Pacific Northwest NATIONAL LABORATORY

PNNL-29587

Evaluation of Foster Dam Juvenile Fish Passage, 2018

Final Report

January 2020

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KR Znotinas
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CR Vernon
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ES Fischer
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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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Pacific Northwest National Laboratory
Richland, Washington 99352

Preface

Pacific Northwest National Laboratory evaluated juvenile salmonid passage and survival at Foster Dam on the South Santiam River in Oregon for the U.S. Army Corps of Engineers Portland District (USACE) to provide data to support decisions for long-term measures to enhance downstream fish passage at Foster Dam. This radio telemetry study was conducted in response to regulatory requirements necessitated by the listing of Upper Willamette River Spring Chinook salmon (*Oncorhynchus tshawytscha*) and Upper Willamette River steelhead (*O. mykiss*) as threatened under the Endangered Species Act. The study results provide active-tag data on survival, passage distributions, and travel times at Foster Dam. This information is applicable to management decisions concerning the design and operation of a new fish weir and potential dam operations to aid in the restoration of listed Chinook salmon and steelhead populations in the South Santiam River Basin.

The study was led by Stephanie Liss (509 375 2988). The USACE technical lead for the study was Fenton Khan (503 808 4777).

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Summary

This report presents the results of a fish passage study conducted by the Pacific Northwest National Laboratory (PNNL) for the U.S. Army Corps of Engineers Portland District (USACE) at Foster Dam (herein, Foster) during the spring (March–June) and fall (October–December) of 2018. The goal of this study was to provide biologists, engineers, resource managers, and regional decision-makers with information about passage of juvenile Chinook salmon and juvenile steelhead (or appropriate surrogates) through specific routes at Foster. The results of this study are intended to help facilitate decision-making regarding long-term measures for enhancing salmonid passage at Foster.

Radio telemetry (RT) methods were instituted at low winter reservoir forebay elevation (low pool, 613 ft mean sea level (msl); spring 2018 and fall 2018) and high summer reservoir forebay elevation (high pool, 635 ft msl; late spring and early summer 2018) to accomplish the following objectives:

I. Estimate the following passage metrics under typical operations (i.e., baseline conditions):
    a. Overall dam-passage survival and survival specific to each route of dam passage, calculated using two different methods:
        i. Cormack-Jolly-Seber (CJS) estimate: Probability of survival from dam passage to detection at the Primary Array, 19 river kilometers (rkm) downstream of Foster.
        ii. Virtual Release/Dead Fish Correction (ViRDCt) estimate: Corrects the bias that occurs from misidentifying fish that did not survive dam-passage as alive at the tailrace Egress Array, allowing an estimate of survival from dam passage to this array, 2.5 rkm downstream of Foster.
    b. Route distribution (passage proportions by route; also known as “passage efficiencies”).
    c. Efficiency metrics
        i. Dam-passage efficiency (DPE), the proportion of total fish passing the dam relative to the number of total fish detected in the near forebay of the dam and therefore available to pass.
        ii. Fish passage efficiency (FPE), the proportion of fish passing via a non-turbine route, relative to the number of total fish in the near forebay and available to pass.
        iii. Fish weir efficiency (FWE) and spill bay efficiency (SBE), the proportion of fish passing the weir or spill bays, respectively, relative to the total number of fish passing the dam.
    d. Reservoir residency time (time elapsed between release into reservoir and dam passage) and travel times through the system.

II. Estimate efficiency and effectiveness of the new fish weir, compared to the turbines and the spillway.

III. Under alternative operations, compare passage through each route (turbines, weir, spillway) using a block/treatment (on/off) design similar to the 2015 and 2016 studies.

IV. Estimate efficiency of the new fish weir operating at a low level of discharge (< 500 cfs) and a high level of discharge (≥ 500 cfs), as well as dam passage survival at each weir discharge level.

V. Evaluate survival and behavior of hatchery summer steelhead to wild surrogate winter steelhead for potential use of summer steelhead as a surrogate species winter steelhead.

VI. Evaluate juvenile passage rates in the auxiliary water supply (AWS), forebay water supply (FWS), and hatchery water supply (HWS).

An optimization task of antenna detection efficiency, originally conducted in fall 2014, ensured deployed RT arrays were configured for maximum likelihood of detection of study fish. Pre-season testing of antenna detection efficiencies was also conducted prior to the start of each study season and year.

Detection zones were created to monitor radio-tagged juvenile salmon and steelhead at 10 locations at Foster: the extended forebay; the near forebay (NF); Turbine Units 1 and 2 (PS1 and PS2, respectively); the fish weir (Spill Bay 4 [SB4]); Spill Bays 1–3 (SB 1–3); the AWS; the FWS; the spillway tailrace (SPT); and the powerhouse tailrace (PHT, Figure S.1).

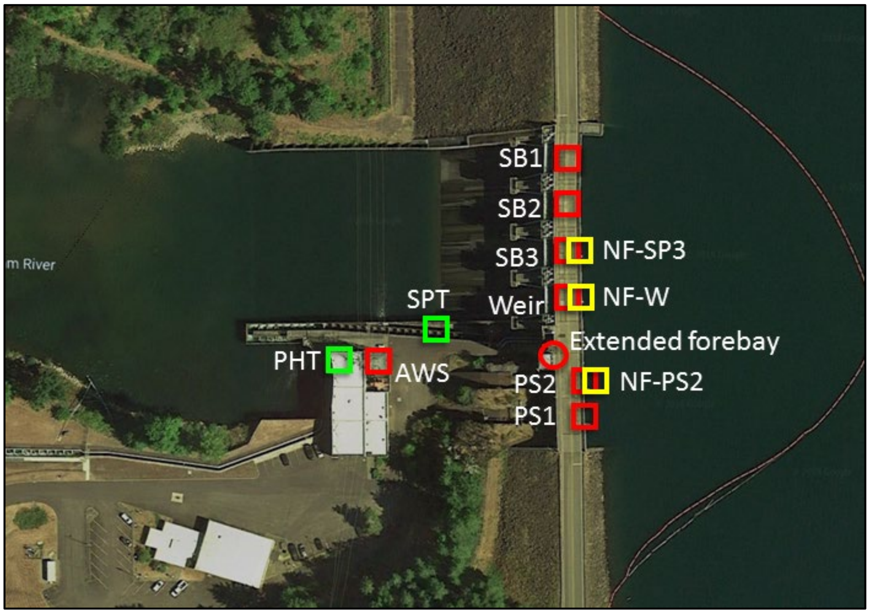

Figure S.1. Radio Telemetry Detection Locations to Assess Route-Specific Survival and Behavior of Juvenile Salmon and Steelhead at Foster, 2018. AWS = auxiliary water supply, NF = near forebay, PHT = powerhouse tailrace, PS = penstock, SB = spill bay, SPT = spillway tailrace, W =weir.

Capture histories required to estimate survival at Foster were compiled from detections on both underwater loop-vee and aerial antennas deployed upstream and downstream of Foster. The release-recapture designs used to estimate survival and associated metrics required the regrouping of fish, double-tagged with radio and passive integrated transponder (PIT) tags, detected at the dam-face telemetry array (V_1), from two release locations in the Foster reservoir (R_1 and R_2; Figure S.2). We used two models to estimate survival in this report. In 2015 and 2016 (i.e., old weir evaluations), survival was estimated using the CJS model, from Foster through 19 rkm of tailwaters to the Primary Array (D_2), using RT detections at the Secondary (D_3) and/or Lebanon Dam (D_4) arrays to estimate the detection probability of the Primary Array. However, in 2018, a new model (ViRDCt) was used to estimate survival of V_1 fish from Foster to the Egress Array located 2.5 rkm downstream. For these estimates, detections at the Primary (D_2), Secondary (D_3), Lebanon Dam (D_4), and Willamette Falls (D_5) arrays were used to estimate the detection probability of the Egress Array. Because the ViRDCt study design was not used in 2015 or 2016, between-year comparisons (2015, 2016, and 2018) were made using the CJS model. ViRDCt and CJS survival estimates were adjusted for the probability of tag failure (i.e., tag life). Although tagged fish could also be detected by PIT antennas at Lebanon Dam, Willamette Falls, and the Estuary Towed Array (D_6), PIT detections were not included in either ViRDCt or CJS survival estimates. CJS survival estimates from 2015 and 2016, which were not adjusted for tag life and included PIT detections, were recalculated to allow for comparison to 2018 estimates.

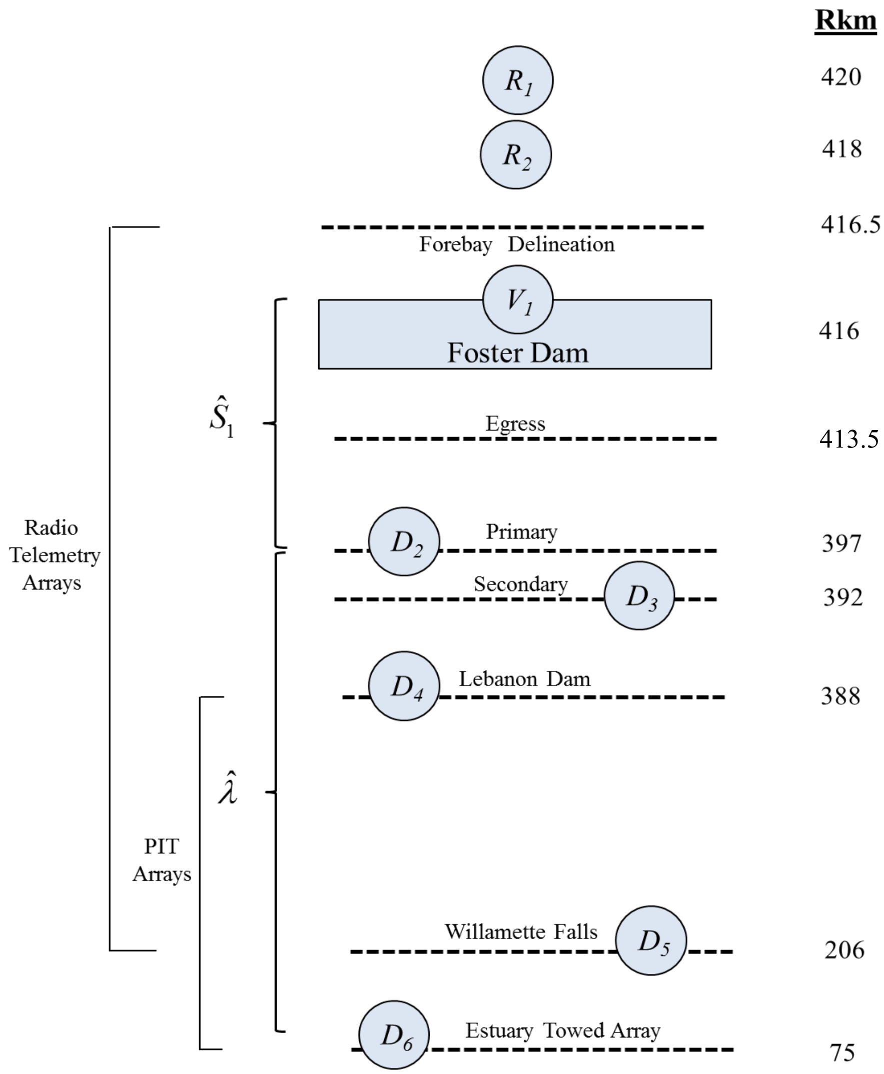

Figure S.2. Schematic of the Study Design Used to Estimate Project Metrics at Foster in 2015, 2016, and 2018. Fish released at R_1 (rkm 418) and R_2 (rkm 420) that were detected at the dam-face array were regrouped to form the virtual release group (V_1). ViRDCt survival (2018 only) was estimated to the Egress Array (rkm 413.5) using detections at the Primary Array (D_2; rkm 397), Secondary Array (D_3; rkm 392), Lebanon Dam (D_4; rkm 388), and Willamette Falls (D_5; rkm 206) to estimate the detection probability of the Egress Array. CJS survival (2015, 2016, and 2018) was estimated to the Primary Array (D_2; rkm 397) using RT detections at the Secondary Array (D_3; rkm 392), Lebanon Dam (D_4; rkm 388), and Willamette Falls (D_5; rkm 206) arrays to estimate detection probability of the Primary Array**.**

In addition to dam-passage and route-specific survival, survival by weir discharge level was also compared in spring 2018 as another metric to evaluate the new weir design. The new weir was designed to pass flows between 300 cfs to 860 cfs, depending on reservoir elevation, with normal discharge operations of approximately 530 cfs (range of 450–550 cfs during spring). During spring 2018, the daily average weir discharge ranged from 161–685 cfs (mean: 519 cfs) due to reservoir fluctuations and project operations. Because there were days that were less or greater than normal discharge operations, we separated the comparison in discharge to < 500 cfs (low) and ≥ 500 cfs (high). In fall 2018, low precipitation caused low river flows; therefore, the new weir was operated at the designed low flow range (approximately 300 cfs) and the daily average discharge ranged from 278–470 cfs (mean: 355 cfs). As such, we only compared survival by the low weir discharge level (< 500 cfs).

The Oregon State University (OSU) Wild Fish Surrogate Program provided study fish, with the exception of the hatchery summer steelhead, which were provided by the South Santiam Fish Hatchery. Fish were reared to the approximate size of wild juveniles migrating through Foster. Study fish were surgically implanted with a RT tag (Lotek NanoTag model NTC-M-2, Newmarket, Ontario, Canada) and a PIT tag. Double-tagged juveniles were released and monitored during three primary time periods: spring low pool, spring high pool, and fall low pool. In 2018, during the spring low pool period (March–April; 613 ft msl forebay elevation), a total of 330 yearling Chinook salmon (CH1), 623 age-2 wild surrogate winter steelhead (STH2), and 191 age-1.5 hatchery summer steelhead (S-STH) were released and used for the statistical metrics evaluated in this study. During spring high pool (May–June; 635 ft msl forebay elevation), a total of 375 CH1, 307 STH2, and 451 S-STH were released. During fall low pool (October–December; 613 ft msl forebay elevation), a total of 738 subyearling Chinook salmon (CH0) were released. Collectively, these sample sizes represent the new weir evaluation of juvenile salmonid passage at Foster and were used in the comparison of data from the old weir evaluations conducted in 2015 and 2016. The data obtained during the 2015, 2016, and 2018 evaluations were used to estimate species-specific survival and passage metrics for each of the time periods. Table S.1 presents dam-passage survival estimates for CH1, STH2, S-STH, and CH0.

Table S.1. Tag Life-Adjusted Single-Release CJS Dam-Passage Survival Estimates for Yearling Chinook Salmon, Wild Surrogate Winter Steelhead, Hatchery Summer Steelhead, and Subyearling Chinook Salmon Released above Foster in 2015, 2016, and 2018

			2015 Dam-Passage Survival		**2016 Dam-Passage Survival**		**2018 Dam-Passage Survival**	
Study Year	**Species**	**Elevation**	***n***	**Estimate (SE)**	***n***	**Estimate (SE)**	***n***	**Estimate (SE)**
Spring	**Yearling Chinook Salmon**	Low Pool (613 ft msl)	457	0.627 (0.026)	273	0.617 (0.030)	267	0.611 (0.030)
		High Pool (635 ft msl)	107	0.758 (0.043)	202	0.844 (0.026)	301	0.646 (0.028)
	Winter Steelhead (Age-2)	Low Pool (613 ft msl)	108	0.614 (0.051)	73	0.470 (0.059)	229	0.546 (0.033)
		High Pool (635 ft msl)	150	0.715 (0.058)	147	0.808 (0.035)	110	0.787 (0.045)
	Summer Steelhead (Age-1.5)	Low Pool (613 ft msl)	N/A	N/A	N/A	N/A	61	0.466 (0.065)
		High Pool (635 ft msl)	N/A	N/A	N/A	N/A	192	0.735 (0.033)
Fall	**Subyearling Chinook Salmon**	Low Pool (613 ft msl)	854	0.855 (0.013)	1012	0.755 (0.014)	405	0.805 (0.020)

N/A = Not Applicable.
n = number of fish that passed Foster per pool elevation by year.

Additionally, we implemented a pseudo-randomized block design to answer the research question, "What is the efficacy of spill as a non-turbine passage route for juvenile salmon and steelhead at Foster?" The null hypothesis for this evaluation was that turbine and spill passage rates were equivalent. In 2018, pseudo-randomized treatment blocks were 4 days long and each block consisted of 2 days of each treatment. Treatments were continuous turbine and weir operation (turbine+weir) compared to continuous spillway and weir operation (spill+weir). However, during the spill+weir treatment, turbines were not truly off but in spin/no-load operation for Station Service (local electrical power for Foster). In 2015 and 2016, treatment blocks were 4 days long and consisted of 2 days of turbine and weir operation (turbine+weir) and 2 days of spillway and weir operation (spill+weir); an additional treatment of turbine+spill+weir was added during spring and fall low pool in 2016 (Table S.2). There was a lot of variability in significant findings within spill vs. turbine tests for each study year. As such, no definite comparative conclusions regarding the efficacy of spill as a non-turbine passage route could be made.

Significant Spill vs. Turbine findings include:

- Variability among study years and within spill vs. turbine tests resulted in an ambiguous conclusion on treatments.
- At low pool, total passage rates for CH1 did not differ significantly between spill+weir and turbine+weir treatments for any study year. At high pool, passage rates for CH1 were significantly higher during the spill+weir treatment compared to other treatments for all study years.
- For CH1, during the low pool turbine+weir treatment, turbine passage was higher than weir passage in 2015 and 2016, but weir passage was higher in 2018, suggesting the new weir design improved CH1 attraction to the route. For the same treatment at high pool, weir passage was higher across all years. During the 2015 and 2016 spill+weir treatment, spill passage was higher than weir passage at both pool stages. This was the same for 2018 during high pool; however, at low pool spill and weir passage were approximately evenly split.
- STH2 passage rates only differed significantly during high pool in 2016, when more fish passed Foster during the spill+weir treatment than during the turbine+weir treatment. They did not differ significantly during low pool in 2016. Passage rates did not differ significantly by treatment in 2015 or 2018 during low and high pool, nor did they differ for S-STH in 2018.
- For all study years, STH2 passage during the turbine+weir treatment was approximately even between the two operational routes at low pool, whereas at high pool, weir passage was much higher. During spill+weir treatment, spill passage was higher at low pool, but weir passage was higher at high pool. These trends were also observed for S-STH in 2018.
- In the fall, treatments were significantly different for CH0 in 2015 and 2018. In 2015, significantly higher proportions of CH0 passed Foster during the spill+weir treatment than the turbine+weir treatment. In 2018, passage during the turbine+weir treatment was significantly higher than passage in the turbine-only treatment, and there was no spill+weir treatment. In 2016, a statistical comparison was not possible due to the inconsistencies in prescribed treatments.
- For CH0 in 2015, weir passage was greater than turbine passage (turbine+weir) and spill passage was greater than weir passage (spill+weir), under the conditions of the study. In 2016, turbine and spill passage were both greater than weir passage for the turbine+weir and spill+weir treatments, respectively. In 2018, weir passage was much higher than turbine passage during the turbine+weir treatment.
- In addition to survival estimates, project metrics, to include passage efficiencies and effectiveness, were estimated (Table S.3).

Table S.2. Summary of Findings for the Spill vs. Turbine Tests by Stock, Season, and Study Period

		Yearling Chinook Salmon (CH1)					
Spring Low Pool		**2015**		**2016**		**2018**	
Treatment	**Passage Route**	**Total Passage (*n*)**	**Passage Proportion**	**Total Passage (*n*)**	**Passage Proportion**	**Total Passage (*n*)**	**Passage Proportion**
turbine+weir	Turbine Units 1–2	82	0.53	89	0.95	33	0.27
	Weir	72	0.47	5	0.05	90	0.73
spill+weir	Spill Bays 1–3	174	0.97	109	0.98	63	0.55
	Weir	5	0.03	2	0.02	51	0.45
turbine+spill +weir	Turbine Units 1–2	–	–	11	0.16	–	–
	Spill Bays 1–3	–	–	46	0.69	–	–
	Weir	–	–	10	0.15	–	–
Spring High Pool		**2015**		**2016**		**2018**	
Treatment	**Passage Route**	**Total Passage (*n*)**	**Passage Proportion**	**Total Passage (*n*)**	**Passage Proportion**	**Total Passage (*n*)**	**Passage Proportion**
turbine+weir	Turbine Units 1–2	1	0.06	5	0.18	1	0.01
	Weir	16	0.94	22	0.82	85	0.99
spill+weir	Spill Bays 1–3	66	0.77	116	0.75	38	0.19
	Weir	20	0.23	39	0.25	161	0.81

		Wild Surrogate Winter Steelhead (STH2)						Hatchery Summer Steelhead (S-STH)	
Spring Low Pool		**2015**		**2016**		**2018**		**2018**	
Treatment	**Passage Route**	**Total Passage (*n*)**	**Passage Proportion**	**Total Passage (*n*)**	**Passage Proportion**	**Total Passage (*n*)**	**Passage Proportion**	**Total Passage (*n*)**	**Passage Proportion**
turbine+ weir	Turbine	13	0.30	15	0.45	26	0.51	5	0.42
	Weir	31	0.70	18	0.55	25	0.49	7	0.58
spill+weir	Spill	39	0.74	19	0.90	64	0.80	22	0.85
	Weir	14	0.26	2	0.10	16	0.20	4	0.15
turbine+ spill+weir	Turbine	–	–	3	0.20	–	–	–	–
	Spill	–	–	2	0.13	–	–	–	–
	Weir	–	–	10	0.67	–	–	–	–
turbine+ weir	Turbine	1	0.02	0	0.00	1	0.02	0	0.00
	Weir	55	0.98	44	1.00	60	0.98	76	1.00
spill+weir	Spill	4	0.05	4	0.05	1	0.02	3	0.03
	Weir	75	0.95	81	0.95	42	0.98	90	0.97

Fall Low Pool		Subyearling Chinook Salmon (CH0)					
		2015		2016		2018	
Treatment	Passage Route	Total Passage (n)	Passage Proportion	Total Passage (n)	Passage Proportion	Total Passage (n)	Passage Proportion
turbine	Turbine Units 1–2	–	–	–	–	110	1.00
	Weir	–	–	–	–	0	0.00
turbine+weir	Turbine Units 1–2	48	0.38	64	0.90	7	0.04
	Weir	77	0.62	7	0.10	188	0.96
spill+weir	Spill Bays 1–3	434	0.97	441	0.98	–	–
	Weir	14	0.03	7	0.02	–	–
turbine+spill+weir	Turbine Units 1–2	–	–	73	0.28	–	–
	Spill Bays 1–3	–	–	174	0.68	–	–
	Weir	–	–	11	0.04	–	–

Table S.3. Project Passage Efficiencies and Effectiveness by Stock, Season, and Study Year. Dam Passage Efficiency (DPE) and Fish Passage Efficiency (FPE) are calculated relative to the number of fish detected in the near forebay, while all other efficiency metrics are relative to the total number of fish that passed the dam (as indicated by "|| Dam").

	CH1 – Spring					
	2015		2016		2018	
Metric	Low Pool	High Pool	Low Pool	High Pool	Low Pool	High Pool
DPE	**0.952 (0.007)**	**0.663 (0.028)**	**0.955 (0.009)**	**0.680 (0.021)**	**0.900 (0.018)**	**0.853 (0.019)**
FPE	**0.642 (0.017)**	**0.645 (0.029)**	**0.589 (0.023)**	**0.630 (0.022)**	**0.756 (0.025)**	**0.850 (0.019)**
SPE || Dam	0.674 (0.022)[b]	0.982 (0.013)[B]	0.628 (0.030)[b]	0.940 (0.017)[B]	0.837 (0.023)[a]	0.997 (0.003)[A]
FWE || Dam	0.171 (0.018)[b]	0.358 (0.046)[B]	0.045 (0.013)[c]	0.363 (0.034)[B]	0.570 (0.031)[a]	0.866 (0.020)[A]
SBE || Dam	0.503 (0.023)[a]	0.624 (0.046)[A]	0.584 (0.030)[a]	0.577 (0.035)[A]	0.266 (0.027)[b]	0.131 (0.020)[B]
Fish Weir Effect.	1.166 (0.120)	2.209 (0.283)	0.490 (0.138)	2.746 (0.256)	3.880 (0.208)	3.054 (0.070)
Spill Bay Effect.	1.119 (0.052)	2.708 (0.201)	1.444 (0.074)	3.066 (0.185)	0.658 (0.067)	0.658 (0.100)
Spillway Effect.	1.131 (0.037)	2.502 (0.033)	1.269 (0.060)	2.934 (0.052)	1.517 (0.041)	2.068 (0.007)

(Table S.3 continued)

Metric	STH2 – Spring						S-STH – Spring	
	2015		2016		2018		2018	
	Low Pool	High Pool	Low Pool	High Pool	Low Pool	High Pool	Low Pool	High Pool
DPE	**0.432 (0.026)**	**0.762 (0.021)**	**0.529 (0.035)**	**0.667 (0.024)**	**0.464 (0.023)**	**0.378 (0.028)**	**0.439 (0.043)**	**0.519 (0.026)**
FPE	**0.355 (0.026)**	**0.749 (0.022)**	**0.375 (0.035)**	**0.649 (0.025)**	**0.319 (0.022)**	**0.371 (0.028)**	**0.341 (0.041)**	**0.517 (0.026)**
SPE || Dam	0.852 (0.034)	0.994 (0.006)	0.739 (0.053)	1.000 (0.000)	0.683 (0.032)	0.982 (0.013)	0.776 (0.055)	0.995 (0.005)
FWE || Dam	0.426 (0.048)	0.971 (0.013)	0.434 (0.060)	0.973 (0.014)	0.318 (0.032)	0.973 (0.016)	0.328 (0.062)	0.979 (0.011)
SBE || Dam	0.426 (0.048)	0.023 (0.012)	0.304 (0.055)	0.027 (0.014)	0.365 (0.033)	0.009 (0.009)	0.448 (0.065)	0.016 (0.009)
Fish Weir Effect.	2.908 (0.325)	5.992 (0.079)	4.782 (0.656)	7.353 (0.102)	2.160 (0.218)	3.430 (0.055)	2.228 (0.419)	3.451 (0.037)
Spill Bay Effect.	0.947 (0.106)	0.102 (0.050)	0.753 (0.137)	0.146 (0.072)	0.903 (0.082)	0.046 (0.046)	1.109 (0.162)	0.081 (0.046)
Spillway Effect.	1.429 (0.057)	2.534 (0.015)	1.493 (0.107)	3.120 (0.000)	1.238 (0.058)	2.037 (0.026)	1.407 (0.099)	2.064 (0.011)

Metric	CH0 - Fall		
	2015	2016	2018
	Fall Low Pool		
DPE	**0.816 (0.009)**	**0.968 (0.004)**	**0.557 (0.019)**
FPE	**0.648 (0.011)**	**0.669 (0.011)**	**0.358 (0.018)**
SPE || Dam	0.810 (0.013)[a]	0.713 (0.015)[b]	0.643 (0.024)[ab]
FWE || Dam	0.110 (0.011)[a]	0.044 (0.007)[b]	0.598 (0.025)[c]
SBE || Dam	0.700 (0.016)	0.669 (0.015)	0.046 (0.011)
Fish Weir Effectiveness	6.261 (0.609)	0.587 (0.088)	28.699 (1.185)
Spill Bay Effectiveness	1.083 (0.024)	1.285 (0.029)	0.178 (0.041)
Spillway Effectiveness	1.220 (0.020)	1.197 (0.024)	2.325 (0.087)

DPE = dam-passage efficiency; proportion of fish passing the dam relative to the number detected in the near forebay (< 100 m from dam-face).

FPE = fish passage efficiency; proportion of fish passing via a non-turbine route relative to the number detected in the near forebay (< 100 m from dam-face).

SPE = spill passage efficiency; proportion of fish that passed Foster through Spill Bays 1–3 and the fish weir in Spill Bay 4.

SBE = spill bay efficiency; proportion of fish that passed Foster through Spill Bays 1–3.

FWE = fish weir efficiency; proportion of fish that passed Foster over the fish weir in Spill Bay 4.

Fish weir/spill bay/spillway effectiveness = proportion of fish passage through a route relative to the proportion of discharge through the same route.

Shared superscript letters for SPE and FWE indicate no significant differences between estimates, whereas different superscript letters indicate significant differences. Lower-case letters refer to low pool comparisons and upper-case letters refer to high pool comparisons. Absence of superscript letters indicates there were no significant differences.

Significant project-passage metrics include:

- Fish weir effectiveness for CH1 more than doubled during low pool in 2018 compared to 2015 and 2016. It also increased during high pool in 2018 compared to 2015 and 2016.
- At low pool, DPE for CH1 was very high for all study years: 0.952 in 2015, 0.955 in 2016, and 0.900 in 2018. At high pool, DPE increased 25–30% in 2018 (0.853) compared to 2015 (0.663) and

2016 (0.680). Overall, in 2018, the overwhelming majority of CH1 detected in the near forebay of Foster ultimately passed.

- In 2018, a greater proportion of CH1 reaching the near forebay passed Foster through the weir compared to previous years. Low pool FPE increased from 0.589–0.642 to 0.756, whereas high pool FPE increased from 0.630–0.645 to 0.850.
- As in previous years for STH2, the weir remained effective at low pool (2.160). At high pool, although STH2 still used the weir in high proportions in 2018 (97%), effectiveness decreased slightly from 5.992 (2015) and 7.353 (2016) to 3.430 (2018), owing to increased discharge through the weir in 2018.
- Low pool DPE for STH2 was comparable across study years, but high pool DPE decreased in 2018. Despite the installation of the new weir, a large proportion (49%) of STH2 detected in the near forebay of the dam still did not pass.
- Trends in FPE mirrored those in DPE for STH2 indicating most STH2 passed Foster via a non-turbine route. Low pool FPE was similar in 2015 (0.355), 2016 (0.375), and 2018 (0.319), whereas high pool FPE was lower in 2018 (0.371) than in previous years (0.649–0.749).
- At low pool, SPE remained moderately high across years (0.683–0.852), whereas FWE remained fairly low (0.318–0.434), because many STH2 passed Foster through non-turbine routes other than the weir. At high pool, both SPE and FWE remained extremely high across years, as the vast majority of fish (≥ 97%) passed through weir.
- In comparison to STH2, S-STH had very similar DPE and FPE at low pool, and slightly higher DPE and FPE at high pool. For both pool stages, SPE, FWE, and effectiveness metrics were similar between steelhead stocks.
- CH0 DPE decreased in 2018 (0.557) compared to 2015 (0.816) and 2016 (0.968), and FPE fell from 0.648–0.669 to 0.358. Fewer fish detected in the near forebay region passed the dam overall, and fewer passed the weir in particular. A large proportion of CH0 detected in the near forebay of the dam did not pass.
- For CH0, SPE remained relatively constant across years (0.643–0.810), but FWE increased by more than fivefold in 2018 (0.598) compared to 2015 (0.110) and 2016 (0.05). As FWE was high and discharge through the weir represented only 2% of total discharge, fish weir effectiveness was exceedingly high (28.699), more than quadruple the weir effectiveness observed in 2015 and 2016.
- In 2018, across stocks, seasons, and pool elevations, efficiency and effectiveness of the new fish weir did not depend strongly on whether the weir discharge level was low (< 500 cfs) or high (≥ 500 cfs).

We also estimated reservoir residence, project egress, and travel times to Willamette Falls Dam (Table S.4) and route-specific survival at Foster (Table S.5).

Table S.4. Estimated Mean and Median Reservoir Residence, Project Egress, and Travel Times in Days (d) for Study Fish during Each Project Study Period

			Reservoir Residence[(a)]				Project Egress[(b)]				Travel Time to Willamette Falls[(c)]			
Stock	**Pool stage**	**Year**	**Median (d)**	**Mean (d)**	**SE**	***n***	**Median (d)**	**Mean (d)**	**SE**	***n***	**Median (d)**	**Mean (d)**	**SE**	***n***
Yearling Chinook Salmon	**Low**	2015	1.5	2.3	0.2	457	0.2	0.9	0.2	327	8.5	13.6	2.1	33
		2016	1.7	2.4	0.1	274	0.1	0.4	0.1	208	4.4	5.0	0.4	50
		2018	1.4	1.7	0.1	262	0.1	0.7	0.4	216	2.9	3.1	0.1	97
	High	2015	2.8	9.0	1.2	109	0.1	0.9	0.4	90	8.0	10.3	1.1	15
		2016	9.7	11.5	0.7	204	0.4	0.6	0.1	181	6.2	6.8	0.4	79
		2018	3.6	4.5	0.2	291	0.1	0.5	0.2	218	5.9	7.5	0.8	47
Wild Surrogate Winter Steelhead (Age-2)	**Low**	2015	1.6	6.6	0.9	108	1.1	4.2	0.8	75	25.4	27.4	2.5	20
		2016	1.9	4.3	0.5	73	0.3	1.3	0.4	47	23.9	23.3	5.8	6
		2018	6.3	10.1	0.7	208	0.4	4.0	0.8	148	13.8	15.7	1.4	65
	High	2015	28.8	25.3	1.3	171	0.9	1.3	0.1	134	6.8	7.5	0.6	12
		2016	15.5	17.3	0.9	150	0.1	0.5	0.1	130	4.9	5.7	0.3	52
		2018	16.1	23.3	1.6	110	0.3	1.1	0.4	91	5.3	6.7	0.8	29
Hatchery Summer Steelhead (Age-1.5)	**Low**	2018	5.9	8.5	1.1	58	0.7	1.9	0.6	39	18.8	19.7	2.7	17
	High	2018	6.7	11.4	0.9	187	0.8	1.8	0.3	140	6.5	8.3	0.6	53
Sub-yearling Chinook Salmon	**Low**	2015	4.5	10.1	0.4	853	0.7	1.9	0.1	817	8.7	10	0.7	63
		2016	0.7	1.6	0.1	1012	0.03	0.1	0.0	914	2.3	2.7	0.1	510
		2018	1.6	5.3	0.5	393	0.7	2.3	0.3	333	11.7	13.7	0.8	150

(a) Difference in time from release time to last detection at the dam.
(b) Difference in time from last detection at the dam to last detection at the Egress Array.
(c) Difference in time from last detection at the dam to detection at Willamette Falls.
n = number of fish that reached the final array in each travel interval.

Table S.5. Estimated Route-Specific Survival for Study Fish during Each Project Study Period in 2015, 2016, and 2018. Survival was estimated from Foster passage to the Primary Array, located ~19 rkm downstream, using the CJS model.

CH1	**2015**				**2016**				**2018**			
	Low Pool		**High Pool**		**Low Pool**		**High Pool**		**Low Pool**		**High Pool**	
Route	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**
Turbine Unit 1	149	0.487 (0.044)	2	*	51	0.529 (0.070)	8	*	25	0.480 (0.100)	–	–
Turbine Unit 2	–	–	–	–	49	0.571 (0.071)	3	*	17	0.529 (0.121)	1	*
Fish Weir	78	0.636 (0.069)	39	0.467 (0.081)[b]	12	0.778 (0.134)	72	0.809 (0.049)[a]	150	0.613 (0.040)	252	0.624 (0.031)[b]
Spill Bay 3	230	0.714 (0.034)	66	0.936 (0.034)	157	0.651 (0.038)	116	0.889 (0.029)	70	0.715 (0.054)	17	0.941 (0.057)
Spill Bay 2	–	–	–	–	–	–	–	–	–	–	21	0.762 (0.093)

STH2	**2015**				**2016**				**2018**			
	Low Pool		**High Pool**		**Low Pool**		**High Pool**		**Low Pool**		**High Pool**	
Route	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**
Turbine Unit 1	16	0.563 (0.124)	1	*	13	0.385 (0.135)	–	–	39	0.520 (0.082)	2	*
Turbine Unit 2	–	–	–	–	5	*	–	–	25	0.640 (0.096)	–	–
Fish Weir	46	0.667 (0.085)	145	0.713 (0.052)	30	0.433 (0.091)	139	0.811 (0.035)	67	0.509 (0.061)	102	0.829 (0.043)
Spill Bay 3	45	0.565 (0.076)	4	*	21	0.572 (0.108)	4	*	56	0.555 (0.067)	–	–
Spill Bay 2	–	–	–	–	–	–	–	–	17	0.648 (0.116)	1	*
Spill Bay 1	1	*	–	–	–	–	–	–	4	*	–	–

CH0	**2015**		**2016**		**2018**	
	Low Pool		**Low Pool**		**Low Pool**	
Route	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**
Turbine Unit 1	122	0.755 (0.049)	165	0.718 (0.035)	134	0.783 (0.036)
Turbine Unit 2	32	0.674 (0.086)	117	0.753 (0.040)	3	*
Fish Weir	96	0.869 (0.035)	43	0.767 (0.064)	236	0.818 (0.025)
Spill Bay 3	587	0.882 (0.014)[a]	490	0.781 (0.019)[b]	12	0.833 (0.108)[ab]
Spill Bay 2	15	1.001[+] (0.107)[a]	162	0.723 (0.035)[b]	4	*
Spill Bay 1	2	*	4	*	ND	ND

n = number of fish that passed Foster per route by pool elevation and year.

* Indicates a small number of fish passed the route; therefore, a survival estimate was not calculated.

[+] One fish had a survival rate of over 100% (Spill Bay 2, 2015) because it skipped a detection at Foster, but was still detected downstream.

Different superscript letters (located after the survival estimate) indicate a significant difference in survival. If no letter is present, there was no significant difference in survival.

Collectively, significant study findings include the following:

- Passage and Survival Synthesis
  - Overall, the modifications to the weir may have contributed to some improved rates of dam passage (DPE and FPE), attracted a greater proportion of fish to the new weir passage route (CH1 and CH0 in particular), and had minimal impact on survival. A higher proportion of high-pool-released CH1 and low-pool-released STH2 passed Foster after installation of the new weir, while low-pool CH1 and high-pool STH2 passage rates did not vary substantially. Although lower proportions of CH0 passed Foster in 2018 than in previous years, this was likely attributable to differences in dam operations in fall 2018 (lower project discharge) compared to previous fall seasons (higher project discharge). In addition, while STH2 passage distributions remained relatively constant, the new weir was successful in passing a greater proportion of all dam-passed CH1 and CH0, likely due to increased weir discharge and attractant flow. As a result, at low pool, the proportion of CH1 passing through the turbines declined with the installation of the new weir. Dam-passage survival generally remained unchanged, except for CH1 high pool survival, which decreased. This was not caused by lower route-specific survival through the new weir compared to the old weir, but rather by the shift in passage distributions from Spill Bay 3, the route with the highest survival, to the weir, which had somewhat lower survival.
- Survival
  - Survival was higher through non-turbine routes of passage (spill bays and fish weir) than through turbine units for all pool elevations, fish stocks, and study years, regardless of old or new weir design.
  - Dam-passage survival of CH1 was not significantly different for the low pool elevation. However, survival observed during the high-pool old-weir evaluations (i.e., 2015 and 2016) was significantly higher than survival observed in 2018 (new weir). The main driver for the difference in high-pool survival in 2018 was decreased passage through Spill Bay 3—the route with the highest survival estimates for all study years—and increased passage through the weir, which had somewhat lower survival.
  - Dam-passage survival of STH2 was not significantly different across study years (old or new weir) at low or high pool elevations.
  - During spring 2018, S-STH dam-passage and route-specific survival were not significantly different than STH2, regardless of pool elevation.
  - Dam-passage survival of CH0 was significantly different across study years at low pool. New weir survival (2018) was intermediate to survival estimates observed during the old weir evaluations (2015 was the highest, 2016 the lowest).
  - Weir discharge (i.e., low [< 500 cfs] vs. high [≥ 500 cfs]) did not affect survival for CH1, STH2, or S-STH during spring low and high pools in 2018 (i.e., new weir).
  - In 2018, ViRDCt Foster-to-Egress Array survival estimates for both seasons and all fish stocks were higher than the tag life-adjusted CJS Foster-to-Primary Array survival estimates. Substantial mortality occurred in the ~16 rkm of tailwaters between the Egress and Primary arrays.

- Passage Distributions
  - During spring low and high pools, passage distributions for CH1 were greatest through Spill Bay 3 during old weir study years. However, passage distributions shifted and were greater through the new fish weir in 2018.
  - During low pool, passage distributions for STH2 during old and new weir evaluations were comparable through both the fish weir and Spill Bays 1–3, whereas the weir was used nearly exclusively during spring high pool for all evaluations.
  - Overall, S-STH passed Foster at similar proportions to STH2 during spring 2018. When comparing by pool elevation, similar proportions of S-STH and STH2 passed Foster during low pool, but a greater proportion of S-STH than STH2 passed during high pool.
  - During fall low pool, passage distributions for CH0 during the old weir evaluations were greatest through Spill Bays 1–3. This shifted during new weir evaluations. Passage distributions were greatest through the new weir in 2018; however, Spill Bays 1–3 were not open for the majority of the study period, resulting in fewer available passage routes.
  - Most study fish passed Foster during the night, for both the old and new weir evaluations (CH1: ≥ 97% and ≥ 77% for all years during low and high pools, respectively; STH2: ≥ 65% for all years during low pool all years and ≥ 64% in 2015 and 2016 for high pool). However, during high pool in 2018, the majority of STH2 passed Foster during the day (62%). S-STH followed similar trends to STH2 for nighttime passage in 2018 (76% and 32% during low and high pools, respectively). CH0 passage at night was ≥ 92% for low pool for all study years.
  - A portion of study fish did not pass Foster before their RT tag battery life expired. The proportion of low-pool-released CH1 that did not pass was consistently low (≤ 23%) for each study year. Of high-pool released fish, 42% of CH1 did not pass the dam in 2015 and 2016, while only 20% did not pass in 2018. Compared to 2015 and 2016, the proportion of STH2 released at low pool and did not pass decreased, while the proportion released at high pool and did not pass increased. The proportion of CH0 that did not pass the dam increased in 2018 (44%) relative to 2015 (29%) and 2016 (25%). Presumably, study fish continued rearing in Foster reservoir during both old and new weir evaluations.
- Project Metrics
  - Overall, the Foster project passed a greater proportion of CH1, CH0, and STH2 via non-turbine routes (high spill passage efficiency) during all study years, regardless of old or new weir evaluations.
  - The old fish weir in Spill Bay 4 was moderately effective at passing CH1. With the new weir, weir effectiveness increased, and spill bay effectiveness decreased.
  - The fish weir was very effective at passing STH2 for all study years, regardless of old or new weir evaluations.
  - Similar to CH1, the old fish weir was moderately effective at passing CH0 during old weir study years and became extremely effective at passing CH0 following the new weir installation, as spill bay effectiveness decreased. However, it should be noted that passage through Spill Bays 1–3 was limited because there was no spill treatment (although some spill operations occurred) and the passage options for the majority of the study were through the fish weir or the turbines.
  - Both stocks of Chinook salmon passed via the spill bays in high proportions (relative to total passage) during the old weir evaluations. Similar to effectiveness, spill bay efficiency

decreased in 2018 for both CH0 and CH1, and weir efficiency increased (although no spill treatment was used in fall 2018 for CH0, there was some limited operation of the spill bays). Overall, the new weir design more efficiently passed CH1 and CH0 compared to the old weir.

- Entrainment
  - Chinook salmon and steelhead were entrained in extremely low numbers in the AWS, FWS, or HWS. One STH2 was detected at the AWS in spring 2015 and three STH2 were detected in the AWS in spring 2018. All fish eventually departed the AWS and migrated downstream.
- Avian Predation
  - Birds preyed upon at least 2.9% of CH1, STH2, and S-STH and 1.8% of CH0 in spring and fall in 2018 (new weir evaluation). Avian predation was not evaluated in 2015 or 2016.

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Acronyms and Abbreviations

°C	degree(s) Celsius
AIC	Akaike's Information Criterion
ANOVA	analysis of variance
ATLAS	acoustic tag life-adjusted survival
AWS	auxiliary water supply
BiOp	Biological Opinion
CENWP	Portland District (U.S. Army Corps of Engineers)
cfs	cubic (foot) feet per second
CH0	subyearling Chinook salmon
CH1	yearling Chinook salmon
CJS	Cormack-Jolly-Seber
COP	Configuration and Operation Plan
d	day(s)
D	detection(s)
DPE	dam-passage efficiency
ESA	Endangered Species Act
FL	fork length
FPE	fish passage efficiency
ft	foot(feet)
FWE	fish weir efficiency
FWS	forebay water supply
g	gram(s)
h	hour(s)
HOR	head-of-reservoir
HWS	hatchery water supply
in.	inch(es)
km	kilometer(s)
L	liter(s)
LRT	likelihood ratio tests
m	meter(s)
MHz	megahertz
min	minute(s)
MITAS	Multiprotocol Integrated Telemetry Acquisition System
mg	milligram(s)
MLE	maximum likelihood estimation
mm	millimeter(s)
MOR	mid-reservoir
msl	mean sea level

MW	megawatt(s)
n	number (sample size)
N/A	not applicable
ND	no data
NF	near-forebay
NMFS	National Marine Fisheries Service
N_{Weir}	non-weir spill
ODFW	Oregon Department of Fish and Wildlife
OSU	Oregon State University
PHT	powerhouse tailrace
PIT	passive integrated transponder
PNNL	Pacific Northwest National Laboratory
psi	pound(s) per square inch
QA	quality assurance
QC	quality control
R	release
rkm	river kilometer(s)
RM&E	research monitoring and investigation
RPA	reasonable and prudent alternative
rpm	revolutions per minute
RT	radio telemetry
S_1	Foster-to-Primary Array survival (CJS estimates)
SBE	spill bay efficiency
S_D	Foster-to-Egress Array survival (ViRDCt estimates)
SE	standard error
sec or s	second(s)
SPE	spill passage efficiency
SPT	spillway tailrace
STH	juvenile steelhead
STH1	juvenile wild surrogate steelhead age-1
STH2	juvenile wild surrogate steelhead age-2
S-STH	juvenile hatchery summer steelhead
SURPH	Survival Under Proportional Hazards
TUR	turbine
USACE	U.S. Army Corps of Engineers
V	virtual release
ViRDCt	Virtual Release/Dead Fish Correction
WVP	Willamette Valley Project

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1.0 Introduction

This report presents the results of a radio telemetry (RT) evaluation of fish passage and survival at Foster Dam (herein, Foster) on the South Santiam River in Oregon. The Pacific Northwest National Laboratory (PNNL) conducted the study for the U.S. Army Corps of Engineers Portland District (USACE). Following previous studies of fish passage and survival at Foster in 2015 and 2016—with a focus of passage and survival through the old fish weir—a new fish weir was designed and installed in early 2018, with the goal of improving downstream passage through this route. In 2018, with the new weir in place, survival and passage of wild surrogate yearling (CH1) and subyearling (CH0) Chinook salmon and age-2 wild surrogate winter steelhead (STH2) stocks were evaluated and compared to previous years with the old weir in place. Hatchery summer steelhead (S-STH) were also released to evaluate survival and dam passage proportions compared to STH2. In this study, changes in downstream survival and passage proportions for specific routes of passage (turbine, spillway, new weir) were of particular interest, with a focus on the new weir. Additionally, the effects of weir flow rate on weir efficiency and survival were evaluated, and passage through the auxiliary water supply (AWS), forebay water supply (FWS), and hatchery water supply (HWS) intakes was evaluated.

1.1 Objectives

In 2018, at low pool (613 ft relative to mean sea level [msl]) forebay elevation (spring and fall) and high pool (635 ft msl) forebay elevation (late spring and early summer); the specific study objectives were to:

I. Estimate the following passage metrics under typical operations (i.e., baseline conditions):
   a. Overall dam-passage survival and survival specific to each route of dam passage, calculated using two different methods:
      i. Cormack-Jolly-Seber (CJS) estimate: Probability of survival from dam passage to detection at the Primary Array, 19 rkm downstream of Foster.
      ii. Virtual Release/Dead Fish Correction (ViRDCt) estimate: Corrects the bias that occurs from misidentifying fish that did not survive dam-passage as alive at the tailrace Egress Array, allowing an estimate of survival from dam passage to this array, 2.5 rkm downstream of Foster.
   b. Route distribution (passage proportions by route; also known as "passage efficiencies").
   c. Efficiency metrics
      i. Dam-passage efficiency (DPE), the proportion of total fish passing the dam relative to the number of total fish detected in the near forebay of the dam and therefore available to pass.
      ii. Fish passage efficiency (FPE), the proportion of fish passing via a non-turbine route, relative to the number of total fish in the near forebay and available to pass.
      iii. Fish weir efficiency (FWE) and spill bay efficiency (SBE), the proportion of fish passing the weir or spill bays, respectively, relative to the total number of fish passing the dam.
   d. Reservoir residency time (time elapsed between release into reservoir and dam passage) and travel times through the system.

II. Estimate efficiency and effectiveness of the new fish weir, compared to the turbines and the spillway.

III. Under alternative operations, compare passage through each route (turbines, weir, spillway) using a block/treatment (on/off) design similar to the 2015 and 2016 studies.

IV. Estimate efficiency of the new fish weir operating at a low level of discharge (< 500 cfs) and a high level of discharge (≥ 500 cfs), as well as dam passage survival at each weir discharge level.
V. Evaluate survival and behavior of hatchery summer steelhead to wild surrogate winter steelhead for potential use of summer steelhead as a surrogate species winter steelhead.
VI. Evaluate juvenile passage rates in the auxiliary water supply (AWS), forebay water supply (FWS), and hatchery water supply (HWS).

1.2 Background and Literature Review

The development and operation of hydroelectric and flood risk management dams have adversely affected salmon and steelhead populations in the Willamette River Basin (Figure 1.1). The Willamette Valley Project (WVP), a group of 13 dams in the Willamette Basin, is owned and operated by the USACE. WVP dams have blocked access to historical spawning habitat, altered river discharge patterns, affected water temperature and sediment supply, and caused mortality to migrating anadromous fish (Keefer and Caudill 2010). In 1999, Upper Willamette River spring Chinook salmon (*Oncorhynchus tshawytscha*) and Upper Willamette River steelhead (*O. mykiss*) were listed as threatened under the Endangered Species Act (ESA). Subsequently, the National Marine Fisheries Service (NMFS) issued a Biological Opinion (BiOp) regarding the operation of the WVP in the Willamette River Basin (NMFS 2008).

