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Behavior of radio-tagged adult steelhead before, during, and after the spill test at The Dalles Dam in September 2014

Letter Report, 24 September 2015

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Introduction

Concerns have been expressed by USACE and NMFS that the disproportionately low use of the north fishway at The Dalles Dam by anadromous adult salmon and steelhead may be impeding passage of the runs at large. High counts of fall Chinook salmon (> 26,000 fish/day) in 2013 prompted managers to suggest that manipulation of spill might increase attraction of adults to the north-shore fishway, increase the proportion that pass the dam via the north ladder, and thereby reduce fish density in the east fishway. The large fall Chinook salmon run in 2014 provided an opportunity to test the effectiveness of using spill to attract migrants to the north fishway and to evaluate the degree to which high daily fish counts might affect steelhead passage times in the east ladder. From 9-15 September 2014, approximately 15 kcfs of spill (total) was released in varying distributions through Bays 1, 7, and 8 from 0500 to 1700 hrs each day. Ladder-specific counts of adult salmonids were collected by USACE contractors and reported by G. Fredericks (NMFS) in a file memorandum dated 24 September 2014. No spill operations were conducted at The Dalles Dam in the weeks before and after the test.

Radiotelemetry evaluation

In the summer and fall of 2014, University of Idaho personnel collected and radio-tagged adult steelhead at Bonneville Dam and monitored their movements through the lower Columbia River hydrosystem as part of other Corps-funded research. Monitoring of tagged steelhead at The Dalles Dam (Figure 1) provided an opportunity to gain insights on the behaviors of adult migrants in relation to the spill evaluation, with an expectation that adult steelhead behave similarly to adult fall Chinook salmon. We addressed five behavioral questions:

(1) Did the percentage of radio-tagged steelhead that approached or first approached the north fishway increase during the spill operation relative to the no-spill operation?

(2) Did north fishway entrance efficiency change for steelhead during the spill operation relative to the no spill operation?

(3) Did steelhead passage times past The Dalles Dam differ during the spill and no-spill operations at the north fishway and at the dam overall?

(4) Independent of spill operations, did the proportion of fishway entries resulting in dam passage events differ between the east and north fishways? (We assume that spill would have negligible to no effects on behavior once a fish entered a fishway.)

(5) Were the daily fish counts in the east ladder positively associated with increased passage times by radio-tagged steelhead through the east fishway? (We assume that any crowding effects on passage times were likely to occur within the east fishway.)

