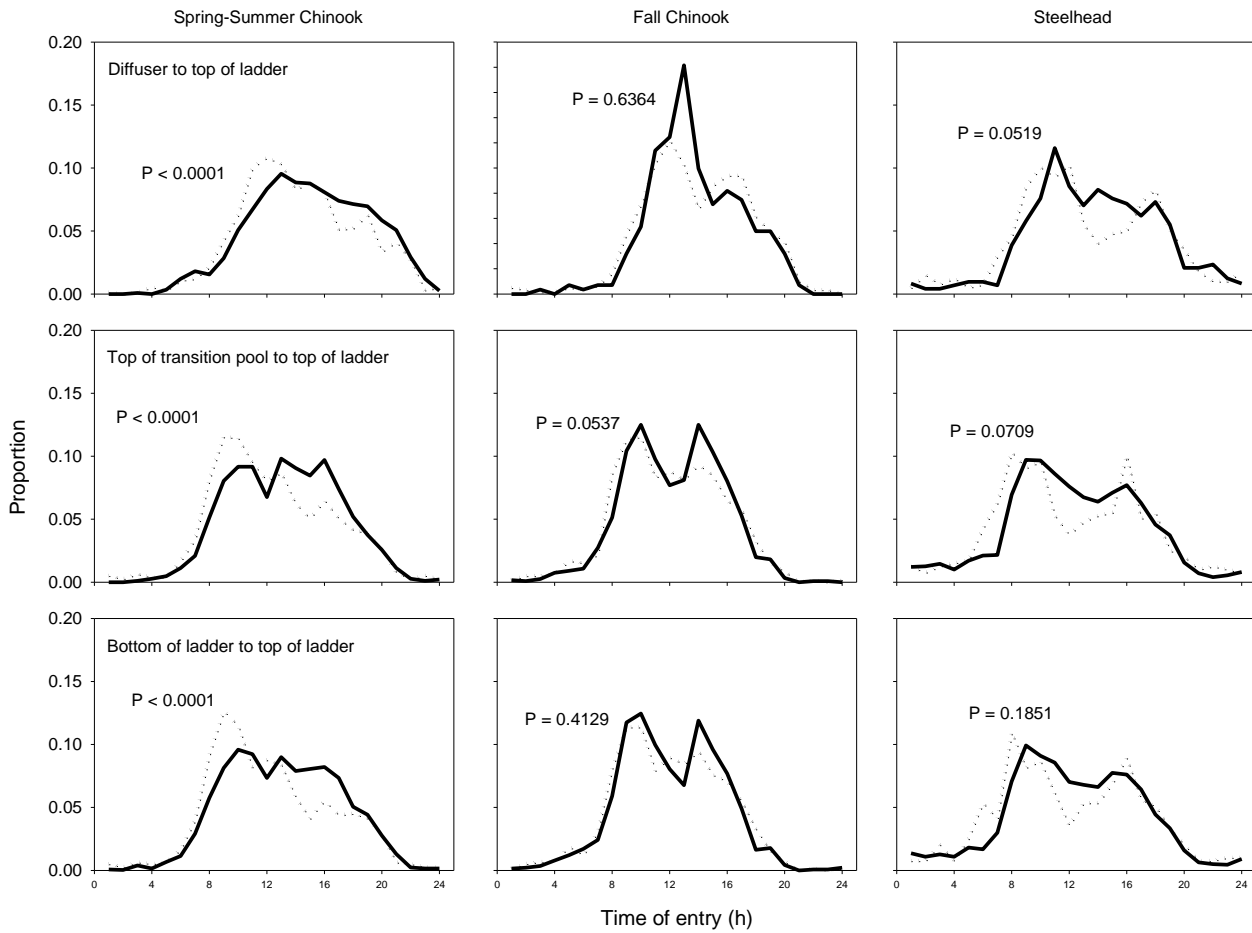
We did find evidence for potential confounding factors, such as shifts in arrival time of day and seasonal migration timing, between the pre- and post-modification years. However, stratifying analyses by month and time of day revealed that patterns were similar across almost all conditions. This further confirmed to us that the ladder modification was successful. We note that our analyses did not consider environmental variability either within or among years, and it is possible that some environmental differences contributed to the observed patterns. For example, temperatures at John Day Dam were generally above average in the later years and discharge was relatively low. Either of these factors could contribute to faster passage at the dam, and some evidence for this was found in the brief summary of full-dam passage times. That full-dam passage times were lower in 2003-2004 by more than would be suggested by the ladder modification alone does indicate that the overall passage environment was favorable at the dam in the post-modification years. We do not, however, think that all (or even much) of the observed changes in fish behaviors in the ladder can be attributable to environmental conditions.

The results here do suggest that similar modifications to the serpentine section of the north-shore ladder at John Day Dam may be worthwhile. Although other passage problems exist for adult migrants at the dam, including fishway temperature issues (Keefer et al. 2003) and high fishway exit rates (Keefer et al. *in review a*), modifying the north-shore ladder would likely further improve overall adult passage efficiency at the dam and warrants consideration.