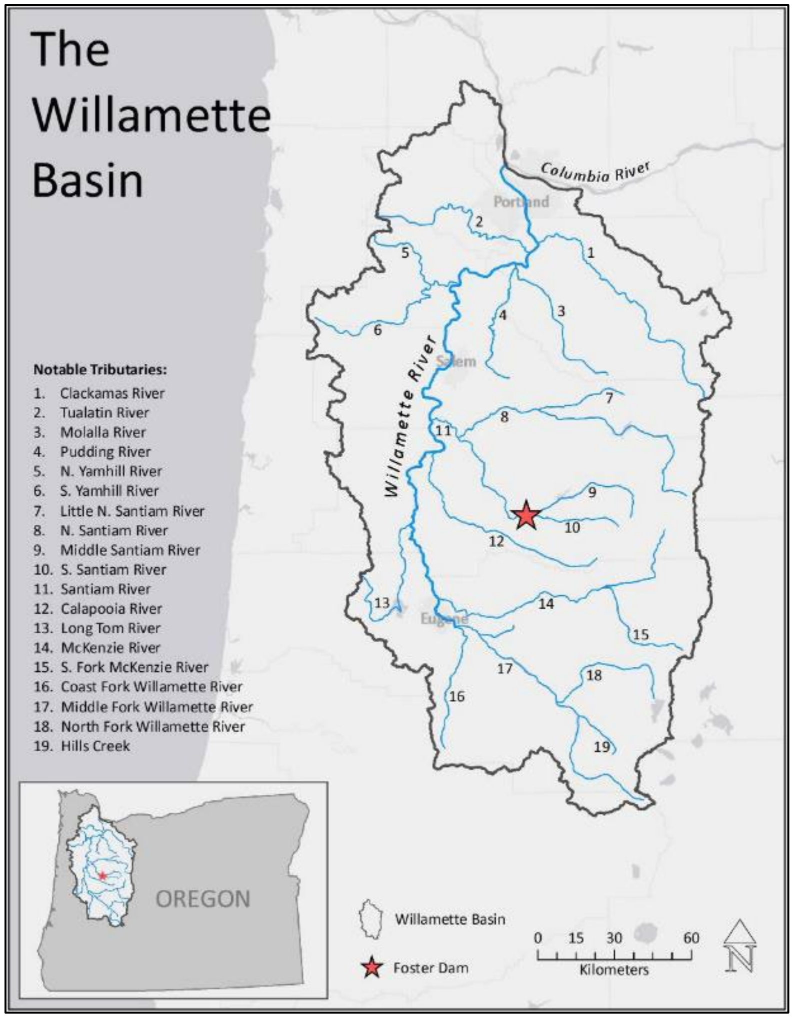

Figure 1.1. Map of the Tributaries that Comprise the Willamette River Basin and the Location of Foster (depicted by the red star)

1.2.1 Biological Opinion and Reasonable and Prudent Alternatives

The NMFS 2008 BiOp includes investigating options for improving downstream fish passage at Foster. Reasonable and Prudent Alternative (RPA) measure 2.8 of the BiOp recognizes that operation of the spillway fish weir at Foster could improve the survival of juvenile Chinook salmon and steelhead emigrating from above Foster (NMFS 2008). RPA measures 2.8, 2.10, 4.8, 4.11, and 4.13 of the BiOp require investigation of operational or structural alternatives at the dam to improve downstream fish passage. The RPA states that:

> *The Action Agencies will evaluate the effectiveness of the fish weir operation on downstream fish passage as part of RM&E (RPA measure 2.10) and COP studies (RPA measure 4.13). Based on the results of these studies, the Action Agencies will recommend modifications to this spill operation or new downstream fish passage facilities or operations.*

1.2.2 Previous Research at Foster

Wagner and Ingram (1973) conducted fish passage studies at Foster and Green Peter Dams and found the two projects were able to pass juvenile Chinook salmon; however, the ability of wild winter steelhead to pass either project was uncertain. For all juvenile salmonids, downstream passage was delayed in late spring months in Foster and Green Peter reservoirs (Wagner and Ingram 1973). Buchanan et al. (1993) used hydroacoustic and direct-capture data acquired between 1979 and 1988 and concluded that a lower reservoir elevation and reduced spill at Foster could enhance passage of downstream-migrating juvenile steelhead. They recommended using stop logs in a spill bay to create a surface spill in the spring to aid in steelhead passage. In general, surface-flow outlets such as top-spill weirs can readily pass juvenile salmonids downstream (Johnson and Dauble 2006).

In 1983, the USACE and the Oregon Department of Fish and Wildlife (ODFW) developed spill operations for juvenile salmonid passage at Foster by installing a notched stop log (fish weir) with a weir crest at an elevation of 611 ft msl (forebay elevation 613 ft msl) in Spill Bay 4. The pool elevation for this operation required a partial drawdown of the reservoir to avoid excessive head pressure on the fish weir and lower spillway stop logs. The USACE acquired new and improved stop logs in 2010, which allowed for weir operation at the 635 ft msl forebay elevation and allowed fish passage operations to occur when the water-surface elevation of the forebay is greater than 633 ft msl. The new operating elevation reduced the impact of the weir spill operation on other project authorizations, specifically water storage and recreation. Spill operations have the potential to decrease the percentage of fish that pass via the powerhouse, thereby presumably benefiting downstream-migrating salmonids. Weir discharge depends on the elevation at which the weir is installed on the stop logs, as well as the difference between the water-surface elevation and the weir-crest elevation. Generally, weir discharge ranged from 200 to 300 cfs.

Normandeau Associates, Inc. conducted studies at Foster in 2012 (Normandeau 2013) and 2018 (Normandeau 2019) to obtain direct survival and injury estimates of juvenile and adult steelhead passing through the turbine and via the weir. In 2012, they determined that the 48-hour survival of tagged fish that passed through the Foster powerhouse ranged from 74.0 to 85.4%. Estimated survival rates through the turbines were considerably lower and injury rates higher compared to other hydropower facilities using propeller/Kaplan turbines. They suggested that the number of blades (6), small size of the turbine (100 in. in diameter), and high rotation rate (257 rpm) may have contributed to the poor survival and injury rates for fish passing through the turbines. Normandeau also determined that juvenile steelhead passing via the fish weir had a much higher survival rate (94.4% at high pool; 99.5% at low pool) than fish passing via the turbines (Normandeau 2013).

PNNL conducted a hydroacoustic evaluation of juvenile fish passage (including non-salmonids) at Foster from April 1, 2013 to May 31, 2014 (Hughes et al. 2014). The primary objective of the evaluation was to estimate project passage, run timing, horizontal and diel distribution, and passage proportion at three passage routes: turbines, spillway, and the fish weir. Results indicated that the majority of juvenile-size fish that passed Foster did so through the turbines; the highest passage rates (peak of run) occurred during winter and the lowest during summer. Spillway passage proportions ranged from 0.10 (summer) to 0.22 (spring 2014). That is, when the spillway was open, 10 to 22% of the fish passing Foster used the spillway and 78 to 90% used the turbines. When the weir was operated simultaneously with the turbines, weir passage proportion ranged from 0.05 (winter) to 0.30 (summer). Results concerning horizontal and diel distribution at the powerhouse indicated that Turbine Unit 1 passed the vast majority of fish compared to Unit 2, and that fish passed through the turbines primarily overnight between 1700–0600 h. At the spillway, twice the number of juvenile-size targets passed via Spill Bay 2 than via Spill Bay 3 during concurrent operations and, in contrast to the diel distribution at the turbines, passage at the spillway peaked from early morning to late afternoon and low passage occurred at night. Data on diel variation in passage at the weir suggested that juvenile-size fish were passing via the weir at all times of the day. PNNL conducted a special weir test during summer 2013 to determine whether using the weir decreased turbine passage rates. Results suggested that 84% of all juvenile-size targets passed via the weir when both weir and turbines were in operation. Whereas differences in turbine and weir passage rates were statistically significant ($p < 0.001$), there was no difference ($p = 0.93$) in total turbine passage rates between the weir open and closed treatments. The findings suggest that fish did not seek to pass into the turbines when the weir was closed, but they passed over it when the weir was open.

In 2015 and in 2016, PNNL conducted RT studies to evaluate the passage and survival of downstream migrating juvenile salmonids (Chinook salmon and steelhead) at varying pool stages (Hughes et al. 2016, 2017). Given the tendency of salmonids to be surface-oriented, the unsuitability of Spill Bays 1–3 as a primary passage route (owing to their infrequent operation and high water usage cost), and the elevated rates of injury and mortality produced by passage through the turbines, a highly effective fish weir as a surface route was required for adequate downstream passage of salmonids at Foster. The 2015 and 2016 studies compared the proportions and survival of fish passing the weir and compared passage and survival at the turbines and Spill Bays 1–3. Those studies found that the fish weir had variable effectiveness at passing CH1 (effectiveness = 0.5–2.2) and CH0 (effectiveness = 0.6–6.1), and was moderately to highly effective at passing steelhead, with effectiveness ranging from 3.0 to 7.2. Both stocks of Chinook salmon preferred to use the non-weir spill bays (i.e., Spill Bays 1–3) when available, and many passed through the turbines even when the weir was open. Survival of all fish passing through the weir ranged from 43–87% depending on the year, fish species and stock, and pool stage at passage. Although survival through the weir was comparable to survival through other routes, which ranged 48–94%, the weir survival rate was lower than desirable. Taken together, these results highlighted a need for a new, improved weir, to better attract and entrain fish (in particular for Chinook salmon) and improve their dam-passage survival. The 2015 and 2016 results provided a baseline for the 2018 study against which the effects of the new fish weir were evaluated.

1.2.3 Entrainment Routes at Foster

In 2014, the USACE constructed an adult fish collection facility below Foster to facilitate upstream migration of adult salmonids. The facility was supplied with fresh river water from the FWS, which also supplied water to the adult fish ladder. The FWS intakes, located on the north wall of the penstock of Turbine Unit 2, were screened to block debris but not to prevent entrainment of juvenile salmonids. No information is available to describe how downstream migrants use this potential route of passage or whether passing juveniles are at risk of entrainment. The AWS intake, located adjacent to the discharge of Turbine Unit 2 in the tailrace, supplied additional attractant flow to the lower portion of the adult fish ladder. Water from the immediate powerhouse tailrace was diverted into the AWS gallery, located adjacent to Unit 2, and forced through a diffuser grate into the fish ladder to supply additional attractant flow in times of low project discharge. Similar to the FWS, the AWS intake was not screened to prevent fish entrainment and limited information is available regarding the potential for juvenile fish that have successfully passed the dam to become entrained in the AWS. The proximity of the AWS intake to both exits of the turbine units has led fishery managers to recommend further investigation of the potential for successfully passed fish exiting the turbines, particularly Unit 2, to become entrained in the AWS. The HWS provides fresh water to the South Santiam Fish Hatchery and the intake is located upstream and on the north guide wall of Spill Bay 1 in the Foster forebay. Like the FWS and AWS, the HWS was screened for debris but not for juvenile-size fish. Assessment of the susceptibility of juvenile salmonids to become entrained in, or pass through, these water supply systems was required by RPA 4.11. In the 2015 and 2016 RT studies, no tagged fish were detected in either the FWS or the HWS. A single STH2 was detected in the AWS during the 2015 spring low pool.

1.3 Study Site Description

Foster (Figure 1.2) is located on the South Santiam River near Sweet Home, Oregon. The congressionally authorized purpose of Foster is to provide for, and ensure flood risk management, power generation, irrigation, recreation, navigation, and water quality. The dam has a powerhouse with two Kaplan turbine units each with one penstock, a total generating capacity of 20 MW, and a total hydraulic capacity of 3,200 cfs. Maximum forebay pool elevation is rated at 641 ft msl and minimum conservation pool is 613 ft msl (http://www.nwd-wc.usace.army.mil/report/fos.htm).

Figure 1.2. Aerial Photograph of Foster (courtesy of the USACE [http://www.nwd-wc.usace.army.mil/report/fos.htm])

The dam has a spillway with four spill bays (Figure 1.3). Operation of the spill bays depends on forebay pool elevation, turbine operations, runoff conditions, season, and other factors. Spill Bay 4, closest to the turbine intakes, was configured with a top-spill fish weir that could be installed on stop logs to achieve a weir crest elevation of 611 ft msl (spring, fall, and winter; 613 ft msl forebay elevation) and 633 ft msl (summer; 635 ft msl forebay elevation). The centerline elevation of the turbine intakes is at 590 ft msl and the spillway crest elevation is at 597 ft msl.

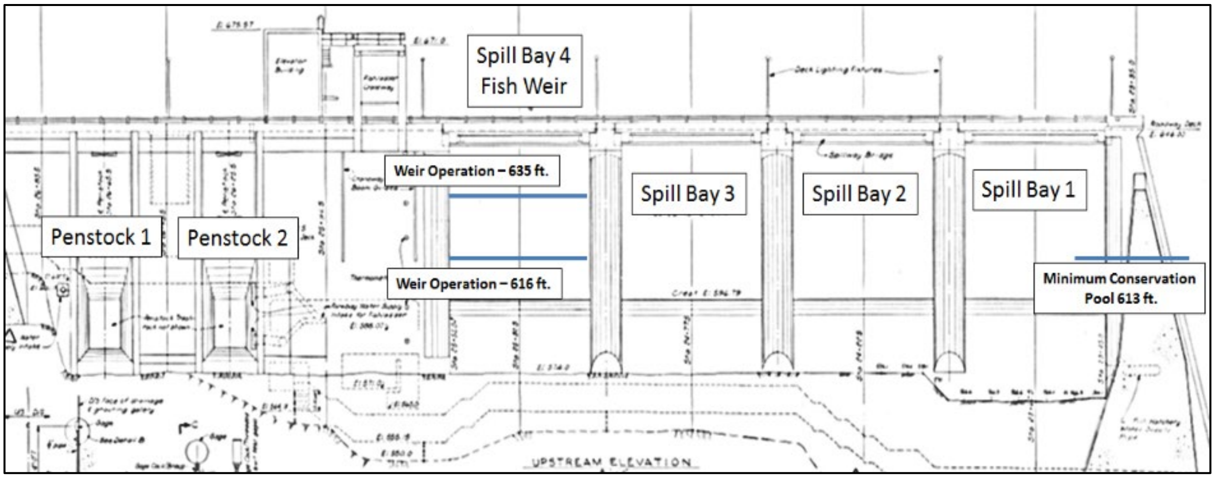

Figure 1.3. Upstream Face of Foster Showing Locations of the Spillway and Turbine Penstock Intakes

1.4 Report Contents

The ensuing sections of this report present the study methods (Section 2.0), environmental conditions during the study periods (Section 3.0), fish passage results (Sections 4.0, 5.0, and 6.0), discussion (Section 7.0), conclusions and recommendations (Section 8.0), and a list of the literature cited (Section 9.0). Appendix A contains a table of the general statistics for fish tagging and releases. Appendix B describes the test schedule for the spill vs. turbine block treatments. Appendix C details the ViRDCt survival model assumptions and testing. Tables containing the survival and passage proportions data corresponding to figures presented in Sections 4.0–6.0 are found in Appendix D. Appendix E presents capture histories and PIT tag detections of study fish. Finally, Appendix F provides an overview of the fish approach route compared to ultimate route of passage.

2.0 Methods

The general approach; release and recapture design and sample sizes; spill vs. turbine block/treatment test; tag specifications; fish handling, tagging, and release procedures; study fish detection capabilities; radio signal acquisition; and data processing and statistical methods pertinent to the study are described in the following sections.

2.1 General Approach

Radio telemetry technology was applied to accomplish the objectives of this study. The general approach for 2018 was based on that of the 2015 and 2016 studies:

- In 2015 and 2016, antenna mount designs successfully used for previous hydroacoustic deployments in the Willamette River Basin (Khan et al. 2012; Hughes et al. 2014) were modified to accommodate RT antennas, then reviewed and approved by USACE engineers and Foster project personnel.
- An optimization task, conducted in fall 2014, ensured deployed RT arrays were configured for the maximum likelihood of detection of study fish (Hughes et al. 2015).
- In 2018, antennas intended to detect fish in the near forebay were added at Foster (< 100 m from dam-face). A south-bank antenna was added at Lebanon Dam, where previously there had been a single antenna on the north riverbank.
- As in previous studies, arrays were also configured and verified before the start of each study period.
- Wild surrogate juvenile Chinook salmon, and winter steelhead, and hatchery summer steelhead were tagged and released to estimate survival and route of passage through Foster.

2.2 Release-Recapture Design and Sample Size

Capture histories required to estimate survival at Foster were compiled from detections on both underwater loop-vee (Gingerich et al. 2012) and aerial antennas deployed upstream and downstream of Foster (Figure 2.1). The release-recapture designs used to estimate survival and associated metrics at Foster required the regrouping of fish, double-tagged with radio and passive integrated transponder (PIT) tags, detected at the dam-face telemetry array (V_1), from two release locations in the Foster reservoir (R_1 and R_2; Figure 2.2). Two models were used to estimate survival in this report. In 2015 and 2016 (i.e., old weir evaluations), survival was estimated using the CJS model, from Foster through 19 rkm of tailwaters to the Primary Array (D_2), using RT detections at the Secondary (D_3) and/or Lebanon Dam (D_4) arrays to estimate the detection probability of the Primary Array. However, in 2018, a new model (ViRDCt) was used to estimate survival of V_1 fish from Foster to the Egress Array located 2.5 rkm downstream. For these estimates, detections at the Primary (D_2), Secondary (D_3), Lebanon Dam (D_4), and Willamette Falls (D_5) arrays were used to estimate the detection probability of the Egress Array (see section 2.9.3 for details). Because the ViRDCt study design was not used in 2015 or 2016, between-year comparisons (2015, 2016, and 2018) were made using the CJS model. Survival estimates for ViRDCt and CJS were adjusted for the probability of tag failure (i.e., tag life). Although PIT antennas at Lebanon Dam, Willamette Falls, and the Estuary Towed Array (D_6) could also detect tagged fish, PIT detections were not included in either ViRDCt or CJS survival estimates. CJS survival estimates from 2015 and 2016, which were not adjusted for tag life and included PIT detections, were recalculated to remove PIT tag detections to allow for comparison to 2018 estimates.

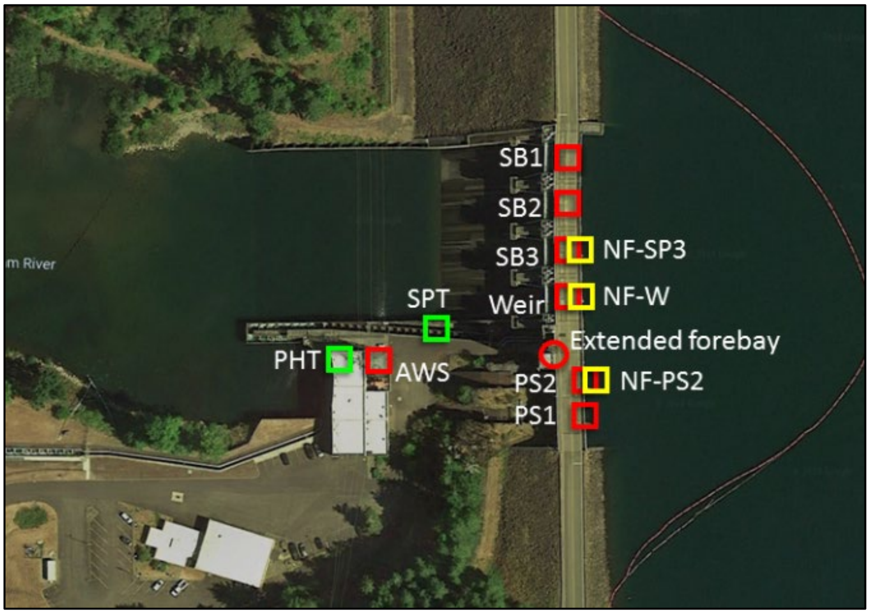

Figure 2.1. Radio Telemetry Detection Locations to Assess Route-Specific Survival and Behavior of Juvenile Salmon and Steelhead at Foster, 2018. AWS = auxiliary water supply, NF = near forebay, PHT = powerhouse tailrace, PS = penstock, SB = spill bay, SPT = spillway tailrace, W =weir.

In addition to dam-passage and route-specific survival, survival by weir discharge level was also compared in spring 2018 as another metric to evaluate the new weir design. The new weir was designed to pass flows between 300 cfs to 860 cfs, depending on reservoir elevation, with normal discharge operations of approximately 530 cfs (range of 450–550 cfs during spring). During spring 2018, the daily average weir discharge ranged from 161–685 cfs (mean: 519 cfs) because of reservoir fluctuations and project operations. Because there were days that were less or greater than normal discharge operations, we separated the comparison in discharge to < 500 cfs (low) and ≥ 500 cfs (high). In fall 2018, low precipitation resulted in low river flows; therefore, the new weir was operated at the designed low flow range (approximately 300 cfs) and the daily average discharge ranged from 278–470 cfs (mean: 355 cfs). As such, we only compared survival by the low weir discharge level (< 500 cfs).

In 2018, a total of 757 yearling Chinook salmon (CH1), 1,016 wild surrogate age-2 winter steelhead (STH2), and 683 age-1.5 hatchery summer steelhead (S-STH) were double-tagged (RT and PIT) and released during the spring low and high pool (Appendix A; Table A.1). Released CH1 had a mean fork lengths (FLs) and weights of 201.0 mm and 76.7 g, STH2 had mean FLs and weights of 177.7 mm and 50.8 g, and S-STH had mean FLs and weights of 220.4 mm and 107.9 g. A total of 749 subyearling Chinook salmon (CH0) were released in the fall (Appendix A; Table A.1). The mean FLs and weights of CH0 were 156.9 mm and 45.4 g.

In addition to the live fish releases, dead fish with active RT transmitters were released throughout the spring and fall release periods into the Foster tailrace from the spillway and powerhouse decks to estimate the proportion of V_1 fish that died during dam passage and were detected at the Egress Array for ViRDCt survival estimation.

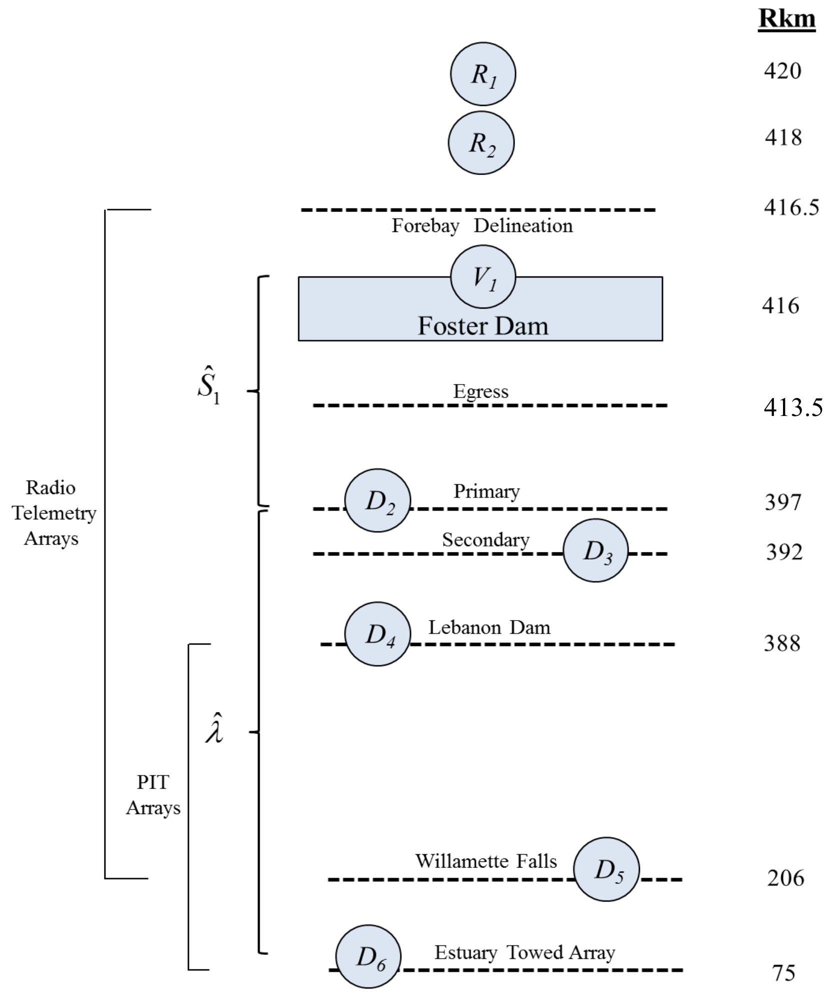

Figure 2.2. Schematic of the Study Design Used to Estimate Project Metrics at Foster in 2015, 2016, and 2018. Fish released at R_1 (rkm 418) and R_2 (rkm 420) that were detected at the dam-face array were regrouped to form the virtual release group (V_1). ViRDCt survival (2018 only) was estimated to the Egress Array (rkm 413.5) using detections at the Primary Array (D_2; rkm 397), Secondary Array (D_3; rkm 392), Lebanon Dam (D_4; rkm 388), and Willamette Falls (D_5; rkm 206) to estimate the detection probability of the Egress Array. CJS survival (2015, 2016, and 2018) was estimated to the Primary Array (D_2; rkm 397) using RT detections at the Secondary Array (D_3; rkm 392), Lebanon Dam (D_4; rkm 388), and Willamette Falls (D_5; rkm 206) arrays to estimate detection probability of the Primary Array.

2.3 Spill vs. Turbine Block Treatments

To evaluate the efficacy of different non-turbine passage routes, treatments consisting of combinations of turbine, spillway and/or weir operation were scheduled for the spring and fall study periods. Rather than randomly ordering the treatments within the blocks, the treatments were systematically alternated from block to block to minimize wear and tear on the spill gate control machinery and turbine operations. Additionally, the Foster Project Operators requested no changes (spill to turbines) on weekends considering mechanics and support staff do not work on weekends, and in case issues arose with starting the turbine units for power generation. These pseudo-randomized treatment blocks were 4 days long and each block consisted of 2 days of each treatment. There were two spring treatments consisting of simultaneous turbine and weir operation compared to simultaneous spillway and weir operation. There were also two fall treatments, different from spring. Fall treatments included simultaneous turbine and weir operation compared to turbine-only operations. The design of the spill study was influenced by operational requirements, project constraints, and Reservoir Control guidelines. The spring low pool block treatment test was planned for 20 March to 12 April 2018, but ended after 10 April 2018, owing to unplanned spillway discharge in the days that followed. The spring high pool block treatment test occurred as planned from 8 May to 4 June 2018 (Table 2.1). The fall low pool block treatment test was planned for 23 October to 9 December 2018, and generally occurred as planned, except that weir operation was not possible after 20 November 2018 (see Appendix B, Table B.1, Table B.2, and Table B.3, for the detailed block treatment schedule by season). The RT detection histories were interrogated by block to better understand the viability of the spillway as a route of passage for study fish.

Table 2.1. Example Sampling Plan for the Spillway Test during High Pool in Spring 2018. The fish weir in Spill Bay 4 was continually operated throughout each treatment block. Turbines were not truly off, but were in spin/no-load condition.

Day	Fish Release	Block	Treatment	Turbine	Spill	Weir
1	X	1	turbine+weir	On	Off	On
2	X	1	turbine+weir	On	Off	On
3	X	1	spill+weir	Off	On	On
4	X	1	spill+weir	Off	On	On
5	X	2	spill+weir	Off	On	On
6		2	spill+weir	Off	On	On
7		2	turbine+weir	On	Off	On
8		2	turbine+weir	On	Off	On
9		3	turbine+weir	On	Off	On
10		3	turbine+weir	On	Off	On
11		3	spill+weir	Off	On	On
12		3	spill+weir	Off	On	On

2.4 Tag Specifications and Radio Frequencies

Study fish were surgically implanted with both an RT tag (Lotek NanoTag model NTC-M-2, Newmarket, Ontario, Canada) and a PIT tag (Figure 2.3). Physical dimensions of the NTC-M-2 radio tag were 5 × 3 × 14 mm (width, height, length) with a weight of 0.43 g in air. Burst rates were distributed from 4.5–5.3 sec and staggered across a 1 MHz bandwidth from 166.550–167.500. Frequencies used for this investigation included 166.620, 166.740, 166.765, 167.340, 167.380, 167.420, and 167.480.

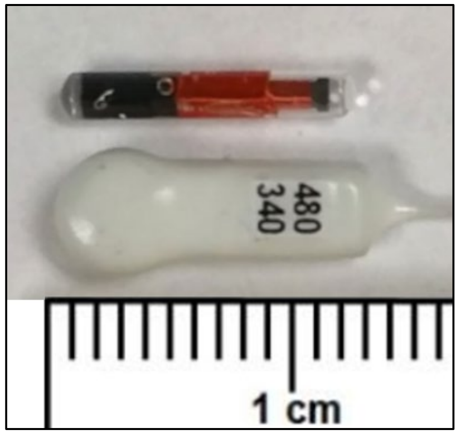

Figure 2.3. The Lotek NanoTag Model NTC-M-2 (bottom) and PIT-Tag (top) that Were Surgically Implanted in Chinook Salmon and Steelhead in 2015, 2016, and 2018

2.5 Fish Handling, Tagging, and Release Procedures

The Oregon State University (OSU) Wild Fish Surrogate Program provided study fish, with the exception of the hatchery summer steelhead, which were provided by the South Santiam Fish Hatchery. Fish were reared to the approximate size of wild juveniles migrating through Foster. Similar to fall 2015, and spring and fall 2016, fish were tagged at OSU facilities.

Study fish were surgically implanted with a RT tag and a PIT tag. All tagged fish were larger than 95 mm FL. This is the recommended minimum length for surgical implantation of tags in Chinook salmon to minimize tag burden (weight of the tag relative to the weight of the fish), as tag presence adversely affects dam passage survival in smaller fish (Geist et al. 2018). The research team used a shielded-needle surgical technique (modified from Adams et al. 1998 and Hockersmith et al. 2003) for implanting the RT tags into the juvenile salmonids. AQUI-S® (Aqui-S New Zealand Ltd, Lower Hutt, New Zealand) was used as a fish anesthetic in this research and was approved by the U.S. Fish and Wildlife Service's Aquatic Animal Drug Approval Partnership Program (study number 11-741-18-367HL [spring 2018] and 11-741-18-368HL [fall 2018]), in cooperation with the U.S. Food and Drug Administration's Investigational New Animal Drug program. Both federal and state take permits were obtained for this study (Federal–NMFS Permit W1-18-PNNL and ODFW Permit 22066) and we abided by all requirements of said permits.

Numerous steps were taken to minimize the impacts of handling the study fish during surgical procedures. First, fish were netted in small groups from pre-surgery holding tanks and placed in 10 L of pre-treated well water containing a 350 mg/L solution of AQUI-S®20E, which provided fish with a 35 mg/L anesthetic dose of the active ingredient, eugenol. Once a fish lost equilibrium, it was transferred to a data collection/processing table in a small container of water and anesthetic. Using a multi-step process, each fish was weighed and measured, assigned a bucket and release location, assigned a RT tag (unique frequency and code) and PIT tag, then returned to the small transfer container. Tagging information was added automatically to the tagging database using "P4" software from the PIT Tag Information System. Finally, fish were transferred to their assigned surgeons for tag implantation.

During surgery, each fish was placed ventral side up and a gravity-fed supply of fresh water was provided through tubing into the fish's mouth. As necessary, a "maintenance" anesthetic (up to 15 mg/L of eugenol; 150 mg/L Aqui-S 20E) was administered through the same gravity-fed supply line. Using a stainless-steel surgical blade, an incision approximately 7 mm long was made on the linea alba

5 to 10 mm anterior of the pelvic girdle. A hollow 19-gauge stainless steel needle, sheathed with 16-gauge stainless steel tubing (catheter), was inserted into the incision to make a small hole through the body wall near the distal end of the pelvic fin. The hollow needle was used as a conduit to insert the antenna of the radio transmitter through the body wall. Then the body of the radio transmitter (with the antenna protruding posteriorly through the body wall) and a PIT tag were inserted. The incision was closed with two interrupted stitches using 5-0 Ethicon Monocryl® monofilament sutures with a reverse cutting needle. Stitches were secured with a knot consisting of four single-wrap throws in alternating directions.

An established protocol was used to help minimize any potential negative effects of surgical procedures and handling. All metal surgical tools (catheters, needles, needle holders, and forceps) were autoclaved prior to the start of each tagging day. After using the surgical tools on a single fish, the tools were disinfected or autoclaved prior to reuse. Needle holders and forceps were disinfected in a hot bead sterilizer for 30 seconds, whereas suture material and needles were disinfected with ultraviolet light for 2 min (Walker et al. 2013). An adequate supply of sterile catheters and needles allowed for the tagging of all fish before needing to be autoclaved at the end of the day. PolyAqua® was applied liberally on all surfaces that came in direct contact with the fish to protect the fish's mucus membrane, reduce the possibility of infection, and to aid in healing. Water in both the anesthesia and recovery buckets was refreshed when switching species, and when necessary to maintain temperatures within ± 2 °C of the fresh water source.

The tagging process required a team of four people to conduct daily operations and all strived to ensure that tagged fish were handled as efficiently and carefully as possible. Tagged fish were held approximately 18 h post-surgery to ensure the short-term effects of the surgical process had dissipated.

Prior to releasing the fish, transport buckets were removed from the post-surgery holding tanks and placed in Bonar transportation totes on the bed of a transport truck, which held up to 18 fish buckets. A network of valves and plastic tubing was attached to a 2,000-psi oxygen tank to deliver oxygen to the totes during transport. A YSI meter (YSI Incorporated, Yellow Springs, Ohio) was used to monitor dissolved oxygen concentrations and water temperatures in the totes before and during transport to ensure that those parameters remained within acceptable limits (80–110% for dissolved oxygen, ±2°C for fresh water supply). If measurements approached unacceptable limits, staff adjusted the flow of oxygen to the tanks or added ice to the fresh water in the tanks to reduce the temperature.

Fish were released at two transects upstream of Foster—head-of-reservoir (HOR) and middle-of-reservoir (MOR)—each with three release points (Figure 2.4). The release locations were chosen to represent juvenile salmonids that rear and migrate from the South Fork South Santiam River into Foster reservoir (HOR), as well as juveniles that rear and migrate from the Foster reservoir (MOR). The bathymetry of Foster reservoir was also taken into consideration for the fish released at MOR to account for a shallow portion of the reservoir on the north side.

Figure 2.4. Bathymetry and Release Locations at Foster Reservoir. For the bathymetry map in the top left, warm colors indicate shallow water and cool colors indicate deep water. Fish were released middle-of-reservoir (MOR) and at the head-of-reservoir (HOR).

Upon arriving at the reservoir in trucks, fish buckets were transferred to a boat for transport to in-reservoir release locations at each cross section. At each release point, all buckets assigned to that location were segregated and the lids were scanned using a Biomark HPR Plus PIT-tag reader, which recorded the Global Positioning System coordinates and time of release. Just before fish were released into the reservoir, buckets were opened and checked for dead or moribund fish. If dead or moribund fish were observed, they were removed, and their PIT codes were noted on the release sheet. All fish buckets for the release location were then lowered over the side of the boat into the water, allowing the fish to swim out of the bucket into the reservoir.

2.6 Detection of Fish Implanted with RT Tags

The deployed RT systems enabled the detection of tagged fish in the forebay, at specific routes through Foster, in the immediate spillway and powerhouse tailraces, and at several locations downstream. Initial RT installation occurred before spring 2015. Originally, detection zones were created to monitor RT-tagged juvenile salmon and steelhead at 11 locations at Foster: Forebay, Turbine Units 1 and 2, Spill Bays 1–3, fish weir in Spill Bay 4, AWS, HWS (2), and FWS. After the spring 2015 study, the system configurations were changed slightly based on the results of the Hughes et al. (2016) study and implemented before the fall 2015 study. Ten locations were used in fall 2015 and throughout 2016: Forebay, Turbine Units 1 and 2, Spill Bays 1–3, fish weir in Spill Bay 4, powerhouse tailrace (PHT), spillway tailrace (SPT), and the AWS. The SPT and PHT receivers were installed to confirm route and time of dam passage. Monitoring stations at the HWS and FWS locations were removed and replaced with frequent manual scans with a Lotek receiver (Newmarket, Ontario, Canada). In 2018, the system configurations were again slightly modified (Table 2.2). Another array was added to the near forebay zone to improve detection probability nearest the dam-face (Figure 2.1). The FWS station was reinstated once more, and the HWS continued to be scanned manually. Finally, an additional antenna was added to south bank of the South Santiam River at Lebanon Dam (Table 2.2).

Table 2.2. Radio Telemetry Station Deployment Type, Location, and Study Purpose

Location	Antenna Type	Rkm below Foster	Elevation (ft msl)	Study Purpose
Extended Forebay	Corner Reflector Dipole	–	–	Extended forebay delineation
Near Forebay	3-Element Yagi	–	–	Near forebay (< 100 m) delineation, additional dam coverage
Spill Bays 1−3	Underwater Loop-Vee(a)	–	610	Route Specific
Turbine Units 1–2	Underwater Loop-Vee(a)	–	597	Route Specific
Fish Weir (Spill Bay 4)	Underwater Loop-Vee(a)	–	610(b) & 629(c)	Route Specific
AWS	Underwater Loop-Vee(a)	–	−	Entrainment
FWS	Underwater Loop-Vee(a)	–	−	Entrainment
Spillway Tailrace	Corner Reflector Dipole	–	−	Dam Passage
Powerhouse Tailrace	Corner Reflector Dipole	–	−	Dam Passage
Egress Array	Corner Reflector Dipole	2.5	−	Project Egress
Primary Array	2 x 6 Element Yagi	19	−	Survival Array
Secondary Array	6 Element Yagi + Corner Reflector Dipole	23	–	Survival Array
Lebanon Dam	6 Element Yagi (North bank), Corner Reflector Dipole (South bank)	28	−	Survival Array
Willamette Falls Dam	6 Element Yagi	210	–	Survival Array

(a) Gingerich et al. 2012.
(b) Forebay elevation 613 ft msl.
(c) Forebay elevation 635 ft msl.

Each detection zone used underwater, baffled (corner reflector), or Yagi aerial antennas to detect study fish according to study objectives. On the dam itself, each antenna was installed with a signal amplifier and connected via LMR200 and/or LMR400 coaxial cable (Times Microwave Systems, Wallingford, Connecticut) to an individual Orion radio receiver (Sigma Eight Inc., Newmarket, Ontario, Canada). The Orion receiver located at each antenna processed analog signals and stored detection data locally to an internal storage card. Orion receivers monitoring passage through the dam were connected to a single "trunk" cable (cat6 Ethernet cable) and digital signals (converted from analog signals received by the antennas) were routed along the tailrace side of the dam to a central computer system network housed in a storage room in the elevator tower at the dam.

A single-dipole 90-degree corner reflector antenna (Hutton Communications, Inc., Dallas, Texas; Figure 2.5a) delineated the extended forebay detection zone in 2015 and 2016; for 2018, this antenna was moved to the east side of the Foster elevator tower (about 20 m closer to dam), due to removal of the gantry crane where the antenna was installed in 2015 and 2016. However, in all study years the detection zone of this antenna extended beyond the current forebay log boom approximately a quarter mile upstream (Figure 2.5b). The first detection of study fish on this array delineated the entrance into the extended forebay at Foster.

The extended forebay antenna did not detect fish within the section of the forebay closest to the dam-face, less than 5–10 m from the dam itself. In 2018, a near forebay array was installed to better cover this region. Three antennas were installed on the upstream side of the dam at road-deck elevation: one in the center of Spill Bay 3, one in the center of Spill Bay 4, and another off the piernose of Penstock 2 (Figure 2.5c). Aside from their improved coverage of the near forebay area closest to the dam, the detection range of these antennas was similar to that of the extended forebay antenna.

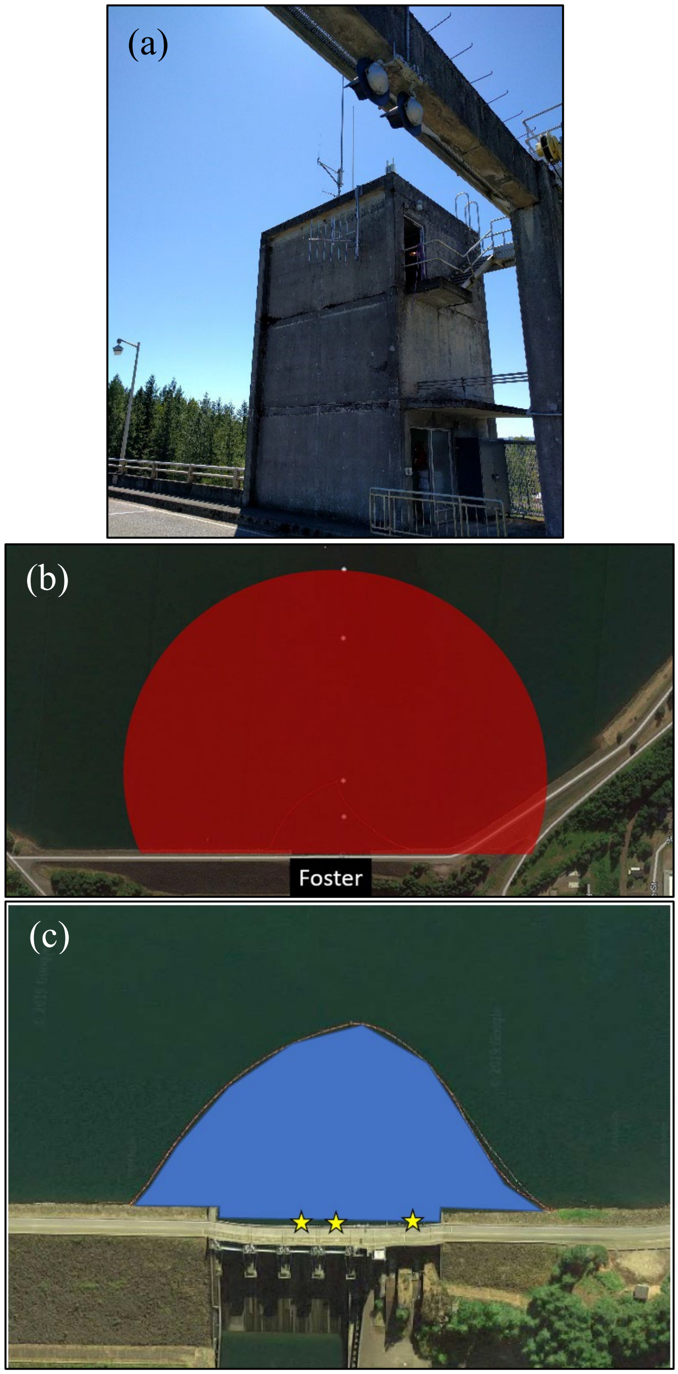

Figure 2.5. Corner Reflector Dipole Antenna Installed at Foster for (a) Extended Forebay Delineation; (b) Approximate Detection Zone of the Forebay Antenna; and (c) Approximate Detection Zone of the Three Near Forebay Antennas (yellow stars)

To detect study fish passing through the penstocks, underwater balanced loop-vee radio antennas (Gingerich et al. 2012; Figure 2.6) were installed by divers by mounting them directly on the penstock trash racks at an elevation of 597 ft msl.

Figure 2.6. Direct-Mounted Underwater Balanced Loop-Vee Radio Antenna as Installed on Penstock Trash Racks at Foster

Underwater balanced loop-vee radio antennas were installed in Spill Bay 4 (fish weir; 4 total) and in Spill Bays 1–3 on each side of the spill bay (north and south), for a total of 10 antennas in 4 spill bays (Figure 2.7). Antennas at Spill Bays 1–3 were deployed at an elevation of 610 ft msl, immediately downstream of the spillway stop log guides and just upstream of the tainter gate. At the fish weir at Spill Bay 4, antennas were deployed just upstream of the spillway stop log guides at an elevation of 610 ft msl (low pool monitoring) and 630 ft msl (high pool monitoring), to allow for movement and removal of stop logs and the spill weir. Each antenna had an effective range of approximately 70 ft (Figure 2.8).

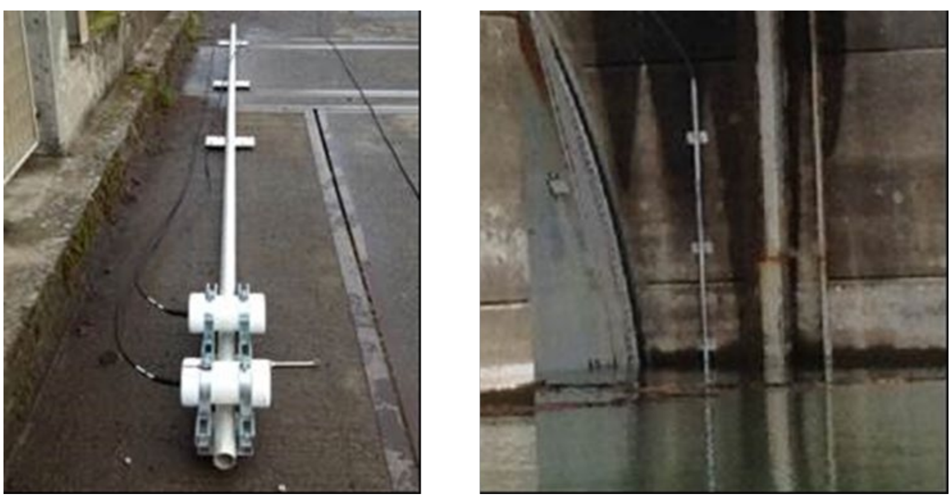

Figure 2.7. Underwater Balanced Loop-Vee Radio Antennas, Showing the Primary and Backup Secondary Antennas, Deployed at Spill Bays 1−4

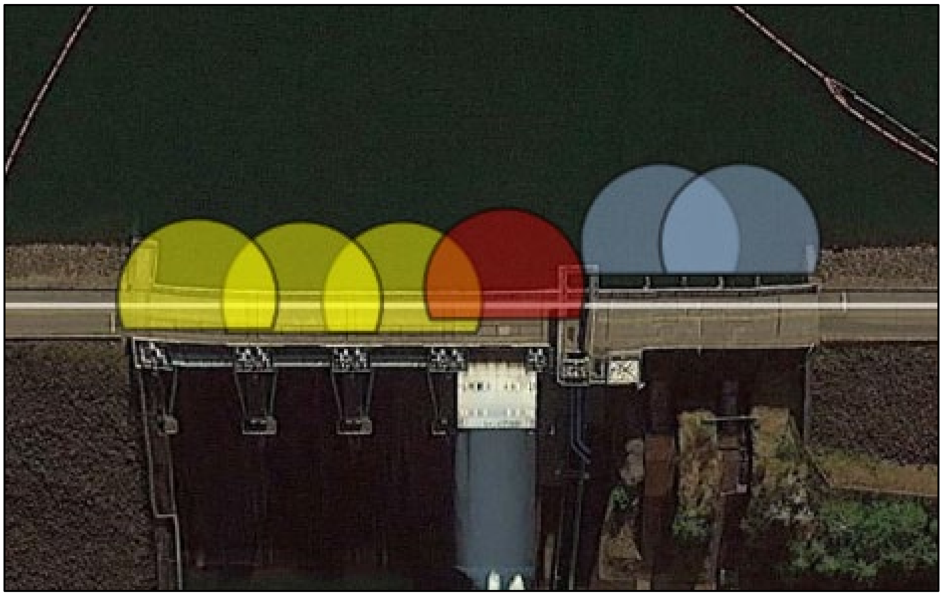

Figure 2.8. Approximate Detection Zone (70 ft) of Underwater Radio Telemetry Antennas Installed at Foster (yellow = Spill Bays 1–3; red = Fish Weir/Spill Bay 4; blue = Turbine Units 1–2)

Throughout the studies from 2015–2018, three autonomous Orion RT stations were used downstream of the dam to detect fish moving through the study area (Figure 2.9). The Egress Array was located approximately 2.5 rkm downstream of the dam and was used to determine project egress times of fish passing through the dam, and for estimating dam-passage survival using the ViRDCt model in 2018. The Primary Array, located approximately 19 rkm downstream of the dam, served as the detection array to which survival was estimated, using the CJS model, in 2015, 2016, and 2018. Two additional downstream arrays were added for the fall of 2015. The additional arrays were located at Lebanon Dam (28 rkm downstream of Foster) and just upstream of Willamette Falls Dam (210 rkm downstream of Foster). A second antenna was installed prior to the 2018 season at Lebanon Dam on the south bank of the river, to improve detection probabilities at this location. The final RT array was located about 206 rkm downstream of Foster (Willamette Falls Array). Each of these stations was installed near the shore and contained two aerial antennas, one pointing upstream and one pointing downstream, to maximize detection probabilities at these areas. Antennas were mounted on antenna masts supported by guy lines, or on steel pipes driven into the substrate.

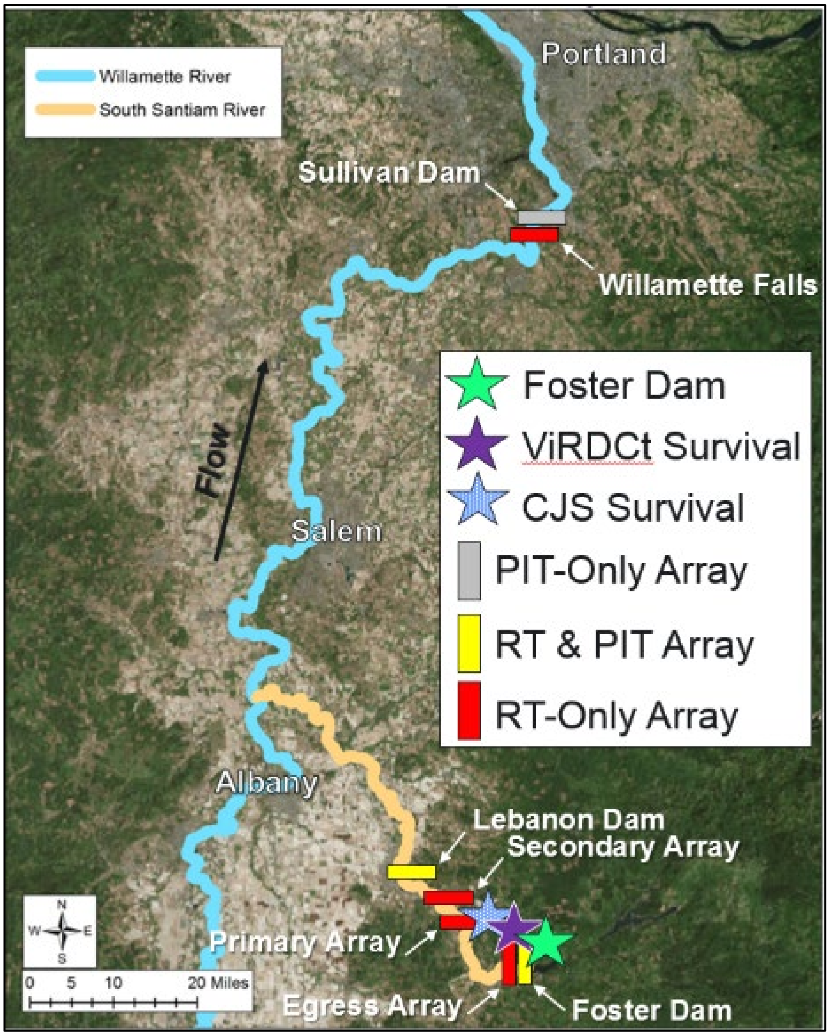

Figure 2.9. Locations of Radio Telemetry (RT) and PIT Tag (PIT) Detection Arrays to Determine Juvenile Chinook Salmon and Steelhead Migration Behavior and Passage through Foster Reservoir, Dam, and Tailwaters. Each of the five Foster tailrace locations (Egress, Primary, Secondary, Lebanon, and Willamette Falls) had a single array, whereas the Foster location had several arrays, as shown in Figure 2.1. Red lines signify RT arrays, yellow lines signify the presence of both PIT and RT arrays.