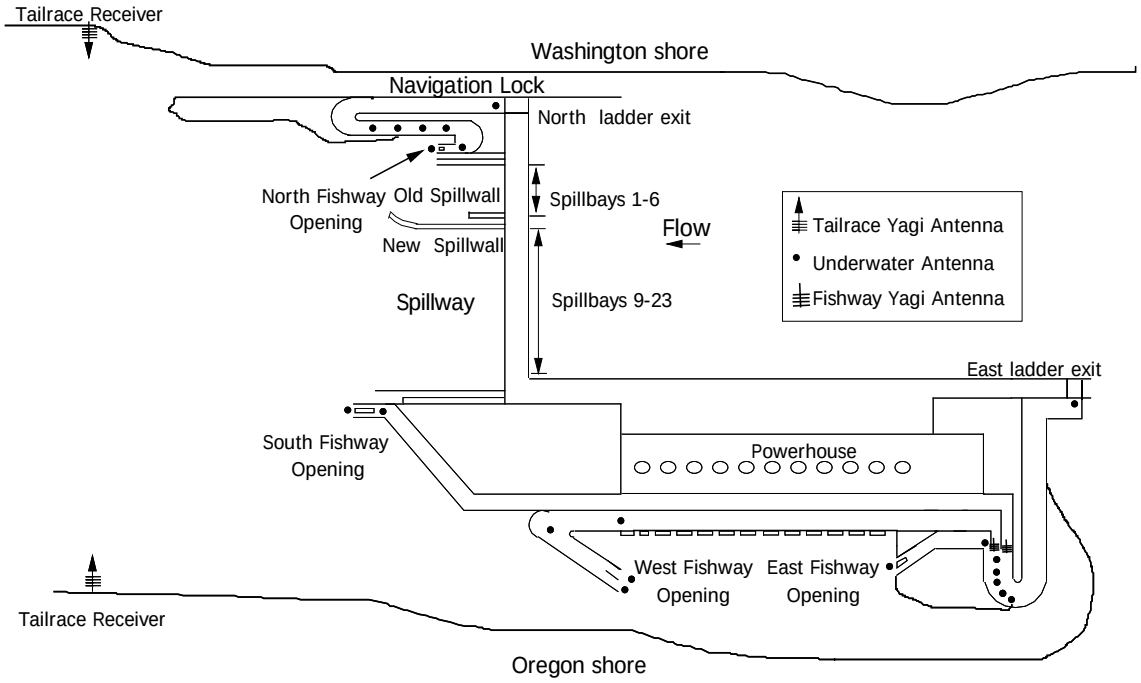

Figure 1. Diagram depicting the radiotelemetry array at The Dalles Dam in fall 2014. Please note that the orifice gates adjacent to the powerhouse/collection channel were closed.

Methods and Results

Sample sizes - Relatively few tagged steelhead were detected each day at The Dalles Dam in the week prior to the spill test (*range* = 1-9 steelhead/d). This was due in part to restrictions placed on tagging efforts at Bonneville Dam from 28 July through 5 September 2014 because of elevated water temperatures. Sample sizes increased to daily totals of 14 to 39 tagged steelhead per day during the test and ranged from 17 to 38 tagged steelhead per day the week after the test (Table 1).

Dam passage - A total of 251 radio-tagged steelhead was detected at The Dalles Dam from 2-22 September 2014. We excluded one steelhead with detections in the tailrace only from 25 July through 13 September, suspecting that it may have been recaptured or may have died. Of the 250 remaining steelhead, 247 (98.8%) passed the dam on dates ranging from 2 September to 9 October 2014. On days with spill, 111 tagged steelhead were first detected and all but one of the steelhead passed the dam (*dam passage efficiency* = 99.1%). For comparison, 137 of the 139 tagged steelhead first detected on days without spill passed the dam (*efficiency* = 98.6%).

Approach frequencies at the north fishway - We assembled the fishway approach detections for all radio-tagged steelhead recorded at all fishway openings at The Dalles Dam from 2-22 September. Before the spill period, daily percentages of tagged steelhead that approached the north fishway ranged from zero to 100%. No tagged steelhead made their first approach at the north fishway in the week prior to the spill test. During the spill period, daily percentages of tagged steelhead that approached and first approached the north fishway ranged from 0-38% (*mean* = 22%) and 0-75% (*mean* = 28%), respectively. In the week after the spill period, daily percentages of tagged fish that approached and first approached the north fishway ranged from 6-28% (*mean* = 16%) and 0-28% (*mean* = 13%), respectively. Generally, daily percentages of total approaches and first approaches by radio-tagged steelhead were consistent with the percentages of steelhead counted at the north fishway, which reflected an overall increase in attraction to the north fishway by steelhead during periods of spill (Figure 2 and Table 1).