References

- Bjornn, T. C., M. L. Keefer, C. A. Peery, K. R. Tolotti, R. R. Ringe, and P. J. Keniry. 2000a. Migration of adult spring and summer Chinook salmon past Columbia and Snake River dams, through reservoirs and distribution into tributaries, 1996. Report for U.S. Army Corps of Engineers, Walla Walla District, Walla, Walla, WA, and Bonneville Power Administration, Portland, OR.
- Burke, B. J., K. E. Frick, M. L. Moser, T. J. Bohn, T. C. Bjornn. 2005. Adult fall Chinook salmon passage through fishways at lower Columbia River dams in 1998, 2000, and 2001. Report of Northwest Fisheries Science Center (National Marine Fisheries Service) and Idaho Cooperative Fish and Wildlife Research Unit to U.S. Army Corps of Engineers, Portland and Walla Walla districts.
- Caudill, C.C., T.S. Clabough, G.P. Naughton, C.A. Peery, and B.J. Burke. 2006. Water temperatures in adult fishways at mainstem dams on the Snake and Columbia rivers: Phase 2 – biological effects. Technical Report 2006-3 of Idaho Cooperative Fish and Wildlife Research Unit and NOAA Fisheries to U.S. Army Corps of Engineers, Walla Walla district.
- Jepson, M. A., C. A. Peery, M. L. Keefer, and B. Burke. 2005. Run-timing, escapement, and estimated harvest of upriver bright fall Chinook salmon in the Columbia River, 1998 and 2000-

2004. Technical Report 2005-4 of Idaho Cooperative Fish and Wildlife Research Unit Technical Report to the Pacific Salmon Commission, Portland, OR.
- Jonas, M. R. and P. L. Madson. 2001. Salmonid jump behavior in John Day Dam fish ladders 2000. U. S. Army Corps of Engineers, CENWP-CO-SRF, Fisheries Field Unit, Bonneville Lock and Dam, Cascade Locks, OR.
- Jonas, M. R., J. T. Dalen, S. T. Jones, and P. L. Madson. 2004. Evaluation of the John Day Dam south fish ladder modification 2003. U. S. Army Corps of Engineers, CENWP-CO-SRF, Fisheries Field Unit, Bonneville Lock and Dam, Cascade Locks, OR.
- Keefer, M.L., C.A. Peery, and B. Burke. 2003. Passage of radio-tagged adult salmon and steelhead at John Day Dam with emphasis on fishway temperatures: 1997-1998. Technical Report 2003-1 of Idaho Cooperative Fish and Wildlife Research Unit to U.S. Army Corps of Engineers, Portland and Walla Walla districts.
- Keefer, M. L., C. A. Peery, T.C. Bjornn, M.A. Jepson, and L.C. Stuehrenberg. 2004a. Hydrosystem, dam, and reservoir passage rates of adult Chinook salmon and steelhead in the Columbia and Snake rivers. *Transactions of the American Fisheries Society* 133:1413-1439.
- Keefer, M. L., C. A. Peery, R. R. Ringe, and T. C. Bjornn. 2004b. Regurgitation rates of intragastric radio transmitters by adult chinook salmon and steelhead during upstream migration in the Columbia and Snake rivers. *North American Journal of Fisheries Management* 24:47-54.
- Keefer, M. L., C. A. Peery, W. R. Daigle, M. A. Jepson, S. R. Lee, C. T. Boggs, K. R. Tolotti, and B. J. Burke. 2005. Escapement, harvest, and unknown loss of radio-tagged adult salmonids in the Columbia River - Snake River hydrosystem. *Canadian Journal of Fisheries and Aquatic Sciences* 62:930-949.
- Keefer, M. L., C. A. Peery, T. C. Bjornn, M. A. Jepson, K.R. Tolotti, S. R. Lee, and L. C. Stuehrenberg. *In review a*. Adult salmon and steelhead passage through fishways and transition pools at John Day Dam, 1997-2001. Draft Technical Report of Idaho Cooperative Fish and Wildlife Research Unit to U.S. Army Corps of Engineers, Portland district.
- Keefer, M. L., D. C. Joosten, C. L. Williams, C. M. Nauman, M. A. Jepson, C. A. Peery, T. C. Bjornn, R. R. Ringe, K. R. Tolotti, S. R. Lee, L. C. Stuehrenberg, M. M. Moser, and B. J. Burke. *In review b*. Adult salmon and steelhead passage through fishways and transition pools at Bonneville Dam, 1997-2002. Draft Technical Report of Idaho Cooperative Fish and Wildlife Research Unit to U.S. Army Corps of Engineers, Portland district.
- Naughton, G. P., C. C. Caudill, M. L. Keefer, T. C. Bjornn, L. C. Stuehrenberg, and C. A. Peery. 2005. Late-season mortality during migration of radio-tagged sockeye salmon (*Oncorhynchus nerka*) in the Columbia River. *Canadian Journal of Fisheries and Aquatic Sciences* 62:30-47.



Appendix 1. Distributions of the time of day that fish were first recorded at the downstream antenna for each passage segment in the south-shore ladder at John Day Dam. Solid lines are for years before ladder modification and dotted lines are for 2003-2004. P values are for Kruskal-Wallis tests of median times. There was a general tendency for earlier arrival timing for spring–summer Chinook and steelhead in 2003-2004.