2.7 Data Acquisition

All data acquired used a combination of the MITAS (Sigma Eight Inc., Newmarket, Ontario, Canada) and autonomous Orion (Sigma Eight Inc.) RT systems and Lotek-manufactured transmitters (Lotek Wireless, Inc., Newmarket, Ontario, Canada). Both the MITAS and Orion receivers were programmable and could be used to detect Lotek transmitters. The MITAS and autonomous Orion receivers were able to simultaneously scan up to 200 frequencies, so total scan time was not an issue. To do this, the MITAS and Orion systems sampled a specified 1 MHz section of the frequency spectrum and processed digital samples using a pair of digital signal processors and a method called Fast Fourier Transform. MITAS software was installed on a central computer system and was used to analyze and monitor the system of connected receivers in real time. Figure 2.10 is a schematic of the MITAS hardware configuration.

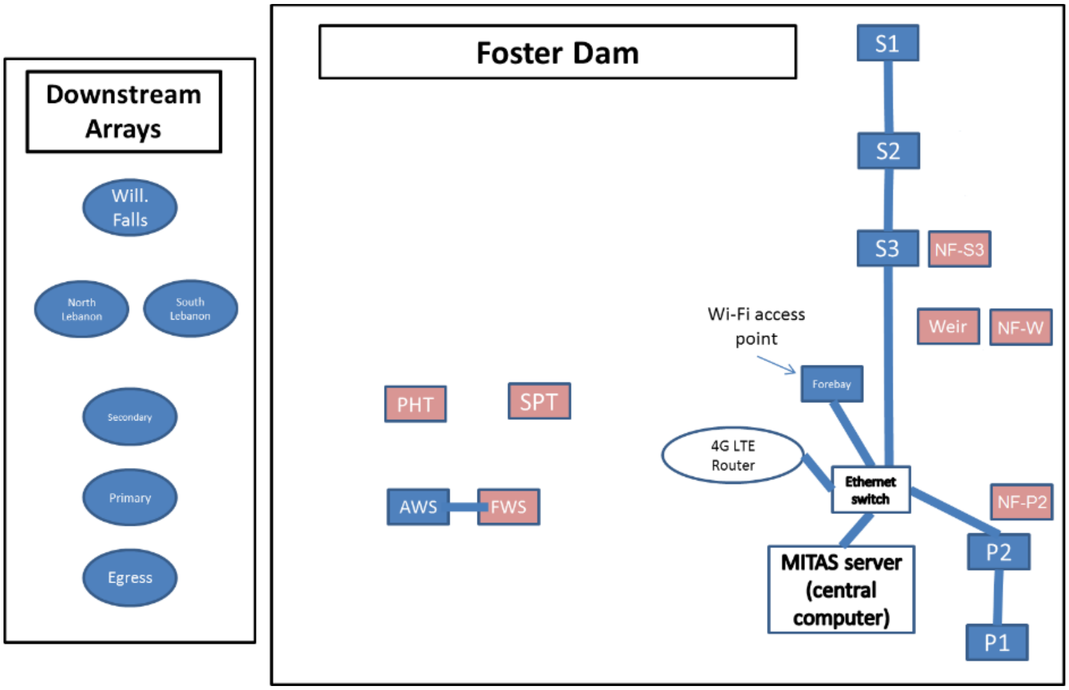

Figure 2.10. Layout of the Multiprotocol Integrated Telemetry Acquisition System (MITAS) for the Foster Evaluation including Networking Routers Paired with Orion Receivers (solid-colored ovals and rectangles) and Location of Wi-Fi and 4G Access Points to the MITAS Server. Blue rectangles are connected by Ethernet cable, pink rectangles are connected by high-powered Wi-Fi, and blue ovals are connected by 4G LTE internet. Components at each router/receiver location also include antennas, signal amplifiers, signal combiners, and a 12-volt backup power system.

2.8 Data Processing

The Orion receivers used in this study were set up to have redundant storage capabilities. The data were stored internally in each receiver, using swappable flash media devices, and were remotely sent to MITAS through either ethernet or wireless connections. All data were then retrieved from either MITAS or the flash media device. Once data were received, a quality assurance/quality control (QA/QC) program was run to ensure raw data integrity, to validate naming conventions, and to check for data recording errors generated by interruptions. The data were then run through a beacon summary program to determine beacon activity per hour, signal strength, and to check for data gaps. Next, manually retrieved data from the flash media cards in each Orion receiver were used to fill in any missing gaps in the remotely retrieved data. The data were then checked for duplicate tag codes and noise codes, all of which were removed from the working data set. Data were then filtered by fish frequencies and code matches that were specific to fish that were released. All valid detections were then bound by date-times for fish release and tag life. All other site-specific filters were then run to create a final data set.

The resulting data set was used to create detection “events.” Events are sequences of detections that occur at a user-specified number of times within a user-specified time period for a single fish (i.e., 3 detections in 60 sec). Fish events help evaluate whether detections are representative of a fish passing a detection site or just “noise” picked up by the antennas that generated a fish frequency by chance.

Once all events were classified and compared to dam operations, the output data underwent QC testing to ensure event definition parameters were correctly set. The corrected summary was then used as part of a feedback loop to adjust the final capture history summary. For each fish, the summary generated indicated whether it had been detected at a particular site, the first and last detection date/time at each site, whether the fish passed during the day or night, the pool elevation at the time of passage, and other metrics. Finally, a full suite of statistics was generated to summarize the fish's migration history within the system: up and downstream movement, passage proportions, efficiencies and effectiveness, travel and residence times, approach to passage scenarios, and others.

2.9 Statistical Methods

Statistical methods used for this investigation are summarized in the following sections.

2.9.1 Estimation of Dam-Passage Survival and Route-Specific Survivals

2.9.1.1 Design Concepts

In 2015, 2016, and 2018, RT-tagged fish were released at two locations, 2 and 4 rkm upstream of Foster at mid-of-reservoir (MOR) and head-of-reservoir (HOR) sites, respectively (Figure 2.4). In 2015 and 2016, the long reservoir residence times of some RT-tagged fish (particularly steelhead) resulted in relatively high proportions of fish passing Foster and detection arrays near or after the end of their tag life. In these cases, tag life-adjusted estimates of survival may be substantially higher than the unadjusted survival estimate. Due to the large effect that delayed migration (relative to tag life) can have on survival estimates, tag life-adjusted estimates of survival were calculated for 2015, 2016, and 2018 using the methods of Townsend et al. (2006) and program Acoustic Tag Life-Adjusted Survival (ATLAS; Columbia Basin Research, University of Washington). In some instances, insufficient numbers of detections precluded estimation of tag failure probability. In these cases, the program Survival Under Proportion Hazards (SURPH; http://www.cbr.washington.edu/analysis/apps/surph) was used to estimate CJS survival probabilities, unadjusted for tag life. These survival estimates were denoted by S_1.

A representative subsample of Lotek NanoTag model NTC-M-2 transmitters was retained from each season/year study for an assessment of RT tag operational life (25 to 60 RT tags for each season). In 2018, RT tags were randomly sampled from one production lot in spring and one in fall. They were monitored continuously from activation until tag failure. Post-processing software calculated the number of hourly decodes for each transmitter, allowing the times that transmitters stopped working to be determined within ± 1 h. Failure times from each tag life study were fit to Weibull 2-parameter (Lawless 1982; Lee 1992), Weibull 3-parameter (Elandt-Johnson and Johnson 1980), and the 4-parameter vitality model (Li and Anderson 2009). The best-fitting model was used to estimate tag life probabilities at each detection array. The Weibull 2-parameter model was fit to the tag life data collected for the spring 2015 and 2016 and fall 2016 and 2018 studies, the Weibull 3-parameter model was fit to the tag life data for the fall 2015 study, and the 4-parameter vitality model was fit to the tag life data collected for the spring 2018 study. In all three years, a small number of fish were detected after the maximum battery life observed in the tag life study, which precluded estimations of tag life-adjusted survival and associated variance. Therefore, detections of fish that occurred after the maximum battery life observed in the tag life study were removed from the survival analysis. For this same reason, PIT detections at Lebanon Dam, Willamette Falls, and the Estuary Towed Array—which sometimes occurred after the maximum RT tag battery life—were excluded from the survival analysis.

Similarities in study designs between years allowed for comparison of survival using ATLAS or CJS from the time of dam-passage to the primary survival array (i.e., Primary Array) located 19 rkm downstream of Foster. Dam-passage and route-specific survival were estimated using fish that were detected passing Foster to form a virtual release group (V_1). Dam and route-specific virtual release groups were identified by detections in zones established to monitor passage of RT-tagged juveniles through the passage routes at Foster.

Dam-passage and route-specific survival, estimated from Foster to the Primary Array, were compared among years (old weir [2015 and 2016] vs. new weir [2018]) using model selection criteria, such as Akaike's Information Criterion (AIC) and likelihood ratio tests (LRTs). The AIC and LRTs were used to determine whether it was appropriate to pool detection data from 2015 and 2016. First, the full model, in which tag life-adjusted survival and detection probabilities differed among years, was fit. Parsimony was then achieved by fitting reduced (i.e., nested) models in which tag life-adjusted survival and/or detection probability was equal between years. An AIC test was used to identify the best-fitting model and LRTs were used to determine whether the best-fitting model differed significantly ($\alpha = 0.05$) from reduced (i.e., nested) models. If no significant difference was observed, the reduced (i.e., more parsimonious) model was selected. If a significant difference was observed between the best-fitting and reduced models, the model with the lowest AIC was retained.

A similar approach was used to evaluate the effect of the new weir on dam-passage and route-specific survival by comparing 2015 and 2016 (old weir, either pooled or individually) to 2018 (new weir). A full model, in which tag life-adjusted survival and detection probabilities differed between old and new weir evaluation years, was fit and compared to reduced models in which tag life-adjusted survival and/or detection probability was equal between old and new weir evaluation years using AIC and LRTs.

The single-release survival estimate included mortality that occurred in the 19 rkm of tailwaters between Foster and the Primary Array. The level of mortality experienced by juvenile salmonids in this tailwater reach may vary temporally due to changing river conditions, which could confound between-year and between-route survival comparisons. Therefore, it was desirable to estimate survival over a shorter reach of river that included only dam passage and the immediate tailrace. As such, in 2018, the ViRDCt model (Harnish et al. 2017) was used to isolate dam-passage and route-specific survival to the river reach from dam passage to the Egress Array, which was located just 2.5 rkm downstream of Foster (for more detailed information about model assumptions and testing, refer to Appendix C). These survival estimates are denoted by S_D. Using ViRDCt, the single-release survival of the virtual release group (estimated to the Egress Array) was adjusted for the bias that occurs from misidentifying dead fish as alive at the Egress Array. An estimate of this bias was obtained as the proportion of dead tagged fish released into the immediate tailrace of Foster that were detected on the Egress Array.

When tag life probability equaled 1.0 at the Egress Array, maximum likelihood estimation (MLE) was used to estimate dam passage survival using the ViRDCt model. The joint likelihood ViRDCt model can be written as follows:

$$L = \binom{V_1}{n}(S_D p_1 + (1 - S_D)\phi)^n \big(S_D(1 - p_1) + (1 - S_D)(1 - \phi)\big)^{V_1 - n}$$
$$\cdot \binom{D_1}{m}\phi^m (1 - \phi)^{D_1 - m} \cdot \binom{n_{11} + n_{01}}{n_{11}} p_1^{n_{11}} (1 - p_1)^{n_{01}}$$

where

n_{ij}	=	number of V_1 release fish with capture history ij (i = 0 or 1 for detection at the Egress Array, j = 0 or 1 for detection at the Primary Array),
S_D	=	dam passage survival,
p_1	=	probability of an alive V_1 fish being detected at the Egress Array,
ϕ	=	joint probability of a dead released fish (D_1) arriving at the tailrace array and being detected at that array,
n	=	number of V_1 fish detected at the tailrace array, and
m	=	number of D_1 fish detected at the tailrace array.

Iterative procedures from program User Specified Estimation Routine (USER; Columbia Basin Research, University of Washington, http://www.cbr.washington.edu/analysis/apps/user), which is a flexible software tool that allows users to develop statistical model for analyzing mark-recapture data, were used to estimate the model parameters and associated variances. The MLE for the estimate of dam passage survival was of closed form for this model where

$$\hat{S}_D = \frac{\left(\frac{n}{V_1} - \frac{m}{D_1}\right)}{\left(\hat{p}_1 - \frac{m}{D_1}\right)}.$$

When a tag life correction was necessary, dam passage survival was estimated using the closed form estimator adjusted for tag life:

$$\hat{S}_D = \frac{\left(\frac{\left(\frac{n}{V_1}\right)}{T_i} - \frac{m}{D_1}\right)}{\left(\hat{p}_1 - \frac{m}{D_1}\right)}$$

where T_i is the probability that a tag was active at event i, given $T_0 = 1$. Assuming the inputs into the ViRDCt-derived survival estimate are uncorrelated, the variance of the survival estimate can be calculated using the delta method (Seber 1982):

$$\widehat{\mathrm{Var}}\left(\hat{S}_D\right) = \widehat{\mathrm{Var}}\left(\frac{n}{V}\right)\left(\frac{1}{\hat{p}-\hat{p}_D}\right)^2 + \widehat{\mathrm{Var}}(\hat{p}_D)\left(\frac{\left(\frac{n}{V}-\hat{p}\right)}{(\hat{p}-\hat{p}_D)^2}\right)^2 + \widehat{\mathrm{Var}}(\hat{p})\left(\frac{\left(\frac{n}{V}-\hat{p}_D\right)}{(\hat{p}-\hat{p}_D)^2}\right)^2 + \widehat{\mathrm{Var}}\left(\hat{T}_i\right)$$

where $\widehat{\mathrm{Var}}\left(\frac{n}{V}\right) = \frac{\frac{n}{V}\left(1-\frac{n}{V}\right)}{V}$ (i.e., binomial variance),

$\widehat{\mathrm{Var}}(\hat{p}_D) = \widehat{\mathrm{Var}}\left(\frac{d}{D}\right) = \frac{\frac{d}{D}\left(1-\frac{d}{D}\right)}{D}$ (i.e., binomial variance),

$\widehat{\mathrm{Var}}(\hat{p}) = \widehat{\mathrm{SE}}(\hat{p})^2$ from the CJS model, and

$\widehat{\mathrm{Var}}\left(\hat{T}_i\right) = \widehat{\mathrm{SE}}\left(\hat{T}_i\right)^2$ the variance of the ATLAS tag-life correction for the Egress Array.

A total of 42 dead tagged fish (CH1 and STH2 combined) were released into the Foster tailrace at low pool and another 41 dead tagged fish were released at high pool during the passage and survival study conducted at Foster in the spring of 2018. Dead tagged fish were released daily during at least two of the spill treatment blocks. During the fall, 40 dead tagged CH0 were released into the tailrace of Foster. During both seasons, dead tagged fish were distributed evenly between the powerhouse and spillway tailrace when both the spillway (including the weir) and powerhouse were operational at the time of the release.

2.9.2 Estimation of Project Passage Metrics

Passage routes were identified by detections in penstock, spill bay, weir, AWS, and FWS zones. The proportion of fish that passed through each of these routes was calculated for each species/stock/year/pool level. Efficiency metrics were calculated based on the numbers of fish passing the dam overall and the number passing through each specific route.

Dam-passage efficiency (DPE), the proportion of total fish passing the dam relative to the number of total fish detected in the near forebay of the dam and therefore available to pass, was estimated by the fraction:

$$DPE = \frac{\hat{N}_{Weir} + \hat{N}_{NWeir} + \hat{N}_{TUR}}{\hat{N}_{NearForebay}} \tag{2.1}$$

Where $\hat{N}_i$ is the estimated abundance of tagged fish that pass Foster through route i (Weir = fish weir, NWeir = non-weir spill, TUR = turbine).

Fish passage efficiency (FPE), the proportion of fish passing via a non-turbine route, again relative to the number of total fish in the near forebay and available to pass, was estimated by the fraction:

$$FPE = \frac{\hat{N}_{Weir} + \hat{N}_{NWeir}}{\hat{N}_{NearForebay}} \tag{2.2}$$

Spillway passage efficiency (SPE), the proportion of fish passaging through non-turbine route relative to the number of total fish passing the dam via any route, was estimated by the fraction:

$$SPE = \frac{\hat{N}_{Weir} + \hat{N}_{NWeir}}{\hat{N}_{NWeir} + \hat{N}_{Weir} + \hat{N}_{TUR}}, \tag{2.3}$$

Spill bay efficiency (SBE) and fish weir efficiency (FWE), defined as the proportion of fish passing through Spill Bays 1–3 only (SBE), and the fish weir only (FWE), relative to the number of total fish passing the dam via any route, were also calculated.

SBE was estimated by the fraction:

$$SBE = \frac{\hat{N}_{NWeir}}{\hat{N}_{Weir} + \hat{N}_{NWeir} + \hat{N}_{TUR}}, \tag{2.4}$$

Similarly, FWE was estimated by the fraction:

$$FWE = \frac{\hat{N}_{Weir}}{\hat{N}_{NWeir} + \hat{N}_{Weir} + \hat{N}_{TUR}}, \tag{2.5}$$

Effectiveness of the spillway, Spill Bays 1–3, and the fish weir were calculated by dividing the SPE, SBE, and FWE, respectively, by the proportion of the total dam discharge (disch.) that passed through that same route, resulting in a unitless measure of effectiveness:

$$Fish\ Weir\ Effect = \frac{FWE}{(Weir\ disch. \div Total\ disch.)}, \tag{2.6}$$

Passage route proportions, FWE, and SPE from 2015 and 2016 were compared to determine whether the observed proportions were similar enough between years to be pooled. These comparisons were conducted using the tabular passage data and Fisher's exact test ($\alpha = 0.05$). If these comparisons revealed no significant differences, data from 2015 and 2016 were pooled for comparison to 2018. Because we expected SPE and FWE to increase in response to weir replacement, one-sided tests were used to test for these changes ($\alpha/2 = 0.025$).

2.9.3 Estimation of Reservoir Residence Time and Travel Times

Reservoir residence time was calculated for each RT-tagged fish detected passing Foster by subtracting the date and time of dam passage from the date and time of release. Dam passage was identified by detections in zones established to monitor passage of RT-tagged juveniles through eight passage routes at Foster (i.e., 2 penstocks, 3 spill bays, 1 fish weir, AWS, and FWS) using the MITAS (Sigma Eight Inc., Newmarket, Ontario, Canada).

Median and mean travel times were computed and reported. Project egress time was measured from the last detection on the dam-face array to the last detection on the Egress Array below the dam. Both the arithmetic average and the median were calculated for all travel times. Only fish known to have passed the dam alive were used in the travel time calculations.

Travel times associated with reservoir residence, project egress, etc., were estimated using arithmetic averages:

$$\bar{t} = \frac{\sum_{i=1}^{n} t_i}{n}, \tag{2.7}$$

with the variance of $\bar{t}$ estimated by:

$$Var(\bar{t}) = \frac{\sum_{i=1}^{n} \left(t_i - \bar{t}\right)^2}{n(n-1)}, \tag{2.8}$$

where t_i was the travel time of the i^{th} fish $(i = 1, \ldots, n)$.

Because fish travel time data were right-skewed, a non-parametric Wilcoxon test (α =0.05) was used to compare reservoir residence times between years. First, residence times from 2015 and 2016 were compared for each species/stock/pool level to determine whether it was appropriate to pool data from 2015 and 2016. Next, residence times from 2015 and 2016 (either pooled or individually) were compared to residence times calculated in 2018 for each species/stock/pool level to evaluate the effect of weir replacement on reservoir residence times.

2.9.4 Analysis of Spill vs. Turbine Block Treatment Test

As in previous years, a pseudo-randomized block design was implemented in 2018 to evaluate the efficacy of spill as a non-turbine passage route for juvenile salmon and steelhead. The null hypothesis for this evaluation was that total dam-passage rates were equivalent during turbine+weir and spill+weir operational treatments. As was the case in 2015 and 2016, two-way ANOVA (block and treatment) was used to test for a treatment (i.e., operational) effect on total dam passage.

3.0 Environmental Condition Results

Results are presented for three 2018 study periods—spring low and high pool elevations and fall low pool elevation—as outlined in Table 3.1. Results from the 2018 study (new weir evaluation) were compared to results from the 2015 and 2016 study years (old weir evaluations). Fish passage study results presented in Sections 4.0, 5.0, and 6.0 include fish species and stock-specific estimates whose results also pertain to these seasonal study periods and are compared to previous study years.

Table 3.1. Low and High Pool Elevation Study Periods, Spring and Fall 2015, 2016, and 2018

Season	Pool Elevation (ft msl)	Study Period
Spring 2015		3/17–4/28
Spring 2016	Low (613)	3/29–4/21
Spring 2018		3/19–4/29
Spring 2015		5/11–6/25
Spring 2016	High (635)	4/30–7/13
Spring 2018		5/7–6/15
Fall 2015		10/6–12/31
Fall 2016	Low (613)	10/14–12/20
Fall 2018		10/23–2/4

3.1 Environmental Conditions

Environmental condition data included forebay elevation by operational/seasonal periods, forebay temperature, project discharge, and operations by route. Discharge and forebay temperature data were provided courtesy of the USACE WVP operations office.

3.1.1 Forebay

The Foster forebay elevation followed a Rule Curve managed by the USACE Water Management Reservoir Regulators. The Rule Curve dictated the lowering of the forebay pool elevation in fall to prepare for storage and flood risk management during winter months. Generally, the fall pool drawdown begins on or after October 1 and refill of the reservoir begins on or around February 1. Any deviations in the timing of refill and drawdown periods were coordinated through the Reservoir Regulators and local stakeholders. For example, during this multi-year study, the reservoir was held at the low pool elevation (613 ft) through the end of April each year before the commencement of refill to the high pool elevation (635 ft). Refill to high pool normally takes about 7 to 10 days.

3.1.1.1 Forebay Elevation

Forebay elevation was dictated largely by the Rule Curve, therefore forebay elevations during 2018 closely resembled those experienced in 2015 and 2016. During both study years, the reservoir was kept at low pool (613 ft msl) for the spring low pool study. After the spring low pool study period, the reservoir was filled until reaching the high pool elevation (635 ft msl) near the end of April. The reservoir remained at high pool until mid-September, when the fall drawdown reduced the forebay to an elevation 613 ft msl. In 2015, high-water events occurred during the late fall and early winter that resulted in the forebay elevation spiking during November (622 ft msl) and December (636 ft msl), respectively.

Similar, but less extreme, late fall fluctuations occurred in 2016. Extreme water fluctuation events during late fall and early winter were not observed in 2018 (Figure 3.1).

3.1.1.2 Forebay Temperature

Forebay temperature data were obtained from a temperature string that recorded hourly temperature data at depths ranging from 0.5–70 ft in 2015 and 2016, and 0.5–60 ft in 2018 (Figure 3.1). As expected, the times at which the reservoir began to warm and cool were similar between study years. However, the warm temperatures experienced during the summer months extended much deeper into the forebay water column in 2015 and 2018 (~60 ft and ~40 ft, respectively) compared to 2016 (~15 ft). Temperature data were unavailable after October 15 in 2016, but the available data suggest that the water column began to mix in October, which is the same pattern observed in 2015. The water column mixing observed in 2018 was similar to that of 2015.

3.1.2 Project Discharge and Operations

Foster is a re-regulating project for the upstream Green Peter Dam that provides hydropower and steady downstream flows. The USACE Water Management Reservoir Regulators control project discharge to maintain forebay pool elevations according to the Rule Curve. Figure 3.2 illustrates daily average discharge through each passage route at Foster during spring and fall 2015, 2016, and 2018 (averages calculated as a sum of all hourly discharges for a given day, divided by 24 hours using discharge data provided by the USACE). For 2015, project discharge hovered between 800–1,100 cfs for the majority of the study period, although high-water events in the fall and early winter resulted in discharge peaks in November and December. For 2016, project discharge was less than 3,000 cfs for the majority of the study period; however, high-water events increased discharge by mid-October and remained high through December. In spring 2018, total discharge through the project had a daily average of 1,800 cfs; however, there was a peak daily average discharge of 6,400 cfs in mid-April released through Spill Bays 1–3. This was similar in fall 2018 with a daily average project discharge of 2,200 cfs and a peak daily average discharge of 3,700 cfs through Spill Bays 1–3 in mid-January. Discharge through the spillway and turbines fluctuated as a result of the pseudo-randomized block design; daily average project discharge fluctuations are shown in Figure 3.2. In spring 2018, daily average weir discharge ranged from 454–685 cfs (mean: 544 cfs). During fall 2018, daily average weir discharge ranged from 278–470 cfs (mean: 355 cfs).

3.1.2.1 Dam Operations

Turbine operations vary throughout the year depending on power demand and maintenance schedules. In general, Turbine Unit 1, which is the priority unit because it provides station service, is operated more frequently than Turbine Unit 2. December 2016 was unique in that both units were operational for the entire month because of high-water events that occurred in late fall and early winter. Similarly, starting in mid-December through the end of January 2018, both units were operational. Of the spill options, Spill Bay 3 and the fish weir in Spill Bay 4 were operated most frequently in the spring for all study years. Spill Bay 2 was not used in the spring but was used frequently in the fall for all study years. Spill Bay 1 was operated only during a few days in the spring in 2018 and in the fall in 2015 and 2016. Generally speaking, when the “spillway” is cited in reference to fish passage and survival in this report, it is understood that this is in primary reference to Spill Bay 3, because Spill Bays 1 and 2 were operated relatively infrequently throughout the period of performance.

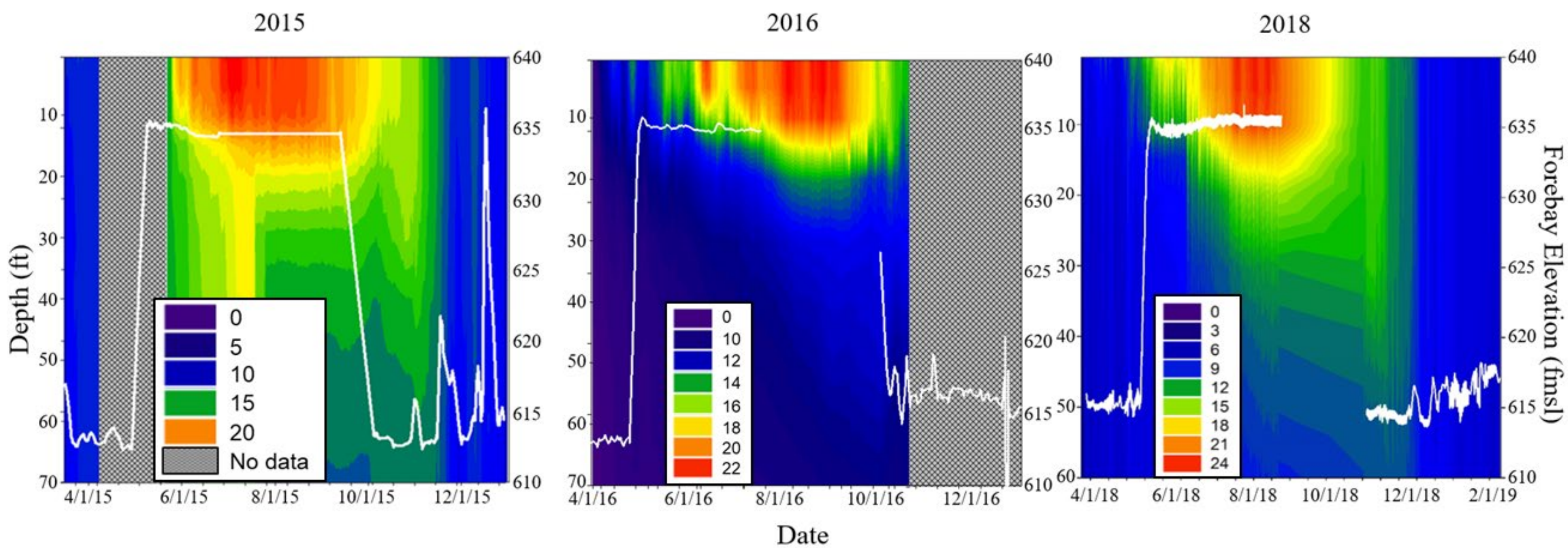

Figure 3.1. Comparison of Daily Average Forebay Elevation (solid white line; right axis) and Temperature (°C) at Depth (contour plot; left axis; 0–70 ft for 2015 and 2016, 0–60 ft for 2018) in the Forebay at Foster for the 2015 (left), 2016 (center), and 2018 (right) Study Periods. Daily forebay elevation data were unavailable from July–September for 2015 and 2016, and from August–October for 2018, but graphics provided by the USACE confirmed that forebay elevation remained at or near 635 ft msl for that period. Hash-mark fill in 2015 and 2016 indicates periods of time during which no data were available from the USACE temperature string.

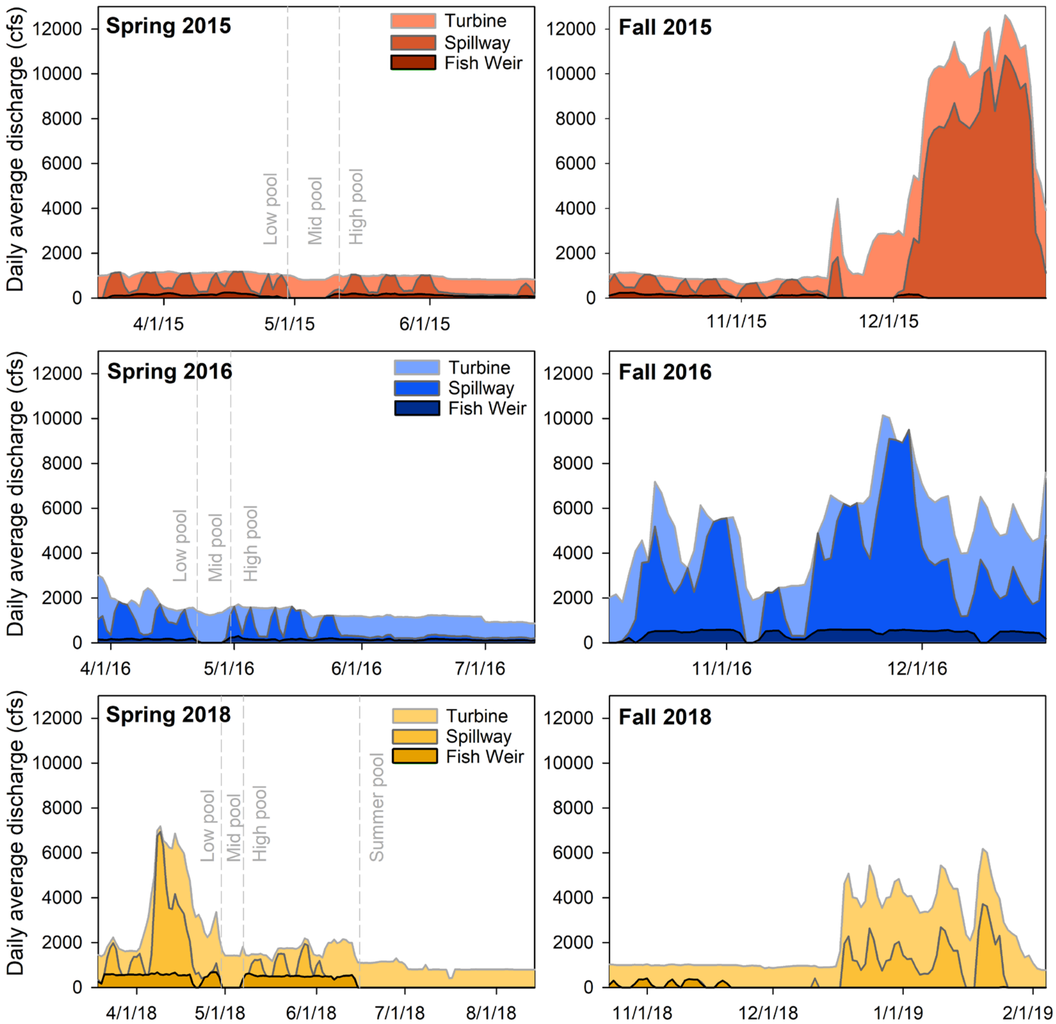

Figure 3.2. Daily Average Project Discharge (cfs) for Spring and Fall Study Periods in 2015, 2016, and 2018. Dotted lines represent transitions between pool stages.

3.2 Tag Life

In 2015, RT tag life was evaluated by randomly sampling tags from three production lots (two from the spring study period [n = 14 and 16] and one from the fall study period [n = 30]) and monitoring those tags continuously until they failed to transmit signals. Results indicated the mean tag life was 40.0 d and 38.4 d for tags used in the spring and fall study periods, respectively. Tag life was evaluated in 2016 by randomly sampling 50 tags from two production lots (n = 25 from spring and n = 25 from fall) and monitoring those tags continuously until they failed to transmit signals. Results were similar to those in 2015 and indicated the mean tag life was 39.8 ± 0.9 d (mean ± SE) and 40.2 ± 0.5 d for tags used in the spring and fall study periods, respectively. In 2018, tag life was evaluated by randomly sampling 120 tags from two production lots (n = 60 from spring and n = 60 from fall) and monitoring those tags continuously until they failed to transmit signals. Results indicated the mean tag life was 51.4 ± 0.6 d and 47.6 ± 0.4 d for tags used in the spring and fall study periods, respectively. Tag life was longer in 2018 than in 2015 and 2016 due to an updated RT tag design of the Lotek NanoTag model NTC-M-2.

4.0 Results – Yearling Chinook Salmon

This section contains estimates of survival, passage distributions, project metrics, travel times, and results from the spill vs. turbine treatment for CH1 at Foster in 2015, 2016, and 2018. Appendices A through F provide additional information: general statistics tables for tagging and releases (Appendix A), spill vs. turbine treatment schedules (Appendix B), supplementary tables for survival estimates and passage proportions (Appendix D), capture histories of study fish (Appendix E), and fish approach vs. route of passage (Appendix F).

4.1 Dam-Passage Survival

For low pool (March–April; 613 ft msl), a total of 505, 367, and 330 CH1 were released into Foster reservoir in 2015, 2016, and 2018, respectively. All Chinook salmon detected at the Foster dam-face array (i.e., were available to pass Foster) were regrouped to form a single virtual-release group (V_1) for each passage pool stage. At low pool, the survival of V_1 fish through the dam and 19 rkm of tailwaters (i.e., Foster-to-Primary Array or CJS; S_1) was not statistically different between 2015, 2016, or 2018 (Figure 4.1, Table 4.1). Compared to the CJS estimate, the ViRDCt survival estimate (i.e., Foster-to-Egress Array; S_D) of V_1 fish through the dam and 2.5 rkm of tailwaters in 2018 was higher (S_D = 0.867), providing a more representative estimate of immediate dam-passage survival.

For high pool (May–June; 635 ft msl), a total of 189 CH1 were released into Foster reservoir in 2015, 372 were released in 2016, and 375 were released in 2018. Again, all fish detected at the Foster dam-face array (i.e., were available to pass Foster) were regrouped to form V_1. The Foster-to-Primary Array survival estimate was significantly lower in 2018 than in either 2015 or 2016 (Figure 4.1, Table 4.1).

Table 4.1. Survival Probability Estimates for CH1 Released in the Foster Reservoir in Spring 2015, 2016, and 2018 at Low (March–April) and High (May–June) Pool Elevations. Survival was estimated from Foster passage to the Primary Array, located ~19 rkm downstream, using the CJS model (2015, 2016, and 2018) and from Foster passage to the Egress Array, located ~2.5 rkm downstream, using the ViRDCt model (2018 only).

	Foster-to-Primary Array						Foster-to-Egress Array	
	2015		2016		2018		2018	
Pool Elevation	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_D (SE)**
Low Pool (613 ft msl)	457	0.627 (0.026)	273	0.617 (0.030)	267	0.611 (0.030)	267	0.867 (0.039)
High Pool (635 ft msl)	107	0.758 (0.043)[a]	202	0.844 (0.026)[a]	301	0.646 (0.028)[b]	301	0.809 (0.034)

n = number of fish that passed Foster per pool elevation by year.
Superscript letters (located after the survival estimate) that are different going across a row indicate a significant difference in survival. If no letters are present, there were no significant differences in survival. ViRDCt estimates of Foster-to- Egress Array survival were not included in the cross-year analysis.

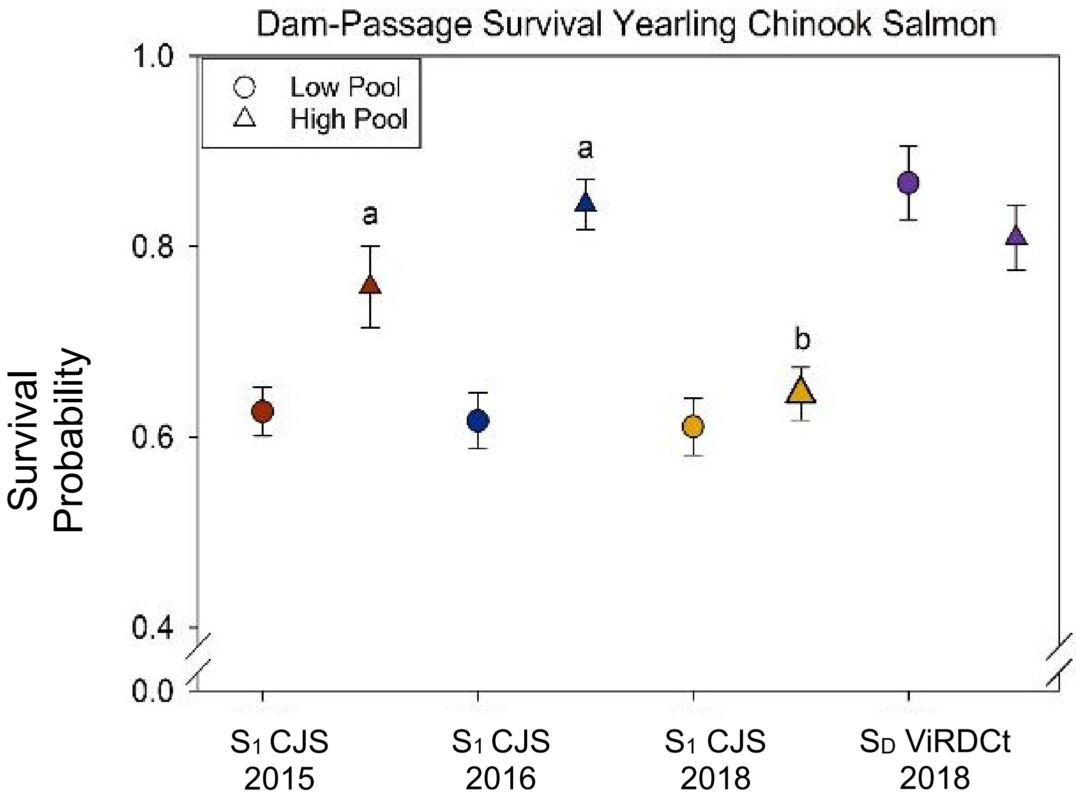

Figure 4.1. Single Release Dam-Passage Survival Estimates of CH1 Released during Spring. Circles represent fish released during Low Pool (March–April) and triangles represent fish released during High Pool (May–June) Elevations. Foster to Primary Array (S_1) CJS survival estimates for 2015 (red), 2016 (blue), and 2018 (yellow) could be compared statistically, whereas ViRDCt estimates (S_D; 2018 only, purple) are stand-alone. Letters above survival estimates (by pool) represent statically significant differences (i.e., 'a' is a higher estimate than 'b'; dam-passage survival in 2018 during high pool was lower than both 2015 and 2016). No letters above survival estimates indicate no significant differences. Table 4.1 and Appendix D contain all dam-passage survival estimates.

4.2 Route-Specific Survival

Route-specific survival estimates for CH1 are presented in Table 4.2 (all years, CJS estimates) and Table 4.3 (2018, CJS, and ViRDCt estimates), Figure 4.2 (low pool, all years, and estimates), Figure 4.3 (high pool, all years, and estimates), and in Appendix D. There were no statistically significant differences in survival for any single route between 2015, 2016, and 2018 (Figure 4.2). At spring low pool in 2015 and 2018, survival to the Primary Array was highest for CH1 that passed Foster through Spill Bay 3, ($S_1 = 0.714$, and $S_1 = 0.715$, respectively, Table 4.2). CH1 that passed through Spill Bay 3 in 2016 had estimated survival probability to the Primary Array of $S_1 = 0.651$. During spring 2016 low pool, CH1 that passed through the fish weir had higher survival to the Primary Array compared to 2015 and 2018 ($S_1 = 0.778$, $S_1 = 0.636$, and $S_1 = 0.613$, respectively). No fish passed through Spill Bays 1 or 2 during low pool in 2015, 2016, or 2018. Survival of CH1 that passed through turbines during low pool was similar between years. CH1 that passed through Turbine Unit 1 during spring 2015 low pool had an estimated survival probability of $S_1 = 0.487$ (Table 4.2) to the Primary Array (no fish passed through Turbine Unit 2 in 2015). In 2016, CH1 survival through Turbine Units 1–2 to the Primary Array was

$S_1 = 0.550$. In 2018, CH1 that passed through Turbine Units 1–2 during spring low pool had an estimated survival probability of $S_1 = 0.488$. The ViRDCt estimates were higher than CJS estimates, providing a more representative estimate of immediate route-specific passage survival (Figure 4.2; Table 4.3, and in Appendix D).

Survival (S_1) for CH1 that passed via the fish weir during spring high pool differed significantly between study years. In 2016, survival was higher than in 2015 or 2018 ($S_1 = 0.809$, $S_1 = 0.467$, and $S_1 = 0.624$, respectively; Figure 4.3, Table 4.2, Appendix D. Survival was highest through Spill Bay 3 in 2015, 2016, and 2018 ($S_1 = 0.936$, $S_1 = 0.889$, and $S_1 = 0.941$, respectively), and was not statistically different among years. During high pool, no fish passed through Spill Bay 1 in 2015, 2016, nor 2018, and only 21 fish passed through Spill Bay 2 in 2018 ($S_1 = 0.762$). During high pool, few to no fish (≤ 2) passed through Turbine Units 1–2; therefore, survival could not be estimated. Again, ViRDCt estimates were higher than CJS estimates (Figure 4.3; Table 4.3, Appendix D).

Table 4.2. Estimated Route-Specific Survival for CH1 (Spring 2015, 2016, and 2018) Released in the Foster Reservoir at Low (March–April) and High (May–June) Pool Elevations. Survival was estimated from Foster passage to the Primary Array, located ~19 rkm downstream, using the CJS model.

	Foster-to-Primary Array											
	2015				2016				2018			
	Low Pool		High Pool		Low Pool		High Pool		Low Pool		High Pool	
Route	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**
Turbine Unit 1	149	0.487 (0.044)	2	*	51	0.529 (0.070)	8	*	25	0.480 (0.100)	–	–
Turbine Unit 2	–	–	–	–	49	0.571 (0.071)	3	*	17	0.529 (0.121)	1	*
Fish Weir	78	0.636 (0.069)	39	0.467 (0.081)[b]	12	0.778 (0.134)	72	0.809 (0.049)[a]	150	0.613 (0.040)	252	0.624 (0.031)[b]
Spill Bay 3	230	0.714 (0.034)	66	0.936 (0.034)	157	0.651 (0.038)	116	0.889 (0.029)	70	0.715 (0.054)	17	0.941 (0.057)
Spill Bay 2	–	–	–	–	–	–	–	–	–	–	21	0.762 (0.093)

n = number of fish that passed Foster per route by pool elevation and year.

* Indicates a small number of fish passed the route; therefore, a survival estimate was not calculated.

Different superscript letters (located after the survival estimate) indicate a significant difference in survival. If no letter is present, there was no significant difference in survival.

Table 4.3. Estimated Survival by Combined Routes for CH1 (Spring 2018) Released in the Foster Reservoir at Low (March–April) and High (May–June) Pool Elevations Comparing CJS Estimates to ViRDCt Estimates. Survival was estimated from Foster passage to the Primary Array, located ~19 rkm downstream, using the CJS model and from Foster passage to the Egress Array, located ~2.5 rkm downstream, using the ViRDCt model.

	Foster-to-Primary Array				Foster-to-Egress Array			
	2018				2018			
	Low Pool		High Pool		Low Pool		High Pool	
Route	***n***	**S_I (SE)**	***n***	**S_I (SE)**	***n***	**S_D (SE)**	***n***	**S_D (SE)**
Turbine Units 1–2	43	0.488 (0.076)	1	*	43	0.807 (0.103)	1	*
Fish Weir	150	0.613 (0.040)	252	0.624 (0.031)	150	0.915 (0.053)	252	0.795 (0.038)
Spill Bays 1–3	70	0.715 (0.054)	38	0.816 (0.063)	70	0.836 (0.056)	38	0.922 (0.061)

n = number of fish that passed Foster by route per pool elevation and survival array.
* Indicates a small number of fish passed the route; therefore, a survival estimate was not calculated.

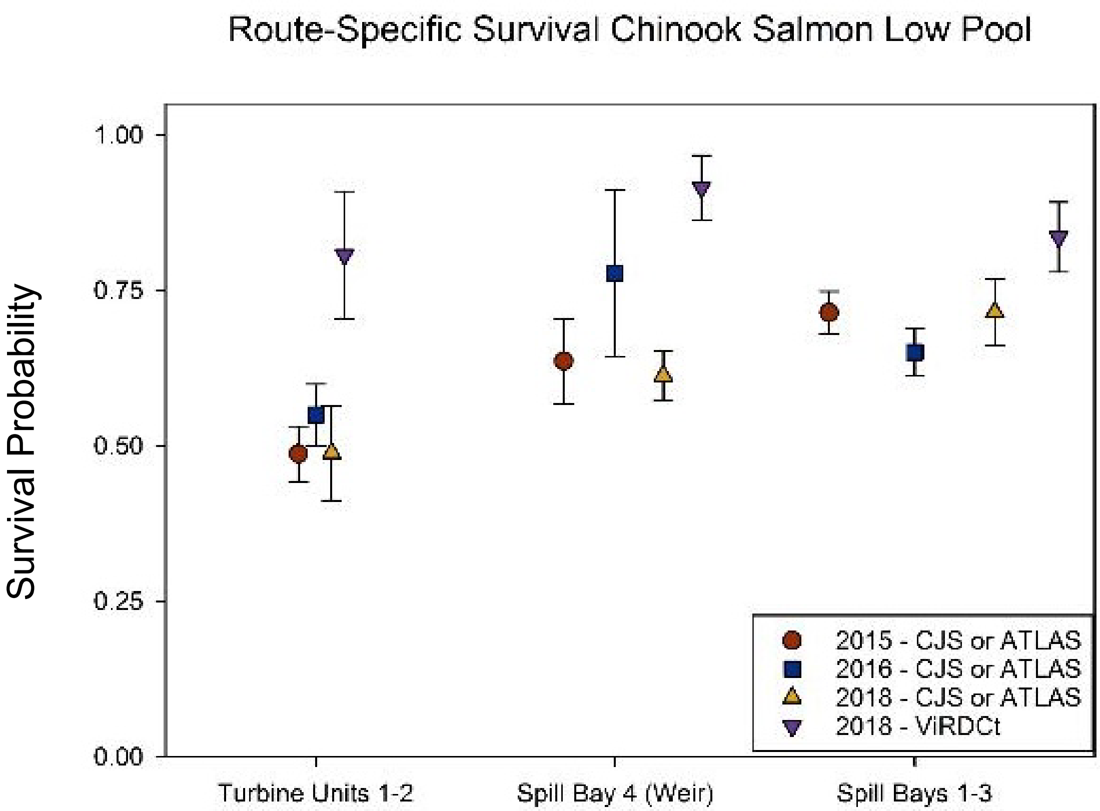

Figure 4.2. Estimated Survival by Combined Routes for CH1 (Spring 2015, 2016, and 2018) Released in the Foster Reservoir at Low Pool Elevation (March–April). Foster-to-Primary Array survival estimates for 2015 (red circle), 2016 (blue square), and 2018 (yellow triangle) could be compared statistically; Foster-to-Egress Array ViRDCt estimates (2018 only, purple inverse triangle) are stand-alone. Lack of letters above survival point estimates indicates no significant differences.

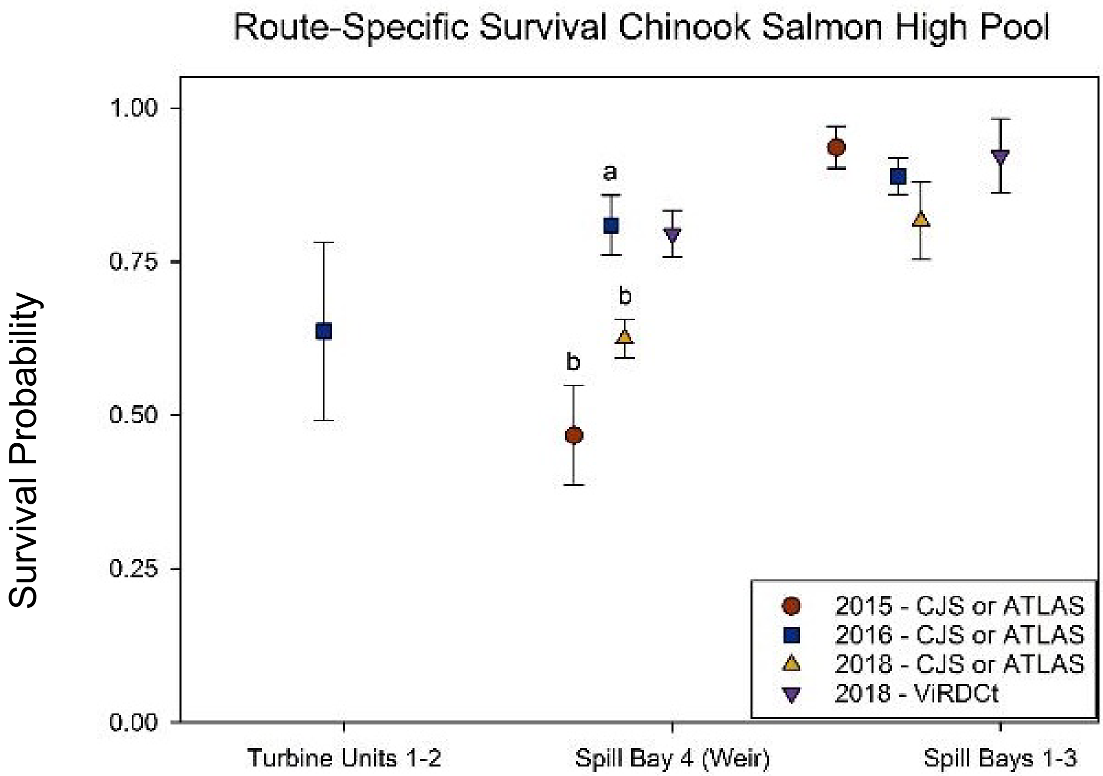

Figure 4.3. Estimated Survival by Combined Routes for CH1 (Spring 2015, 2016, and 2018) Released in the Foster Reservoir at High Pool Elevation (May–June). Foster-to-Primary Array survival estimates for 2015 (red circle), 2016 (blue square), and 2018 (yellow triangle) could be compared statistically; Foster-to-Egress Array ViRDCt estimates (2018 only, purple inverse triangle) are stand-alone. Letters above survival estimates (by route) represent statically significant differences (i.e., ‘a’ is a higher estimate than ‘b’; survival through Spill Bay 4 survival was higher in 2016 than 2015 and 2018, and 2015 and 2018 were not different).