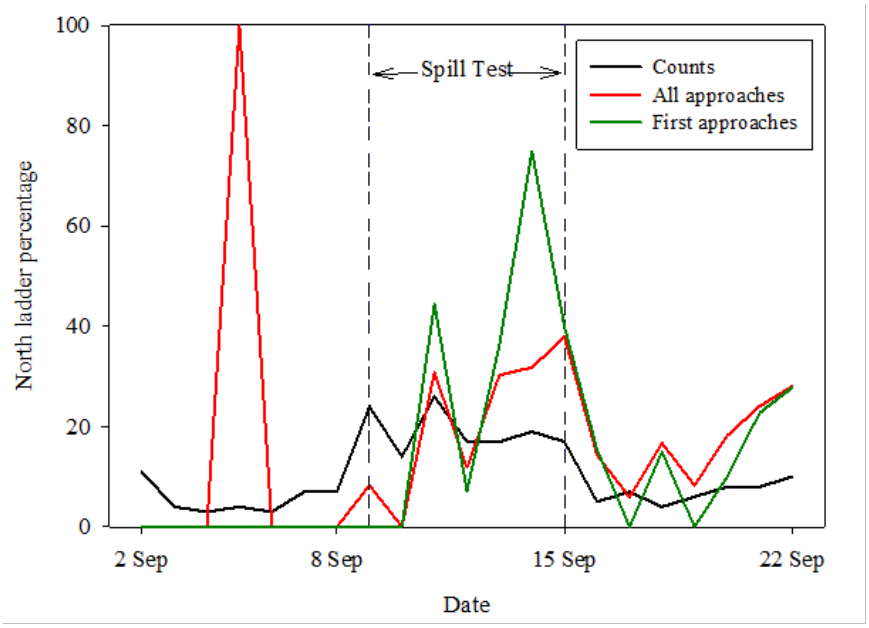

Figure 2. Daily percent use of the north fishway at The Dalles Dam by adult steelhead based on ladder-specific counts (of steelhead only) and of total fishway approaches and first fishway approaches by unique, radio-tagged steelhead in September 2014 before, during, and after the spill test. Note that sample sizes were low (<10) during the pre-spill period.

Table 1. The number of unique, radio-tagged steelhead (SH) detected at The Dalles Dam, the number making an approach at any fishway, and those making an approach or first approach at the north fishway or east[1] fishway routes, 2-22 September 2014.

Date (Sept.)	Spill (y/n)	Uniq. SH at TD	Uniq. SH that approached any fishway	Uniq. SH that 1st approached any fishway	Uniq. SH that approached N. fishway	Uniq. SH that approached N. fishway (%)[2]	Uniq. SH that 1st approached N. fishway	Uniq SH that 1st approached N. fishway (%)[2]	Uniq. SH that approached E. fishways	Uniq. SH that 1st approached E. fishways
2	No	3	3	3	0	0	0	0	3	3
3	No	4	0	0	-	0	0	-	0	-
4	No	6	5	5	0	0	0	0	5	5
5	No	2	1	0	1	100	0	0	1	0
6	No	1	0	0	-	0	0	-	0	-
7	No	2	1	1	0	0	0	0	1	1
8	No	9	4	4	0	0	0	0	4	4
9	**Yes**	**14**	**12**	**10**	**1**	**8**	**0**	**0**	**12**	**5**
10	**Yes**	**15**	**13**	**9**	**0**	**0**	**0**	**0**	**13**	**8**
11	**Yes**	**19**	**13**	**9**	**4**	**31**	**4**	**44**	**13**	**9**
12	**Yes**	**24**	**17**	**14**	**2**	**12**	**1**	**7**	**17**	**13**
13	**Yes**	**39**	**33**	**22**	**10**	**30**	**8**	**36**	**30**	**22**
14	**Yes**	**34**	**22**	**8**	**7**	**32**	**6**	**75**	**20**	**8**
15	**Yes**	**32**	**29**	**15**	**11**	**38**	**6**	**40**	**24**	**13**
16	No	26	21	13	3	14	2	15	30	13
17	No	28	17	13	1	6	0	0	17	13
18	No	31	24	20	4	17	3	15	23	20
19	No	17	12	10	1	8	0	0	12	10
20	No	20	11	10	2	18	1	10	10	10
21	No	38	29	22	7	24	5	23	29	22
22	No	34	25	18	7	28	5	28	23	18

[1] East fishway includes the south, west, and east openings – see Figure1.

[2] denominator = number of unique steelhead that made a fishway approach.

[3] denominator = number of unique steelhead that made a first fishway approach.

Fishway-specific passage frequencies in relation to spill - We used a Chi-squared test to evaluate the proportions of tagged steelhead that passed the dam via the two fishways based on whether they made their first approach on days with and without spill. We limited our sample to tagged steelhead that passed the dam during the test period, 2-22 September (n = 232). As the observed increases in approach frequencies suggested, the presence of spill was associated with proportionately more tagged steelhead passing The Dalles Dam via the north fishway than the east fishway (Table 2).

Table 2. Frequencies and percentages (parentheses) of radio-tagged steelhead that passed The Dalles Dam via the north or east fishways based on the presence or absence of spill on the day of their first fishway approach.