Survival estimates based on weir discharge during spring low pool at low weir discharge (< 500 cfs) and high weir discharge (≥ 500 cfs) were also compared for CH1. There did not appear to be an effect on survival caused by weir discharge, as survival estimates were not significantly different (Figure 4.4; Appendix D, Table D.1).

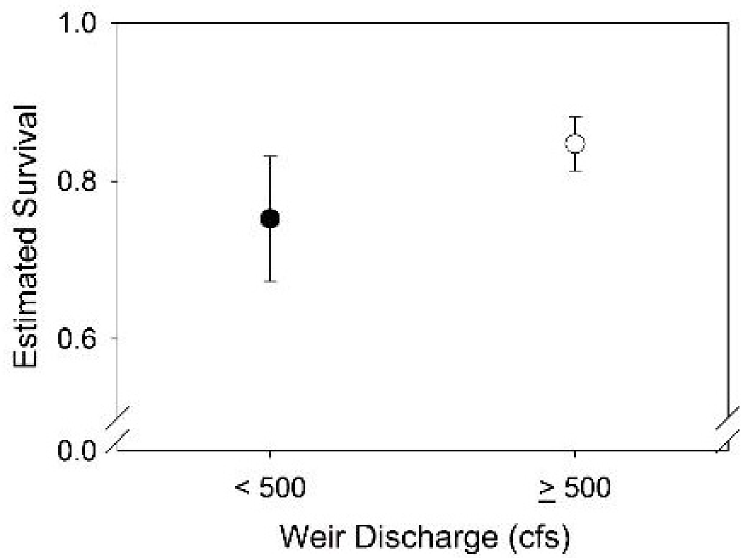

Figure 4.4. Estimated Survival for CH1 at Low (< 500 cfs; black circle) and High (≥ 500 cfs; white circle) Weir Discharge in Spring 2018 at Foster using Foster-to-Egress Array ViRDCt Estimates (Appendix D, Table D.1).

4.3 Passage Distributions

4.3.1 Spring Low Pool

In contrast to previous study years with the old weir, the greatest percentage of CH1 passed through the new weir during the spring 2018 low pool study period. More than 57% of CH1 passing the dam used the weir in 2018, compared to 17.1% in 2015 and just 4.5% in 2016 (Figure 4.5; Appendix D, Table D.2). Furthermore, whereas more than 30% of CH1 passed through the turbines in spring 2015 and 2016, only 16.4% of CH1 used this route in 2018 (Appendix D, Table D.2). The percentage of CH1 passing Spill Bay 3 also decreased by about half, from over 50% to 26.7%. The proportions of fish passing through turbine, weir, and non-weir routes differed significantly between all study years (Fisher's exact test, $p < 0.001$ for all pairwise comparisons; Appendix D, Table D.3 and Table D.4).

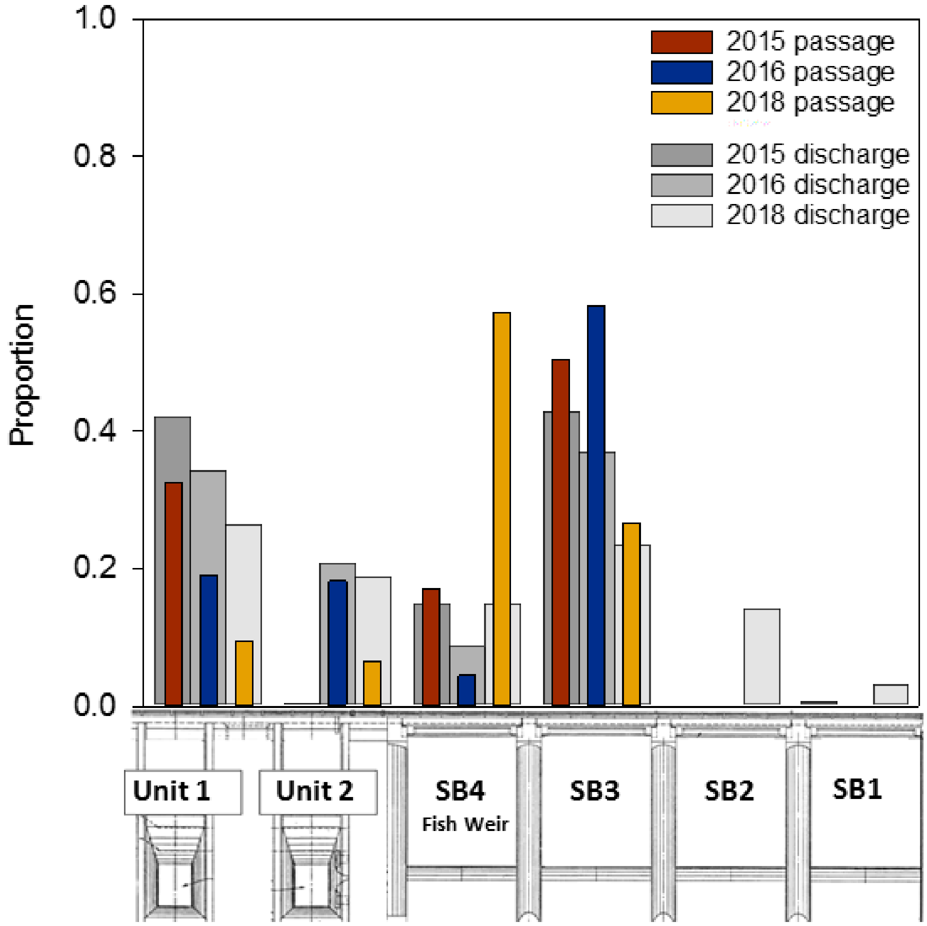

Figure 4.5. Passage Distributions of CH1 at Foster in Spring 2015 (red), 2016 (blue), and 2018 (yellow) during Low Pool Elevation. The gray vertical bars indicate water discharge proportions by route, per year (Appendix D, Table D.2).

As in previous years, estimates of the overall number of fish that passed during the day vs. night indicate that nearly all of the CH1 that passed Foster during the 2018 spring low pool study did so during the night (97%; Table 4.4). As previously, the propensity towards nighttime passage did not differ between specific routes of passage.

Table 4.4. Day vs. Night Passage Distributions of CH1 Released above Foster that Passed the Dam during Low Pool in Spring 2015, 2016, and 2018

	2015				2016				2018			
Spring Low Pool	**Day**		**Night**		**Day**		**Night**		**Day**		**Night**	
Location	***n***	**Prop.**	***n***	**Prop.**	***n***	**Prop.**	***n***	**Prop.**	***n***	**Prop.**	***n***	**Prop.**
Overall	10	0.02	447	**0.97**	7	0.03	262	**0.97**	8	0.031	254	**0.97**
Turbine Unit 1	4	0.03	145	**0.97**	1	0.02	50	**0.98**	1	0.040	24	**0.96**
Turbine Unit 2	–	–	–	**–**	–	–	49	**1.00**	1	0.059	16	**0.94**
Fish Weir	2	0.03	76	**0.97**	0	0.00	12	**1.00**	3	0.020	147	**0.98**
Spill Bay 3	4	0.02	226	**0.98**	6	0.04	151	**0.96**	3	0.043	67	**0.96**

n = number of fish that passed Foster by route per diel period and year.
Prop. = proportion that passed Foster by route per diel period and year.

4.3.2 Spring High Pool

The increase in the proportion of CH1 passing the weir in 2018 compared to previous years was more pronounced at spring high pool than at spring low pool. In 2015 and 2016, approximately 35% of CH1 passed through the old weir at high pool, whereas more than half of the fish passed through Spill Bay 3 (Figure 4.6; Appendix D, Table D.5). In 2018, 86.6% of CH1 passing the dam at high pool passed through the new weir, and the percentage of fish passing through non-weir spill routes was 0.3% (Appendix D, Table D.5). The proportions of fish passing through turbine, weir, and non-weir routes did not differ significantly from 2015 to 2016 (Fisher's exact test, $p = 0.241$; Appendix D, Table D.3 and Table D.4), but the pooled passage proportions from old weir (years 2015 and 2016) were significantly different from the new weir design proportions in 2018 (Fisher's exact test, $p < 0.001$; Appendix D, Table D.3 and Table D.4).

Estimates of the overall number of fish that passed during the day versus during the night indicated that the majority of CH1 passing the dam during spring high pool in 2018 did so at night (77%; Table 4.5). As in 2015 and 2016, the proportion of fish passing at night vs. during the day did not vary greatly depending on route of passage. Daytime passage was slightly more common than in previous years (22.7% in 2018 compared to 11.9% in 2015 and 14.2% in 2016).

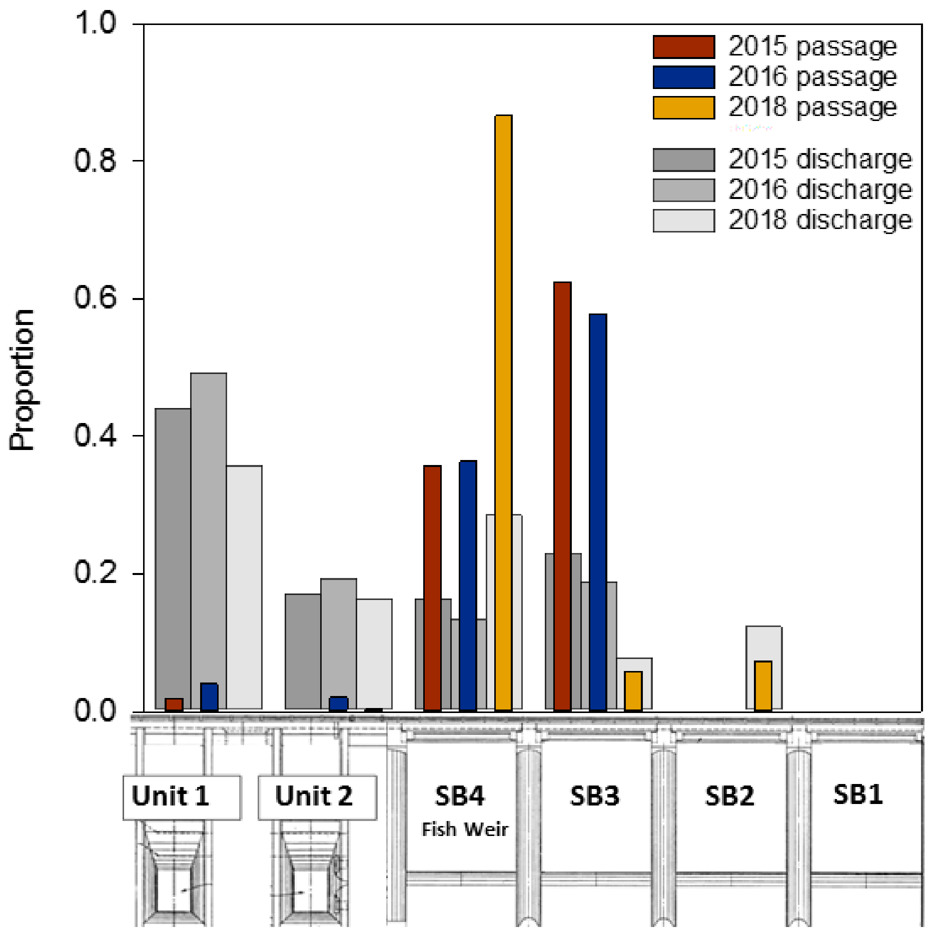

Figure 4.6. Passage Distributions of CH1 at Foster in Spring 2015 (red), 2016 (blue), and 2018 (yellow) during High Pool Elevation. The gray vertical bars indicate water discharge proportions by route, per year (Appendix D, Table D.5).

Table 4.5. Day vs. Night Passage Distributions of CH1 Released above Foster that Passed the Dam during High Pool in Spring 2015, 2016, and 2018

	2015				2016				2018			
Spring High Pool	**Day**		**Night**		**Day**		**Night**		**Day**		**Night**	
Location	***n***	**Prop.**	***n***	**Prop.**	***n***	**Prop.**	***n***	**Prop.**	***n***	**Prop.**	***n***	**Prop.**
Overall	13	0.12	96	**0.88**	29	0.14	175	**0.86**	66	0.23	225	**0.77**
Turbine Unit 1	1	0.50	1	**0.50**	1	0.13	7	**0.88**	–	–	–	**–**
Turbine Unit 2	–	–	–	**–**	–	–	4	**1.00**	0	0	1	**1.00**
Fish Weir	10	0.26	29	**0.74**	6	0.08	67	**0.92**	56	0.22	196	**0.78**
Spill Bay 3	2	0.03	66	**0.97**	21	0.18	95	**0.82**	5	0.29	12	**0.71**
Spill Bay 2	–	–	–	**–**	–	–	–	**–**	5	0.24	16	**0.76**

n = number of fish that passed Foster by route per diel period and year.
Prop. = proportion that passed Foster by route per diel period and year.

4.4 Project Passage Metrics

Low pool DPE was exceedingly high for CH1 in 2015 and 2016 (DPE > 0.952; Table 4.6). DPE fell slightly in 2018 (DPE = 0.900 ± 0.018); however, the majority of CH1 reaching the near forebay still ultimately passed the dam (Table 4.6; Figure 4.7). Despite this small decrease in overall passage efficiency, the decrease in the proportion of fish passing the turbines resulted in higher FPE (0.756) than in previous years. Additionally, SPE demonstrated a significant increase of more than 20% between pooled old weir evaluation study years (2015 and 2016) and 2018 (Fisher's exact test, $p < 0.001$; Figure 4.8). FWE differed significantly between all study years (Fisher's exact test, $p < 0.001$ for all pairwise comparisons). Whereas FWE was very low in previous years (0.171 in 2015 and 0.045 in 2016), in 2018, it increased more than threefold to 0.570 in 2018. In 2018, SBE decreased by about half, as more fish passed through the weir (Fisher's exact test, $p < 0.001$; Table 4.6). As proportional discharge by route did not vary greatly between years, all increased passage efficiencies in 2018 resulted in corresponding increased passage effectiveness as well. The effectiveness of the new weir was more than three times greater than in previous years (old weir).

In 2018, at high pool, both DPE and FPE increased approximately 25–35% compared to previous years (Table 4.6; Figure 4.7). More CH1 reached the near forebay and passed the dam than previously, and they did so using the new weir. SPE remained extremely high (SPE ≥ 0.940 for all study years; Figure 4.8), indicating that nearly all tagged CH1 passed Foster through non-turbine passage routes. SPE was significantly higher in 2018 compared to pooled 2015 and 2016 study years (Fisher's exact test, $p < 0.001$). FWE also increased significantly (Fisher's exact test, $p < 0.001$ for 2018 compared to pooled 2015 and 2016) and was more than two times greater in 2018 compared to past years. In 2018, SBE decreased steeply, owing to the increase in proportion of fish passing through the weir (Table 4.6). As in low pool, increased FWE in 2018 resulted in corresponding increased fish weir effectiveness as well, although the difference was much smaller than at low pool.

For both high and low pool study periods, efficiency and effectiveness of the new fish weir did not depend strongly on the weir discharge (Table 4.7).

Table 4.6. Passage Efficiencies and Effectiveness for CH1 at Foster in Spring 2015, 2016, and 2018. Dam Passage Efficiency (DPE) and Fish Passage Efficiency (FPE) are calculated relative to the number of fish detected in the near forebay, while all other efficiency metrics are relative to the total number of fish that passed the dam (as indicated by "‖ Dam").

	CH1					
	2015		2016		2018	
Metric	**Low Pool**	**High Pool**	**Low Pool**	**High Pool**	**Low Pool**	**High Pool**
DPE	**0.952 (0.007)**	**0.663 (0.028)**	**0.955 (0.009)**	**0.680 (0.021)**	**0.900 (0.018)**	**0.853 (0.019)**
FPE	**0.642 (0.017)**	**0.645 (0.029)**	**0.589 (0.023)**	**0.630 (0.022)**	**0.756 (0.025)**	**0.850 (0.019)**
SPE ‖ Dam	0.674 (0.022)$^{\mathbf{b}}$	0.982 (0.013)$^{\mathbf{B}}$	0.628 (0.030)$^{\mathbf{b}}$	0.940 (0.017)$^{\mathbf{B}}$	0.837 (0.023)$^{\mathbf{a}}$	0.997 (0.003)$^{\mathbf{A}}$
FWE ‖ Dam	0.171 (0.018)$^{\mathbf{b}}$	0.358 (0.046)$^{\mathbf{B}}$	0.045 (0.013)$^{\mathbf{c}}$	0.363 (0.034)$^{\mathbf{B}}$	0.570 (0.031)$^{\mathbf{a}}$	0.866 (0.020)$^{\mathbf{A}}$
SBE ‖ Dam	0.503 (0.023)$^{\mathbf{a}}$	0.624 (0.046)$^{\mathbf{A}}$	0.584 (0.030)$^{\mathbf{a}}$	0.577 (0.035)$^{\mathbf{A}}$	0.266 (0.027)$^{\mathbf{b}}$	0.131 (0.020)$^{\mathbf{B}}$
Fish Weir Effect.	1.166 (0.120)	2.209 (0.283)	0.490 (0.138)	2.746 (0.256)	3.880 (0.208)	3.054 (0.070)
Spill Bay Effect.	1.119 (0.052)	2.708 (0.201)	1.444 (0.074)	3.066 (0.185)	0.658 (0.067)	0.658 (0.100)
Spillway Effect.	1.131 (0.037)	2.502 (0.033)	1.269 (0.060)	2.934 (0.052)	1.517 (0.041)	2.068 (0.007)

DPE = dam-passage efficiency; proportion of fish passing the dam relative to the number detected in the near forebay (< 100 m from dam-face).
FPE = fish passage efficiency; proportion of fish passing via a non-turbine route relative to the number detected in the near forebay (< 100 m from dam-face).
SPE = spill passage efficiency; proportion of fish that passed Foster through Spill Bays 1–3 and the fish weir in Spill Bay 4.
SBE = spill bay efficiency; proportion of fish that passed Foster through Spill Bays 1–3.
FWE = fish weir efficiency; proportion of fish that passed Foster over the fish weir in Spill Bay 4.
Fish weir/spill bay/spillway effectiveness = proportion of fish passage through a route relative to the proportion of discharge through the same route.
Shared superscript letters for SPE and FWE indicate no significant differences between estimates, whereas different superscript letters indicate significant differences. Lower-case letters refer to low pool comparisons and upper-case letters refer to high pool comparisons. Absence of superscript letters indicates there were no significant differences.

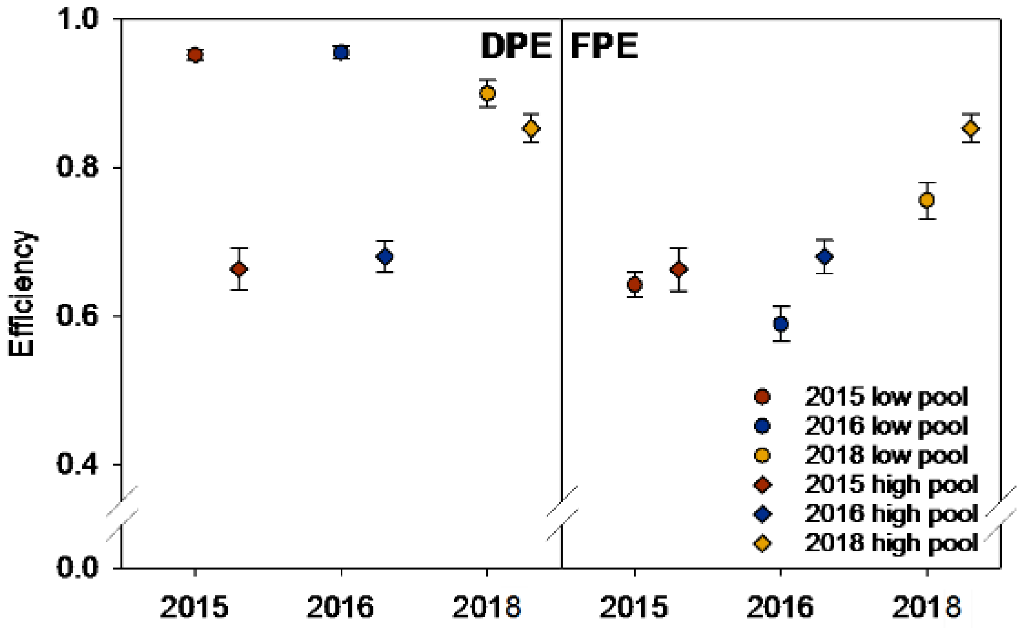

Figure 4.7. Dam-Passage Efficiency (DPE) and Fish Passage Efficiency (FPE) of CH1 at Foster in Spring 2015 (red), 2016 (blue), and 2018 (yellow). Circles represent low pool estimates; diamonds represent high pool estimates.

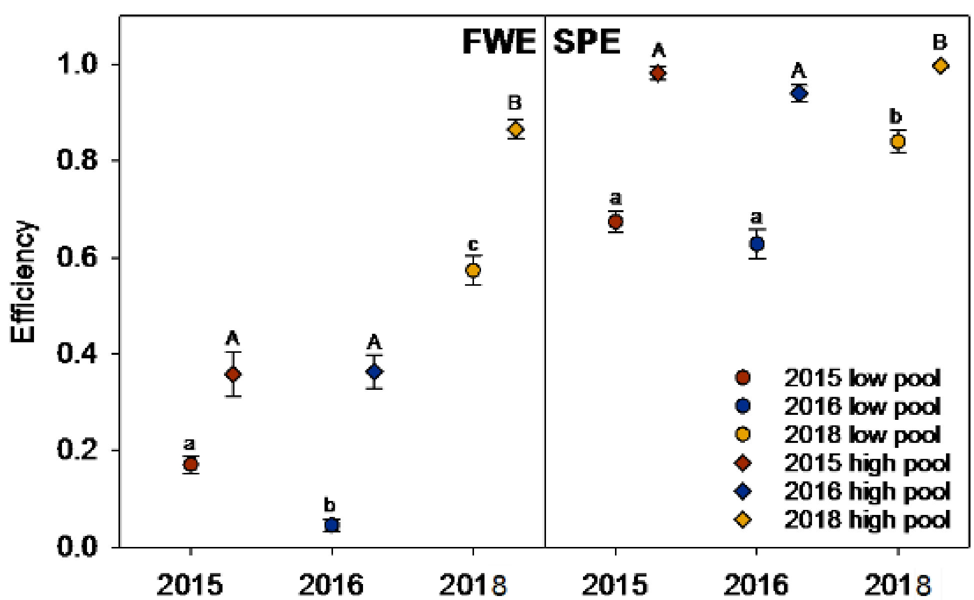

Figure 4.8. Fish Weir Efficiency (FWE) and Spill Passage Efficiency (SPE) of CH1 at Foster in Spring 2015 (red), 2016 (blue), and 2018 (yellow). Shared letter labels indicate no significant difference between estimates; different letters indicate significant differences (Fisher's exact test, $\alpha = 0.05$). Low pool estimates are represented by circles and lower-case letters; high pool estimates are represented by diamonds and upper-case letters.

Table 4.7. Fish Weir Efficiency (FWE) and Effectiveness for CH1 that Passed Foster at Low (< 500 cfs) and High (≥ 500 cfs) Weir Discharge, in Spring 2018

Pool Stage	Weir Discharge	*n*	FWE	Effectiveness
Low	< 500 cfs	2	–	–
	≥ 500 cfs	260	0.569 (0.031)	3.534 (0.191)
High	< 500 cfs	80	0.725 (0.050)	2.722 (0.187)
	≥ 500 cfs	211	0.919 (0.019)	2.886 (0.059)

n = number of fish that passed Foster by pool stage and weir discharge level.

4.5 Travel Times

Reservoir residence time, project egress, and travel time to Lebanon Dam and Willamette Falls for 2015, 2016, and 2018 are presented in Figure 4.9 and Figure 4.10 for CH1 at low and high pool, respectively. The Secondary Array is only 5 rkm above Lebanon Dam; as such the Secondary and Lebanon Dam arrays reflect similar travel times, and only the Secondary Array travel times are presented in Figure 4.9. At low pool, mean CH1 reservoir residence time did not vary substantially between 2015 (2.3 ± 0.2 d), 2016 (2.4 ± 0.1 d), and 2018 (1.7 ± 0.1 d; Figure 4.9). Although the median 2016 reservoir residence time was significantly different than that of other study years (Wilcoxon Signed-Rank Test, $p < 0.001$, Appendix D, Table D.6), the median difference of less than 4 hours is unlikely to be biologically relevant. Mean travel times between detection arrays were generally similar across all study years, with the exception of the travel time to Willamette Falls, which was more than twice as long in 2015 in comparison to subsequent years.

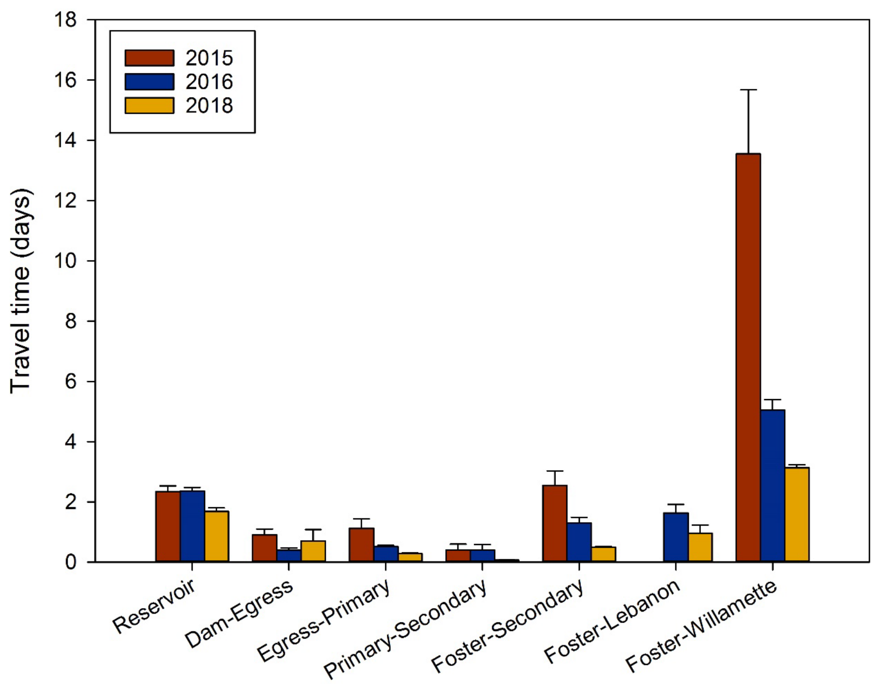

Figure 4.9. Estimated Mean Reservoir Residence Time, Project Egress, and Travel Times (days) between Arrays for CH1 in Spring 2015 (red), 2016 (blue), and 2018 (yellow) during Low Pool Elevation. The error bars depict the standard error of the mean.

At high pool, CH1 reservoir residence time was at least 50% less in 2018 (4.5 ± 0.2 d) compared to 2015 (9.0 ± 1.2 d) or 2016 (11.5 ± 0.6 d; Figure 4.10). Similar to low pool, median reservoir residence time in 2016 differed significantly from that of other years (Wilcoxon Signed-Rank Test, $p < 0.001$, Appendix D, Table D.6). Mean travel times between detection arrays were similar across study years. High pool travel times also resembled low pool travel times, except for travel time to Willamette Falls. In general, during both low and high pool, CH1 reached Lebanon Dam within 1–2 days of passing the dam and arrived at Willamette Falls within a couple weeks of dam passage.

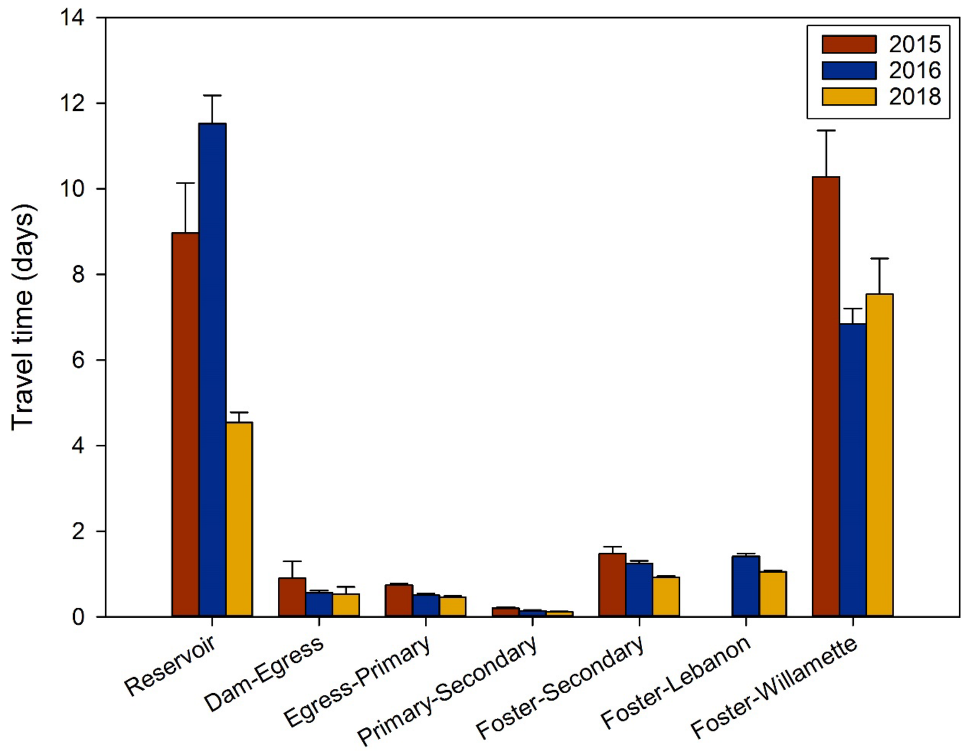

Figure 4.10. Estimated Mean Reservoir Residence Time, Project Egress, and Travel Times (days) between Arrays for CH1 in Spring 2015 (red), 2016 (blue), and 2018 (yellow) during High Pool Elevation. The error bars depict the standard error of the mean.

4.6 Spill vs. Turbine Block Treatment Test

At low pool, passage rates during the turbine+weir treatment indicated that 73% of all CH1 passing under these conditions did so via the weir, whereas 27% passed via the turbines (Table 4.8; Figure 4.11). For the spill+weir treatment, 55% of CH1 passed via the spillway. Passage was highly variable within treatments; however, and total passage was not found to differ significantly between treatments ($p = 0.46$; Table 4.9).

Table 4.8. Passage Estimates during the Low Pool Spill vs. Turbine Test for CH1 in 2015, 2016, and 2018. The fish weir, located in Spill Bay 4 was continuously operated during both treatments.

Spring Low Pool		CH1					
		2015		2016		2018	
Treatment	**Passage Route**	**Total Passage (*n*)**	**Passage Proportion**	**Total Passage (*n*)**	**Passage Proportion**	**Total Passage (*n*)**	**Passage Proportion**
turbine+weir	Turbine Units 1–2	82	0.53	89	0.95	33	0.27
	Weir	72	0.47	5	0.05	90	0.73
spill+weir	Spill Bays 1–3	174	0.97	109	0.98	63	0.55
	Weir	5	0.03	2	0.02	51	0.45
turbine+spill+weir	Turbine Units 1–2	–	–	11	0.16	–	–
	Spill Bays 1–3	–	–	46	0.69	–	–
	Weir	–	–	10	0.15	–	–

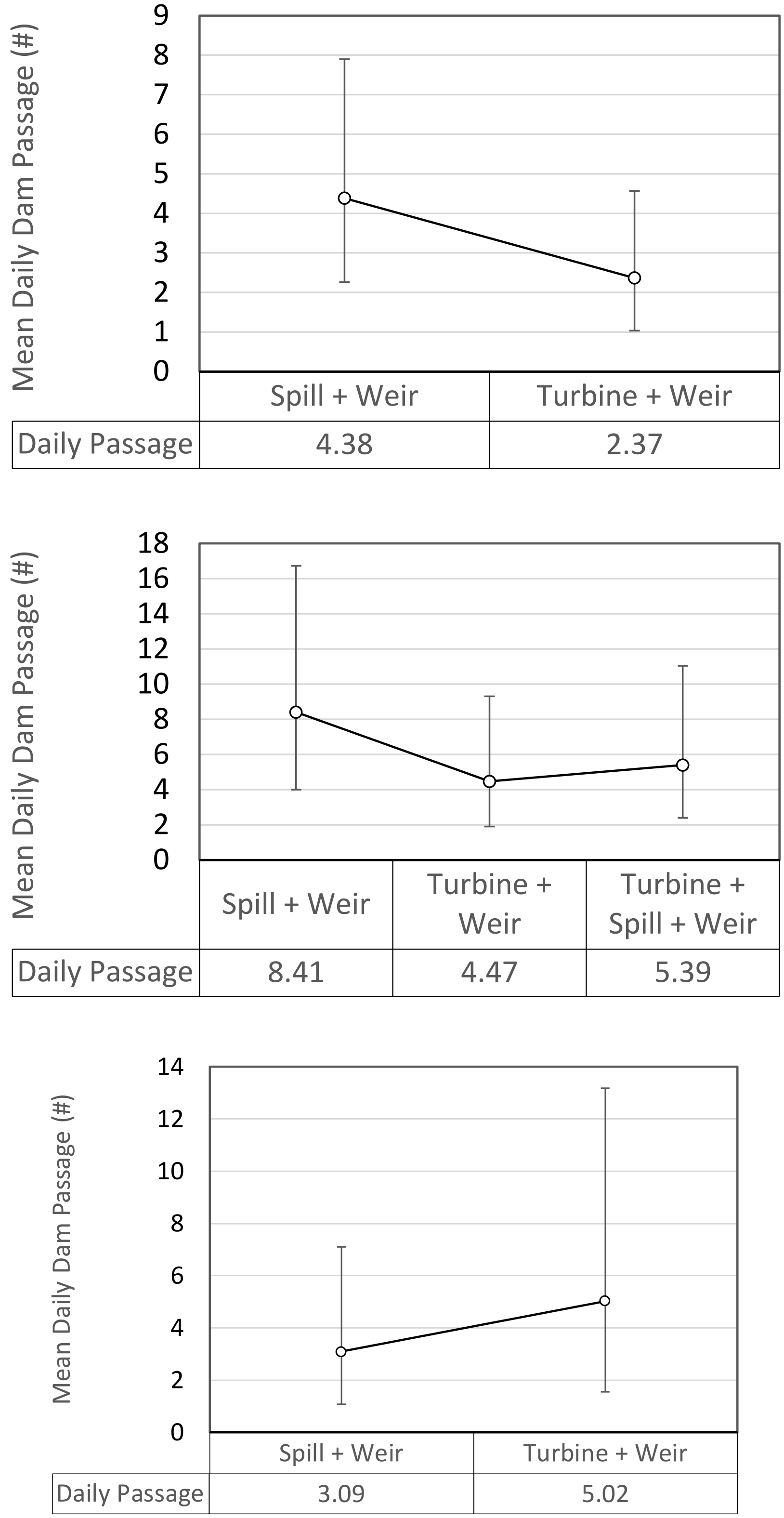

Figure 4.11. Mean Daily Dam Passage of CH1 by Treatment during Spring Low Pool in 2015 (top), 2016 (middle), and 2018 (bottom)

Table 4.9. Univariate ANOVA Results for CH1 during Spring Low Pool 2015, 2016, and 2018. A *p*-value < 0.05 indicates a significant difference.

Spring Low Pool	Effect	Degrees of Freedom	Sum of Squares	Mean Squares	F-Statistic	*p*-value
2015	Intercept	1	14.25	14.25	70.23	< 0.001
	Block	8	6.25	0.78	3.85	0.004
	Treatment	1	0.37	0.37	1.84	0.19
	Error	26	5.28	0.20		
2016	Intercept	1	16.90	16.90	123.20	< 0.001
	Block	3	3.14	1.05	7.63	0.002
	Treatment	2	0.24	0.12	0.86	0.44
	Error	18	2.47	0.14		
2018	Intercept	1	9.04	9.04	39.41	< 0.001
	Block	5	4.31	0.86	3.76	0.02
	Treatment	1	0.13	0.13	0.57	0.46
	Error	14	3.21	0.23		

At high pool, passage rates during the turbine+weir treatment indicated that 99% of all CH1 passing under these conditions did so via the weir, whereas 1% passed via the turbines (Table 4.10; Figure 4.12). For the spill+weir treatment, 19% of CH1 passed via the spillway. Total passage was found to differ significantly between treatments ($p = 0.002$, Table 4.11).

Table 4.10. Passage Estimates during High Pool Spill vs. Turbine Operations for CH1 in 2015, 2016, and 2018. The fish weir, located in Spill Bay 4, was continuously operated during both treatments.

Spring High Pool		CH1					
		2015		2016		2018	
Treatment	Passage Route	Total Passage (*n*)	Passage Proportion	Total Passage (*n*)	Passage Proportion	Total Passage (*n*)	Passage Proportion
turbine+weir	Turbine Units 1–2	1	0.06	5	0.18	1	0.01
	Weir	16	0.94	22	0.82	85	0.99
spill+weir	Spill Bays 1–3	66	0.77	116	0.75	38	0.19
	Weir	20	0.23	39	0.25	161	0.81

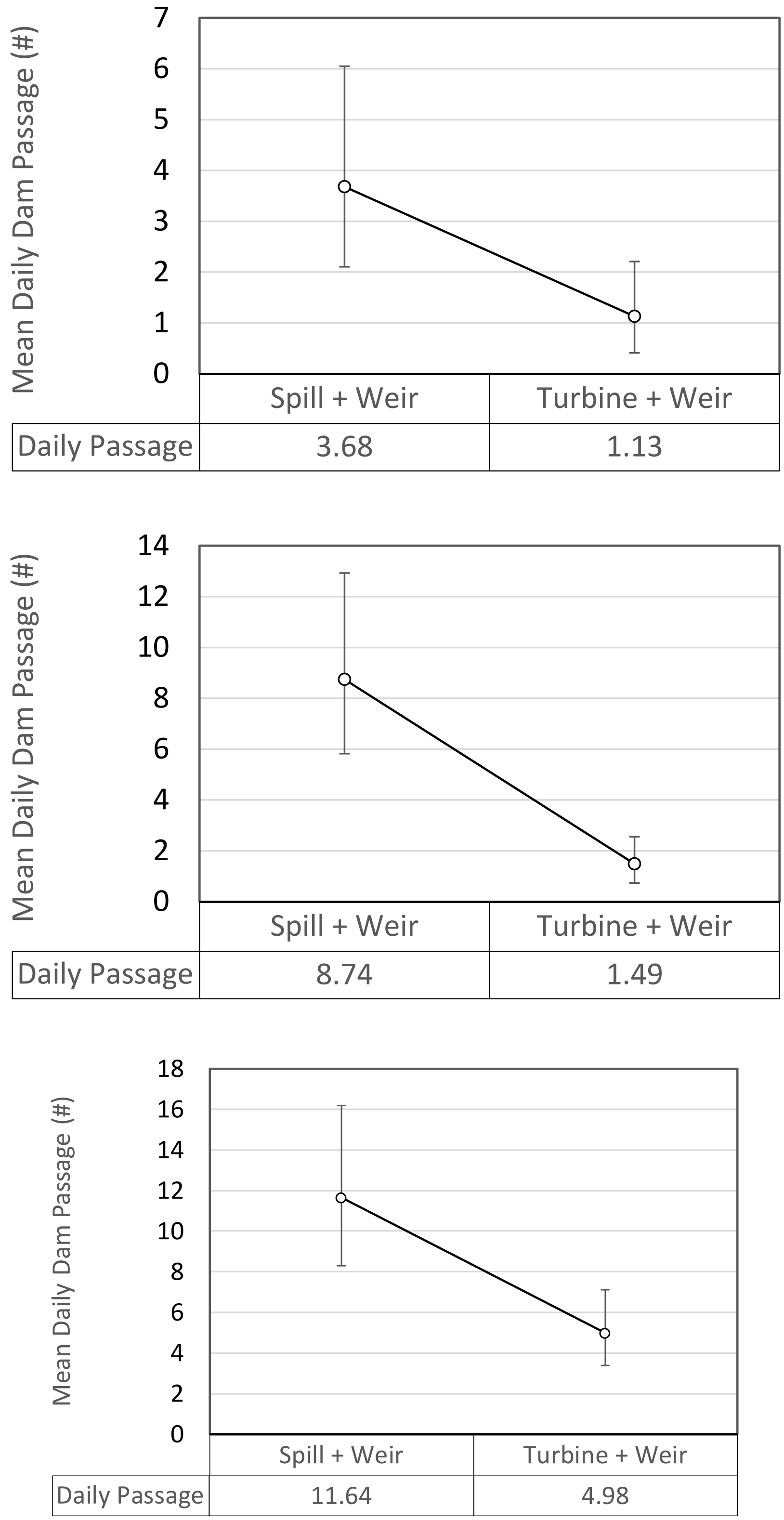

Figure 4.12. Total Passage of CH1 by Treatment during Spring High Pool in 2015 (top), 2016 (middle), and 2018 (bottom)

Table 4.11. Univariate ANOVA Results for CH1 during Spring High Pool 2015 and 2016. A *p*-value < 0.05 indicates a significant difference.

Spring High Pool	Effect	Degrees of Freedom	Sum of Squares	Mean Squares	F-Statistic	*p*-value
2015	Intercept	1	5.98	5.98	69.86	< 0.001
	Block	5	1.34	0.27	3.13	0.03
	Treatment	1	0.70	0.70	8.20	0.01
	Error	17	1.45	0.09		
2016	Intercept	1	13.41	13.41	173.44	< 0.001
	Block	6	0.69	0.12	1.49	0.23
	Treatment	1	2.46	2.46	31.84	< 0.001
	Error	20	1.55	0.08		
2018	Intercept	1	24.69	24.69	432.51	< 0.001
	Block	6	0.87	0.14	2.54	0.05
	Treatment	1	0.74	0.74	12.98	0.002
	Error	20	1.14	0.06		

5.0 Results – Steelhead

This section contains estimates of survival, passage distributions, project metrics, travel times, and results from the spill vs. turbine treatments for STH2 at Foster in 2015, 2016, and 2018, and S-STH in 2018. Appendices A through F provide additional information: general statistics tables for tagging and releases (Appendix A), spill vs. turbine treatment schedules (Appendix B), supplementary tables for survival estimates and passage proportions (Appendix D), capture histories of study fish (Appendix E), and fish approach vs. route of passage (Appendix F).

5.1 Dam-Passage Survival

For low pool (March–April; 613 ft msl), a total of 465, 344, and 623 STH2 were released in 2015, 2016, and 2018, respectively, at R_1 and R_2. In 2018 only, 191 S-STH were also released. Steelhead detected at the Foster dam-face array (i.e., available to pass Foster) were regrouped to form a virtual-release group (V_1). The Foster-to-Primary Array survival (S_1) for STH2 was not significantly different across study years (Figure 5.1). The Foster-to-Egress Array survival (S_D) in 2018 was $S_D = 0.734$ (Table 5.1, Appendix D). For S-STH in 2018, survival to the Primary Array was $S_1 = 0.466$ and the ViRDCt survival estimate was $S_D = 0.719$.

For high pool (May–June; 635 ft msl), a total of 306 STH2 were released in 2015, 438 were released in 2016, and 307 were released in 2018. In 2018 only, 451 S-STH were also released. Detected (i.e., available to pass the dam) fish were formed V_1. The Foster-to-Primary Array survival was not significantly different across study years for STH2 at high pool (Figure 5.1). The Foster-to-Egress Array ViRDCt survival was $S_D = 0.885$ (Table 5.1). For S-STH in 2018, survival to the Primary Array was $S_1 = 0.735$ and the ViRDCt survival estimate was $S_D = 0.830$ (Figure 5.1, Table 5.1, Appendix D).

Table 5.1. Survival Probability Estimates for STH2 (Spring 2015, 2016, and 2018) and S-STH (Spring 2018) Released in the Foster Reservoir at Low (March–April) and High (May–June) Pool Elevation. Survival was estimated from Foster passage to the Primary Array, located ~19 rkm downstream, using the CJS model (2015, 2016, and 2018) and from Foster passage to the Egress Array, located ~2.5 rkm downstream, using the ViRDCt model (2018 only).

	STH2								S-STH			
	Foster-to-Primary Array						Foster-to-Egress Array		Foster-to-Primary Array		Foster-to-Egress Array	
	2015		2016		2018		2018		2018		2018	
Pool Elevation	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_D (SE)**	***n***	**S_1 (SE)**	***n***	**S_D (SE)**
Low (613 ft msl)	108	0.614 (0.051)	73	0.470 (0.059)	229	0.546 (0.033)	229	0.734 (0.047)	61	0.466 (0.065)	61	0.719 (0.110)
High (635 ft msl)	150	0.715 (0.058)	147	0.808 (0.035)	110	0.787 (0.045)	110	0.885 (0.108)	192	0.735 (0.033)	192	0.830 (0.047)

n = number of fish that passed Foster by pool elevation per year, survival array, and species.

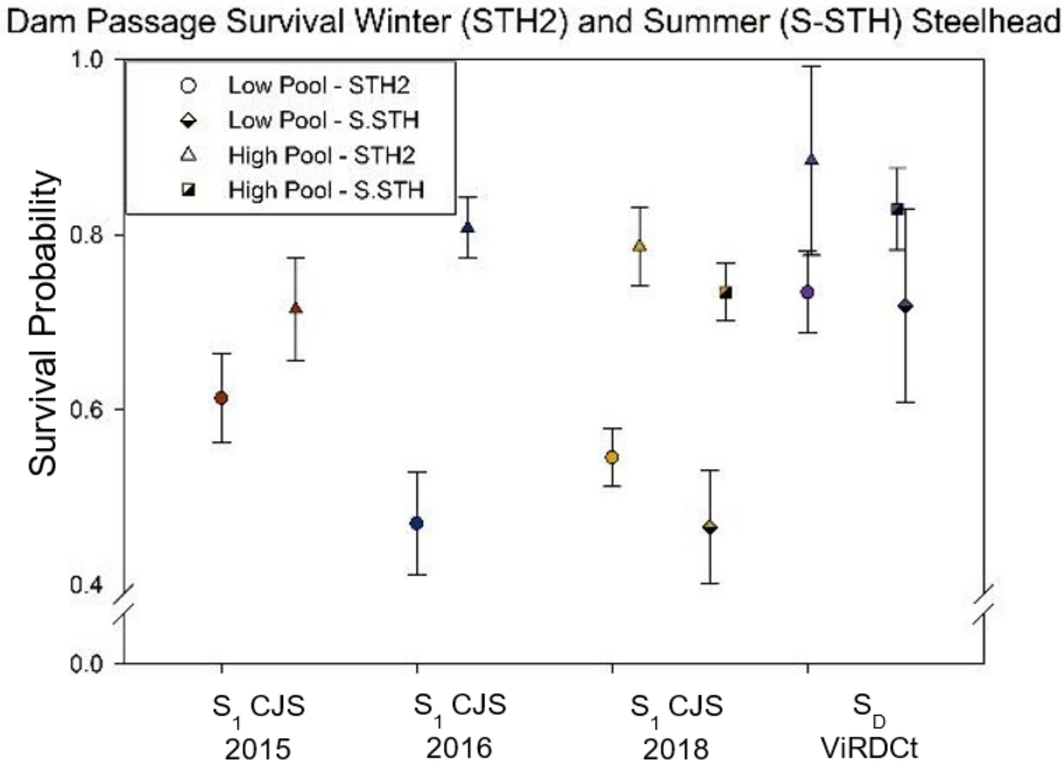

Figure 5.1. Single Release Dam-Passage Survival Estimates of STH2 and S-STH Released during Spring. Circles represent STH2 released during low pool (March–April); partially shaded diamonds represent S-STH. For high pool (May–June), triangles represent STH2; partially shaded squares represent S-STH. Foster-to-Primary Array survival estimates for 2015 (red), 2016 (blue), and 2018 (yellow) could be compared statistically for STH2; Foster-to-Egress Array ViRDCt estimates (2018 only, purple) are stand-alone. Table 5.1 and Appendix D contain all dam-passage survival estimates. No letters indicate no significant differences.

5.2 Route-Specific Survival

Route-specific survival estimates for STH2 for low and high pool are presented in Table 5.2 (all years, CJS estimates), Table 5.3 (2018, CJS, and ViRDCt estimates), Figure 5.2 (low pool, all years and estimates), Figure 5.3 (high pool, all years and estimates), and in Appendix D. During spring low pool in 2016 and 2018, Spill Bays 3 and 2 (respectively) had the highest Foster-to-Primary Array survival, whereas in 2015, survival was highest through the old fish weir (Figure 5.2, Table 5.2). Neither Spill Bay 3 survival nor weir survival was statistically different between years (Figure 5.2; Table 5.2). Turbine Unit 1 survival during low pool was $S_1 = 0.563$ in 2015, 0.385 in 2016, and 0.520 in 2018. No fish passed through Spill Bay 2 or Turbine Unit 2 in 2015 or 2016; however, in 2018, survival through Spill Bay 2 was $S_1 = 0.648$, and survival through Turbine Unit 2 was $S_1 = 0.640$. Few to no fish (≤ 5) passed through Spill Bays 1–2 during spring low pool in 2015 and 2016, or Spill Bay 1 in 2018; therefore, survival could not be estimated. For S-STH, survival during low pool was greatest through the weir in 2018 ($S_1 = 0.633$), followed by Spill Bays 1–3 ($S_1 = 0.462$). ViRDCt estimates for both STH2 and S-STH were higher than CJS estimates, providing a more representative estimate of immediate route-specific passage survival (Figure 5.2; Table 5.3).

Table 5.2. Estimated Route-Specific Survival for STH2 (Spring 2015, 2016, and 2018) Released in the Foster Reservoir at Low (March–April) and High (May–June) Pool Elevations. Survival was estimated from Foster passage to the Primary Array, located ~19 rkm downstream, using the CJS model.

	Foster-to-Primary Array											
	2015				2016				2018			
	Low Pool		High Pool		Low Pool		High Pool		Low Pool		High Pool	
Route	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**
Turbine Unit 1	16	0.563 (0.124)	1	*	13	0.385 (0.135)	–	–	39	0.520 (0.082)	2	*
Turbine Unit 2	–	–	–	–	5	*	–	–	25	0.640 (0.096)	–	–
Fish Weir	46	0.667 (0.085)	145	0.713 (0.052)	30	0.433 (0.091)	139	0.811 (0.035)	67	0.509 (0.061)	102	0.829 (0.043)
Spill Bay 3	45	0.565 (0.076)	4	*	21	0.572 (0.108)	4	*	56	0.555 (0.067)	–	–
Spill Bay 2	–	–	–	–	–	–	–	–	17	0.648 (0.116)	1	*
Spill Bay 1	1	*	–	–	–	–	–	–	4	*	–	–

n = number of fish that passed Foster by route per pool elevation and year.
* Indicates a small number of fish passed the route; therefore, a survival estimate was not calculated.

Table 5.3. Estimated Survival by Combined Routes for STH2 and S-STH (Spring 2018) Released in the Foster Reservoir at Low (March–April) and High (May–June) Pool Elevations Comparing CJS Estimates to ViRDCt Estimates. Survival was estimated from Foster passage to the Primary Array, located ~19 rkm downstream, using the CJS model and from Foster passage to the Egress Array, located ~2.5 rkm downstream, using the ViRDCt model.

	STH2								S-STH							
	Foster-to-Primary Array				Foster-to-Egress Array				Foster-to-Primary Array				Foster-to-Egress Array			
	Low Pool		High Pool		Low Pool		High Pool		Low Pool		High Pool		Low Pool		High Pool	
Route	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_D (SE)**	***n***	**S_D (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_D (SE)**	***n***	**S_D (SE)**
Turbine Units 1–2	67	0.531 (0.062)	2	*	67	0.744 (0.089)	2	*	13	0.308 (0.128)	1	*	13	1.385[a] (0.577)	1	*
Fish Weir	67	0.509 (0.061)	102	0.829 (0.043)	67	0.600 (0.072)	102	0.937 (0.106)	19	0.633 (0.111)	180	0.767 (0.033)	19	0.755 (0.110)	180	0.863 (0.047)
Spill Bays 1–3	77	0.599 (0.056)	1	*	77	0.846 (0.062)	1	*	26	0.462 (0.098)	3	*	26	0.686 (0.176)	3	*

n = number of fish that passed Foster by route per pool elevation, survival array, and species.
* Indicates a small number of fish passed the route; therefore, a survival estimate was not calculated.
[a] Estimates of survival probability under the single-release model are random variables, subject to sampling variability. When true survival probabilities are near 1.0 and/or sampling variability is high, it is possible for survival probability estimates to exceed 1.0. For practical purposes, these estimates should be considered to equal 1.0 (Faulkner et al. 2015).

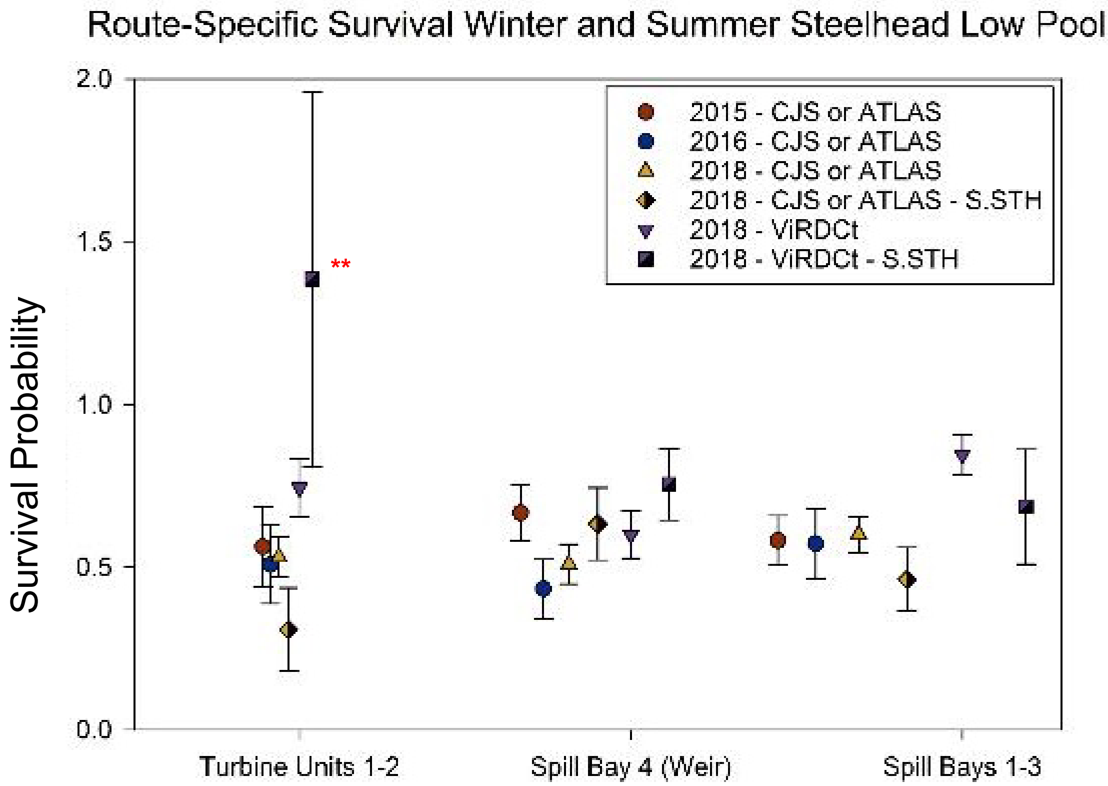

Figure 5.2. Estimated Survival by Combined Routes for STH2 and S-STH (Spring 2015, 2016, and 2018) Released in the Foster Reservoir at Low Pool Elevation (March–April). Foster-to-Primary Array survival estimates for 2015 (red circle), 2016 (blue circle), and 2018 (yellow triangle) could be compared statistically, whereas Foster-to-Egress Array ViRDCt estimates (2018 only, purple inverse triangle) are stand-alone. S-STH are represented by the partially shaded diamond (2018, S_1 CJS) and the partially shaded square (2018, S_D ViRDCt). Tables 5.2 and 5.3, and Appendix D contain all low pool route-specific survival estimates. Lack of letters indicates no significant differences.

** Estimates of survival probability under the single-release model are random variables, subject to sampling variability. When true survival probabilities are close to 1.0 and/or when sampling variability is high, it is possible for estimates of survival probabilities to exceed 1.0. For practical purposes, these estimates should be considered to equal 1.0 (Faulkner et al. 2015).

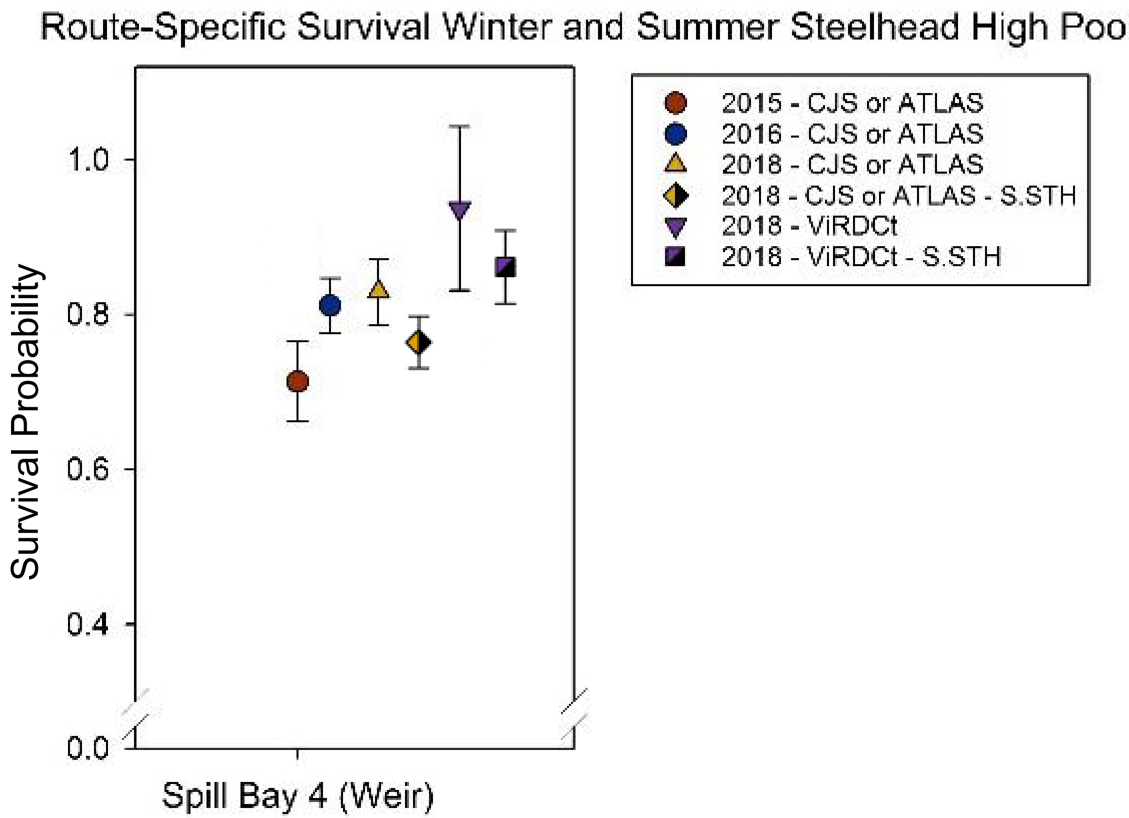

Figure 5.3. Estimated Survival by Combined Routes for STH2 (Spring 2015, 2016, and 2018) and S-STH (2018) Released in the Foster Reservoir at High Pool Elevation (May–June). Foster-to-Primary Array survival estimates for 2015 (red circle), 2016 (blue circle), and 2018 (yellow triangle) could be compared statistically, whereas Foster-to-Egress Array ViRDCt estimates (2018 only, purple inverse triangle) are stand-alone. S-STH are represented by the partially shaded diamond (2018, S_1) and the partially shaded square (2018, S_D ViRDCt). Appendix D contains all low pool route-specific survival estimates. Lack of letters indicates no significant differences.

Foster-to-Primary Array survival for STH2 at spring high pool was not statistically different across study years. It was highest through the fish weir for all study years, with estimates of $S_1 = 0.713$, $S_1 = 0.811$, and $S_1 = 0.829$ for 2015, 2016, and 2018, respectively (Table 5.2). During high pool little to no fish (≤ 4) passed through any other route (Spill Bays 1–3, Turbine Units 1–2); therefore, survival could not be estimated. For S-STH during high pool, survival through the fish weir was similar to STH2 ($S_1 = 0.767$), with little to no fish (< 3) passing through any other route). Again, ViRDCt estimates for both STH2 and S-STH were higher than CJS estimates (Figure 5.3; Table 5.3).

Survival estimates based on weir discharge during spring low pool at low (< 500 cfs) weir discharge and high (≥ 500 cfs) weir discharge were also compared for STH2 and S-STH. There did not appear to be an effect on survival by weir discharge or among species, as survival estimates were not significantly different (Figure 5.4; Appendix D, Table D.7)

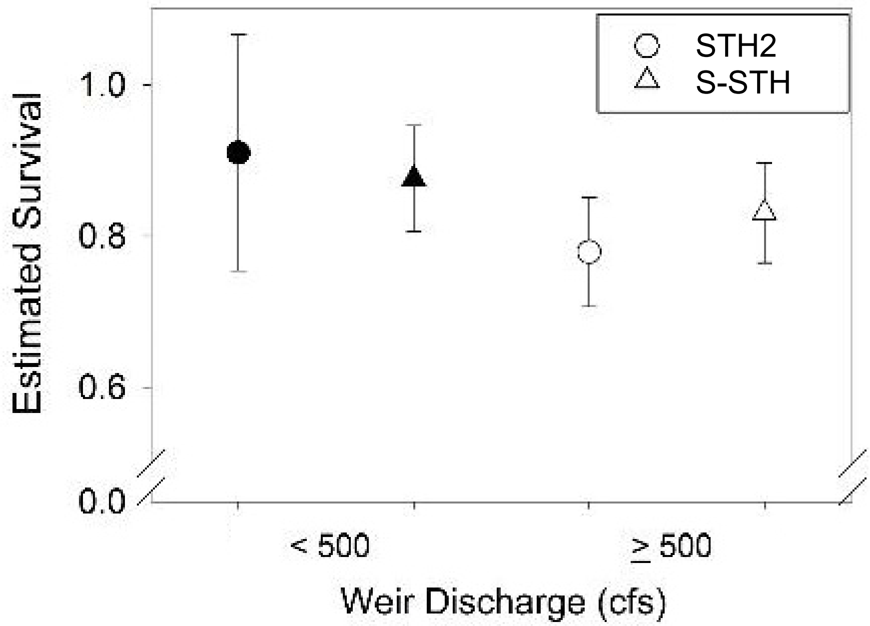

Figure 5.4. Estimated Survival for STH2 (circles) and S-STH (triangle) at Low (< 500 cfs; black shapes) and High (≥ 500 cfs; white shapes) Weir Discharge in Spring 2018 at Foster using ViRDCt Estimates (Appendix D, Table D.7)

5.3 Passage Distributions

5.3.1 Spring Low Pool

In spring 2018 at low pool, STH2 passed the dam using turbine, weir, and non-weir routes in approximately equal proportions (Figure 5.5; Appendix D, Table D.8). This was significantly different than in 2015 and 2016 (Fisher's exact test, $p = 0.01$ for 2018 compared to pooled 2015 and 2016; Appendix D, Table D.3 and Table D.4), when a preference for the weir was slightly higher (> 40%), and a lower proportion of fish passed the turbines. Discharge proportions by route were fairly similar across study years, with the exception of increased discharge through Spill Bays 1 and 2 in 2018. Unlike in previous years, about 10% of STH2 passed through these spill bay routes in low pool 2018 (Appendix D, Table D.8). The passage proportions of S-STH during low pool did differ not significantly from those of STH2 (Fisher's exact test, $p = 0.35$, Appendix D, Table D.3 and Table D.4).

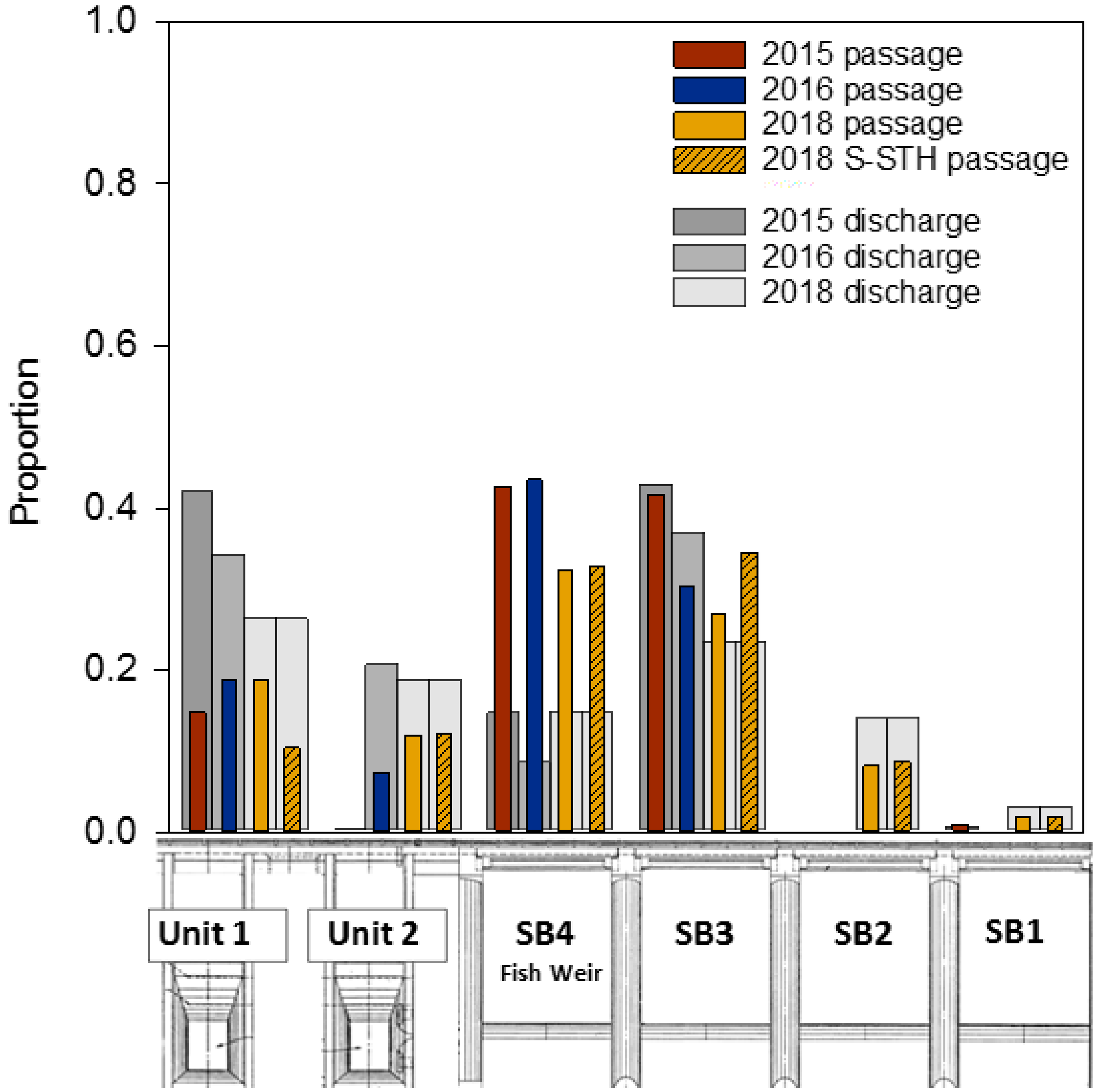

Figure 5.5. Passage Distributions of STH2 at Foster in Spring 2015 (red), 2016 (blue), and 2018 (yellow) during Low Pool Elevation. The gray vertical bars indicate water discharge proportions by route, per year (Appendix D, Table D.8).

Across study years, most STH2 passing the dam did so at night (> 65%, Table 5.4). Variation in day vs. night passage proportions differed between the old weir and new weir years and differences between all three years were substantial, both overall and for specific routes. However, preference for nighttime weir passage was especially pronounced across all years (> 83%). S-STH day vs. night passage proportions were reasonably similar to those of STH2 in 2018.

Table 5.4. Day vs. Night Passage Distributions of STH2 (Spring 2015, 2016, and 2018) and S-STH (Spring 2018) Released above Foster that Passed the Dam during Low Pool

Spring Low Pool	STH2												S-STH			
	2015				2016				2018				2018			
	Day		Night		Day		Night		Day		Night		Day		Night	
Location	***n***	**Prop.**	***n***	**Prop.**	***n***	**Prop.**	***n***	**Prop.**	***n***	**Prop.**	***n***	**Prop.**	***n***	**Prop.**	***n***	**Prop.**
Overall	17	0.16	91	**0.84**	24	0.35	45	**0.65**	55	0.26	153	**0.74**	14	0.24	44	**0.76**
Turbine Unit 1	4	0.25	12	**0.75**	7	0.54	6	**0.46**	8	0.20	31	**0.80**	1	0.17	5	**0.83**
Turbine Unit 2	–	–	–	–	1	0.20	4	**0.80**	8	0.32	17	**0.68**	3	0.43	4	**0.57**
Fish Weir	4	0.09	42	**0.91**	5	0.17	25	**0.83**	11	0.16	56	**0.84**	–	–	19	**1.00**
Spill Bay 3	8	0.18	37	**0.82**	11	0.52	10	**0.48**	18	0.32	38	**0.68**	8	0.400	12	**0.60**
Spill Bay 2	–	–	–	–	–	–	–	–	7	0.41	10	**0.59**	2	0.400	3	**0.60**
Spill Bay 1	1	1.00	–	–	–	–	–	–	3	0.750	1	**0.25**	–	–	1	**1.00**

n = number of fish that passed Foster by route per diel period, year, and species.
Prop. = proportion that passed Foster by route per diel period, year, and species.

5.3.2 Spring High Pool

At high pool, as in previous study years, > 97% of the STH2 passing Foster passed by way of the fish weir (Figure 5.6; Appendix D, Table D.9); therefore, there were no significant differences in the proportions of STH2 passing the turbines, weir, and non-weir routes between years (Fisher's exact test, $p > 0.18$ for all pairwise comparisons; Appendix D; Table D.3 and Table D.4). Discharge proportions by route were also fairly similar across study years, with the exception of increased discharge through Spill Bay 2 in 2018. Similar to the low pool period, the passage proportions of S-STH did not differ significantly from those of STH2 (Fisher's exact test, $p = 0.69$; Appendix D, Table D.10).

In 2015 and 2016, the majority of STH2 passing the dam during spring high pool passed at night (overall: 64% and 80%, respectively; Table 5.5). Conversely, in 2018, only 38% of STH2 and 32% of S-STH passed the dam at night (overall). For all years, day vs. night dam passage is essentially equivalent to day vs. night weir passage, as so few steelhead passed by other routes.

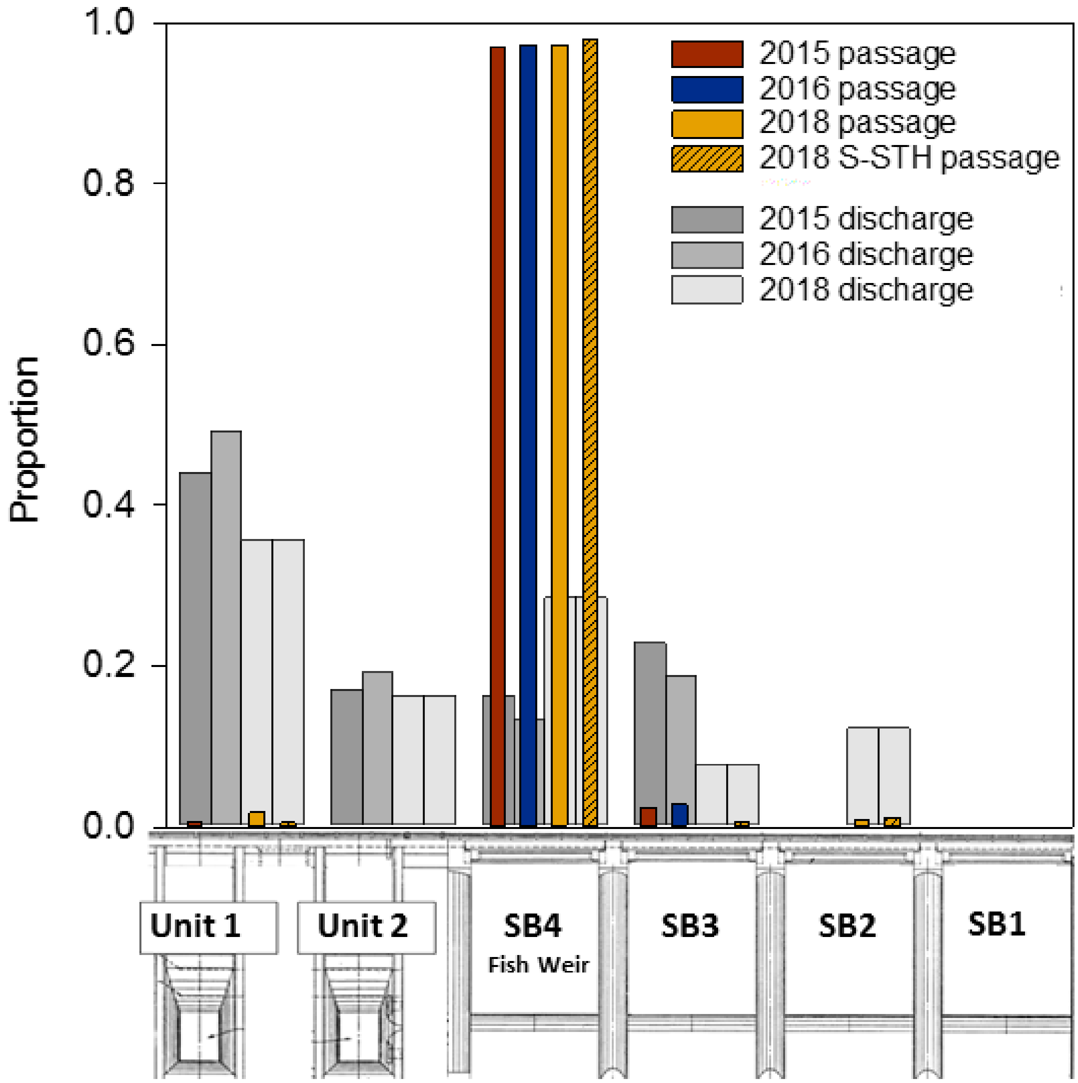

Figure 5.6. Passage Distributions of STH2 at Foster in Spring 2015 (red), 2016 (blue), and 2018 (yellow) during High Pool Elevation. The gray vertical bars indicate water discharge proportions by route, per year (Appendix D, Table D.9).

Table 5.5. Day vs. Night Passage Distributions of STH2 (Spring 2015, 2016, and 2018) and S-STH (Spring 2018) Released above Foster that Passed the Dam during High Pool

Spring High Pool	STH2												S-STH			
	2015				2016				2018				2018			
	Day		Night		Day		Night		Day		Night		Day		Night	
Location	*n*	Prop.	*n*	Prop.	*n*	Prop.	*n*	Prop.	*n*	Prop.	*n*	Prop.	*n*	Prop.	*n*	Prop.
Overall	62	0.36	109	**0.64**	29	0.20	117	**0.80**	68	0.62	42	**0.38**	127	0.68	60	**0.32**
Turbine Unit 1	1	1.00	–	**–**	–	–	–	**–**	1	0.50	1	**0.50**	1	1.00	–	**–**
Turbine Unit 2	–	–	–	**–**	–	–	–	**–**	–	–	–	**–**	–	–	–	**–**
Fish Weir	61	0.37	105	**0.63**	29	0.20	113	**0.80**	67	0.63	40	**0.37**	125	0.68	58	**0.32**
Spill Bay 3	–	–	4	**1.00**	–	–	4	**1.00**	–	–	–	**–**	–	–	1	**1.00**
Spill Bay 2	–	–	–	**–**	–	–	–	**–**	–	–	1	**1.00**	1	0.50	1	**0.50**

n = number of fish that passed Foster by route per diel period, year, and species.
Prop. = proportion that passed Foster by route per diel period, year, and species.

5.4 Project Passage Metrics

In 2018, low pool DPE for STH2 was similar to 2015 and 2016, indicating that despite the new weir installation, a large proportion of STH2 that encountered the dam near the forebay still did not pass downstream (0.432–0.529; Table 5.6; Figure 5.7). FPE also remained approximately constant (0.319–0.375; Table 5.6). In 2018, DPE and FPE for S-STH were very similar to those of STH2. SPE did not vary significantly between years (Fisher's exact test, $p > 0.08$ for all pairwise comparisons), remaining moderately high (0.683–0.852; Figure 5.8). FWE also did not vary significantly (Fisher's exact test, $p > 0.43$ for all pairwise comparisons), remaining fairly low (0.318–0.434). Taken together, these metrics indicate that a large proportion of STH2 passed Foster through non-turbine routes other than the weir. Neither SPE nor FWE differed significantly between STH2 and S-STH (Fisher's exact test, SPE: $p = 0.20$, FWE: $p = 0.88$). SBE also did not differ substantially between years or stocks. As neither proportional discharge by route nor passage efficiencies varied greatly between 2015, 2016, and 2018, weir and spillway passage effectiveness remained moderately high in all years, whereas spill bay effectiveness remained lower (Table 5.7). S-STH effectiveness metrics were similar to those for STH2.

At high pool, STH2 DPE was lower in 2018 (0.378) than in 2015 (0.762) and 2016 (0.667) and a similar trend was observed for FPE (0.371 in 2018 compared to 0.749 and 0.649 in 2015 and 2016, respectively; Table 5.6; Figure 5.7). Compared to previous years, a smaller proportion of STH2 that reached the near forebay passed the weir, and a smaller proportion passed the dam overall. DPE and FPE for S-STH were both slightly higher (DPE: 0.519 and FPE: 0.517) than those of STH2 (DPE: 0.38 and FPE: 0.37). Neither SPE and FWE varied significantly between years (Fisher's exact test, SPE: $p > 0.98$; FWE: $p > 0.63$ for all pairwise comparisons), but remained extremely high (≥ 0.973), indicating that the vast majority of STH2 passing the dam during high pool passed through weir. In addition, neither SPE nor FWE differed significantly between STH2 and S-STH (Fisher's exact test, SPE: $p = 0.56$, FWE: $p = 0.71$). As in low pool, SBE did not differ substantially between years or stocks. Spillway effectiveness more than doubled in 2018, whereas spill bay effectiveness decreased somewhat (Table 5.7). Although still relatively high, weir effectiveness decreased slightly between 2015–2016 and

2018, falling from approximately 5.992–7.353 to 3.430. Summer steelhead effectiveness metrics were very similar to those for STH2.

For both high and low pool study periods, efficiency and effectiveness of the new fish weir for either STH2 or S-STH did not depend strongly on the weir discharge (Table 5.7).

Table 5.6. Passage Efficiencies and Effectiveness for STH2 (Spring 2015, 2016, and 2018) and S-STH (Spring 2018) at Foster. Dam Passage Efficiency (DPE) and Fish Passage Efficiency (FPE) are calculated relative to the number of fish detected in the near forebay, while all other efficiency metrics are relative to the total number of fish that passed the dam (as indicated by "|| Dam").

	STH2						S-STH	
	2015		2016		2018		2018	
Metric	**Low Pool**	**High Pool**	**Low Pool**	**High Pool**	**Low Pool**	**High Pool**	**Low Pool**	**High Pool**
DPE	**0.432 (0.026)**	**0.762 (0.021)**	**0.529 (0.035)**	**0.667 (0.024)**	**0.464 (0.023)**	**0.378 (0.028)**	**0.439 (0.043)**	**0.519 (0.026)**
FPE	**0.355 (0.026)**	**0.749 (0.022)**	**0.375 (0.035)**	**0.649 (0.025)**	**0.319 (0.022)**	**0.371 (0.028)**	**0.341 (0.041)**	**0.517 (0.026)**
SPE || Dam	0.852 (0.034)	0.994 (0.006)	0.739 (0.053)	1.000 (0.000)	0.683 (0.032)	0.982 (0.013)	0.776 (0.055)	0.995 (0.005)
FWE || Dam	0.426 (0.048)	0.971 (0.013)	0.434 (0.060)	0.973 (0.014)	0.318 (0.032)	0.973 (0.016)	0.328 (0.062)	0.979 (0.011)
SBE || Dam	0.426 (0.048)	0.023 (0.012)	0.304 (0.055)	0.027 (0.014)	0.365 (0.033)	0.009 (0.009)	0.448 (0.065)	0.016 (0.009)
Fish Weir Effect.	2.908 (0.325)	5.992 (0.079)	4.782 (0.656)	7.353 (0.102)	2.160 (0.218)	3.430 (0.055)	2.228 (0.419)	3.451 (0.037)
Spill Bay Effect.	0.947 (0.106)	0.102 (0.050)	0.753 (0.137)	0.146 (0.072)	0.903 (0.082)	0.046 (0.046)	1.109 (0.162)	0.081 (0.046)
Spillway Effect.	1.429 (0.057)	2.534 (0.015)	1.493 (0.107)	3.120 (0.000)	1.238 (0.058)	2.037 (0.026)	1.407 (0.099)	2.064 (0.011)

DPE = dam-passage efficiency; proportion of fish passing the dam relative to the number detected in the near forebay (< 100 m from dam-face).
FPE = fish passage efficiency; proportion of fish passing via a non-turbine route relative to the number detected in the near forebay (< 100 m from dam-face).
SPE = spill passage efficiency; proportion of fish that passed Foster through Spill Bays 1–3 and the fish weir in Spill Bay 4.
SBE = spill bay efficiency; proportion of fish that passed Foster through Spill Bays 1–3.
FWE = fish weir efficiency; proportion of fish that passed Foster over the fish weir in Spill Bay 4.
Fish weir/ spill bay/spillway effectiveness = proportion of fish passage through a route relative to the proportion of discharge through the same route.
Absence of superscript letters indicates there were no significant differences.

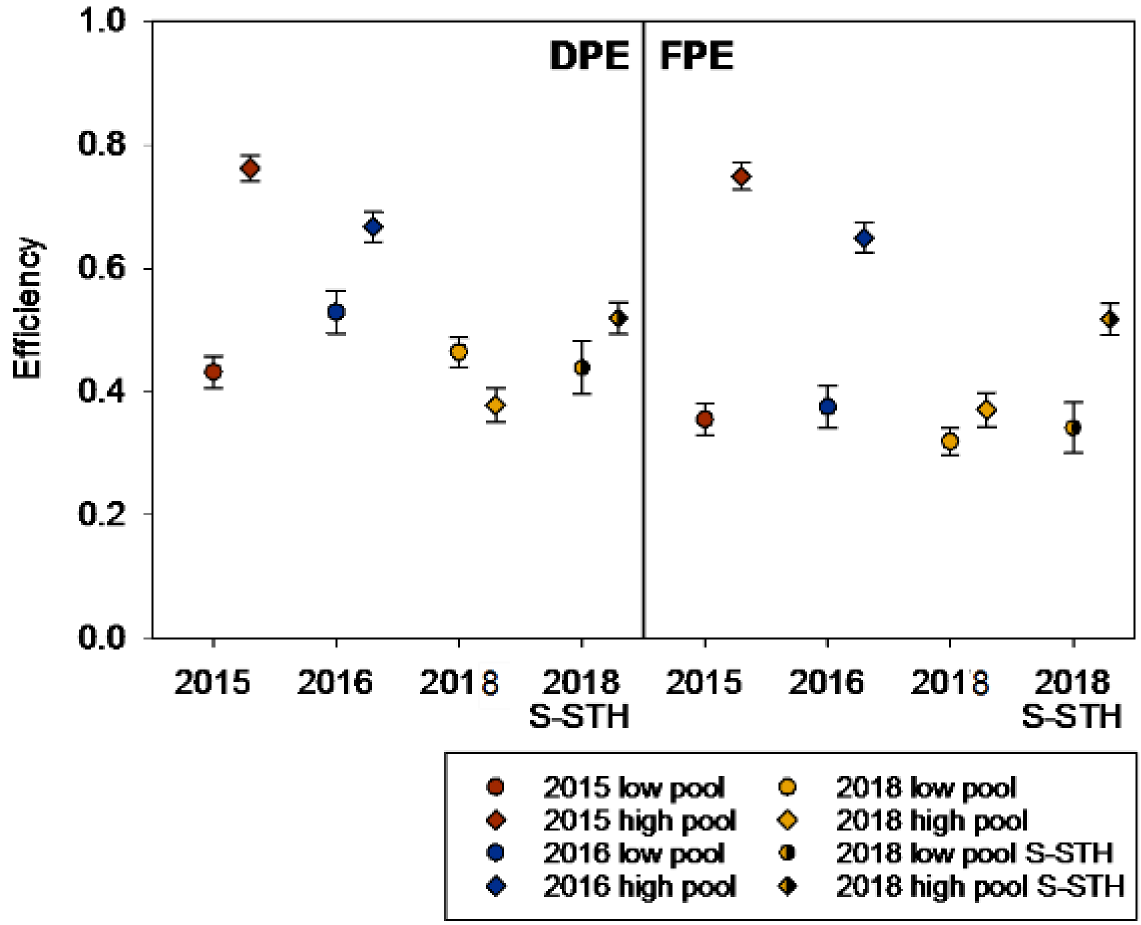

Figure 5.7. Dam-Passage Efficiency (DPE) and Fish Passage Efficiency (FPE) of STH2 at Foster in Spring 2015 (red), 2016 (blue), and 2018 (yellow), as well as S-STH in Spring 2018 (partially shaded yellow). Circles represent low pool estimates, whereas diamonds represent high pool estimates.

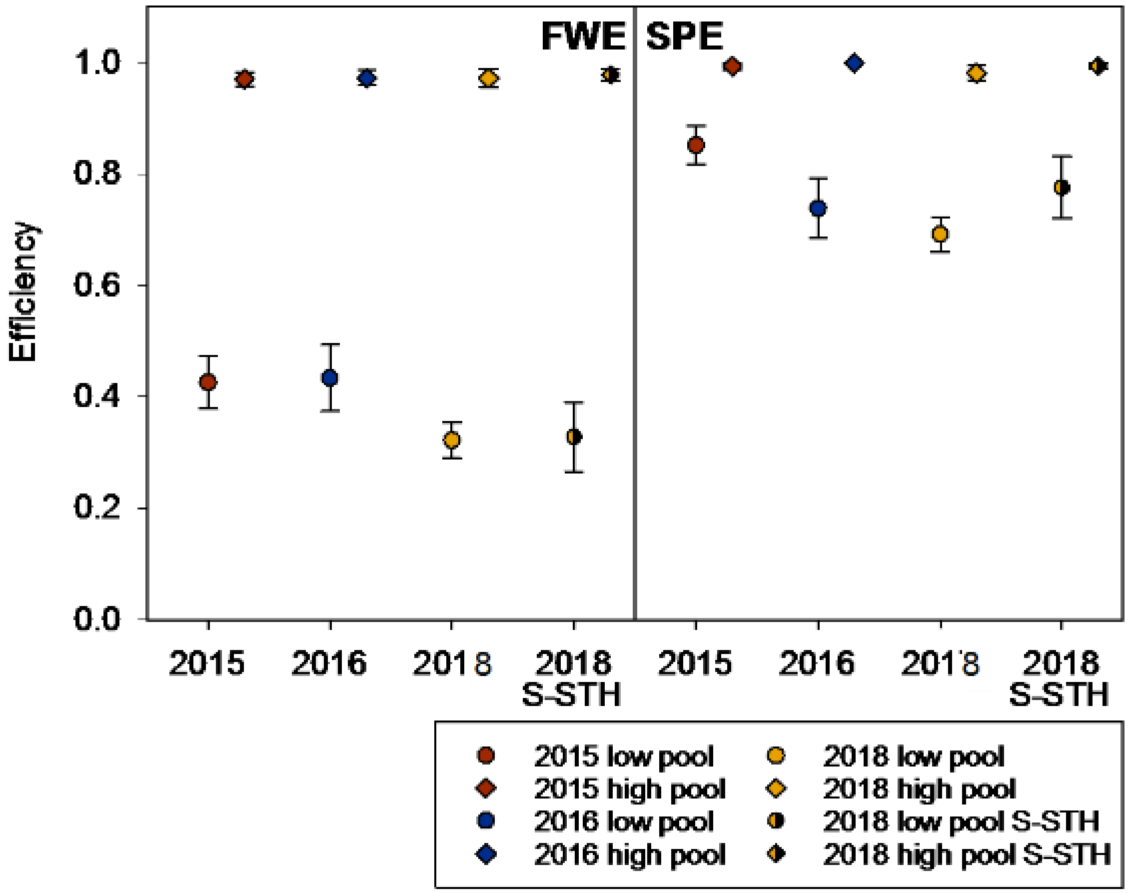

Figure 5.8. Fish Weir Efficiency (FWE) and Spill Passage Efficiency (SPE) of STH2 at Foster in Spring 2015 (red), 2016 (blue), and 2018 (yellow), as well as S-STH in Spring 2018 (partially shaded yellow). Low pool estimates are represented by circles, whereas high pool estimates are represented by diamonds.

Table 5.7. Fish Weir Efficiency (FWE) and Effectiveness for STH2 and S-STH that Passed Foster at Low (< 500 cfs) and High (≥ 500 cfs) Weir Discharge in Spring 2018

Pool Stage	Weir Discharge	STH2			S-STH		
		n	FWE	Effectiveness	*n*	FWE	Effectiveness
Low	< 500 cfs	10	0.400 (0.155)	2.593 (1.004)	1	–	–
	≥ 500 cfs	190	0.332 (0.034)	2.059 (0.212)	57	0.333 (0.062)	2.070 (0.388)
High	< 500 cfs	39	1.000 (0.000)	3.754 (0.000)	67	0.970 (0.022)	3.642 (0.081)
	≥ 500 cfs	71	0.958 (0.024)	3.007 (0.075)	120	0.983 (0.012)	3.087 (0.039)

n = number of fish that passed Foster by pool stage and weir discharge level per species.

5.5 Travel Times

Reservoir residence time, project egress, and travel time to the Secondary Array and Willamette Falls are presented in Figure 5.9 for STH2 at low and high pool in 2015, 2016, and 2018. At low pool, STH2 reservoir residence time was significantly higher in 2018 compared to previous years (Wilcoxon Signed-Rank Test, $p < 0.001$, Appendix D, Table D.6). Mean reservoir residence time was 6.6 ± 0.9 d in 2015, 4.3 ± 0.5 d in 2016, and 10.1 ± 0.7 d in 2018. Mean S-STH reservoir residence time was 8.5 ± 1.1 d

(Figure 5.9). Travel times between detection arrays varied somewhat between years, but these differences were relatively small, especially considering variation within years. S-STH traveled through the system at a similar rate to STH2. At low pool, STH2 and S-STH reached Lebanon Dam several days after dam passage and may take several weeks to travel from the dam to Willamette Falls.

At high pool, there was no substantial change in mean STH2 reservoir residence time after installation of the new weir (Figure 5.10). STH2 residence time was only significantly different between 2015 (25.3 ± 1.3 d) and 2016 (17.3 ± 0.9 d), but not between 2018 and 2015 or 2016 (Wilcoxon Signed-Rank Test, p = 0.003, Appendix D, Table D.6). However, in 2018, mean reservoir residence time for S-STH (11.4 ± 0.9 d) was less than half the mean STH2 residence time (23.3 ± 1.6 d). Travel times between detection arrays were similar across study years for STH2, and for STH2 compared to S-STH. Although reservoir residence time was longer at high pool than at low pool, travel times were generally shorter, with fish reaching Lebanon Dam within 2–3 days of passing Foster, and arriving at Willamette Falls after approximately one week, on average.

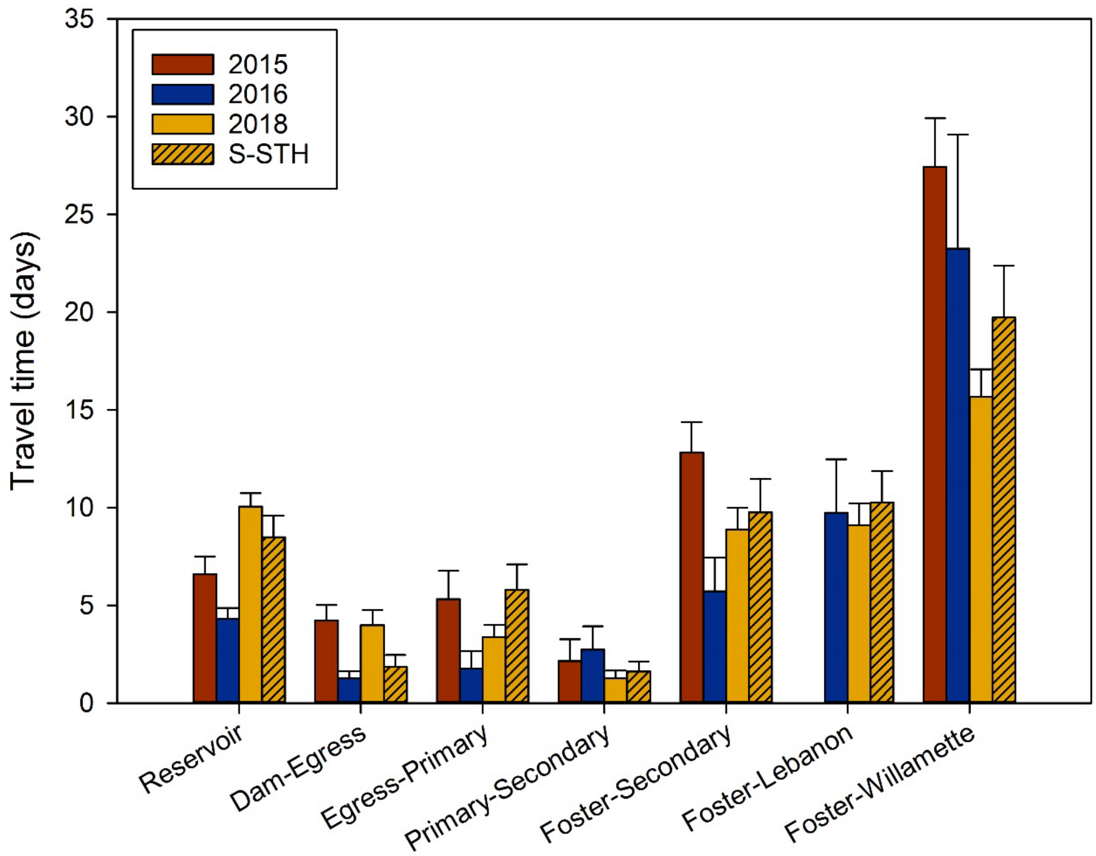

Figure 5.9. Estimated Mean Reservoir Residence Time, Project Egress, and Travel Times (days) between Arrays for STH2 in Spring 2015 (red), 2016 (blue), and 2018 (yellow) during Low Pool Elevation. Summer steelhead (S-STH) were only released in 2018 (yellow with diagonal black lines). The error bars depict the standard error of the mean.

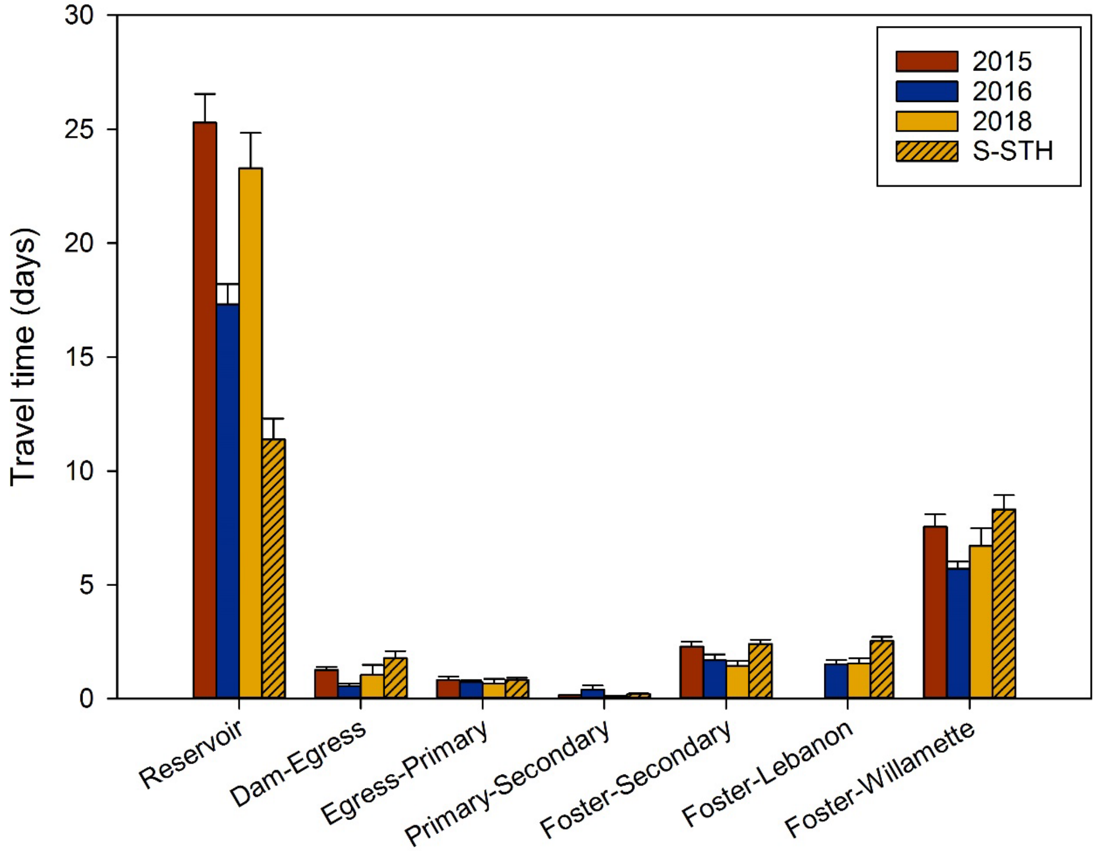

Figure 5.10. Estimated Mean Reservoir Residence Time, Project Egress, and Travel Times (days) between Arrays for STH2 in Spring 2015 (red), 2016 (blue), and 2018 (yellow) during High Pool Elevation. Summer steelhead (S-STH) were only released in 2018 (yellow with diagonal black lines). The error bars depict the standard error of the mean.

5.6 Spill vs. Turbine Block Treatment Test

For STH2 at low pool, passage rates during the turbine+weir treatment—when only the turbines and weir were operated—indicated that 49% of all STH2 passing under these conditions did so via the weir, whereas 51% passed via the turbines (Table 5.8; Figure 5.11). For the spill+weir treatment, 80% of STH2 passed via the spillway compared to 20% passing via the fish weir. Passage was highly variable within treatments; however, total passage was not found to differ significantly between treatments ($p = 0.37$; Table 5.9).

For S-STH at low pool, passage rates during the turbine+weir treatment indicated that 58% of all S-STH passing under these conditions did so via the weir, whereas 42% passed via the turbines (Table 5.8; Figure 5.12). For the spill+weir treatment, 85% of S-STH passed via the spillway compared to 15% passing via the fish weir. Passage was highly variable within treatments; however, total passage was not found to differ significantly between treatments ($p = 0.20$, Table 5.9).

Table 5.8. Passage Estimates during the Low Pool Spill vs. Turbine Test for STH2 (Spring 2015, 2016, and 2018) and S-STH (Spring 2018)

Spring Low Pool		STH2						S-STH	
		2015		2016		2018		2018	
Treatment	**Passage Route**	**Total Passage (*n*)**	**Passage Proportion**	**Total Passage (*n*)**	**Passage Proportion**	**Total Passage (*n*)**	**Passage Proportion**	**Total Passage (*n*)**	**Passage Proportion**
turbine+weir	Turbine Units 1–2	13	0.30	15	0.45	26	0.51	5	0.42
	Weir	31	0.70	18	0.55	25	0.49	7	0.58
spill+weir	Spill Bays 1–3	39	0.74	19	0.90	64	0.80	22	0.85
	Weir	14	0.26	2	0.10	16	0.20	4	0.15
turbine+spill+weir	Turbine Units 1–2	–	–	3	0.20	–	–	–	–
	Spill Bays 1–3	–	–	2	0.13	–	–	–	–
	Weir	–	–	10	0.67	–	–	–	–

Table 5.9. Univariate ANOVA Results for STH2 (Spring 2015, 2016, and 2018) and S-STH (Spring 2018) during Low Pool. A *p*-value < 0.05 indicates a significant difference.