	East fishway	North fishway	Prob. > χ^2
No Spill	115 (49.6)	6 (2.6)	0.014
Spill	95 (40.9)	16 (6.9)	

Comparisons of fishway entrance efficiencies - We compared the north fishway entrance efficiency during periods of spill and no spill where entrance efficiency = (total number of entries / total number of approaches). Of the 46 approaches made by tagged steelhead at the north fishway during periods of no spill, (33, 71%) resulted in fishway entries whereas 31 of the 37 (84%) approaches made during spill resulted in entries. There was no difference in these proportions based on a χ^2 test ($P > 0.64$). Similarly, we found no difference in entrance efficiency for tagged steelhead that approached east fishway openings during periods of spill (99 entries/192 approaches = 52% efficiency) compared to periods of no spill (222 entries/342 approaches = 65% efficiency; χ^2test $P = 0.13$). ~~Overall, entrance efficiency trended lower during the spill period at both locations but the trend was not statistically significant.~~

Ranked passage times in relation to spill and fishway - We calculated the time that tagged steelhead used to swim from their first fishway approach (A1) and first fishway entry (E1) to their last detection (LT) at a top-of-ladder antenna (A1toLT and E1toLT, respectively). We ranked the passage times and performed Kruskal-Wallis (K-W) tests, non-parametric analogs of analyses of variance, to evaluate differences in ranks based on the ladder used to pass the dam. We also used K-W tests to evaluate differences in ranked passage times based on whether tagged steelhead made their first fishway approach on days with or without spill.

Mean and median passage times for tagged steelhead were similar between fishways (Table 2) and results from the K-W tests suggested there were no statistically significant differences in steelhead passage times between fishways (Table 3).

Table 3. Mean and median times used by radio-tagged steelhead at The Dalles Dam to swim from their first fishway approach (A1) or entry (E1) to their last detection at a ladder exit (LT) based on ladder used to pass. Mean ranks, samples sizes, and K-W results are also provided.

	East fishway				North fishway				
	Mean (h)	Median (h)	Mean rank	n	Mean (h)	Median (h)	n	Mean rank	K-W *P*
A1 to LT	9.2	4.7	118.2	210	9.5	2.9	22	99.9	0.225
E1 to LT	7.6	3.0	117.7	210	7.9	2.4	22	104.8	0.392

With both fishways combined, mean and median passage times were longer for tagged steelhead that made their first fishway approach on days with spill compared to no spill though the differences were not statistically significant based on K-W tests at $\alpha = 0.05$ (Table 4). Passage times after first ladder entry did not differ between spill categories.

Table 4. Mean and median times used by radio-tagged steelhead at The Dalles Dam to swim from their first fishway approach or entry to their last detection at a ladder exit based on the presence of spill on the date of first approach. Mean ranks, samples sizes, and K-W results are also provided.

		Spill			No Spill				
	Mean (h)	Median (h)	Mean rank	n	Mean (h)	Median (h)	n	Mean rank	K-W *P*
A1 to LT	11.6	5.8	125.4	111	7.0	3.9	121	108.3	0.053
E1 to LT	9.6	3.0	120.3	111	5.8	2.8	121	113.0	0.410

Log^e-transformed passage times in relation to spill and fishway – Because passage times are highly variable and strongly right-skewed, due primarily to reduced fish activity at night, we applied a natural log transformation to normalize the data. We then used analysis of variance (ANOVA) tests to evaluate differences in passage times using the general linear model:

Log^e(passage time) = Spill (y,n) + LT Site + Spill*LT Site

where LT Site = the fishway used to pass the dam.

The interaction term was not significant in either model so we removed it and retested the main effects. We found significant differences in transformed A1toLT times based on the presence of spill on the date that steelhead first approached a fishway ($P > 0.009$; Table 5). Based on these parametric tests, spill operations were associated with longer A1 to LT passage times, independent of the fishway used to pass the dam. We found no significant variables in the overall model for transformed E1toLT times ($P = 0.134$).

Table 5. ANOVA results for tests of differences in transformed passage times at The Dalles Dam by radio-tagged steelhead based on the presence of spill on date of first fishway approach.