Spring Low Pool		Effect	Degrees of Freedom	Sum of Squares	Mean Squares	F-Statistic	*p*-value
STH2	2015	Intercept	1	6.63	6.63	152.09	< 0.001
		Block	8	2.76	0.35	7.93	< 0.001
		Treatment	1	0.04	0.04	1.00	0.33
		Error	26	1.13	0.04		
	2016	Intercept	1	5.90	5.90	117.45	< 0.001
		Block	2	0.89	0.30	5.89	0.006
		Treatment	3	0.21	0.11	2.11	0.15
		Error	18	0.90	0.05		
	2018	Intercept	1	11.91	11.91	144.03	< 0.001
		Block	5	0.82	0.16	1.98	0.14
		Treatment	1	0.07	0.07	0.84	0.37
		Error	14	1.16	0.08		
S-STH	2018	Intercept	1	2.55	2.55	48.61	< 0.001
		Block	5	0.99	0.20	3.77	0.02
		Treatment	1	0.09	0.09	1.78	0.20
		Error	14	0.74	0.05		

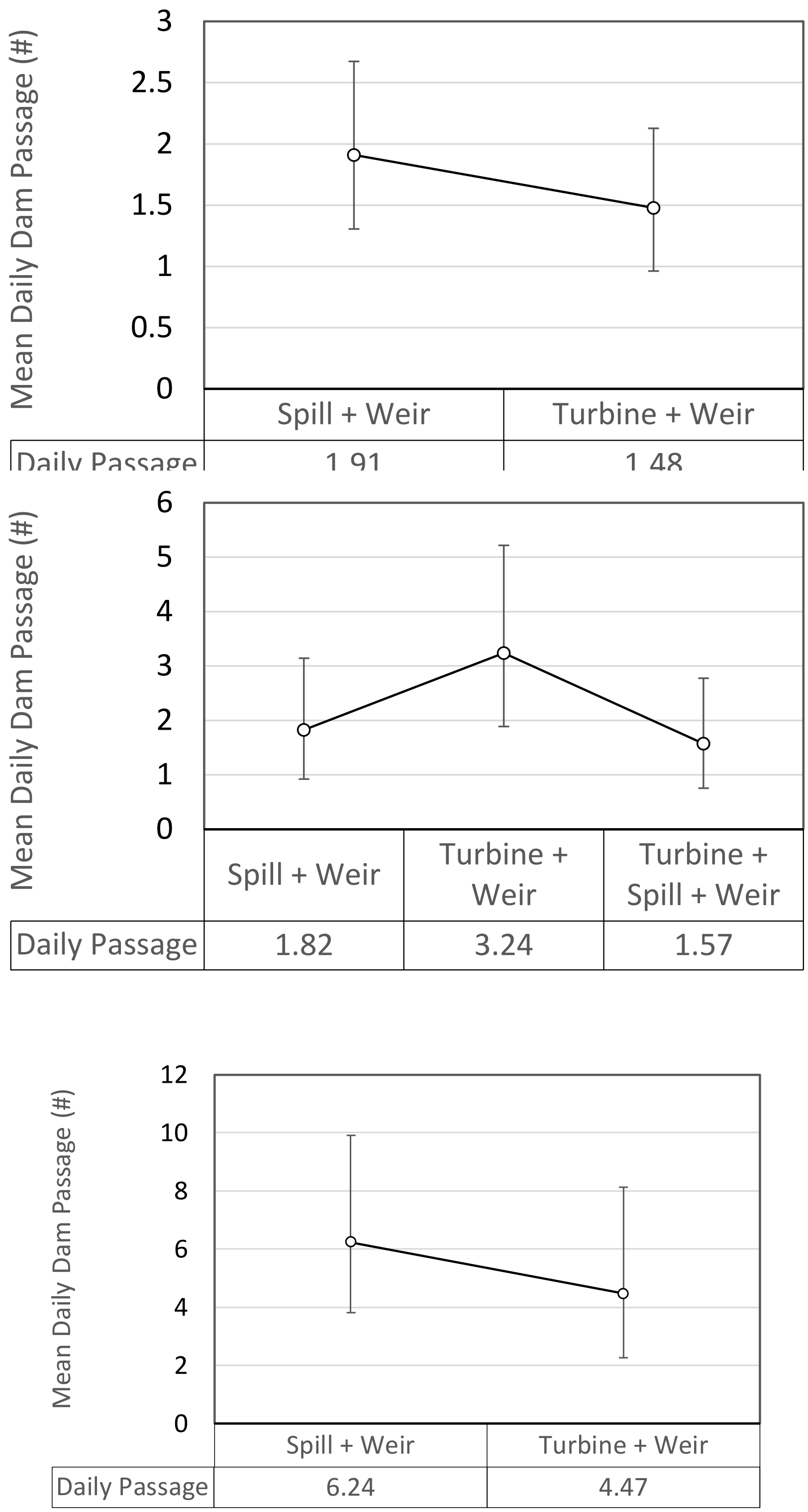

Figure 5.11. Total Passage of STH2 by Treatment during Spring Low Pool in 2015 (top), 2016 (middle), and 2018 (bottom)

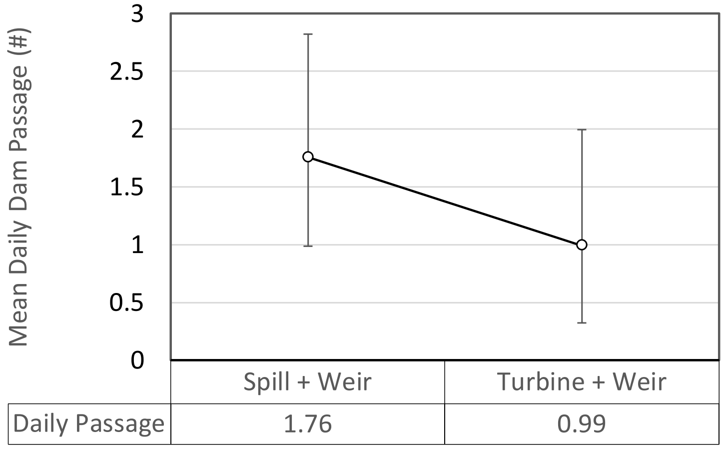

Figure 5.12. Total Passage of S-STH by Treatment during Spring Low Pool in 2018

At high pool, passage rates during the turbine+weir treatment indicated that 98% of all STH2 passing under these conditions did so via the fish weir, whereas 2% passed via the turbines (Table 5.10; Figure 5.13). For the spill+weir treatment, 98% of STH2 passed via the fish weir. The ANOVA did not reveal a significant difference in passage rates for spill-passed fish and turbine-passed fish between the treatments (p = 0.24; Table 5.11).

At high pool, passage rates during the turbine+weir treatment indicated that 100% of all S-STH passing under these conditions did so via the fish weir (Table 5.10; Figure 5.14). For the spill+weir treatment, 97% of S-STH passed via the fish weir. The ANOVA did not reveal a significant difference in passage rates for spill-passed fish and turbine-passed fish between the treatments (p = 0.14, Table 5.11).

Table 5.10. Passage Estimates during High Pool Spill vs. Turbine Operations for STH2 (Spring 2015, 2016, and 2018) and S-STH (Spring 2018). The fish weir, located in Spill Bay 4, was continuously operated during both treatments.

Spring High Pool		**STH2**						**S-STH**	
		2015		**2016**		**2018**		**2018**	
Treatment	**Passage Route**	**Total Passage (*n*)**	**Passage Proportion**	**Total Passage (*n*)**	**Passage Proportion**	**Total Passage (*n*)**	**Passage Proportion**	**Total Passage (*n*)**	**Passage Proportion**
turbine+weir	Turbine Units 1–2	1	0.02	0	0.00	1	0.02	0	0.00
	Weir	55	0.98	44	1.00	60	0.98	76	1.00
spill+weir	Spill Bays 1–3	4	0.05	4	0.05	1	0.02	3	0.03
	Weir	75	0.95	81	0.95	42	0.98	90	0.97

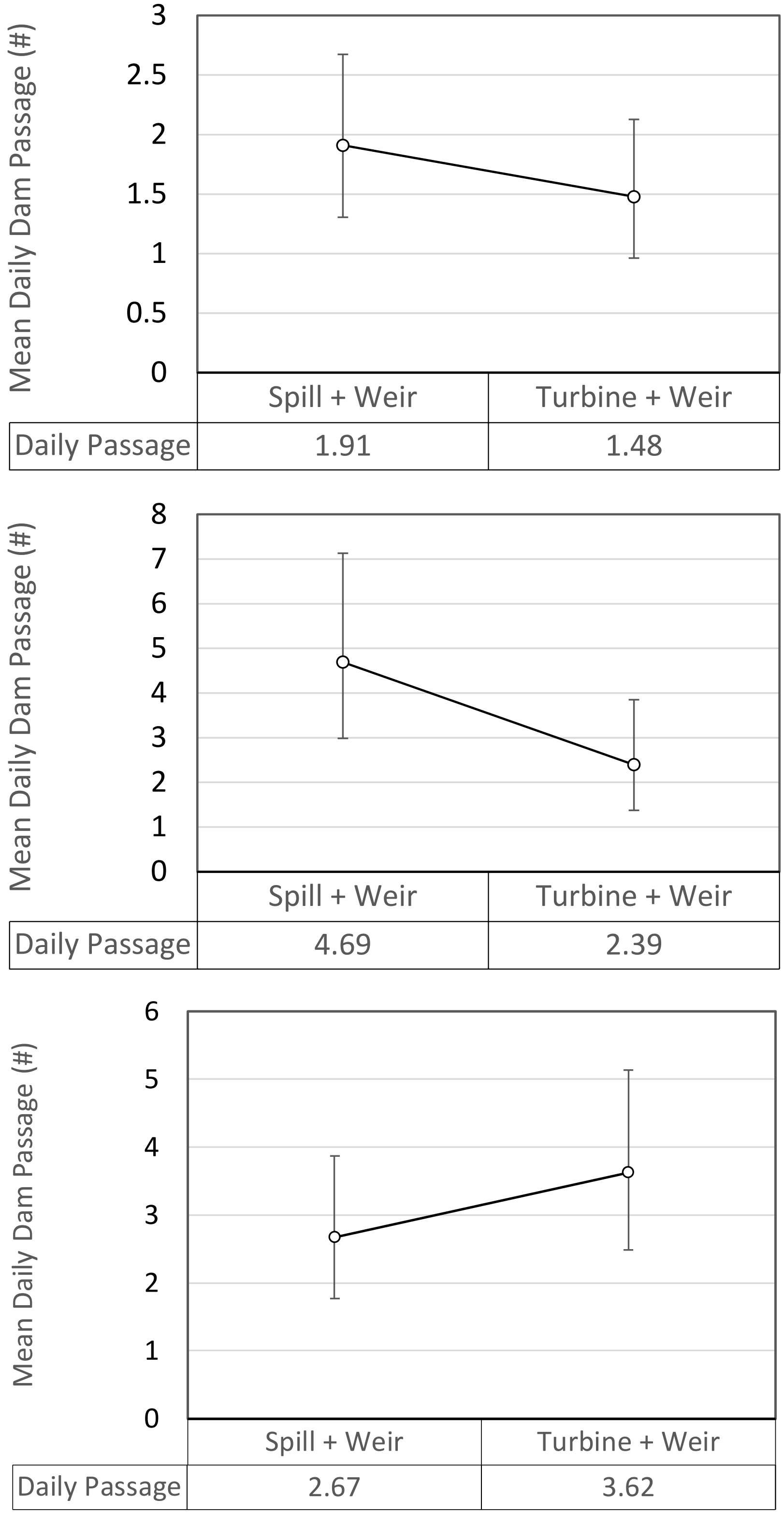

Figure 5.13. Total Passage of STH2 by Treatment during Spring High Pool in 2015 (top), 2016 (middle), and 2018 (bottom)

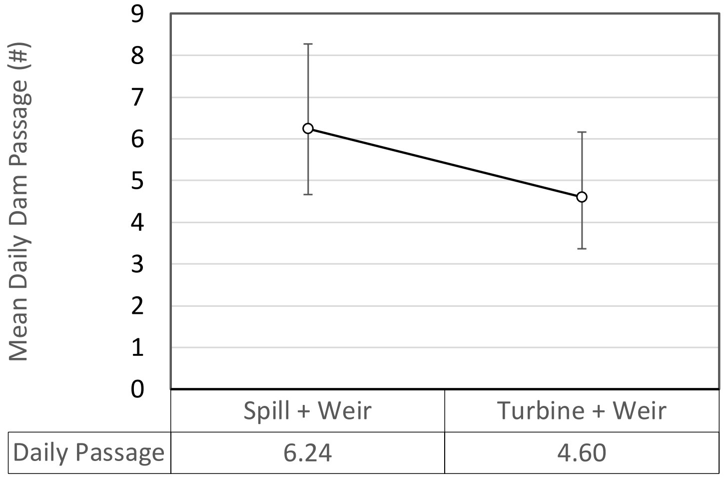

Figure 5.14. Total Passage of S-STH by Treatment during Spring High Pool in 2018

Table 5.11. Univariate ANOVA Results for STH2 (Spring 2015, 2016, and 2018) and S-STH (Spring 2018) during High Pool. A *p*-value < 0.05 indicates a significant difference.

Spring High Pool		Effect	Degrees of Freedom	Sum of Squares	Mean Squares	F-Statistic	*p*-value
STH2	2015	Intercept	1	10.52	10.52	98.96	< 0.001
		Block	5	1.44	0.29	2.72	0.06
		Treatment	1	0.03	0.03	0.32	0.58
		Error	17	1.81	0.11		
	2016	Intercept	1	11.58	11.58	149.96	< 0.001
		Block	6	0.56	0.09	1.22	0.34
		Treatment	1	0.35	0.35	4.58	0.04
		Error	20	1.54	0.08		
	2018	Intercept	1	10.59	10.59	219.30	< 0.001
		Block	6	0.64	0.11	2.21	0.09
		Treatment	1	0.07	0.07	1.45	0.24
		Error	20	0.97	0.05		
S-STH	2018	Intercept	1	18.10	18.10	487.06	< 0.001
		Block	6	0.39	0.06	1.74	0.16
		Treatment	1	0.09	0.09	2.37	0.14
		Error	20	0.74	0.04		

6.0 Results – Subyearling Chinook Salmon

This section contains estimates of survival, passage distributions, project metrics, travel times, and results from the spill vs. turbine treatments for CH0 at Foster in 2015, 2016, and 2018. Appendices A through F provide additional information: general statistics tables for tagging and releases (Appendix A), spill vs. turbine treatment schedules (Appendix B), supplementary tables for survival estimates and passage proportions (Appendix D), capture histories of study fish (Appendix E), and fish approach vs. route of passage (Appendix F.

6.1 Dam-Passage Survival

For the fall low pool study period (October–December; 613 ft msl and a daily average discharge of 2,219 cfs), a total of 1,222, 1,352, and 738 CH0 were released at R_1 and R_2 in 2015, 2016, and 2018, respectively. CH0 detected at the Foster dam-face array were regrouped and used to form a virtual-release group (V_1). The Foster-to-Primary Array survival estimates were significantly different. Survival was highest in 2015 and lowest in 2016 (Figure 6.1). The Foster-to-Egress Array ViRDCt estimates were higher (S_D = 0.879) than Foster-to-Primary CJS estimates, as ViRDCt is more representative of immediate dam-passage survival (Table 6.1 and Appendix D).

Table 6.1. Survival Probability Estimates for CH0 Released in the Foster Reservoir in Spring 2015, 2016, and 2018 at Low Pool Elevation (October–December). Survival was estimated from Foster passage to the Primary Array, located ~19 rkm downstream, using the CJS model (2015, 2016, and 2018) and from Foster passage to the Egress Array, located ~2.5 rkm downstream, using the ViRDCt model (2018 only).

	Foster-to-Primary Array						Foster-to-Egress Array	
	2015		2016		2018		2018	
Pool Elevation	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_D (SE)**
Low (613 ft msl)	854	0.855 (0.013)[a]	1012	0.755 (0.014)[c]	405	0.805 (0.020)[b]	405	0.879 (0.017)

n = number of fish that passed Foster by year and survival array.
Different superscript letters (located after the survival estimate) across a row indicate a significant difference in survival. If no letters are present, there were no significant differences in survival. ViRDCt estimates were not included the cross-year analysis.

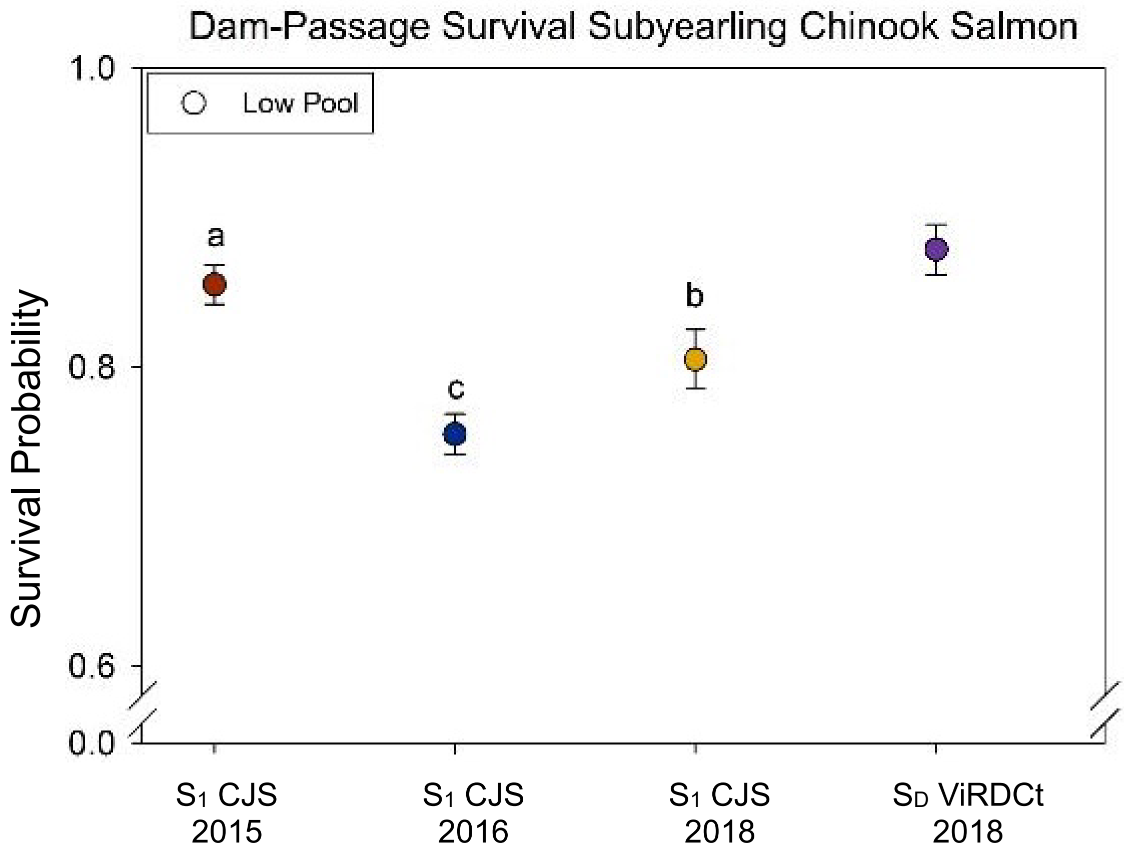

Figure 6.1. Single Release Dam-Passage Survival Estimates of CH0 Released during Fall. Circles represent fish released during the low pool elevation (October–December). Foster-to-Primary Array survival estimates for 2015 (red), 2016 (blue), and 2018 (yellow) could be compared statistically, whereas Foster-to-Egress Array ViRDCt estimates (2018 only, purple) are stand-alone. Letters above survival estimates represent statically significant differences (i.e., ‘a’ is a higher estimate than ‘b’ and ‘b’ is a higher estimate than ‘c’; 2015 had the highest survival, 2016 had the lowest and 2018 was intermediate). Table 6.1 and Appendix D contain all dam-passage survival estimates.

6.2 Route-Specific Survival

Route-specific survival estimates for CH0 for low pool are presented in Table 6.2 (all years, CJS estimates), Table 6.3 (2018, CJS and ViRDCt estimates), Figure 6.2, and in Appendix D. At fall low pool, Foster-to-Primary Array survival for Spill Bays 1–3 was significantly different between 2015 and 2016, but not between 2015 and 2018, nor between 2016 and 2018 (Table 6.2 and Table 6.3, Figure 6.2, and Appendix D). Survival was highest through Spill Bay 3 for all three study years, although survival for fish passing via the weir was also high. Survival for Spill Bay 2 in 2016 was $S_1 = 0.723$. In 2018, Spill Bay 2 survival could not be calculated due to the small number of fish that passed that route. Spill Bay 1 survival was not be estimated in any year for the same reason. Survival through Turbine Units 1 and 2 was similar in 2015 ($S_1 = 0.674$–0.755) and 2016 ($S_1 = 0.718$–0.753). In 2018, not enough fish passed through Turbine Unit 2 to estimate survival, but Turbine Unit 1 survival was $S_1 = 0.783$. ViRDCt estimates were higher than CJS estimates, providing a more representative estimate of immediate route-specific passage survival (Table 6.3, Figure 6.2, and Appendix D).

During fall low pool we were unable to estimate dam-passage survival for CH0 at different weir flow rates, as hourly weir discharge was consistently low (< 500 cfs). As such, dam-passage survival results shown in Table 6.2, Figure 6.2, and Appendix D also represent weir discharge survival estimates.

Table 6.2. Estimated Route-Specific Survival for CH0 (Fall 2015, 2016, and 2018) Released in the Foster Reservoir at Low Pool Elevation (October–December). Survival was estimated from Foster passage to the Primary Array, located ~19 rkm downstream, using the CJS model.

	Foster-to-Primary Array					
	2015		2016		2018	
Route	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**	***n***	**S_1 (SE)**
Turbine Unit 1	122	0.755 (0.049)	165	0.718 (0.035)	134	0.783 (0.036)
Turbine Unit 2	32	0.674 (0.086)	117	0.753 (0.040)	3	*
Fish Weir	96	0.869 (0.035)	43	0.767 (0.064)	236	0.818 (0.025)
Spill Bay 3	587	0.882 (0.014)[a]	490	0.781 (0.019)[b]	12	0.833 (0.108)[ab]
Spill Bay 2	15	1.001[+] (0.107)[a]	162	0.723 (0.035)[b]	4	*
Spill Bay 1	2	*	4	*	ND	ND

n = number of fish that passed Foster by route per year.
* Indicates a low proportion of fish passed the route; therefore, a survival estimate was not calculated.
[+] One fish had a survival rate of over 100% (Spill Bay 2, 2015) because it skipped a detection at Foster, but was still detected downstream.
Different superscript letters (located after the survival estimate) across a row indicate a significant difference in survival. If no letters are present, there were no significant differences in survival.

Table 6.3. Estimated Survival by Combined Routes for CH0 (Fall 2018) Released in the Foster Reservoir at Low Pool Elevation (October–December) Comparing CJS Estimates to ViRDCt Estiamtes. Survival was estimated from Foster passage to the Primary Array, located ~19 rkm downstream, using the CJS model and from Foster passage to the Egress Array, located ~2.5 rkm downstream, using the ViRDCt model.

	Foster-to-Primary Array		Foster-to-Egress Array	
	2018		2018	
Route	***n***	**S_1 (SE)**	***n***	**S_D (SE)**
Turbine Units 1–2	138	0.782 (0.036)	138	0.849 (0.032)
Fish Weir	236	0.818 (0.025)	236	0.888 (0.021)
Spill Bays 1–3	16	0.961 (0.092)	16	1.000 (0.000)

n = number of fish that passed Foster by route per survival array.

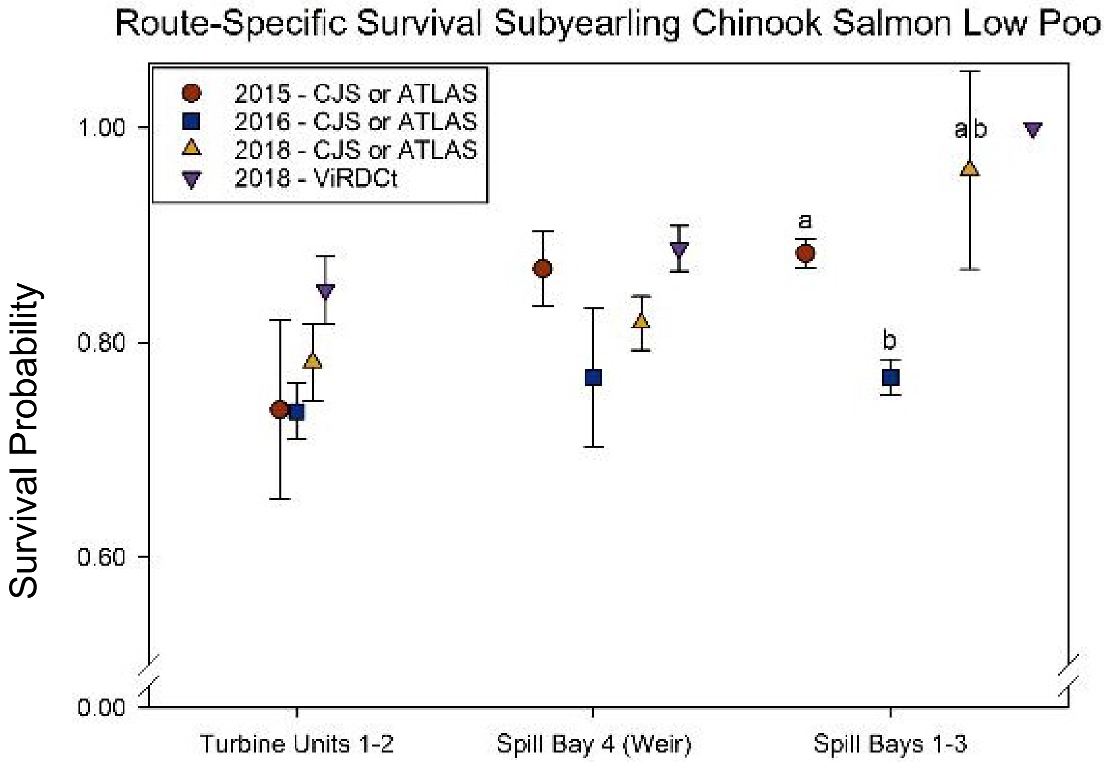

Figure 6.2. Estimated Survival by Combined Routes for CH0 (Fall 2015, 2016, and 2018) Released in the Foster Reservoir at Low Pool Elevation (October–December). Foster-to-Primary survival estimates for 2015 (red circle), 2016 (blue square), and 2018 (yellow triangle) could be compared statistically, whereas Foster-to-Egress Array ViRDCt estimates (2018 only, purple inverse triangle) are stand-alone. Tables 6.2 and 6.3 and Appendix D contain all low pool route-specific survival estimates. Different letters above survival estimates (by route) represent statically significant differences (i.e., ‘a’ is a higher estimate than ‘b’; 2018 had the highest survival estimate but did not differ significantly from 2015 or 2016).

6.3 Passage Distributions

In fall 2018, 60.1% of CH0 passing Foster passed through the new weir, an increase of more than five-fold from previous years, despite a minimal increase in weir discharge for the new weir compared to the old weir (daily average of 355 cfs at the new weir; 150–500 cfs at the old weir; Figure 6.3; Appendix D, Table D.11). Passage via Spill Bay 3 also dropped from ≥ 50% to < 4%. The final substantial difference compared to previous years was a doubling of the proportion of fish passing through Turbine Unit 1. Discharge was fairly similar across study years, though Turbine Unit 1 discharge was somewhat higher and Spill Bay 3 discharge was slightly lower in 2018. The proportions of fish passing through turbine, weir, and non-weir routes were significantly different between all study years (Fisher’s exact test, $p < 0.001$ for all pairwise comparisons; Appendix D, Table D.3, and Table D.4).

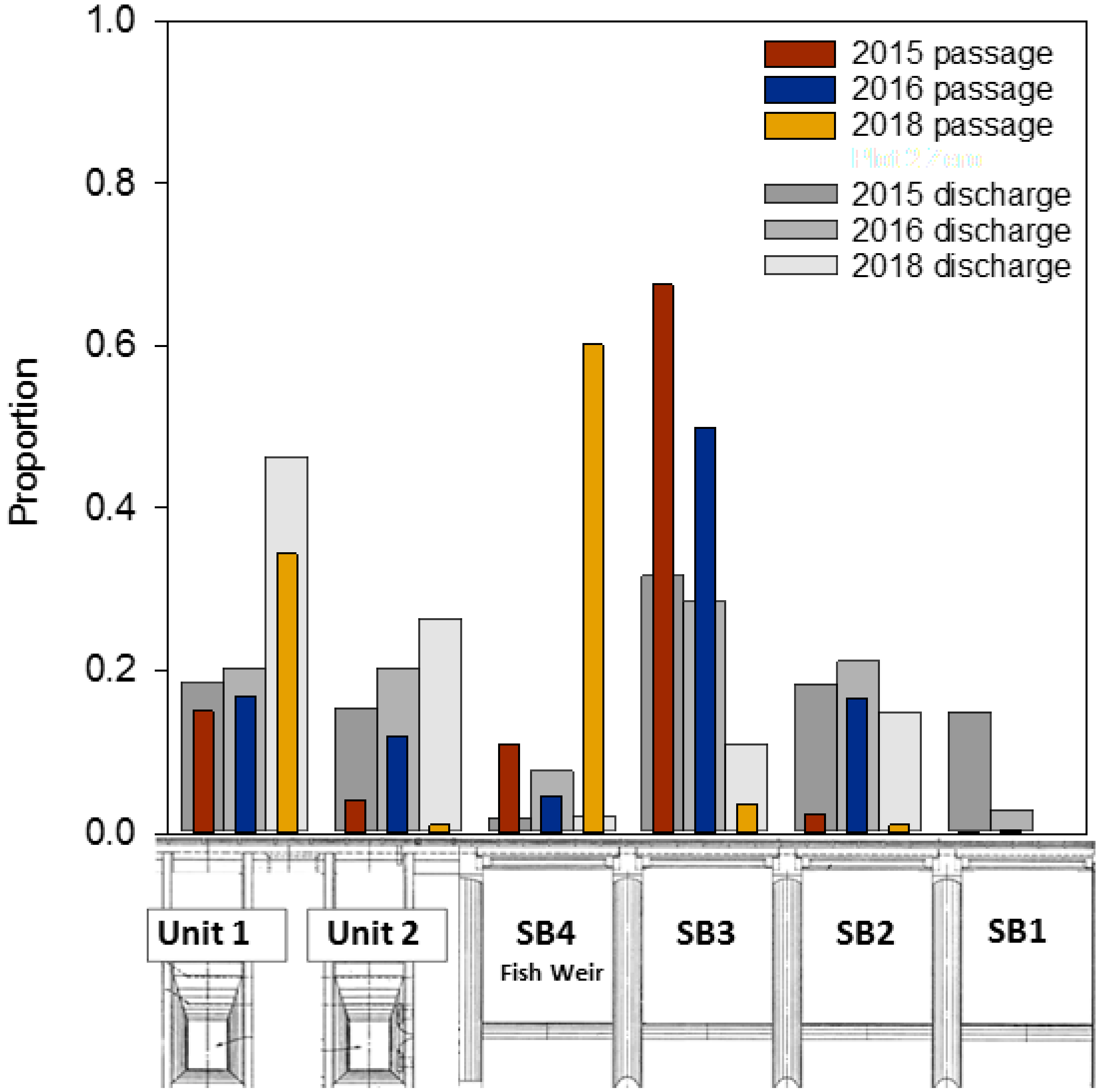

Figure 6.3. Passage Distributions of CH0 at Foster in Fall 2015 (red), 2016 (blue), and 2018 (yellow) during Low Pool Elevation. The gray vertical bars indicate water discharge proportions by route, per year (Appendix D, Table D.11).

In 2018, the proportion of CH0 that passed at night was even greater than in previous years (> 98%; Table 6.4). The proportion of fish passing at night vs. during the day did not vary greatly depending on route of passage.

Table 6.4. Day vs. Night Passage Distributions of CH0 Released above Foster that Passed the Dam during Low Pool in Fall 2015, 2016, and 2018

Fall Low Pool	2015				2016				2018			
	Day		Night		Day		Night		Day		Night	
Location	*n*	Prop.	*n*	Prop.	*n*	Prop.	*n*	Prop.	*n*	Prop.	*n*	Prop.
Overall	32	0.04	821	**0.96**	75	0.08	906	**0.92**	5	0.01	388	**0.99**
Turbine Unit 1	5	0.04	120	**0.96**	19	0.12	146	**0.89**	4	0.03	131	**0.97**
Turbine Unit 2	3	0.08	34	**0.92**	6	0.05	111	**0.95**	0	0.00	4	**1.00**
Spill Bay 1	1	0.50	1	**0.50**	0	0.00	4	**1.00**	0	–	0	–
Spill Bay 2	6	0.30	14	**0.70**	11	0.07	151	**0.93**	0	0.00	4	**1.00**
Spill Bay 3	17	0.03	558	**0.97**	38	0.08	452	**0.92**	0	0.00	14	**1.00**
Fish Weir (Spill Bay 4)	0	0.00	94	**1.00**	1	0.02	42	**0.98**	1	0.004	235	**0.996**

n = number of fish that passed Foster by route per diel period and year.
Prop. = proportion that passed Foster by route per diel period and year.

6.4 Project Passage Metrics

For fall low pool, both the proportion of CH0 detected in the near forebay zone that passed by any route, and the proportion that passed through the new weir, decreased in 2018. CH0 DPE was lower in 2018 (0.557) than in either 2015 (0.816) or 2016 (0.968), and FPE fell by approximately 50% (from 0.648–0.669 to 0.358; Table 6.5; Figure 6.4). The decrease in SPE between the old weir and the new weir study years was not significant (Fisher's exact test, $p \geq 0.99$; Figure 6.5), but SPE for 2015 and 2016 were significantly different from each other (Fisher's exact test, $p < 0.001$). In contrast, FWE differed significantly between all study years (Fisher's exact test, $p < 0.001$ for all pairwise comparisons), and increased by more than fivefold in 2018 compared to 2015 and 2016. In 2018, SBE decreased considerably (0.046) compared to previous years (0.700 and 0.669 in 2015 and 2016, respectively). Taken together, the SPE, FWE, and SBE results indicated that in 2018, compared to 2015 and 2016, a greater proportion of CH0 that passed Foster did so via the new weir. Overall spillway effectiveness doubled, but spill bay effectiveness decreased, owing to the decrease in SBE (Table 6.5). In 2018, as FWE was high and discharge through the weir represented only 2% of total discharge, fish weir effectiveness was exceedingly high (28.699), both compared to previous years and to other fish stocks studied in 2018. It should be noted that Spill Bays 1–3 had limited operation during fall 2018, therefore they were not typically an option as a passage route.

Table 6.5. Passage Efficiencies and Effectiveness for CH0 during Low Pool at Foster in Fall 2015, 2016, and 2018. Dam Passage Efficiency (DPE) and Fish Passage Efficiency (FPE) are calculated relative to the number of fish detected in the near forebay, while all other efficiency metrics are relative to the total number of fish that passed the dam (as indicated by "|| Dam").

	CH0		
Fall Low Pool	**2015**	**2016**	**2018**
DPE	**0.816 (0.009)**	**0.968 (0.004)**	**0.557 (0.019)**
FPE	**0.648 (0.011)**	**0.669 (0.011)**	**0.358 (0.018)**
SPE || Dam	0.810 (0.013)[b]	0.713 (0.015)[a]	0.643 (0.024)[ab]
FWE || Dam	0.110 (0.011)[b]	0.044 (0.007)[c]	0.598 (0.025)[a]
SBE || Dam	0.700 (0.016)	0.669 (0.015)	0.046 (0.011)
Fish Weir Effectiveness	6.261 (0.609)	0.587 (0.088)	28.699 (1.185)
Spill Bay Effectiveness	1.083 (0.024)	1.285 (0.029)	0.178 (0.041)
Spillway Effectiveness	1.220 (0.020)	1.197 (0.024)	2.325 (0.087)

DPE = dam-passage efficiency; proportion of fish passing the dam relative to the number detected in the near forebay (< 100 m from dam-face).
FPE = fish passage efficiency; proportion of fish passing via a non-turbine route relative to the number detected in the near forebay (< 100 m from dam-face).
SPE = spill passage efficiency; proportion of fish that passed Foster through Spill Bays 1–3 and the fish weir in Spill Bay 4.
SBE = spill bay efficiency; proportion of fish that passed Foster through Spill Bays 1–3.
FWE = fish weir efficiency; proportion of fish that passed Foster over the fish weir in Spill Bay 4.
Fish weir/ spill bay/spillway effectiveness = proportion of fish passage through a route relative to the proportion of discharge through the same route.
Shared superscript letters for SPE and FWE indicate no significant differences between estimates, whereas different superscript letters indicate significant differences. Lower-case letters refer to low pool comparisons and upper-case letters refer to high pool comparisons. Absence of superscript letters indicates there were no significant differences.

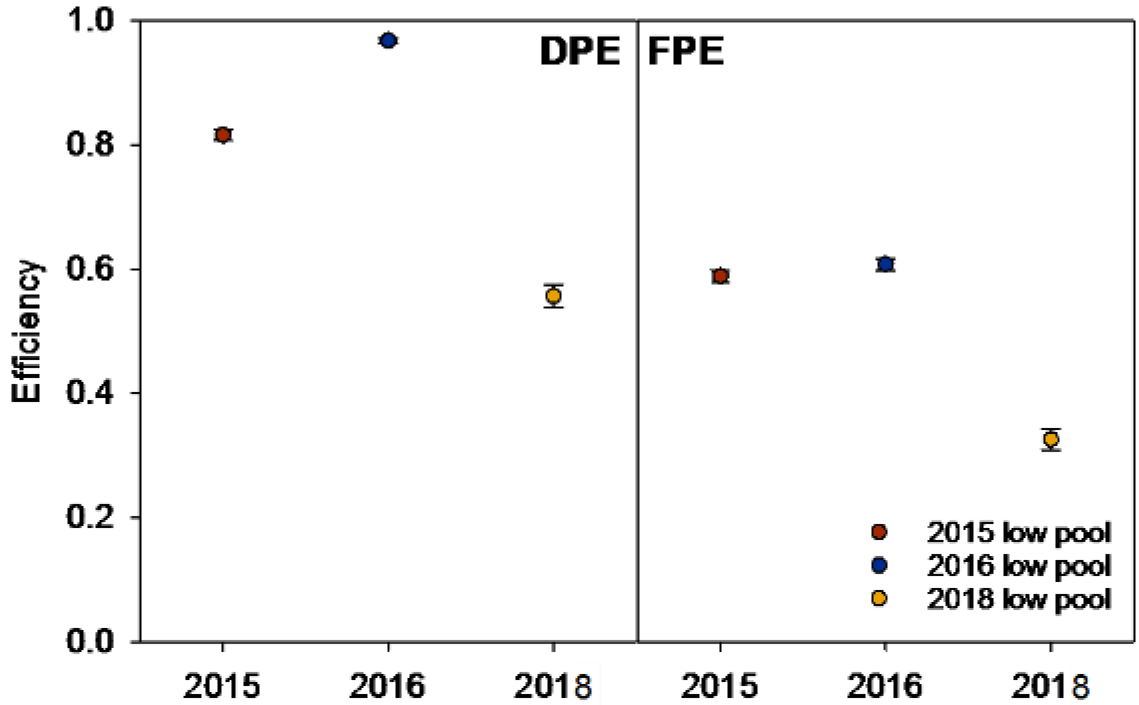

Figure 6.4. Dam-Passage Efficiency (DPE) and Fish Passage Efficiency (FPE) of CH0 at Foster in Fall 2015 (red), 2016 (blue), and 2018 (yellow)

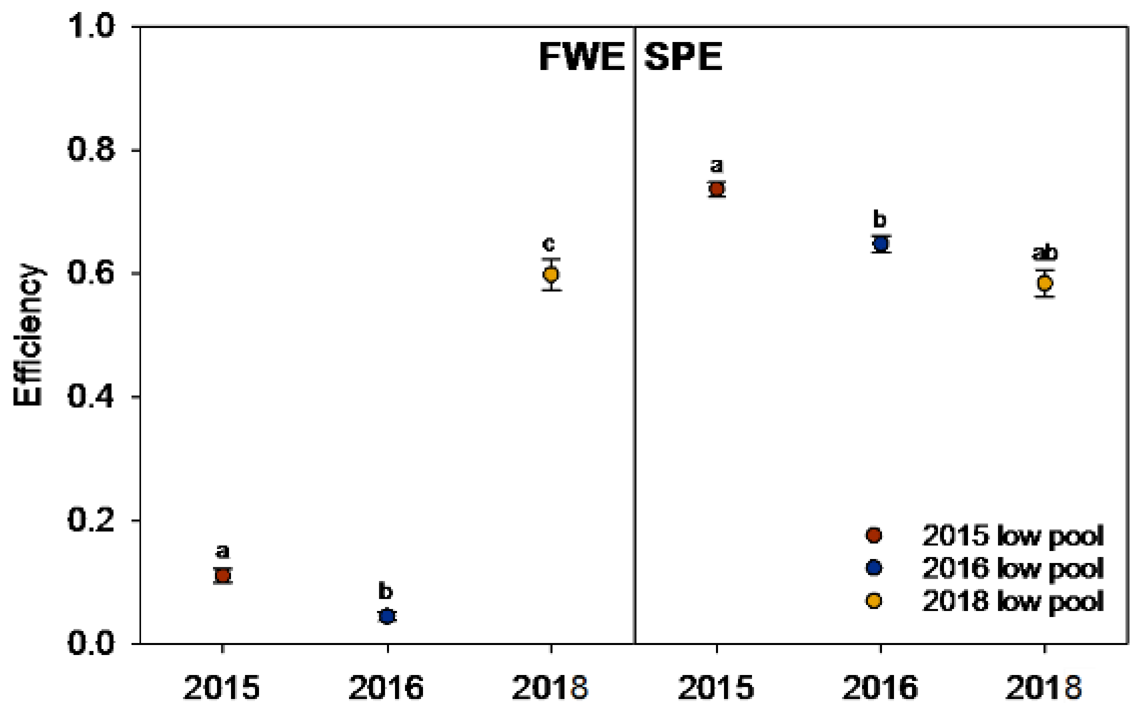

Figure 6.5. Fish Weir Efficiency (FWE) and Spill Passage Efficiency (SPE) of CH0 at Foster in Fall 2015 (red), 2016 (blue), and 2018 (yellow). Shared letter labels indicate no significant difference between estimates, whereas different letters indicate significant differences (Fisher's exact test, $\alpha = 0.05$).

In the fall study period, hourly weir discharge was consistently low (< 500 cfs; Table 6.6); therefore, possible differences in weir efficiency and effectiveness depending on discharge could not be assessed. Results reported in Table 6.6 are identical to the overall fish weir efficiency (FWE) and effectiveness for fall (Table 6.5).

Table 6.6. Fish Weir Efficiency (FWE) and Effectiveness for CH0 that Passed Foster at Low (< 500 cfs) Weir Discharge in Fall 2018

Pool Stage	Weir Discharge	*n*	FWE	Effectiveness
Low Pool	< 500 cfs	236	0.598 (0.025)	28.669 (1.185)

n = number of fish that passed Foster by pool stage and weir discharge level.

6.5 Travel Times

Reservoir residence time, project egress, and travel time through the study area (to the Secondary Array), and to Willamette Falls are presented in Figure 6.6 for CH0 during low pool in fall 2015, 2016, and 2018. For fall low pool, mean reservoir residence time of CH0 varied greatly between years, ranging from 10.1 ± 0.4 d in 2015 to 1.6 ± 0.1 d in 2016; 2018 residence time was 5.3 ± 0.5 d (Figure 6.6). CH0 reservoir residence time differed significantly between all study years (Wilcoxon Signed-Rank Test, $p < 0.001$, Appendix D, Table D.6). All mean travel times between detection arrays were shorter by 50% or more in 2016, compared to either 2015 or 2018. In 2018, CH0 reached Lebanon Dam approximately 4 d after dam passage, on average, and were detected at Willamette Falls an average of two weeks after passing the dam.

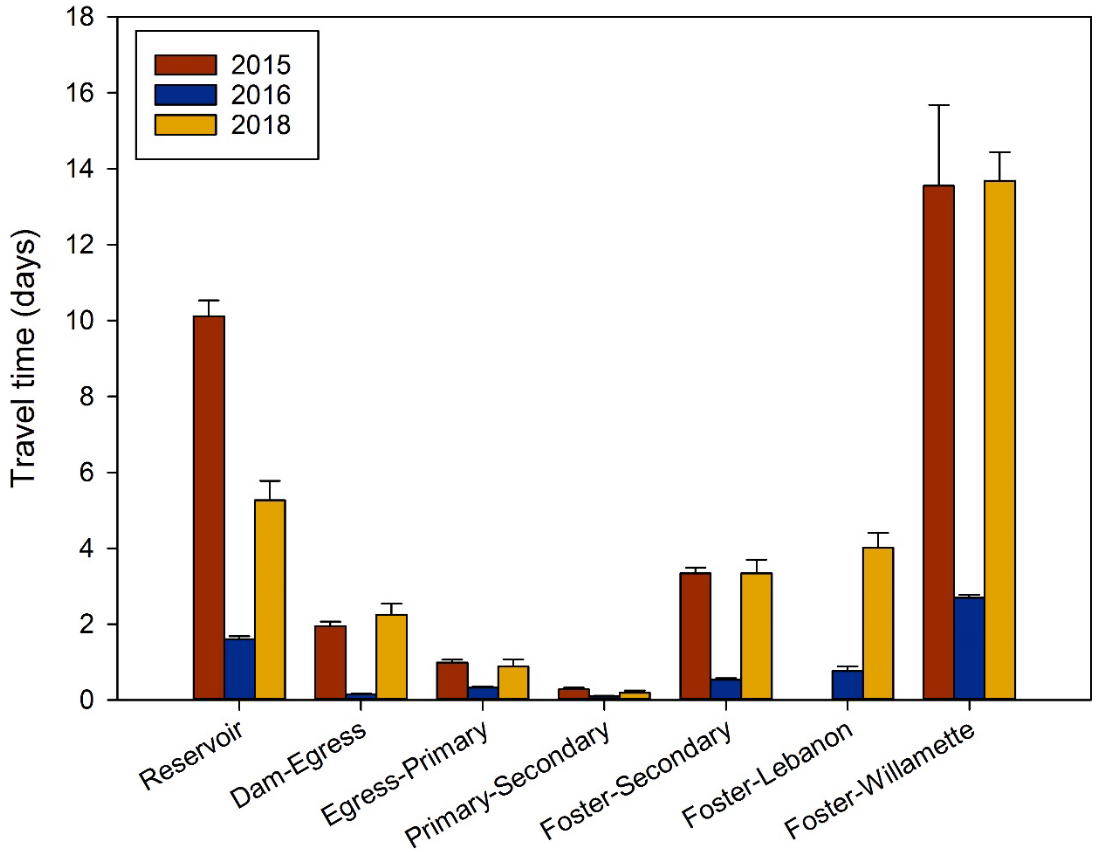

Figure 6.6. Estimated Mean Reservoir Residence Time, Project Egress, and Travel Times (days) between Arrays for CH0 in fall 2015 (red), 2016 (blue), and 2018 (yellow) during Low Pool Elevation. The error bars depict the standard error of the mean.

6.6 Spill vs. Turbine Block Treatment Test

For CH0 at low pool, passage rates during the turbine treatment, when only the turbines were operated, indicated that 100% of all CH0 passing under these conditions did so via the turbines (Table 6.7; Figure 6.7). For the turbine+weir treatment, 96% of CH0 passed via the weir and 4% passed turbines. Total passage was found to differ significantly between treatments, with greater passage during the turbine+weir treatment ($p = 0.003$, Table 6.8). It is noteworthy that the planned treatments for fall 2016 were spill+weir vs. turbine+weir; however, due to highly variable project discharge, these treatments were not always possible and all three operations (turbine+spill+weir) had to be implemented as project discharge required. As such, an opportunistic approach to the spill test analysis for fall 2016 was attempted to determine whether passage rates differed between the three treatments; however, an ANOVA was not possible due to the inconsistencies in prescribed treatments. Figure 6.7 presents total daily passage by treatment for fall 2016.

Table 6.7. Passage Estimates during Fall Low Pool Spill vs. Turbine Operations for CH0 in 2015, 2016, and 2018

Fall Low Pool		CH0					
		2015		2016		2018	
Treatment	**Passage Route**	**Total Passage (*n*)**	**Passage Proportion**	**Total Passage (*n*)**	**Passage Proportion**	**Total Passage (*n*)**	**Passage Proportion**
turbine	Turbine Units 1–2	–	–	–	–	110	1.00
	Weir	–	–	–	–	0	0.00
turbine+weir	Turbine Units 1–2	48	0.38	64	0.90	7	0.04
	Weir	77	0.62	7	0.10	188	0.96
spill+weir	Spill Bays 1–3	434	0.97	441	0.98	–	–
	Weir	14	0.03	7	0.02	–	–
turbine+spill+weir	Turbine Units 1–2	–	–	73	0.28	–	–
	Spill Bays 1–3	–	–	174	0.68	–	–
	Weir	–	–	11	0.04	–	–

Table 6.8. Univariate ANOVA Results for CH0 during Fall Low Pool in 2015 and 2018. Due to highly variable project discharge and inconsistencies, an ANOVA for 2016 was not possible. A *p*-value < 0.05 indicates a significant difference.

Fall Low Pool	Effect	Degrees of Freedom	Sum of Squares	Mean Squares	F-Statistic	*p*-value
2015	Intercept	1	36.47	36.47	372.66	< 0.001
	Block	7	1.29	0.18	1.88	0.12
	Treatment	1	1.96	1.96	19.99	< 0.001
	Error	23	2.25	0.10		
2018	Intercept	1	10.69	10.69	160.59	< 0.001
	Block	11	5.19	0.47	7.08	< 0.001
	Treatment	1	0.77	0.77	11.53	0.003
	Error	22	1.46	0.079		

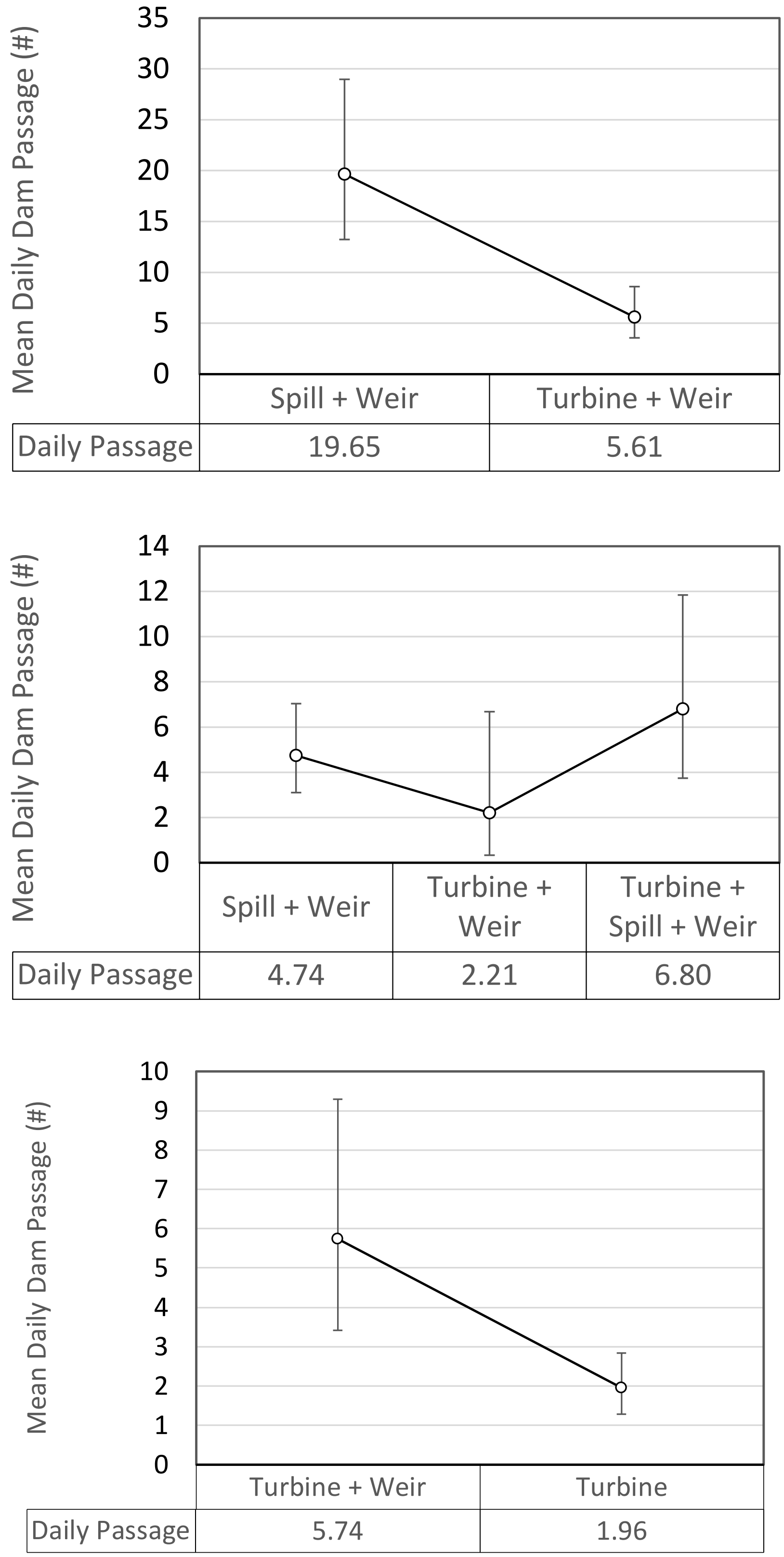

Figure 6.7. Mean Daily Dam Passage (n) of CH0 by Treatment during Fall Low Pool in 2015 (top), 2016 (middle), and 2018 (bottom)

7.0 Discussion

This section includes a discussion comparing fish movement through the study area; survival and passage of study fish, project metrics and travel times; summarizing the spill vs. turbine block treatment test; describing entrainment route detections; and providing a historical comparison of passage estimates at Foster for the 2015, 2016, and 2018 studies. It also includes and evaluation of potential avian predation during the 2018 study.

7.1 Fish Movement through the Study Area

7.1.1 Detections and Passage at Foster

A large proportion of tagged fish were either never detected or were detected but never passed Foster. Regardless of old weir (i.e., 2015 and 2016 study years) or new weir (i.e., 2018 study year), this phenomenon occurred across species, pool elevations, and years. For CH1, the trend was most pronounced during spring high pool in 2015 and 2016 (57–81% never passed), and in 2018 during spring low pool (47% never passed). For STH2 it was most evident during spring low pool in 2015 and 2016 (63–68% never passed), compared to 2018 during spring high pool (67% never passed); see Appendix D for detailed results.

Findings from Romer et al. (2014, 2015, 2016) may offer one explanation for the markedly low numbers of CH1 that passed Foster during spring high pool. Romer et al. (2014, 2015, 2016) suggests a majority of Chinook salmon enter and pass through Foster reservoir as fry during fall low pool. Additionally, Romer et al. (2014, 2015, 2016) suggests there is a strong current through the reservoir at spring low pool that guides fish to a passage route. In fact, a downstream current in Foster reservoir during low pool has been observed to be strong enough to bow out trap nets set in the reservoir (Fred Monzyk, personal communication). Therefore, it is possible the behavior of fry observed by Romer et al. (2014, 2015, 2016) is shared by the tagged CH1 during this study, which may explain the reason greater proportions of CH1 passed during low pool than during high pool. Interestingly, the proportions of CH1 that never passed changed from old weir to new weir evaluations. The number of CH1 that never passed was higher in spring high pool in 2015 and 2016, whereas in 2018 the highest proportion of CH1 that didn't pass was during spring low pool in 2018.

Another explanation as to why a large proportion of CH0, CH1, and STH2 never passed Foster may be because they are rearing in the reservoir. Additional findings from Romer et al. (2016) showed steelhead enter the reservoir at all ages (0-, 1-, and 2-year old), but pass primarily as 2-year olds in the spring months. The proportion of STH2 that were either never detected at the dam and or were detected and failed to pass the dam was comparable among study years (63% in 2015, 70% in 2016, and 63% in 2018). Additionally, few STH2 (4 in 2015 [with 1 of 4 detections occurring in 2016], 4 in 2016 [with 3 of the 4 detections occurring in 2018], and 4 in 2018) and 7 S-STH in 2018 had PIT-detections after the battery life of the RT tag had expired, potentially indicating that STH2 are continuing to rear in the reservoir (Appendix E).

Evidence indicates Chinook salmon may share the same in-reservoir rearing behavior exhibited by steelhead. Although Romer et al. (2014, 2015, 2016) suggest the vast majority of Chinook salmon pass through Foster as fry, a portion of the population undoubtedly stay behind and rear in-reservoir. Schroeder et al. (2016) identified two general Chinook salmon life histories in the Willamette River Basin: "movers" and "stayers." The movers are broken down into fry migrants (which migrate late winter/early spring), such as those described by Romer et al. (2014, 2015, 2016), and subyearling smolts (which migrate in the spring). Similarly, the stayers can be broken down into fall migrants (those that migrate in the fall as subyearlings) and spring migrants (those that overwinter and migrate the following spring as 1-year olds). This study investigated the "stayer" life histories by tagging and releasing subyearlings in the fall and yearlings in the spring. However, post-RT tag life PIT detections suggest a portion of the CH1 released in the spring may have been genetically predisposed to be subyearling movers. For example, the proportion of CH1 that were either never detected at the dam and or were detected and failed to pass the dam was comparable among study years (17% in 2015, 33% in 2016, and 19% in 2018). Additionally, only 9 CH1 were detected post-RT tag life for all study years combined. Specifically, in 2018 only one CH1 was detected at a PIT array after its RT tag battery expired. All CH1 that were detected on PIT arrays post-RT tag life were detected in the fall, as would be expected for a subyearling mover according to Schroeder et al. (2016) (Appendix E). The important difference is these salmon were 1-year olds. However, it still raises the question of if these fish had not been raised in a hatchery (OSU Surrogate Program), would they have emigrated as subyearlings in the fall? Interestingly, CH1 being reared at surrogate facilities have been observed smolting in the fall (as subyearlings), de-smolting, and then re-smolting before being tagged and released the following spring (Karen Cogliati, personal communication). Were those fish genetically predisposed to be subyearling movers? Did the process of smolting and de-smolting leave them too physiologically drained to migrate downstream in the spring? Further research is needed to answer these questions, but presumably one contributing factor to the reason a large proportion of Chinook salmon that were either never detected or were detected but failed to pass Foster in the spring is that some of them are choosing to rear in-reservoir.

Another possible explanation for why notable proportions of study fish, regardless of species, never passed Foster is that they were preyed upon. Foster is home to healthy populations of northern pike minnow (*Ptychocheilus oregonensis*) and smallmouth bass (*Micropterus dolomieu*), both of which are known to prey on juvenile salmonids. Foster reservoir is also a popular sport fishing destination, making it possible that a few of the study fish were removed from the reservoir via hook and line. In spring 2018, ten RT tags were returned to ODFW by fishermen, representing seven S-STH, two STH2, and one CH1. In fall 2018, no RT tags were reported by anglers. The abundance of piscivorous fish and fishermen at Foster likely explains an unknown portion of the fish that were never detected.

Certain fish movement patterns can also bias survival estimates. The lack of migration behavior and long reservoir residence times observed in 2015 and 2016, particularly for STH2, would tend to bias survival estimates low as a relatively high proportion of fish passed Foster and the detection arrays near or after the tag's expected battery life expired. For example, a STH2 observed passing the dam but holding over in the tailrace until RT tag failure, would be recorded as a mortality when it actually was not dead. This behavior has been identified in individual fish capture histories when the time difference of dam passage to detection at a downstream PIT array (Lebanon Dam and Willamette Falls) was greater than the average tag life of ~40 d. To address this in 2018, we increased the sample size of tags used for tag-life analysis to 60 tags. Additionally, to address the large effect that delayed migration (relative to tag life) can have on survival estimates, we calculated tag life-adjusted estimates of survival for 2015, 2016, and 2018 using the methods of Townsend et al. (2006) and program ATLAS.

7.2 Survival, Passage, Project Passage Metrics, and Travel Times

Two models were used to estimate survival in this report. In 2015 and 2016 (i.e., old weir evaluations or baseline data), survival was estimated from Foster passage to the Primary Array (S_1) located ~19 rkm downstream using the CJS model (adjusted for tag life when possible). To achieve a direct comparison of new weir survival (i.e., 2018) to old weir survival (i.e., 2015 and 2016), survival was estimated in the same manner. However, in 2018, a new model (ViRDCt) was also used to isolate dam-passage and route-specific survival from Foster to the Egress Array, which was located just 2.5 rkm downstream. By removing the extra ~16 rkm between the Egress and Primary arrays, the ViRDCt model produced estimates that were more representative of immediate dam-passage survival. ViRDCt dam-passage survival estimates averaged 82% for all seasons and stocks during 2018 (i.e., CH1, STH2, S-STH, and CH0 during low and high pools) compared to the tag life-adjusted CJS estimates during 2018, which averaged 66% for all seasons and stocks, indicating that substantial mortality occurs in the ~16 rkm of tailwaters between the Egress and Primary arrays (Appendix C). It is unknown what proportion of tailwater mortality may be delayed dam-passage mortality owing to injury or stress, compared to the proportion which may be attributable to non-passage-related causes such as predation. In addition to dam-passage and route-specific survival, survival by weir discharge (low and high) was also compared for spring 2018 as another metric to evaluate the new weir design. Finally, passage proportions and travel times were compared for all three study years and seasons.

Passage project metrics had improved accuracy in 2018 compared to 2015 and 2016 because of the addition of three antennas that created the near forebay zone. The near forebay zone improved detection at Foster by creating overlapping coverage nearest the dam-face (< 100 m). We operated under the assumption that these detections would represent fish searching for a route of passage because they were right at the dam-face. In 2015 and 2016, the extended forebay zone was used to estimate detection probability, but did not have the breadth of coverage nearest the dam-face that the near forebay zone did, and could detect fish as far out from the dam-face as 500 m. As such, this likely affected the DPE (the proportion of total fish passing the dam relative to the number of total fish detected in the forebay of the dam) and FPE (the proportion of total fish passing the dam via a non-turbine route relative to the total fish detected in the forebay of the dam) results in 2018 compared to 2015 and 2016. For example, the denominator for DPE and FPE is the total number of fish detected < 100 m from the dam-face. In 2018, we used detections at the near forebay as the denominator. The number of detections at the near forebay was smaller than the number of fish detected in the extended forebay because of the closer range to the dam-face. In 2015 and 2016, the extended forebay was used as the denominator for DPE and FPE (i.e., was a larger number). This could make a big difference in the DPE and FPE results. Because DPE and FPE were divided by a smaller denominator in 2018, the estimate was likely more representative of true DPE and FPE than in 2015 and 2016.

7.2.1 Yearling Chinook Salmon

7.2.1.1 Survival

Dam-passage survival of CH1 to the Primary Array was similar across study years during spring low pool (63% in 2015, 62% in 2016, and 61% in 2018). ViRDCt survival to the Egress Array was 87% for CH1 during low pool in 2018, providing a more representative estimate of immediate dam-passage survival. Interestingly, during spring high pool, CH1 dam-passage survival to the Primary Array was significantly greater in 2015 and 2016 (old weir) than 2018 (new weir) (81% in 2015 and 2016 [pooled], compared to 65% in 2018). The ViRDCt estimate for CH1 during high pool in 2018 was 81%, again observed to be more representative of immediate survival than the 2018 CJS survival.

There were no significant differences in CH1 survival between routes during low pool across study years and the highest estimates of survival were variable. Survival was highest through Spill Bay 3 for low pool study periods in 2015 (old weir) and 2018 (new weir;71% and 72%, respectively); however, in 2016 survival through the old fish weir (78%) was observed to be higher than survival through Spill Bay 3 (65%). Specifically, for the fish weir survival comparing old and new weir evaluations during low pool was not significantly different among study years (66% in 2015 and 2016 [pooled], and 61% in 2018). Because of lack of trends, no conclusive statements can be made above CH1 survival based on for old weir and new weir survival evaluations during low pool.

During high pool, CH1 survival through the old fish weir was significantly greater in 2016 (81%) than 2015 (47%) or with the new weir in 2018 (62%). There were no significant differences for survival through Spill Bay 3 among study years, remaining high for old and new weir evaluations (94%, 89%, and 94% for 2015, 2016, and 2018, respectively). Interestingly, the significantly lower survival of CH1 through the new fish weir in 2018 may be correlated to (or a driver of) the significantly lower 2018 overall dam-passage survival. It may indicate that the fish weir performed poorly for CH1 survival during high pool.

The ViRDCt route-specific survival estimates were pooled by route (i.e., Turbine Units 1–2, fish weir [Spill Bay 4], and Spill Bays 1–3). Survival through the fish weir was estimated to be 92% during low pool and 80% for high pool. For Spill Bays 1–3 survival was 84% during low pool and 92% for high pool. The higher survival estimates observed during high pool (80% for ViRDCt compared to 62% for CJS) may indicate that mortality may not be immediate (i.e., in the first 2.5 rkm downstream), but passage through the weir may have resulted in delayed mortality (i.e., within 19 rkm downstream).

In 2018 we also evaluated CH1 survival at two weir discharge rates, as the design of the new fish weir allowed for more variability in discharge (~300, ~500, and ~800 cfs) than the old fish weir (~250 cfs). However, we were only able to evaluate two discharges; < 500 cfs (low) and ≥ 500 cfs (high). No significant difference in Foster-to-Egress Array survival (S_D) was observed between CH1 that passed the weir at the low weir discharge and those that passed the weir at high discharges (75% and 85%, respectively).

7.2.1.2 Passage Distributions and Effectiveness

Passage distributions varied among study years; however, during spring low and high pools there was a distribution shift to the fish weir in 2018. During spring low pool in 2015 and 2016, the majority of CH1 that passed Foster did so via Spill Bay 3 (50% and 59%, respectively). However, during spring low pool in 2018, the majority of CH1 that passed Foster did so via the fish weir (58%). A comparable number of CH1 passed during low pool in 2018 and 2016, although it was less than in 2015 (n = 262, 269, and 457, respectively). The shift in passage distribution is reflected in the spill bay effectiveness, which incorporates discharge in the evaluation. The spill bays were more effective in 2015 and 2016, compared to 2018, as more CH1 chose that route in 2015 and 2016 than in 2018 (1.12 and 1.44, compared to 0.66, respectively). However, the higher spill bay effectiveness in 2015 and 2016 could have also been a result of more discharge through Spill Bay 3 compared to 2018 (43%, and 37%, compared to 23%). The decrease in spill bay effectiveness in 2018 also resulted in an increase in fish weir effectiveness. Fish weir effectiveness more than doubled in 2018 (3.90) with the new weir compared to 1.12 and 0.49 in 2015 and 2016, respectively with the old weir. This is particularly interesting because the discharge through the weir was very low compared to total project discharge in all study years (15% in 2015 and 2018, 8% in 2016 of total project discharge).

The passage distribution shift to the fish weir in 2018 also occurred during high pool, and there was a greater number of CH1 that passed in 2018 compared to 2015 and 2016 (n =291 compared to 109 and 201, respectively). In 2015 and 2016, the majority of fish passed Foster via Spill Bay 3 (62% and 58%, respectively). In 2018, only 6% of CH1 passed via Spill Bay 3 and 87% passed via the fish weir. This was also evidenced with the shift in spill bay and fish weir effectiveness from 2015 and 2016 to 2018. The spill bays were more effective for old weir evaluations compared to the new weir evaluation (2.71 and 3.1 in 2015 and 2016, respectively, compared to 0.66 in 2018), although there was also a greater discharge through Spill Bay 3 in 2015 and 2016 than in 2018 (23%, 19%, and 8%, respectively of total project discharge). Similar to low pool, the new fish weir was more effective in 2018 (3.05) compared to the old weir in 2015 and 2016 (2.21 and 2.75, respectively), although the discharge through the new weir was also greater in 2018 (28%) compared to the old weir in 2015 and 2016 (16% and 13%, respectively).

Collectively, this may indicate the design of the new fish weir is successfully attracting CH1 as a viable route of passage on the upstream side; however, downstream survival was still lower in 2018 compared to the old weir in 2015 and 2016 during high pool.

7.2.1.3 Project Metrics

The overall trend for the new weir was DPE and FPE were generally comparable or higher than they were for the old weir evaluations. This may be because of the near forebay detection zone that was utilized in 2018 but was not available for 2015 and 2016. Regardless, it is a positive trend, as Foster is better at passing available CH1 than previously thought. For example, during low pool in 2018, DPE was comparable to 2015 and 2016 (0.90 compared to 0.95 and 0.96, respectively), indicating the dam was efficient at passing available CH1 during both old and new weir evaluations. Interestingly, during low pool FPE was higher in 2018 than in 2015 and 2016 (0.76 compared to 0.64 and 0.59, respectively). This indicates the new fish weir may be more efficient at passing CH1 than the old weir.

The increase in DPE and FPE was particularly evident during spring high pool in 2018 (DPE and FPE: 0.85) compared to 2015 (DPE: 0.66; FPE: 0.65) and 2016 (DPE: 0.68; FPE: 0.63). The upstream side of the new weir was successfully attracting fish. This is particularly interesting because the dam-passage survival was significantly lower in 2018 than in 2015 and 2016, even though the dam was more efficient at passing available CH1. The survival through the new fish weir was also lower in 2018 compared to the old weir in 2016, although it was not significantly different than in 2015.

Combining results from survival, passage distributions, and project metrics indicates that operating the spillway and fish weir facilitates downstream passage of juvenile CH1 at Foster. Improvements to the fish weir—including better approach and passage conditions and a higher flow capacity—likely contributed to the increase of CH1 DPE and FPE through that route.

7.2.1.4 Travel Times

Overall CH1 travel times through the study area were not considerably different in the cross-years comparison during spring low pool but trended towards 2018 having the fastest travel times during spring high pool. Specifically, during low pool mean reservoir residence times for CH1 were less in 2018 (1.7 d) than in 2015 and 2016 (2.3 and 2.4 d, respectively), indicating fish moved out at a slightly faster rate. The mean travel times to each of the arrays were generally consistent for all study years, except for travel times to Willamette Falls. CH1 were slowest to travel to Willamette Falls during spring low pool in 2015, but travel times were comparable in 2016 and 2018 (13.6 d compared to 5.0 d and 3.1 d, respectively). These differences are likely explained by a higher average discharge into and out of Foster reservoir during the spring of 2016 and 2018 compared to 2015. In 2018, discharge peaked in mid-April, likely contributing to the quick travel times of fish released during low pool. During high pool, discharges were generally more similar in 2015, 2016, and 2018, and were lower than low pool discharges. Mean reservoir residence time for CH1 during spring high pool was much shorter in 2018 (4.5 d) compared to 2015 and 2016 (9.0 and 11.5 d, respectively), again indicating fish that moved out did so quickly. This did not affect travel times through the rest of the system (i.e., to Willamette Falls) though, as CH1 travel time was still comparable for 2016 and 2018, and faster than 2015 (mean travel times of 6.8 d, 7.5 d, and 10.3 d, respectively). The increased attraction flow design of the new fish weir may also explain why CH1 during low and high pool in 2018 exited the reservoir at a faster rate than CH1 in 2015 or 2016.

7.2.2 Winter and Summer Steelhead

7.2.2.1 Survival

In general, old and new weir evaluations for Foster-to-Primary Array survival did not differ significantly, regardless of pool elevation. Cross-years comparisons of dam-passage survival for STH2 during low pool showed similar estimates in 2015, 2016, and 2018 (61%, 47%, and 55%, respectively) and during high pool (72%, 81%, and 79%, respectively), although STH2 survival during high pool was consistently higher than low pool. This indicates there were no clear survival benefits for STH2 observed during new weir evaluations; however, it also indicates the new weir had no negative effects on STH2 survival either. Taken together, this is a good thing and may demonstrate that STH2 are robust survivors. Similar to the estimates for CH1, the Foster-to-Egress Array ViRDCt survival was higher for STH2 that passed Foster during low and high pools (73% and 89%, respectively). Again, ViRDCt provided a more representative estimate of immediate dam-passage survival.

Route-specific survival was similar for old and new weir evaluations, for low and high pool. During low pool in 2015 and 2016, STH2 had similar survival estimates through both the fish weir and Spill Bay 3 (weir: 67%, and 43% for 2015 and 2016; Spill Bay 3: 57% for 2015 and 2016). This trend was the same for 2018 during low pool (weir: 51%; Spill Bay 3: 56%). During high pool in 2015 and 2016, STH2 survival estimates were exclusively through the fish weir; this trend was the same in 2018 (71%, 81%, and 83% survival, respectively). This supports the conclusions of STH2 as robust survivors, demonstrated by no clear route-specific survival benefits for old and new weir evaluations, and no negative effects on survival.

The ViRDCt route-specific survival estimates were pooled by route (i.e., Turbine Units 1–2, fish weir [Spill Bay 4], and Spill Bays 1–3). During low pool, survival through the weir was 60% and was 85% through Spill Bays 1–3, whereas survival was 94% through the weir during high pool. This finding further supports the same trend that was observed for CH1—that Foster-to-Egress Array ViRDCt survival provided a more representative estimate of immediate route-specific survival.

In 2018, we also evaluated survival at two weir discharge rates, < 500 cfs (low) and ≥ 500 cfs (high). There was no significant difference in Foster-to-Egress Array ViRDCt survival estimates between the low and high weir discharges for STH2 (91% for low, 78% for high), indicating that STH2 survival was unaffected by discharge.

7.2.2.2 Passage Distributions and Effectiveness

Passage distributions for STH2 were generally consistent among study years and pool elevations, regardless of old or new weir, even though a greater number of STH2 individuals passed Foster in 2018 during low pool than in 2015 or 2016 (n = 208 compared to 108 and 69, respectively). During low pool in 2015, 2016, and 2018, comparable proportions of STH2 passed Foster via the fish weir (43%, 44%, and 32%, respectively) and Spill Bay 3 (42%, 30%, and 27%). Spill bay effectiveness increased in 2018 compared to 2016 (0.903 compared to 0.753, respectively), but was similar to 2015 (0.947), even though there was a decrease in project discharge through the route (43%, 37%, and 23%, for 2015, 2016, and 2018, respectively). Similar to findings for CH1, fish weir effectiveness was inversely related to spill bay effectiveness for STH2 and was lower in 2018 compared to 2015 and 2016 (2.160 compared to 2.908 and 4.782, respectively), although it was comparable to 2015. This may have been affected by the low project discharges through the weir in 2018 (8% of total project discharge compared to 15% of total project discharge for 2015 and 2016).

During high pool, STH2 passed via the fish weir almost exclusively, regardless of the old or new weir. For all study years during high pool, 97% of STH2 passed via the weir, although the number of STH2 passing in 2018 was lower than in 2015 or 2016 (n = 110 compared to 171 and 146, respectively). Interestingly, the spill bay effectiveness and the fish weir effectiveness decreased in 2018 compared to 2015 and 2016. In 2018 spill bay effectiveness was 0.046 compared to 0.102 in 2015 and 0.146 in 2016. This is likely due to the lack of STH2 passing Spill Bay 3, coupled with the low discharge through Spill Bay 3 in 2018 (8%) compared to 2015 and 2016 (23% and 19%, respectively). However, fish weir effectiveness was also lower in 2018 than in 2015 or 2016 (3.430 compared to 5.992 and 7.353, respectively), even though discharge was greater (28% compared to 16% and 13%, respectively). It is unclear why spill bay effectiveness and fish weir effectiveness were both lower in 2018; however, it did not affect passage distributions or survival of STH2 compared to old weir evaluations.

With survival, passage distributions, and project metrics considered, it is apparent that for both old and new weir evaluations, STH2 use the fish weir as the preferred passage alternative during spring high pool; however, there does not appear to be a distinguishable passage preference for STH2 during spring low pool because the spillway and fish weir appear to be equally beneficial.

7.2.2.3 Project Metrics

During low pool, the overall trend for the new weir was DPE and FPE were relatively consistent for the cross-years comparison, even though the near forebay detection zone was utilized in 2018 (DPE ranged from 0.43–0.53 and FPE ranged from 0.32–0.38 in 2015, 2016, and 2018). This indicates the new weir did not increase the efficiency of Foster passing available STH2, although there were no negative effects on DPE and FPE either.

For high pool the overall trend for the new weir was DPE and FPE decreased in 2018 compared to old weir evaluations. For STH2 in 2018, DPE and FPE were 0.38 and 0.37, respectively. This was considerably lower than the DPE and FPE compared to 2015 (0.76 and 0.75, respectively) and 2016 (0.67 and 0.65, respectively). The new weir was not efficient at passing available STH2 during high pool; however, survival was not affected in 2018 compared to the old weir in 2015 and 2016.

7.2.2.4 Travel Times

Similar to CH1, STH2 had faster travel times in 2016 and 2018 compared to 2015, likely because of higher discharge. However, STH2 travel times were notably different between the spring low and high pools. During low pool in 2018, STH2 reservoir residence time was longer than 2015 or 2016 (10.1 d compared to 6.6 d and 4.3 d). This did not affect travel times for STH2 in 2018 compared to 2015 and 2016, as fish traveled faster in 2018 to the Willamette Falls Array (15.7 d) compared to 2015 (27.4 d) and 2016 (23.3 d).

During high pool, STH2 reservoir residence time in 2018 was intermediate to 2015 and 2016 (23.3 d, compared to 25.3 d and 17.3 d, respectively). Travel times to Willamette Falls were more consistent during high pool (7.5 d [2015], 5.7 d [2016], and 6.7 d [2018]). The reason for the differences between low and high pool travel times for STH2 is unknown and cannot be directly related to project discharge or other operational patterns, because discharge was higher in the South Santiam at low pool than at high pool, yet STH2 traveled faster during high pool (once they left the reservoir; Figure 3.2). This trend continued for spring high pool with the long reservoir residence times during high pool suggesting that it may take STH2 more time to find a passage route from Foster, even with the new weir design.

7.2.2.5 Comparison between Winter and Summer Steelhead

In 2018, we compared all dam-passage metrics between S-STH and STH2 to determine whether S-STH were viable as surrogates for STH2. Overall, the dam-passage behavior of S-STH and STH2 were virtually indistinguishable at low pool. At high pool, S-STH traveled through the reservoir more quickly, and passed the dam in greater proportions, but passage distributions and survival rates remained very similar to STH2.

Summer steelhead Foster-to-Primary Array survival did not differ significantly from STH2 survival, at either low pool (S-STH: 47%, STH2: 55%) or high pool (S-STH: 73%, STH2: 79%). The Foster-to-Egress Array ViRDCt survival was also statistically similar, both at low pool (S-STH: 72%, STH2: 73%) and at high pool (S-STH: 83%, STH2: 89%). In addition, route-specific survival did not differ significantly, and S-STH survival, like STH2 survival, was unaffected by weir discharge rate.

Passage distributions for S-STH and STH2 were generally similar to one another at both low and high pool stages. At low pool, similar proportions of released fish passed Foster (S-STH: 39%, STH2: 41%, Appendix D, Table D.10). Approximately 33% of S-STH passed via the weir (vs. 32% of STH2) and 35% of S-STH passed via Spill Bay 3 (vs. 27% of STH2; Appendix D, Table D.8). Additionally, spill bay and fish weir effectiveness were comparable for S-STH and STH2 during low pool (spill: 1.11 and 0.92, respectively; weir: 2.23 and 2.19, respectively). A significantly greater proportion of high-pool-released S-STH passed Foster, compared to STH2 (40% compared to 27%; Appendix D, Table D.9 and Table D.10); however, passage distributions remained similar. Both species passed almost exclusively through the fish weir (S-STH: 98%, STH2: 97%). The spill bay and fish weir effectiveness were again similar for S-STH and STH2 (spill: 0.08 and 0.05, respectively; weir: 3.45 and 3.43, respectively). The DPE and FPE of S-STH were comparable to STH2 during low pool (0.44 and 0.34 for S-STH, respectively, and 0.46 and 0.32 for STH2, respectively). However, DPE and FPE were higher for S-STH than STH2 during high pool (0.52 for both DPE and FPE for S-STH and 0.38 and 0.37 for STH2, respectively). This indicates that at high pool, the dam was more efficient at passing available S-STH than STH2.

During low pool, S-STH and STH had comparable mean reservoir residence times (8.5 d and 10.1 d, respectively). However, S-STH appeared to move out of the reservoir at a much faster rate than STH2 during high pool, with a mean of 11.4 d compared to 23.3 d.

7.2.3 Subyearling Chinook Salmon

7.2.3.1 Survival

Overall dam-passage Foster-to-Primary Array survival of CH0 during fall low pool was generally high but differed significantly among study years. Interestingly, survival of CH0 during the new weir evaluation year (2018) was statistically different than the old weir evaluation years (2015 and 2016) but was intermediate to the two. Survival was highest in 2015 at 86%, lowest in 2016 at 76%, and was intermediate in 2018 at 81%. Because 2018 was intermediate, the differences in survival could be indicative of inter-annual environmental variability or operations, as opposed to effects caused by the old weir design compared to the new weir design. The Foster-to-Egress Array ViRDCt survival estimate in 2018 was again higher than the CJS estimate (88%), providing a more representative immediate dam-passage survival estimate.

For CH0 route-specific survival during fall low pool, there were no significant differences among routes for turbine units or for the fish weir. However, there were significant differences in survival through Spill

Bays 1–3. Similar to the overall dam-passage survival, 2018 was intermediate to 2015 and 2016, although it was not statistically different from either year (83% compared to 88% and 78%, respectively). In general, survival was moderate (> 67%) through all available routes of passage. It should be noted that in 2018 there was no spill treatment due to a low water year, although Spill Bay 3 was in operation on 23 days (duration of operations varied) during the fall data collection period (total of 105 days from October 23, 2018 to February 4, 2019). Spill Bay 2 was also in operation for 17 of the same 23 days as Spill Bay 3 (duration of operations varied). It was also in operation for an additional 15 days (totaling 32 days in operation, of 105 days of data collection). As such, the estimates from 2018 need to be interpreted with caution, as only 12 CH0 passed through Spill Bay 3.

The ViRDCt route-specific survival estimates were pooled by route (i.e., Turbine Units 1–2, fish weir [Spill Bay 4], and spillway [Spill Bays 1–3]). Once again, the Foster-to-Egress Array survival of CH0 was representative immediate route-specific passage survival estimate, as survival through the fish weir was estimated to be 89% and 100% through the spillway (albeit a small sample size).

7.2.3.2 Passage Distributions and Effectiveness

Similar to CH1, passage distributions shifted to the new fish weir in 2018 for CH0 during fall low pool. During fall low pool in 2015 and 2016, the majority of CH0 that passed Foster did so via Spill Bay 3 (68% and 50%, respectively). However, during fall low pool in 2018, the majority of CH0 that passed Foster did so via the fish weir (60%), despite relatively low discharge through that route (range: 278–470 cfs; mean: 355 cfs). There were fewer CH0 that passed during low pool in 2018 compared to 2015 and 2016 (n = 393 compared to 853 and 981, respectively), although the total number of CH0 that were released was also smaller (n = 738 compared to 1,222 and 1,352, respectively). The shift in passage distribution is also reflected in spill bay effectiveness. The spill bays were more effective in 2015 and 2016, compared to 2018—keeping in mind the Spill Bays 1–3 had limited operation in 2018 compared to 2015 and 2018—at 1.08 and 1.29, compared to 0.18, respectively. The higher spill bay effectiveness in 2015 and 2016 was also likely a result of more discharge through Spill Bay 3 compared to 2018 (32%, and 28%, compared to 2%). The low spill bay effectiveness in 2018 may again be inversely correlated to the extremely high fish weir effectiveness, which more than quadrupled in 2018 (28.70) compared to 2015 and 2016 (6.26 and 0.59, respectively). Discharge may have influenced the new fish weir effectiveness, as there were only two open passage routes for the majority of the season (turbines and weir). Discharge through the old weir was extremely low in 2015 and 2016 (2% and 8% of total project discharge, respectively) compared to 2018 (60% of total project discharge).

Considering survival, passage distributions, and project metrics, it appears that the spill bays are the preferred alternative for facilitating downstream passage of CH0 at Foster, although the fish weir may also be an effective route of passage for CH0 when the spill bays are not available.

7.2.3.3 Project Metrics

For CH0, DPE and FPE were much lower in 2018 during new weir evaluations than during old weir evaluations in 2015 and 2016, even though the near forebay detection zone was utilized in 2018. In 2018, DPE was 0.56 compared to 0.82 and 0.97 in 2015 and 2016, respectively, and FPE in 2018 was 0.36 compared to 0.65 and 0.67 in 2015 and 2016, respectively. This may indicate that even though the near forebay detection zone was used as the DPE and FPE denominator in 2018 and should only be using CH0 closest to the dam, those CH0 still did not want to pass. The CH0 were not being entrained in any flow, and potentially did not have the disposition to pass (i.e., they were stayers, supported by the hypothesis by Romer et al. [2014, 2015, 2016], even though they were right at the dam-face). It is also possible fewer

CH0 that were available to pass actually passed due to the low water year (resulting in reduced attractant flows), with no large discharge peaks (such as the peaks observed in 2015 and 2016).

7.2.3.4 Travel Times

CH0 travel times through the study area and to Willamette Falls were very different for fall low pool in 2015 and 2018 compared to 2016, although the trend of faster travel times in 2016 held true for CH0 for all travel times. Mean reservoir residence time was much shorter in 2016 (1.6 d). However, 2018 was intermediate to the old weir study years and was much faster than 2015 (5.3 d compared to the 10.1 d, respectively). This is interesting as 2018 was a low water year and fish moved out of the reservoir quicker than in 2015 despite the lower discharge. Although CH0 moved out at a faster rate in 2018 than 2015, it did not indicate that fish traveled faster through the rest of the system. Mean travel times to Willamette Falls were slowest in 2018 (13.7 d) compared to 2015 (10.0 d) and 2016 (2.7 d). These between-year discrepancies and fast travel times for CH0 in 2016 may be explained by the higher rates of discharge at Foster earlier in the fall during 2016 (i.e., November) than in 2015 (i.e., December), whereas discharge stayed relatively consistent for 2018 when more CH0 were passing Foster.

7.3 Spill vs. Turbine Treatment Test

The objective of the spill vs. turbine treatment tests during 2015, 2016, and 2018 was to examine the efficacy of spill as a non-turbine passage route for juvenile salmon and steelhead at Foster. The null hypothesis for this evaluation was total passage was equivalent among treatment blocks. Two treatments were tested in 2015: turbine+weir and spill+weir. In 2016, three treatments were tested during spring low pool and fall low pool: turbine+weir, spill+weir, and turbine+spill+weir, and only two treatments during spring high pool (turbine+weir and spill+weir). The pseudo-randomized treatment blocks in spring 2018 were similar to 2015, with two treatments tested: turbine+weir and spill+weir. However, due to a low water year and the unavailability to pass water through the spillways in fall 2018, different treatments were tested: turbine only and turbine+weir.

Ultimately, there was a lot of variability in spill vs. turbine tests for each study year, season, and stock (Table 4.6; Table 4.8; Table 5.6; Table 5.8; and Table 6.5), due in part to environmental and operational conditions. As such, the variability among study years resulted in an ambiguous conclusion on treatments. There were some significant differences identified by species and by pool within years; however, examination of project passage metrics during the 2018 spring study confirms the suggestions made in 2015 and 2016; spill can be used as an effective non-turbine passage route for juvenile salmon and steelhead at Foster. The spillway provides a viable alternative to the turbines for downstream fish passage for CH1 and CH0, and the weir provides a viable alternative for STH2. However, the new fish weir was successful in attracting and collecting fish, as was evident with project passage metrics, proportions, and survival in 2018.

7.4 Entrainment Route Detections

In spring 2015, one CH1 was detected in the AWS at Foster. It passed Foster via Turbine Unit 1 and entered the AWS for a short period of time (~16 minutes), with a strong signal strength. In spring 2018 three STH2 were detected in the AWS. One STH2 passed via Turbine Unit 2, one passed via Spill Bay 3, and the third passed the dam but route of passage could not be determined. Pre-season testing of the AWS RT antennas for all study years confirmed that a strong tag signal can only be detected in close proximity to the antenna itself and not outside the AWS in the adjacent fish ladder. This solidifies the fact that, at minimum, the RT tags were in the AWS; however, these same tags were also detected downstream, and three of the four fish were also detected at the Egress Array (the STH2 that passed via Turbine Unit 2 in 2018 was not detected at the Egress Array). This indicates movement into, within, and out of the AWS. No other tags were detected in the AWS, FWS, or HWS in spring 2015 or 2018, and no tags were detected in the AWS, FWS, or HWS during fall 2015, spring or fall 2016, or fall 2018.

7.5 Historical Context

For historical comparison, hydroacoustic estimates from the 2013–2014 fish passage evaluation at Foster are presented with 2015, 2016, and 2018 RT passage distributions during spring low pool, high pool, and fall low pool elevations in Table 7.1. RT passage distributions in 2015, 2016, and 2018 showed similar trends among seasons—the highest proportions of study fish passed via the fish weir in Spill Bay 4 and conventional Spill Bays 1–3. In contrast, hydroacoustic passage estimates from 2013–2014 noted the highest proportions of juvenile-sized targets passing via Turbine Unit 1 (Hughes et al. 2014). It is important to note that hydroacoustic technology does not utilize active tags; it is a passive sonar tool that identifies swim bladders in passing fish. It can estimate the total number of fish passing by a specific route although it cannot determine fish species because unique identifiers (i.e., tags) are not used. Hughes et al. (2014) noted that large proportions of yellow perch were also observed passing Foster in 2013 and 2014. With the advantage of RT technology, the results from the 2015, 2016, and 2018 studies have effectively noted that CH1 and STH2, and S-STH for 2018, use non-turbine routes of passage in greater proportions than were observed during the hydroacoustic evaluation in 2013–2014.

Table 7.1. Historical Comparison of Passage Distributions from the Hydroacoustics Study in 2013–2014 and Radio Telemetry Evaluations in 2015, 2016, and 2018

	2015 Radio Telemetry		2016 Radio Telemetry		2018 Radio Telemetry			2013–2014 Hydroacoustics
Pool Elevation	**Chinook Salmon**	**Winter Steelhead (Age-2)**	**Chinook Salmon**	**Winter Steelhead (Age-2)**	**Chinook Salmon**	**Winter Steelhead (Age-2)**	**Summer Steelhead (Age-1.5)**	**N/A**
Spring Low Pool	**March–April (2015)**		**March–mid-April (2016)**		**March–April (2018)**			**March–April (2014)**
Turbine Unit 1	0.326	0.148	0.189	0.189	0.095	0.188	0.103	0.647
Turbine Unit 2	–	–	0.182	0.072	0.065	0.120	0.121	0.134
Fish Weir (Spill Bay 4)	0.171	0.426	0.045	0.435	0.573	0.322	0.328	0.009
Spill Bays 1–3	0.503	0.426	0.584	0.304	0.267	0.370	0.448	0.210
Spring High Pool	**May–June (2015)**		**end-April–June (2016)**		**May–June (2018)**			**April–May (2014)**
Turbine Unit 1	0.018	0.006	0.040	–	0.003	0.018	0.005	0.478
Turbine Unit 2	–	–	0.020	–	0.866	–	–	0.037
Fish Weir (Spill Bay 4)	0.358	0.971	0.363	0.973	0.058	0.973	0.979	0.116
Spill Bays 1–3	0.624	0.023	0.577	0.027	0.072	0.009	0.016	0.369
Fall Low Pool	**October–December (2015)**		**October–December (2016)**		**October–December (2018)**			**September–November (2013)**
Turbine Unit 1	0.150	–	0.168	–	0.344	–	–	0.643
Turbine Unit 2	0.040	–	0.119	–	0.010	–	–	0.124
Fish Weir (Spill Bay 4)	0.110	–	0.045	–	0.601	–	–	0.048
Spill Bays 1–3	0.700	–	0.668	–	0.046	–	–	0.186

N/A = Not Applicable

7.6 Fish Injury and Sensor Fish Studies

Generally, passage through the spill bay or weir routes was thought to be preferable to passage through the turbines. In 2018, survival of fish passing via the new weir was usually higher than turbine survival, but lower than survival of fish passing through unmodified spill bays. Survival rates of fish passing the new weir were as low as 51% (STH2 during low pool in 2018), although these survival rates were no lower than some survival rates identified for the old weir (47% for CH1 during high pool in 2015).

Causes of weir-passage mortality at Foster have been investigated using fish injury studies. In 2012, Normandeau Associates Inc., used balloon tags to evaluate survival and injury rates for juvenile steelhead passing through the old weir at Foster. In 2018, Normandeau repeated the study for the new weir, and juvenile Chinook survival and injury rates were also evaluated (Normandeau 2019). Normandeau 2012 and 2018 results are compared to Foster 2015, 2016 and 2018 RT survival estimates in Table 7.2.

For steelhead released at low pool, Normandeau (2019) reported high survival (99.7%) and injury-free (88%) rates. By contrast, the CJS and ViRDCt survival estimates from our RT study were much lower for STH2 during the same pool stage (51% and 60%, respectively). High pool estimates were in better coherence. Normandeau reported 96% survival and 85% were injury-free, while 94% of RT-tagged STH2 survived to the Egress (ViRDCt) and 83% survived to the Primary Array (CJS).

Normandeau (2019) found that nearly all Chinook salmon released at low pool survived (98%), and that 89% were injury-free. However, out of all juvenile fish groups they tested, Chinook salmon released at high pool had the highest rates of injury and mortality and the results varied by release day. For example, on day 1, 77% survived and 62% were injury-free, while on day 2, 89% survived and 86% were injury-free. Our RT study ViRDCt survival estimates were also lower for CH1 passing at high pool (80%) than at low pool (92%); however, CJS survival was approximately the same at both pool stages (61–62%).

Injury and mortality rates from Normandeau (2019) balloon tag studies do not appear to offer an explanation for poor low-pool STH2 survival rates in our RT study; however, they do provide context for lower CH1 survival at high pool. Over 18% of balloon-tagged Chinook salmon that passed through the weir at high pool had scrapes and/or bruising of the head, 12% had hemorrhaged eyes, and 7% had damage to the operculum. Head injuries in particular are likely to negatively impact long-term survival.

Sensor Fish devices were also used to compared physical characteristics of passage through the new weir to the old weir (Deng et al. 2019). After installation of the new weir, the number of severe impact events onto the concrete chute decreased at both high and low pool elevations, as did the magnitude of maximum acceleration at impact. However, the hydraulic conditions did not improve as greatly for high-pool passage as they did for low-pool passage. The increased likelihood of severe impact during high pool passage compared to low-pool passage may explain higher prevalence of injury and decreased survival in Chinook salmon that pass through the weir at high pool.

Table 7.2. Historical Comparison of Survival from the Normandeau Associates 2012 and 2018 Direct-Injury Study and RT Evaluations in 2015, 2016, and 2018 for Yearling Chinook Salmon (CH1), Age-2 Winter Steelhead (STH2), and Subyearling Chinook Salmon (CH0)

	2015 Radio Telemetry[(a)]			2016 Radio Telemetry[(b)]			2018 Radio Telemetry[(c)]			2012 Normandeau Assoc.[(d)]	2018 Normandeau Assoc.[(e)]	
Pool Elevation	**CH1**	**STH2**	**CH0**	**CH1**	**STH2**	**CH0**	**CH1**	**STH2**	**CH0**	**CH1**	**STH2**	**CH0**
Low												
Turbine Unit 1	0.487	0.563	0.755	0.529	0.385	0.718	0.480	0.520	0.783	0.740–0.854		
Fish Weir (Spill Bay 4)	0.636	0.667	0.869	0.778	0.433	0.767	0.613	0.509	0.818	0.995	98.0	99.7
High												
Turbine Unit 1	–	–	–		–	–	–	–	–	0.759–0.882		
Fish Weir (Spill Bay 4)	0.467	0.713	–	0.809	0.811	–	0.624	0.829	–	0.944	84.7	95.9

(a) Hughes et al. 2016.
(b) Hughes et al. 2017.
(c) Current results.
(d) Normandeau 2013.
(e) Normandeau 2019.

7.7 Avian Predation

Avian predation has been recognized as an additional factor hindering the recovery of several ESA-listed salmonid populations in the Columbia River basin, including Chinook salmon and steelhead (NOAA 2008; Evans et al. 2012, Hostetter et al. 2012). Although not as extensively studied in the Willamette River basin, there is evidence to suggest that salmonids may be experiencing high levels of avian predation at Foster.

Estimating avian predation was not an objective of our study, but we noticed an increase in the number of double-crested cormorants (*Phalacrocorax auritus*) sitting on the log boom in the Foster forebay during fish releases. As such, we performed post-hoc analyses to estimate avian predation in Foster reservoir. We predicted a fish had been preyed upon by a piscivorous bird based upon abnormalities in the capture histories generated from the RT data. Abnormalities in these data included extremely rapid downstream movement (i.e., < 2 min) between arrays below the dam, unexpected travel times in and around the reservoir, and detections in the forebay after the fish had been detected at downstream arrays.

In spring 2018, we estimated that at least 2.9% (n = 57) of the study fish detected in the forebay of Foster (n = 1,939) were preyed upon by birds. Of these predated fish, 2.7% (n = 18) were CH1, 3.4% (n = 26) were STH2, and 2.5% (n = 13) were S-STH. Interestingly, most (i.e., 82%, n = 52 of 57) predation occurred during low pool (between release dates of March 20 and April 3, 2018). Additionally, most of the predated fish (54%, n = 31 of 57) were released at the head of reservoir. Fish were preyed upon proportionally across species and length distributions; however, avian predators appeared to avoid selecting the smallest study fish. The explanation behind these trends is currently unclear.

In fall 2018, avian predation was also observed at Foster, but in lower numbers. In fall, we estimated at least 1.8% (n = 13 of 711) of CH0 detected in the forebay were preyed upon by birds. The lower number of predated fish could be attributed to fewer number of released fish in the fall than the spring, or the release of only one species, CH0. The fall study period occurs during low pool, which was also the elevation at which the majority of fish were predated on during the spring season. Generally, CH0 were preyed upon proportionally across length distributions while excluding the smallest released fish. Again, potential explanations for these trends are difficult to discern.

Although an avian predation estimate of 2.9% may not seem like a high statistic, it is a cause for concern because it is a minimum estimate. Our threshold for concluding that a fish had been preyed upon was strict and we could not account for fish that were undetected in the reservoir, so predation is likely higher. Our estimates of salmonid mortalities attributed to avian predation are higher than previous studies in the Willamette River basin. Zamon et al. (2014) observed predation rates of < 1.0% for double-crested cormorants on Upper Willamette River Chinook salmon. However, their predation estimates were calculated from PIT-tagged groups of salmonids at Sullivan Dam and tag recovery at East Sand Island, Oregon (Columbia River). Furthermore, the authors concluded their findings were limited to specific tagging groups and may not be an accurate representation of avian predation throughout the entire basin. A study by Evans et al. (2012) reported minimum annual predation rates of 0.4–3.1% by double-crested cormorants and Caspian terns (*Hydroprogne caspia*) on Chinook salmon in the Willamette River basin based upon PIT tag retrievals on East Sand Island. Our results may not be directly comparable to Evans et al. (2012) or Zamon et al. (2014) because both studies generated predation estimates using a multistep modeling approach and PIT tag recoveries from bird colonies near the mouth of the Columbia River, and their study fish were wild-caught and tagged with PIT and acoustic tags. Our study occurred in the Willamette River basin and our fish were wild surrogates and tagged with PIT and RT tags. However, these studies may still allow for a general comparison of avian predation.

Collectively, our estimates suggest a portion of salmonid mortality at Foster is likely due to piscivorous birds. Fluctuating environmental conditions at hydroelectric projects such as discharge, water flow, river conditions, turbidity, and temperature may also increase a juvenile salmonid's susceptibility to predation during out-migration through reservoirs and high-head dams (Gregory 1993; Schreck et al. 2006; Evans et al. 2012; Hostetter et al. 2012). For instance, decreased discharge has been strongly associated with higher rates of Caspian tern predation on steelhead smolts (Hostetter et al. 2012). Additional research is needed to provide a better understanding of the magnitude and influence of avian predation at Foster, as an accurate assessment of specific mortality factors is critical for the recovery of ESA-listed species (Hostetter et al. 2012).

8.0 Conclusions and Recommendations

This report presents the RT evaluation of fish passage and survival at Foster on the South Santiam River in Oregon during 2015, 2016, and 2018. The RT arrays and tags performed well. The probability of fish bearing RT tags and being detected at the dam-face telemetry array was > 90% for all study years. For downstream arrays, the probability of being detected ranged from ~62 to ~97%, and varied by season, discharge, and fish stock. Detection probabilities at the survival arrays (i.e., Primary and Egress arrays) ranged from 86 to 99%. Data derived from the RT evaluation of juvenile salmonid passage at Foster in 2015 and 2016 (i.e., old weir) compared to 2018 (i.e., new weir) support the following conclusions:

- Passage and Survival Synthesis
  - Overall, the modifications to the weir may have contributed to some improved rates of dam passage (DPE and FPE), attracted a greater proportion of fish to the new weir passage route (CH1 and CH0 in particular), and had minimal impact on survival. A higher proportion of high-pool-released CH1 and low-pool-released STH2 passed Foster after installation of the new weir, while low-pool CH1 and high-pool STH2 passage rates did not vary substantially. Although lower proportions of CH0 passed Foster in 2018 than in previous years, this was likely attributable to differences in dam operations in fall 2018 (lower project discharge) compared to previous fall seasons (higher project discharge). In addition, while STH2 passage distributions remained relatively constant, the new weir was successful in passing a greater proportion of all dam-passed CH1 and CH0, likely due to increased weir discharge and attractant flow. As a result, at low pool, the proportion of CH1 passing through the turbines declined with the installation of the new weir. Dam-passage survival generally remained unchanged, except for CH1 high pool survival, which decreased. This was not caused by lower route-specific survival through the new weir compared to the old weir, but rather by the shift in passage distributions from Spill Bay 3, the route with the highest survival, to the weir, which had somewhat lower survival.
- Survival
  - Survival was higher through non-turbine routes of passage (spill bays and fish weir) than through turbine units for all pool elevations, fish stocks, and study years, regardless of old or new weir design.
  - Dam-passage survival of CH1 was not significantly different for the low pool elevation. However, survival observed during the high-pool old-weir evaluations (i.e., 2015 and 2016) was significantly higher than survival observed in 2018 (new weir). The main driver for the difference in high-pool survival in 2018 was decreased passage through Spill Bay 3—the route with the highest survival estimates for all study years—and increased passage through the weir, which had somewhat lower survival.
  - Dam-passage survival of STH2 was not significantly different across study years (old or new weir) at low or high pool elevations.
  - During spring 2018, S-STH dam-passage and route-specific survival were not significantly different than STH2, regardless of pool elevation.
  - Dam-passage survival of CH0 was significantly different across study years at low pool. New weir survival (2018) was intermediate to survival estimates observed during the old weir evaluations (2015 was the highest, 2016 the lowest).
  - Weir discharge (i.e., low [< 500 cfs] vs. high [≥ 500 cfs]) did not affect survival for CH1, STH2, or S-STH during spring low and high pools in 2018 (i.e., new weir).