	Log^eA1toLT			Log^eE1toLT		
Variable(s)	df	F	*P* > F	df	F	P > F
Spill + LT Site	2	3.93	**0.021**	2	2.03	0.134
Spill	1	6.86	**0.009**	1	3.38	0.067
LT Site	1	1.99	0.160	1	1.23	0.269

Extended passage times in relation to spill - We converted passage times to binary responses based on an 8 hr threshold (response = 0 if < 8 hr and 1 if > 8 hr) and used a χ^2 test to evaluate whether the frequencies of longer passage times by tagged steelhead were associated with spill. We found that spill was associated with a higher frequency of steelhead with A1to LT and E1toLT times > 8 hours when steelhead passage at both fishways was combined (Table 6). This may indicate that spill resulted in more fish spending a night at the dam.

Table 6. Frequencies and percentages (parentheses) of radio-tagged steelhead that used more than 8 hours to pass The Dalles Dam after making their first fishway approach (A1) or first fishway entry (E1) based on the presence of spill on the day of their first fishway approach. LT = top-of-fishway exit.

	A1 to LT			E1 to LT		
	< 8 hr	≥ 8 hr	Prob. > χ^2	< 8 hr	≥ 8 hr	Prob. > χ2
No Spill	88 (37.9)	33 (14.2)	0.011	96 (41.4)	25 (10.8)	0.029
Spill	63 (27.2)	48 (20.7)		74 (31.9)	37 (15.9)	

Logistic regression models of extended passage times versus fish abundance - We used the binary response data and logistic regression models to test whether longer passage times were associated with the daily counts of all salmonids combined (i.e., adult Chinook, jack Chinook, adult steelhead, adult coho, and jack coho). We summed the daily, ladder-specific counts of all salmonids to generate an index of crowding. We found that the total counts of all salmonids on either the date of first approach (A1) or date of first entry (E1) were not significant explanatory variables for A1toLT or E1toLT binary response data. Maximum likelihood estimates were *P* = 0.10 and 0.76 for total counts on the A1 date and E1 date, respectively.

Dam passage efficiencies by fishway – If crowding impedes dam passage via the east fishway, one might expect to see proportionately fewer entries there that result in dam passage events compared to the north fishway. We used a Chi-square Test to evaluate whether there were differences in dam passage efficiencies between the two fishways. Of the 63 entries made by radio-tagged steelhead to the north fishway, 23 (37%) resulted in dam passage events. In contrast, the east fishway was nearly twice as efficient, with 323 entries resulting in 220 (68%) passage events. Based on results from the χ^2 test, the east fishway was significantly more efficient at passing radio-tagged steelhead than the north fishway ($P < 0.015$).

Linear regression models of transformed fishway passage times vs. ladder-specific counts - If crowding impedes passage in the east ladder, one might expect to see increased fishway passage times when daily counts of salmonids are high. We calculated the time that tagged steelhead used from the final entry (E_{last}) to a fishway before passing the dam to their last record at a ladder exit (LT). We log^e-transformed the times and plotted them against the ladder-specific sum of all salmonids counted passing on the date of their dam passage. We evaluated whether the slopes of the linear regression models were significantly different from zero to see if passage times were directly related to the ladder-specific indices of crowding. We found that the slopes of the regression models for both ladders were not different from zero ($P = 0.63$ [north] and $P = 0.72$ [east]; Figure 3). This suggests that steelhead passage times through fishways were independent of the number of salmonids counted passing either ladder over the range of ladder-specific counts.

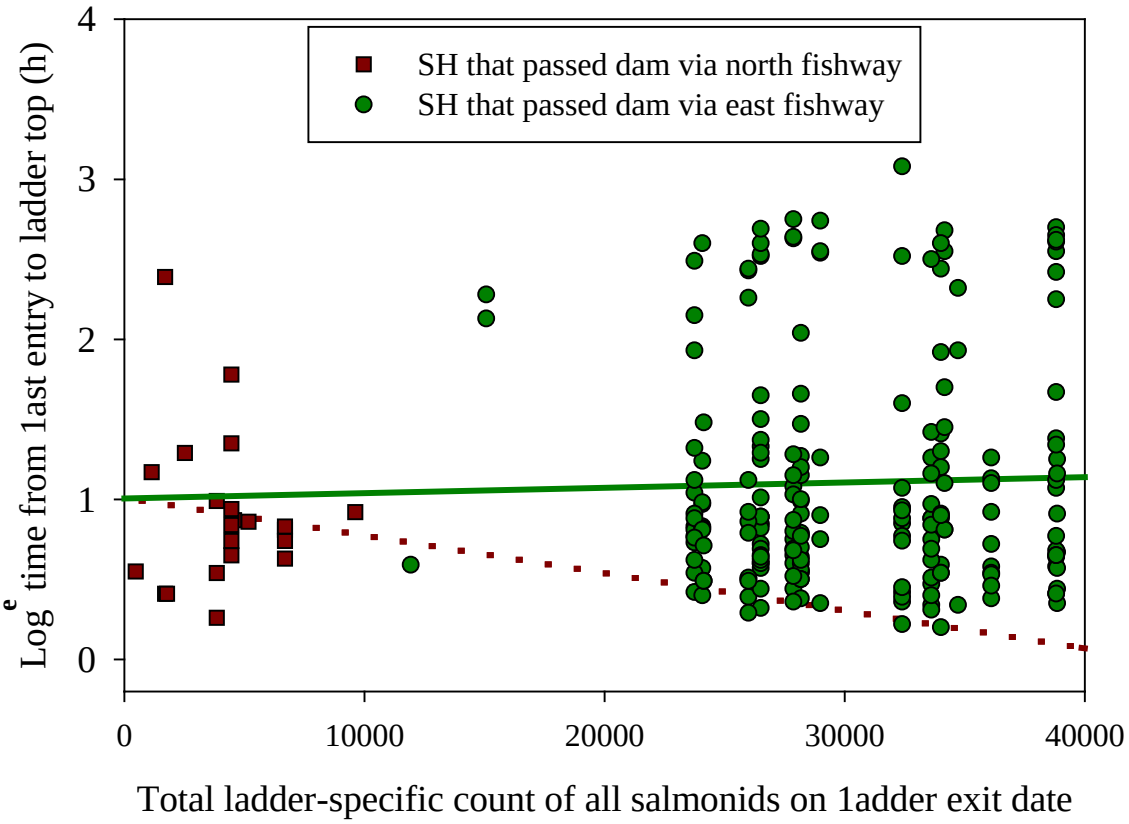

Figure 3. Scatterplots and linear regression models for log^e-transformed fishway passage times by radio-tagged steelhead versus ladder-specific, summed counts of salmonids passing The Dalles Dam on the date of the ladder exit by the tagged fish, 2-22 September 2014.

Conclusions

In summary, it was clear that the spill operation attracted proportionately more steelhead to the north fishway based on the radiotelemetry data and this was consistent with the increases in proportionate dam passage based on adult steelhead count data. It was not abundantly clear from the telemetry data, however, that fishway entrance efficiency improved at the north fishway when spill was present. Moreover, the fishway passage efficiency of tagged steelhead that did enter the north fishway was almost half that of tagged steelhead that entered the east fishway, on a per attempt basis (though almost all fish passed eventually). The combined results suggest that attracting steelhead to the north fishway effectively redistributes them in the tailrace and between the two fishways, but with an apparent cost in terms of passage efficiency and time.

Evaluations of passage times provided mixed results. Mean and median passage times were nearly significantly different between spill treatments based on nonparametric tests at alpha = 0.05 but proportions of tagged steelhead with passage times greater than 8 hours increased significantly during periods of spill. Parametric tests also suggested that transformed A1 to LT times were significantly higher for tagged steelhead that first approached the dam on days with spill. On balance, we expect that steelhead passage times are likely to increase moderately during periods of daytime September spill totaling ~15 kcfs.

Importantly, the radiotelemetry data failed to provide support for the premise that steelhead (vis à vis fall Chinook salmon) passage times increase when there are high abundances of salmonids passing the Dalles Dam via the east versus the north fishway. Logistic regression models of binary response passage time data (< 8 h versus > 8 h) suggested that the sum of all salmonids counted on either the date of first fishway approach or date of first fishway entry were not significant explanatory variables for A1toLT or E1toLT times, respectively. This was consistent with linear regression models of transformed fishway passage times versus ladder-specific counts, which suggested that fishway passage times were independent of the number of salmonids counted passing either ladder over the range of ladder-specific counts (i.e., passage times were not density-dependent).