- In 2018, ViRDCt Foster-to-Egress Array survival estimates for both seasons and all fish stocks were higher than the tag life-adjusted CJS Foster-to-Primary Array survival estimates. Substantial mortality occurred in the ~16 rkm of tailwaters between the Egress and Primary arrays.

- Passage Distributions
  - During spring low and high pools, passage distributions for CH1 were greatest through Spill Bay 3 during old weir study years. However, passage distributions shifted and were greater through the new fish weir in 2018.
  - During low pool, passage distributions for STH2 during old and new weir evaluations were comparable through both the fish weir and Spill Bays 1–3, whereas the weir was used nearly exclusively during spring high pool for all evaluations.
  - Overall, S-STH passed Foster at similar proportions to STH2 during spring 2018. When comparing by pool elevation, similar proportions of S-STH and STH2 passed Foster during low pool, but a greater proportion of S-STH than STH2 passed during high pool.
  - During fall low pool, passage distributions for CH0 during the old weir evaluations were greatest through Spill Bays 1–3. This shifted during new weir evaluations. Passage distributions were greatest through the new weir in 2018; however, Spill Bays 1–3 were not open for the majority of the study period, resulting in fewer available passage routes.
  - Most study fish passed Foster during the night, for both the old and new weir evaluations (CH1: ≥ 97% and ≥ 77% for all years during low and high pools, respectively; STH2: ≥ 65% for all years during low pool all years and ≥ 64% in 2015 and 2016 for high pool). However, during high pool in 2018, the majority of STH2 passed Foster during the day (62%). S-STH followed similar trends to STH2 for nighttime passage in 2018 (76% and 32% during low and high pools, respectively). CH0 passage at night was ≥ 92% for low pool for all study years.
  - A portion of study fish did not pass Foster before their RT tag battery life expired. The proportion of low-pool-released CH1 that did not pass was consistently low (≤ 23%) for each study year. Of high-pool released fish, 42% of CH1 did not pass the dam in 2015 and 2016, while only 20% did not pass in 2018. Compared to 2015 and 2016, the proportion of STH2 released at low pool and did not pass decreased, while the proportion released at high pool and did not pass increased. The proportion of CH0 that did not pass the dam increased in 2018 (44%) relative to 2015 (29%) and 2016 (25%). Presumably, study fish continued rearing in Foster reservoir during both old and new weir evaluations.

- Project Metrics
  - Overall, the Foster project passed a greater proportion of CH1, CH0, and STH2 via non-turbine routes (high spill passage efficiency) during all study years, regardless of old or new weir evaluations.
  - The old fish weir in Spill Bay 4 was moderately effective at passing CH1. With the new weir, weir effectiveness increased, and spill bay effectiveness decreased.
  - The fish weir was very effective at passing STH2 for all study years, regardless of old or new weir evaluations.
  - Similar to CH1, the old fish weir was moderately effective at passing CH0 during old weir study years and became extremely effective at passing CH0 following the new weir installation, as spill bay effectiveness decreased. However, it should be noted that passage through Spill Bays 1–3 was limited because there was no spill treatment (although some spill

operations occurred) and the passage options for the majority of the study were through the fish weir or the turbines.

    - Both stocks of Chinook salmon passed via the spill bays in high proportions (relative to total passage) during the old weir evaluations. Similar to effectiveness, spill bay efficiency decreased in 2018 for both CH0 and CH1, and weir efficiency increased (although no spill treatment was used in fall 2018 for CH0, there was some limited operation of the spill bays). Overall, the new weir design more efficiently passed CH1 and CH0 compared to the old weir.

- Entrainment
    - Chinook salmon and steelhead were entrained in extremely low numbers in the AWS, FWS, or HWS. One STH2 was detected at the AWS in spring 2015 and three STH2 were detected in the AWS in spring 2018. All fish eventually departed the AWS and migrated downstream.
- Avian Predation
    - Birds preyed upon at least 2.9% of CH1, STH2, and S-STH and 1.8% of CH0 in spring and fall in 2018 (new weir evaluation). Avian predation was not evaluated in 2015 or 2016.

The following research is recommended to support alternative operations at Foster to improve downstream fish passage:

- Consider additional evaluations of the new weir design to explain inter-annual variability (i.e., caused by environmental conditions, project discharge and operations, etc.).
- Consider evaluation of spillway operations to further validate spill as an alternative for passing juvenile salmonids via a non-turbine route.
- Consider operational patterns that maximize spillway discharge (weir and non-weir) at night to facilitate downstream passage of juvenile salmonids.
- Consider further evaluating the effect of increasing entraining flows (via weir discharge manipulation) on survival. Consider the continuation of using ViRDCt in future studies to obtain estimates more representative of immediate dam-passage survival.
- Consider a more in-depth evaluation of avian predation in Foster Reservoir and tailrace.

9.0 Literature Cited

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Appendix A

General Statistics for Fish Tagging and Releases

Appendix A

General Statistics for Fish Tagging and Releases

This appendix contains the general statistics (sample sizes and mean lengths and weights) of fish double-tagged with an RT tag and a PIT tag in spring and fall 2015, 2016, and 2018, by pool stage. Release periods provide general timeframes of fish releases.

Table A.1. Total Number (*n*) and Mean Lengths and Weights of Juvenile Salmonids Implanted with an RT Tag and a PIT Tag, Released during 2015, 2016, and 2018. The release periods provide general timeframes.

				2015			2016			2018		
Season	**Species**	**Pool Stage**	**Release Period**	***n***	**Mean Length (mm)**	**Mean Weight (g)**	***n***	**Mean Length (mm)**	**Mean Weight (g)**	***n***	**Mean Length (mm)**	**Mean Weight (g)**
Spring	Yearling Chinook Salmon (CH1)	Low	March–April	523	159.0	39.8	373	166.6	51.1	373	199.0	74.9
		High	April–June	182	178.1	55.0	372	186.6	76.1	384	202.9	78.4
		Total		705	164.0	43.8	745	176.6	63.6	757	201.0	76.7
	Steelhead (STH2)	Low	March–April	581	169.4	45.1	392	162.7	40.2	698	175.8	48.7
		High	April–June	215	193.6	68.5	409	181.1	54.6	318	182.0	55.5
		Total		796	175.9	51.4	801	172.1	47.6	1016	177.7	50.8
	Summer Steelhead (S-STH)	Low	March–April	N/A			N/A			215	205.2	88.1
		High	April–June							468	227.4	117.0
		Total								683	220.4	107.9
	Dead Fish Releases		March–June	30	167.3	47.3	25	164.4	45.0	83	191.1	63.4
Fall	Subyearling Chinook Salmon (CH0)	Low	October–November	1256	173.1	57.8	1371	164	46.6	749	156.9	45.4
	Steelhead (STH1)	Low	October	98	144.3	30.0	149	146.5	34.1	N/A		
	Dead Fish Releases		October–November	30	165.3	48.9	25	164.0	46.0	40	161.4	48.1

Appendix B

Spill vs. Turbine Test Schedules

Appendix B

Spill vs. Turbine Test Schedules

This appendix contains the results of the Spill vs. Turbine block treatment test schedules for spring and fall 2015, 2016, and 2018.

Table B.1. Spring 2018 Low Pool Pseudo-Randomized Block Treatment Schedule. Days run from 08:00 h to 08:00 h on the following day.

Date	Block	Treatment	Turbine	Spill	Weir
20-Mar	1	turbine+weir [P]	On	Off	On
21-Mar	1	turbine+weir	On	Off	On
22-Mar	1	spill+weir	Off	On	On
23-Mar	1	spill+weir	Off	On	On
24-Mar	2	spill+weir	Off	On	On
25-Mar	2	spill+weir	Off	On	On
26-Mar	2	turbine+weir	On	Off	On
27-Mar	2	turbine+weir	On	Off	On
28-Mar	3	turbine+weir	On	Off	On
29-Mar	3	turbine+weir	On	Off	On
30-Mar	3	spill+weir	Off	On	On
31-Mar	3	spill+weir	Off	On	On
1-Apr	4	spill+weir	Off	On	On
2-Apr	4	spill+weir	Off	On	On
3-Apr	4	turbine+weir	On	Off	On
4-Apr	4	turbine+weir	On	Off	On
5-Apr	5	turbine+weir	On	Off	On
6-Apr	5	NT	On	On	On
7-Apr	5	spill+weir	Off	On	On
8-Apr	5	spill+weir	Off	On	On
9-Apr	6	spill+weir	Off	On	On
10-Apr	6	spill+weir	Off	On	On
11-Apr	6	NT	On	On	On
12-Apr	6	NT	On	On	On

[P] = Partial treatment (treatment went as planned for most but not all of 24 h period).
NT = No treatment as planned (unplanned spill operation).

Table B.2. Spring 2018 High Pool Pseudo-Randomized Block Treatment Schedule. Days run from 08:00 h to 08:00 h on the following day.

Date	Block	Treatment	Turbine	Spill	Weir
8-May	1	turbine+weir	On	Off	On
9-May	1	turbine+weir	On	Off	On
10-May	1	spill+weir	Off	On	On
11-May	1	spill+weir	Off	On	On
12-May	2	spill+weir	Off	On	On
13-May	2	spill+weir	Off	On	On
14-May	2	turbine+weir	On	Off	On
15-May	2	turbine+weir	On	Off	On
16-May	3	turbine+weir	On	Off	On
17-May	3	turbine+weir	On	Off	On
18-May	3	spill+weir	Off	On	On
19-May	3	spill+weir	Off	On	On
20-May	4	spill+weir	Off	On	On
21-May	4	spill+weir	Off	On	On
22-May	4	turbine+weir	On	Off	On
23-May	4	turbine+weir	On	Off	On
24-May	5	turbine+weir	On	Off	On
25-May	5	turbine+weir	On	Off	On
26-May	5	spill+weir	Off	On	On
27-May	5	spill+weir	Off	On	On
28-May	6	spill+weir	Off	On	On
29-May	6	spill+weir	Off	On	On
30-May	6	turbine+weir	On	Off	On
31-May	6	turbine+weir	On	Off	On
1-Jun	7	spill+weir	Off	On	On
2-Jun	7	spill+weir	Off	On	On
3-Jun	7	turbine+weir	On	Off	On
4-Jun	7	turbine+weir	On	Off	On

Table B.3. Fall 2018 Pseudo-Randomized Block Treatment Schedule. Days run from 08:00 h to 08:00 h on the following day.

Date	Block	Treatment	Turbine	Spill	Weir
23-Oct	1	turbine+weir ^{P}	On	Off	On
24-Oct	1	turbine+weir	On	Off	On
25-Oct	1	turbine	On	Off	Off
26-Oct	1	turbine	On	Off	Off
27-Oct	2	turbine	On	Off	Off
28-Oct	2	turbine	On	Off	Off
29-Oct	2	turbine+weir ^{P}	On	Off	On
30-Oct	2	turbine+weir	On	Off	On
31-Oct	3	turbine+weir	On	Off	On
1-Nov	3	turbine+weir	On	Off	On
2-Nov	3	turbine	On	Off	Off
3-Nov	3	turbine	On	Off	Off
4-Nov	4	turbine	On	Off	Off
5-Nov	4	turbine	On	Off	Off
6-Nov	4	turbine+weir	On	Off	On
7-Nov	4	turbine+weir	On	Off	On
8-Nov	5	turbine	On	Off	Off
9-Nov	5	turbine	On	Off	Off
10-Nov	5	turbine+weir	On	Off	On
11-Nov	5	turbine+weir	On	Off	On
12-Nov	6	turbine+weir	On	Off	On
13-Nov	6	turbine+weir	On	Off	On
14-Nov	6	turbine ^{P}	On	On	Off
15-Nov	6	turbine	On	Off	Off
16-Nov	7	turbine	On	Off	Off
17-Nov	7	turbine	On	Off	Off
18-Nov	7	turbine+weir	On	Off	On
19-Nov	7	turbine+weir	On	Off	On
20-Nov	8	turbine+weir ^{P}	On	Off	On
21-Nov	8	NT	On	Off	Off
22-Nov	8	turbine	On	Off	Off
23-Nov	8	turbine	On	Off	Off
24-Nov	9	turbine	On	Off	Off
25-Nov	9	turbine	On	Off	Off
26-Nov	9	NT	On	Off	Off
27-Nov	9	NT	On	Off	Off

Date	Block	Treatment	Turbine	Spill	Weir
28-Nov	10	NT	On	Off	Off
29-Nov	10	NT	On	Off	Off
30-Nov	10	turbine	On	Off	Off
1-Dec	10	turbine	On	Off	Off
2-Dec	11	turbine	On	Off	Off
3-Dec	11	turbine	On	Off	Off
4-Dec	11	NT	On	Off	Off
5-Dec	11	NT	On	Off	Off
6-Dec	12	NT	On	Off	Off
7-Dec	12	NT	On	Off	Off
8-Dec	12	turbine	On	Off	Off
9-Dec	12	turbine	On	Off	Off

[P] = Partial treatment (treatment went as planned for most but not all of 24 h period).
NT = No treatment as planned (no weir operation, turbine only).

Appendix C

ViRDCt Survival Model Assumptions and Testing

Appendix C

ViRDCt Model Assumptions and Testing

This appendix contains CJS and ViRDCt model assumptions and tests of ViRDCt model assumptions. These tests are used to assess the ViRDCt model assumption that the estimated dead tagged fish detection rate is representative of the probability of detecting fish from the virtual release group that die during dam-passage.

C.1 Model Assumptions

Assumptions associated with the designs presented here for estimating Foster dam-passage survival include several assumptions that are common to mark-recapture studies of fish survival using telemetry and have been described previously (e.g., Skalski 2009) as well as two additional assumptions that are unique to the ViRDCt model. The assumptions are as follows:

- A1. Individuals marked for the study are a representative sample from the population of inference.
- A2. All sampling events are "instantaneous." That is, sampling occurs over a negligible distance relative to the length of the intervals between sampling events.
- A3. The fate of each tagged individual is independent of the fate of all others.
- A4. All tagged individuals alive at a sampling location have the same probability of surviving until the end of that event.
- A5. All tagged individuals alive at a sampling location have the same probability of being detected on that event.
- A6. All fish arriving at the array at which the virtual release group is formed have an equal probability of inclusion in the virtual release group.
- A7. The virtual release group is constructed of tagged fish known to have passed the array at which the virtual release group is formed.
- A8. The estimated dead tagged fish detection rate is representative of the probability of detecting fish from the virtual release group that die during dam passage.
- A9. Dead tagged fish are released into each route in similar proportions to the distribution of mortality of fish from the virtual release group.

The first assumption (A1) concerns making inferences from the sample to the target population. The timing of tagging, and/or passage of radio-tagged fish was conducted to represent the passage timing and size distribution of the taggable, smolt-sized run-at-large as indicated from the best available information (Romer et al. 2014, 2015, and 2016). Finally, tagged fish were released 2 and 4 rkm upstream of Foster to allow tagged fish to distribute themselves as other run-of-river (ROR) fish before arriving at the dam.

The second assumption (A2) specifies that mortality is negligible immediately in the vicinity of the detection arrays, so that the estimated mortality is related to the river reaches in question and not the sampling event (Skalski 2009). Out-migrating smolts are likely to spend a brief amount of time in the vicinity of the detection arrays relative to the size of the river reaches in question. Therefore, there is no test for this assumption.

The independence assumption (A3) implies that the survival or mortality of one smolt has no effect on the fates of others. This assumption is common to all tag analyses with little or no evidence collected to suggest it is not generally true (Skalski 2009).

The fourth assumption (A4) specifies that a smolt's prior detection history has no effect on subsequent survival. This assumption could be violated if smolts were physically recaptured. The lack of handling following initial release and the use of telemetry minimizes the risk that subsequent detections influence survival. Therefore, we did not test this assumption using Burnham et al. (1987) tests T_2 and T_3, which are routinely nonsignificant in telemetry studies (Skalski 2009).

Assumptions A5 and A6 are satisfied by detection arrays that can detect radio-tagged fish across the entire width of the river so that all fish, regardless of cross-channel location, have the same probability of detection. Therefore, there is no test for this assumption.

Assumption A7 implies that tagged smolts do no lose their tags, have their tags fail, or cease migration and are subsequently misidentified as dead after being detected by the array at which the virtual release group is formed. The risk of fish losing their tags was minimized by only tagging fish that weigh $\geq$ 13 g with a radio tag that weighs just 0.43 g and PIT tag that weighs 0.1 g to maintain tag burdens $\leq$ 4.1%. The possibility of tag failure depends on travel time relative to battery life. Tags had a nominal life of 51 days, which was sufficient for the large majority of tagged fish that were motivated to migrate from Foster Reservoir to do so before battery failure. However, 60 tags were retained each season and tested in the laboratory for tag life. Survival estimates were adjusted for the probability of tag failure using results from the tag life study and the methods of Townsend et al. (2006).

Assumptions A8 and A9 are specific to the ViRDCt model and are related to the representativeness of the dead tagged fish releases to fish from the virtual release group that died during dam passage. In order to make the dead tagged fish releases as representative as possible, dead tagged fish were released downstream of the powerhouse and spillway depending on which routes were operational at the time of release. In addition, dead tagged fish were released daily during at least two spill treatment blocks in an attempt to capture the variability in environmental and operational conditions that could influence survival.

The representativeness of the dead tagged fish releases was tested by comparing the spatial and temporal distribution of dead tagged fish releases to the spatial (i.e., route) and temporal distribution of fish from the virtual release group that were not detected downstream of the egress array. Fisher's exact test (α = 0.05) was used to compare spatial proportions and the Log-Rank test (α = 0.05) was used to compare temporal distributions. Fisher's exact test (α = 0.05) was also used to compare detection rates between dead tagged fish released downstream of the spillway to those released downstream of the powerhouse to determine whether a bias could exist. If the two routes were associated with a similar dead tagged fish detection rate, the distribution of dead tagged fish among the routes has little to no effect on the ViRDCt survival estimate.

C.2 Tests of Assumptions Results

Detection rates were compared between dead tagged fish released downstream of the spillway to those released downstream of the powerhouse to determine whether they were similar. During the spring low pool study, 4 of 21 (m/D = 0.190) dead tagged fish released into the spillway tailrace were detected at the egress array, which was not significantly different than the proportion of dead tagged fish released into the powerhouse tailrace that were detected (2 of 21; $m/D = 0.095$; Fisher's exact test $p = 0.66$).

During spring high pool, 1 of 20 ($m/D = 0.050$) and 0 of 20 ($m/D = 0.000$) dead tagged fish released into the spillway and powerhouse tailraces, respectively, were detected at the egress array (Fisher's exact test $p = 0.49$). During the fall, 20 dead tagged fish were released into the spillway and powerhouse tailraces of Foster and none of these fish were detected at the Egress Array. In each season/pool elevation study, the two routes were associated with a similar dead tagged fish detection rate. Therefore, the spatial distribution of dead tagged fish releases was not compared to the spatial (i.e., route) distribution of fish from V_1 that were not detected downstream of the egress array and dead tagged fish released into each route were pooled for each season/pool elevation.

The temporal distributions of dead tagged fish releases were compared to those of fish from the virtual release groups that were not detected downstream of the egress array (and were therefore assumed to represent the timing of mortality). The release of dead tagged fish during spring low pool matched the timing of mortality of the V_1 group for CH1 that passed Foster during low pool reasonably well (Log-Rank $\chi^2 = 3.480$; $p = 0.06$; Figure C.1). However, releases of dead tagged fish during the spring occurred too early to match the timing of V_1 mortality of CH1 during high pool (Log-Rank $\chi^2 = 10.567$; $p = 0.001$; Figure C.2), and STH2 and S-STH during both low and high pools (Log-Rank $\chi^2 \geq 11.539$; $p < 0.001$; Figure C.3, Figure C.4, Figure C.5, Figure C.6). In the fall, the release of dead tagged fish matched the timing of mortality of the CH0 V_1 group (Log-Rank $\chi^2 = 1.651$; $p = 0.20$; Figure C.7).

All dead tagged fish releases during spring low pool occurred prior to an increase in discharge from about 1500 cfs to 7000 cfs. A logistic regression model constructed using dead tagged fish release and detection data from 2015, 2016, and 2018 indicated the dead tagged fish detection rate at the Egress Array was significantly (positively) correlated with Foster discharge at the time of release (LRT $\chi^2 = 7.115$; $p = 0.008$). Therefore, the dead tagged fish detection rate obtained during the spring low pool study may have been biased low for STH2 and S-STH, which continued passing Foster during the peak in discharge. If the dead tagged fish detection rate was underestimated, the ViRDCt dam-passage survival estimates would be biased high for STH2 and S-STH that passed Foster during spring low pool 2018.

A sensitivity analysis was conducted to evaluate the magnitude to which this bias would be expected to affect the STH2 and S-STH low pool ViRDCt survival estimates. The relationship between the dead tagged fish detection rate and discharge (described above) was applied to mean daily discharges to obtain an estimate of the dead fish detection rate on each day of spring low pool. The daily rates were then weighted by the daily proportion of fish from the STH2 and S-STH V_1 groups that were not detected downstream of the egress array to obtain a season-wide dead fish detection rate estimate. This resulted in dead fish detection rates of 0.244 and 0.209 for S-STH and STH2, respectively, which was 6.6 to 10.1 percentage points higher than the observed rate of 0.143. Using the adjusted dead fish detection rates in the ViRDCt model reduced the S-STH estimate from 0.719 (SE = 0.110) to 0.672 (SE = 0.128) and the STH2 estimate from 0.734 (SE = 0.047) to 0.710 (SE = 0.053). As expected, increasing the dead fish detection rate reduced the ViRDCt survival point estimates and increased their variance. However, the changes were relatively small, with the estimates differing by 2.4 to 4.7 percentage points.

Although the dead tagged fish releases occurred too early during spring high pool to mimic the timing of CH1 and juvenile steelhead mortality, discharge remained relatively stable, fluctuating between about 1500 and 2000 cfs throughout the spring high pool study. Thus, there is little reason to suspect the dead tagged fish detection rate varied across the spring high pool study period and should therefore provide an unbiased estimate of the dead tagged fish detection rate for CH1, STH2, and S-STH that passed Foster during spring high pool 2018.

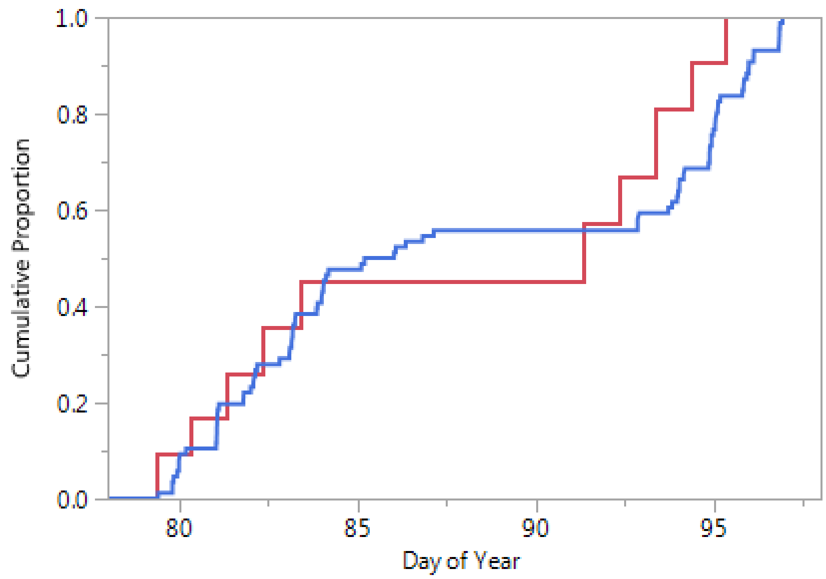

Figure C.1. Cumulative Proportion of Yearling Chinook Salmon from the 2018 Spring Low Pool Virtual Release Group Formed at Foster that were not Detected Downstream of the Egress Array (blue) Compared to the Cumulative Proportion of Dead Tagged Fish Released into the Tailrace over the Course of the 2018 Spring Low Pool Elevation Passage and Survival Study (red). Log-Rank $\chi^2 = 3.480$; $p = 0.06$.

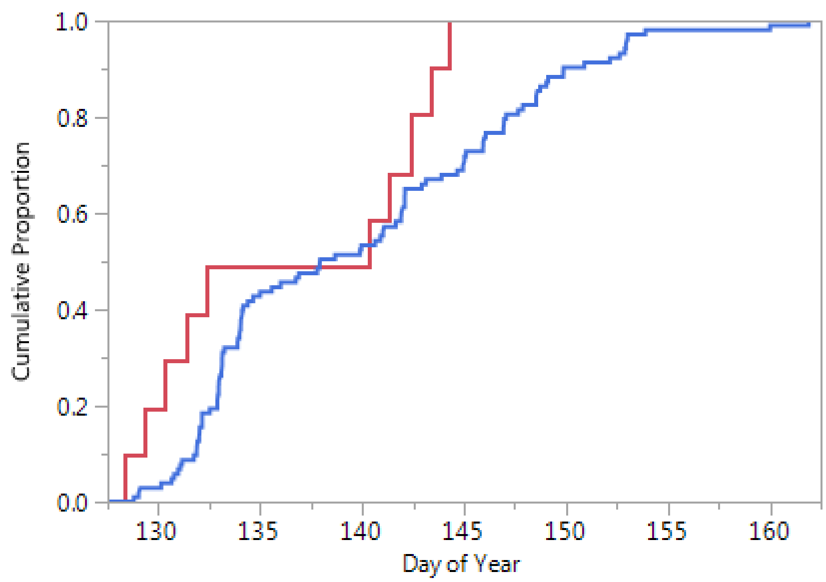

Figure C.2. Cumulative Proportion of Yearling Chinook Salmon from the 2018 Spring High Pool Virtual Release Group Formed at Foster that were not Detected Downstream of the Egress Array (blue) Compared to the Cumulative Proportion of Dead Tagged Fish Released into the Tailrace over the Course of the 2018 Spring High Pool Elevation Passage and Survival Study (red). Log-Rank $\chi^2 = 10.567$; $p = 0.001$.

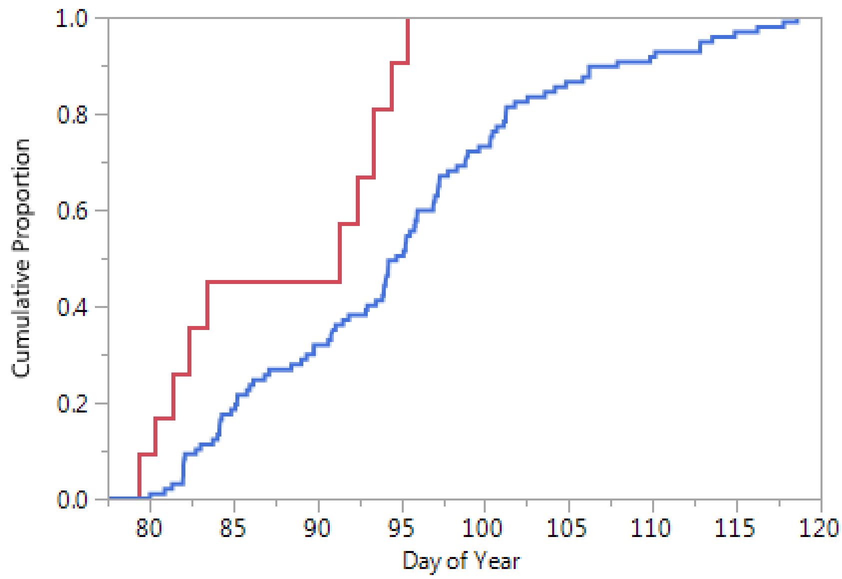

Figure C.3. Cumulative Proportion of Wild Surrogate Winter Steelhead from the 2018 Spring Low Pool Virtual Release Group Formed at Foster that were not Detected Downstream of the Egress Array (blue) Compared to the Cumulative Proportion of Dead Tagged Fish Released into the Tailrace over the Course of the 2018 Spring Low Pool Elevation Passage and Survival Study (red). Log-Rank $\chi^2 = 31.012$; $p < 0.001$.

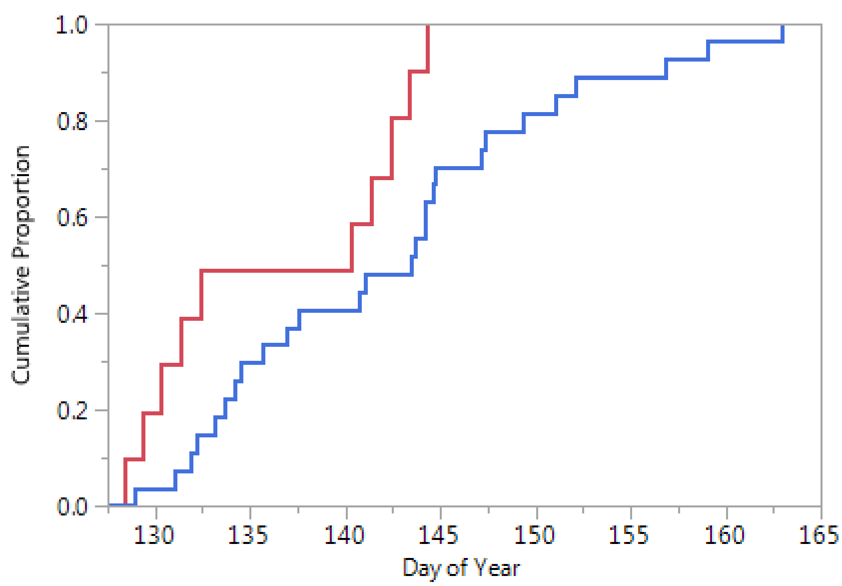

Figure C.4. Cumulative Proportion of Wild Surrogate Winter Steelhead from the 2018 Spring High Pool Virtual Release Group Formed at Foster that were not Detected Downstream of the Egress Array (blue) Compared to the Cumulative Proportion of Dead Tagged Fish Released into the Tailrace over the Course of the 2018 Spring High Pool Elevation Passage and Survival Study (red). Log-Rank $\chi^2 = 12.265$; $p < 0.001$.

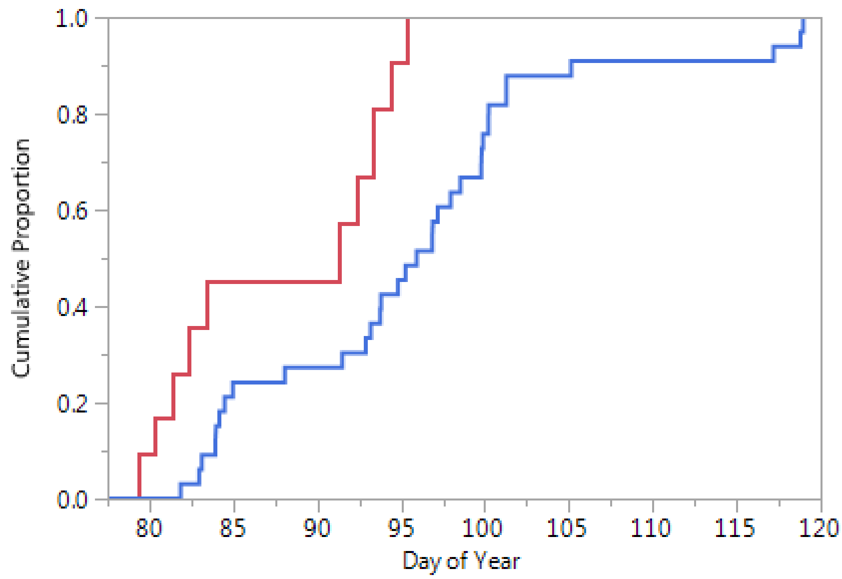

Figure C.5. Cumulative Proportion of Hatchery Summer Steelhead from the 2018 Spring Low Pool Virtual Release Group Formed at Foster that were not Detected Downstream of the Egress Array (blue) Compared to the Cumulative Proportion of Dead Tagged Fish Released into the Tailrace over the Course of the 2018 Spring Low Pool Elevation Passage and Survival Study (red). Log-Rank $\chi^2 = 23.892$; $p < 0.001$.

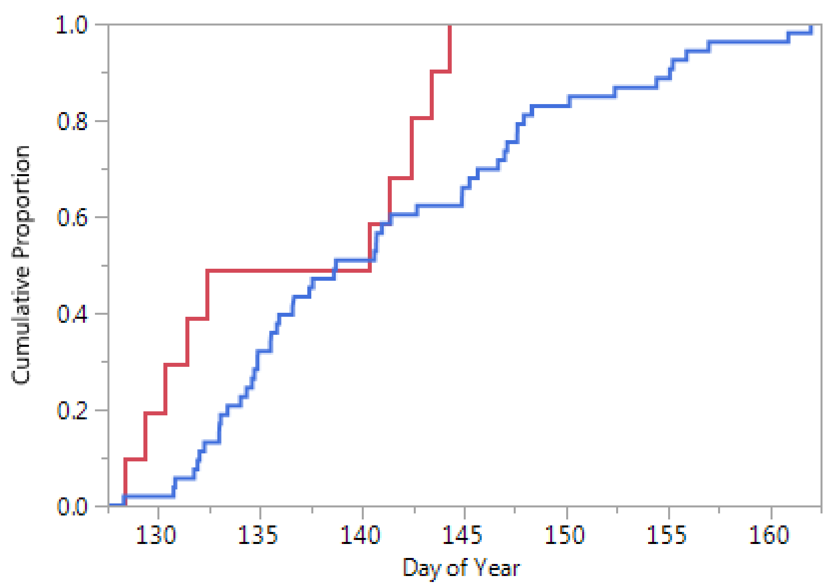

Figure C.6. Cumulative Proportion of Hatchery Summer Steelhead from the 2018 Spring High Pool Virtual Release Group Formed at Foster that were not Detected Downstream of the Egress Array (blue) Compared to the Cumulative Proportion of Dead Tagged Fish Released into the Tailrace over the Course of the 2018 Spring High Pool Elevation Passage and Survival Study (red). Log-Rank $\chi^2 = 11.539$; $p < 0.001$.

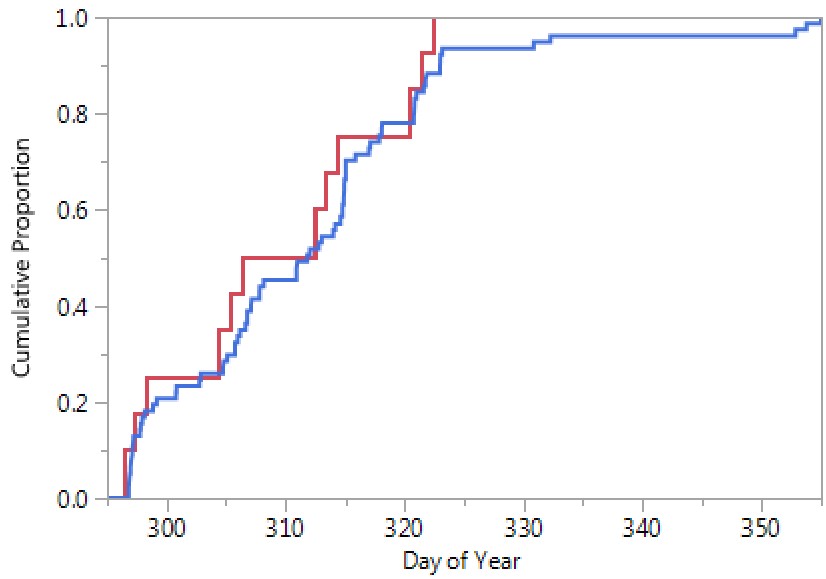

Figure C.7. Cumulative Proportion of Subyearling Chinook Salmon from the 2018 Fall Low Pool Virtual Release Group Formed at Foster that were not Detected Downstream of the Egress Array (blue) Compared to the Cumulative Proportion of Dead Tagged Fish Released into the Tailrace over the Course of the 2018 Spring High Pool Elevation Passage and Survival Study (red). Log-Rank $\chi^2 = 1.651$; $p = 0.20$.

Appendix D

Supplementary Survival and Passage Proportions Tables

Appendix D

Supplementary Survival and Passage Proportions Tables

This appendix contains supplementary results tables for yearling Chinook salmon (CH1) in spring 2015, 2016, and 2018, wild surrogate winter steelhead (STH2) in spring 2015, 2016, and 2018, hatchery summer steelhead (S-STH) in spring 2018, and subyearling Chinook salmon (CH0) in 2015, 2016, and 2018.

Table D.1. Estimated Survival of CH1 that Passed Foster Via the Weir at Low (< 500 cfs) and High (≥ 500 cfs) Weir Discharge in Spring 2018. Survival was estimated from Foster passage to the Egress Array, located ~2.5 rkm downstream, using the ViRDCt model.

Weir Discharge	*n*	S_D (SE)
< 500 cfs*	60	0.752 (0.079)
≥ 500 cfs*	342	0.847 (0.034)

n = number of fish that passed Foster by weir discharge level.
*Dead fish released at weir discharge < 500 cfs pooled with those released ≥500 cfs.

Table D.2. Passage Distributions of CH1 Released above Foster that Passed Foster during Low Pool in Spring 2015, 2016, and 2018

Spring Low Pool	2015		2016		2018	
Location	*n*	Proportion	*n*	Proportion	*n*	Proportion
Overall	457		269		262	
Turbine Unit 1	149	0.33	51	0.19	25	0.095
Turbine Unit 2	–	–	49	0.18	17	0.07
Fish Weir	78	0.17	12	0.05	150	0.57
Spill Bay 3	230	0.50	157	0.58	70	0.27

n = number of fish that passed Foster by route per year.

Table D.3. Passage Distributions of All Study Fish, Grouped By Turbine Units 1–2, Weir, and Spill Bays 1–3 for 2015, 2016, and 2018

Study season	Stock	Pool stage	Route	2015		2016		2018	
				n	Proportion	*n*	Proportion	*n*	Proportion
Spring	CH1	Low	Turbine Units 1–2	149	0.33	100	0.37	43	0.16
			Weir	78	0.17	12	0.05	150	0.57
			Spill Bays 1–3	230	0.50	157	0.58	70	0.27
		High	Turbine Units 1–2	2	0.02	12	0.06	1	0.003
			Weir	39	0.36	73	0.36	252	0.87
			Spill Bays 1–3	68	0.62	116	0.58	38	0.13
	STH2	Low	Turbine Units 1–2	16	0.15	18	0.26	67	0.32
			Weir	46	0.43	30	0.44	67	0.32
			Spill Bays 1–3	46	0.43	21	0.30	77	0.37
		High	Turbine Units 1–2	1	0.01	0	0.00	2	0.02
			Weir	166	0.97	142	0.97	107	0.97
			Spill Bays 1–3	4	0.02	4	0.03	1	0.01
	S-STH	Low	Turbine Units 1–2	—	—	—	—	13	0.22
			Weir	—	—	—	—	19	0.33
			Spill Bays 1–3	—	—	—	—	26	0.45
		High	Turbine Units 1–2	—	—	—	—	1	0.01
			Weir	—	—	—	—	183	0.98
			Spill Bays 1–3	—	—	—	—	3	0.02
Fall	CH0	Low	Turbine Units 1–2	168	0.19	286	0.29	141	0.36
			Weir	97	0.11	43	0.04	236	0.60
			Spill Bay 1–3	613	0.70	656	0.67	18	0.05

n = number of fish that passed Foster by route, pool stage, stock, and season, per year.

Table D.4. Fisher's Exact Test Results of Between-Year Comparisons of Foster Passage Distributions (Turbine Units 1–2, Weir, and Spill Bays 1–3 Routes) for All Fish Stocks. A p-value < 0.05 indicates a significant difference.

Study season	Stock	Pool stage	Fisher's test comparison	*p*-value	Significant difference?
Spring	CH1	Low	2015 vs. 2016	< 0.001	Yes
			2015 vs. 2018	< 0.001	Yes
			2016 vs. 2018	< 0.001	Yes
		High	2015 vs. 2016	0.241	No
			2015 & 2016 vs. 2018	< 0.001	Yes
	STH2	Low	2015 vs. 2016	0.114	No
			2015 & 2016 vs. 2018	0.010	Yes
		High	2015 vs. 2016	1.000	No
			2015 & 2016 vs. 2018	0.184	No
Fall	CH0	Low	2015 vs. 2016	< 0.001	Yes
			2015 vs. 2018	< 0.001	Yes
			2016 vs. 2018	< 0.001	Yes

Table D.5. Passage Distributions of CH1 Released above Foster that Passed the Dam during High Pool in Spring 2015, 2016, and 2018

Spring High Pool	2015		2016		2018	
Location	***n***	**Proportion**	***n***	**Proportion**	***n***	**Proportion**
Overall	109		201		291	
Turbine Unit 1	2	0.02	8	0.04	–	–
Turbine Unit 2	–	–	4	0.02	1	0.003
Fish Weir	39	0.36	73	0.36	252	0.87
Spill Bay 3	68	0.62	116	0.58	17	0.06
Spill Bay 2	–	–	–	–	21	0.07

n = number of fish that passed Foster by route per year.

Table D.6. Wilcoxon's Signed-Rank Test Results of Between-Year Comparisons of Foster Reservoir Residence Time for All Fish Stocks. A *p*-value < 0.05 indicates a significant difference.

Study season	Stock	Pool stage	Wilcoxon comparison	*p*-value	Significant difference?
Spring	CH1	Low	2015 vs. 2016	< 0.001	Yes
			2015 vs. 2018	0.081	No
			2016 vs. 2018	< 0.001	Yes
		High	2015 vs. 2016	< 0.001	Yes
			2015 vs. 2018	0.145	No
			2016 vs. 2018	< 0.001	Yes
	STH2	Low	2015 vs. 2016	0.742	No
			2015 & 2016 vs. 2018	< 0.001	Yes
		High	2015 vs. 2016	0.003	Yes
			2015 vs. 2018	0.859	No
			2016 vs. 2018	0.115	No
Fall	CH0	Low	2015 vs. 2016	< 0.001	Yes
			2015 vs. 2018	< 0.001	Yes
			2016 vs. 2018	< 0.001	Yes

Table D.7. Estimated Survival of STH2 and S-STH that Passed Foster Via the Weir at Low (< 500 cfs) and High (≥ 500 cfs) Weir Discharge in Spring 2018. Survival was estimated from Foster passage to the Egress Array, located ~2.5 rkm downstream, using the ViRDCt model.

	STH2		S-STH	
Weir Discharge	***n***	**S_D (SE)**	***n***	**S_D (SE)**
< 500 cfs*	41	0.910 (0.156)	66	0.876 (0.070)
≥ 500 cfs*	128	0.779 (0.072)	133	0.831 (0.066)

n = number of fish that passed Foster by weir discharge level.
*Dead fish released at weir discharge < 500 cfs pooled with those released ≥500 cfs.

Table D.8. Passage Distributions of STH2 (Spring 2015, 2016 and 2018) and S-STH (Spring 2018) Released above Foster that Passed the Dam during Low Pool

	STH2						S-STH	
Spring Low Pool	**2015**		**2016**		**2018**		**2018**	
Location	***n***	**Proportion**	***n***	**Proportion**	***n***	**Proportion**	***n***	**Proportion**
Overall	108		69		208		58	
Turbine Unit 1	16	0.15	13	0.19	39	0.19	6	0.10
Turbine Unit 2	–	–	5	0.07	25	0.12	7	0.12
Fish Weir	46	0.43	30	0.44	67	0.32	19	0.33
Spill Bay 3	45	0.42	21	0.30	56	0.27	20	0.35
Spill Bay 2	–	–	–	–	17	0.08	5	0.09
Spill Bay 1	1	0.01	–	–	4	0.02	1	0.02

n = number of fish that passed Foster by route per year and species.

Table D.9. Passage Distributions of STH2 (Spring 2015, 2016 and 2018) and S-STH (Spring 2018) Released above Foster that Passed the Dam during High Pool

	STH2						S-STH	
Spring High Pool	**2015**		**2016**		**2018**		**2018**	
Location	***n***	**Proportion**	***n***	**Proportion**	***n***	**Proportion**	***n***	**Proportion**
Overall	171		146		110		187	
Turbine Unit 1	1	0.01	–	–	2	0.02	1	0.01
Turbine Unit 2	–	–	–	–	–	–	–	–
Fish Weir	166	0.97	142	0.97	107	0.97	183	0.98
Spill Bay 3	4	0.02	4	0.03	–	–	1	0.01
Spill Bay 2	–	–	–	–	1	0.01	2	0.01

n = number of fish that passed Foster by route per year and species.

Table D.10. Fisher's Exact Test Results of Between-Stock Comparisons of STH2 and S-STH Foster Passage Proportions. A p-value < 0.05 indicates a significant difference.

Pool stage	Stock	Number released	Number passed	Passage proportion	p-value	Significant difference?
Low	STH2	623	258	0.41	0.615	No
	S-STH	191	75	0.39		
High	STH2	307	83	0.27	< 0.001	Yes
	S-STH	451	179	0.40		
All	STH2	930	341	0.37	0.245	No
	S-STH	642	254	0.40		

Table D.11. Passage Distributions of CH0 Released above Foster that Passed the Dam during Low Pool in Fall 2015, 2016, and 2018

Fall Low Pool	**2015**		**2016**		**2018**	
Location	***n***	**Proportion**	***n***	**Proportion**	***n***	**Proportion**
Overall	853		981		393	
Turbine Unit 1	125	0.15	165	0.17	135	0.34
Turbine Unit 2	37	0.04	117	0.12	4	0.01
Fish Weir	94	0.11	43	0.05	236	0.60
Spill Bay 3	575	0.68	490	0.50	14	0.04
Spill Bay 2	20	0.02	162	0.17	4	0.01
Spill Bay 1	2	0.002	4	0.004	0	0.00

n = number of fish that passed Foster by route per year.

Appendix E

Capture Histories and PIT Tag Detections

Appendix E

Capture Histories and PIT Tag Detections

This appendix contains detailed capture histories for each of the four fish runs studied at Foster in 2015, the four runs studied in 2016, and the four studied in 2018.

E.1 Capture Histories of Yearling Chinook Salmon and Steelhead in Spring 2015, 2016 and 2018

Table E.1. Capture Histories at the Primary and Combined Downstream Arrays for Release Group V_1 for Spring 2015, 2016, and 2018, used in Estimating Dam-Passage Survival by High and Low Pool Elevations. The "Capture History" column has two numbers. The number on the left represents capture history at the Primary Array, and the number on the right represents the combined capture histories as downstream arrays. A "1" denotes detection, "0" denotes non-detection.

		Dam-Passage Survival								
		Chinook Salmon			Surrogate Winter Steelhead			Hatchery Summer Steelhead		
Study Year	Capture History	High Pool	Low Pool	Overall	High Pool	Low Pool	Overall	High Pool	Low Pool	Overall
2015	1 1	69	183	252	102	48	150	N/A		
	0 1	4	47	51	3	16	19			
	1 0	10	54	64	4	5	9			
	0 0	27	181	208	64	43	107			
	Total	110	465	575	173	112	285			
2016	1 1	169	145	314	114	28	142	N/A		
	0 1	2	26	28	2	5	7			
	1 0	0	3	3	1	3	4			
	0 0	33	100	133	33	36	69			
	Total	204	274	478	150	72	222			
2018	1 1	184	158	342	84	115	199	139	24	163
	0 1	10	21	31	3	13	16	5	2	7
	1 0	5	4	9	1	6	7	0	2	2
	0 0	102	84	186	27	95	124	51	33	85
	Total	301	267	568	115	229	346	195	61	257

Table E.2. Capture Histories at the Primary and Combined Downstream Arrays for Release Group V_1 for Chinook Salmon in Spring 2015, 2016, and 2018 used in Estimating Dam-Passage Survival by Low and High Pool Elevations and Day and Night. The “Capture History” column has two numbers. The number on the left represents capture history at the Primary Array, and the number on the right represents the combined capture histories as downstream arrays. A "1" denotes detection, "0" denotes non-detection.

		Dam-Passage Survival					
		High Pool			Low Pool		
Study Year	**Capture History**	**Day**	**Night**	**Overall**	**Day**	**Night**	**Overall**
2015	**1 1**	4	65	69	3	178	181
	0 1	0	4	4	0	45	45
	1 0	3	7	10	3	50	53
	0 0	6	20	26	4	174	178
	Total	13	96	109	10	447	457
2016	**1 1**	26	143	169	2	143	145
	0 1	1	1	2	0	26	26
	1 0	0	0	0	0	3	3
	0 0	2	31	33	5	95	100
	Total	29	175	204	7	267	274
2018	**1 1**	44	140	184	4	154	158
	0 1	1	9	10	1	20	21
	1 0	2	3	5	0	4	4
	0 0	21	81	102	5	79	84
	Total	68	233	301	10	257	267

Table E.3. Capture Histories at the Primary and Combined Downstream Arrays for Release Group V_1 for Wild Surrogate Winter Steelhead (STH2) in Spring 2015, 2016, and 2018, and Hatchery Summer Steelhead (S-STH) in Spring 2018 used in Estimating Dam-Passage Survival by Low and High Pool Elevations and Day and Night. The “Capture History” column has two numbers. The number on the left represents capture history at the Primary Array, and the number on the right represents the combined capture histories as downstream arrays. A "1" denotes detection, "0" denotes non-detection.

		Dam-Passage Survival					
		High Pool			Low Pool		
Study Year	**Capture History**	**Day**	**Night**	**Overall**	**Day**	**Night**	**Overall**
2015 STH2	**1 1**	39	63	102	7	41	48
	0 1	1	0	1	1	14	15
	1 0	3	1	4	1	3	4
	0 0	19	45	64	8	33	41
	Total	62	109	171	17	91	108
2016 STH2	**1 1**	22	92	114	8	20	28
	0 1	1	1	2	1	4	5
	1 0	1	0	1	2	1	3
	0 0	6	27	33	14	22	36
	Total	30	120	150	25	47	72
2018 STH2	**1 1**	53	31	84	26	89	115
	0 1	2	1	3	3	10	13
	1 0	1	0	1	2	4	6
	0 0	15	12	27	30	65	95
	Total	71	44	115	61	168	229
2018 S-STH	**1 1**	98	41	139	6	18	24
	0 1	4	1	5	1	1	2
	1 0	0	0	0	0	2	2
	0 0	28	23	51	8	25	33
	Total	130	65	195	15	46	61

Table E.4. Capture Histories at the Primary and Combined Downstream Arrays for Chinook Salmon Release Group V_1 for Spring 2015, 2016, and 2018 used in Estimating Survival by High and Low Pool Elevations and Individual Route of Passage at Foster. The “Capture History” column has two numbers. The number on the left represents capture history at the Primary Array, and the number on the right represents the combined capture histories as downstream arrays. A "1" denotes detection, "0" denotes non-detection.

		Dam-Passage Survival													
		High Pool							Low Pool						
Study Year	**Capture History**	**DAM**	**PS1**	**PS2**	**SP2**	**SP3**	**SW4**	**Overall**	**DAM**	**PS1**	**PS2**	**SP3**	**SW4**	**Overall**
	1 1	0	1	–	–	54	14	69	2	44	–	110	27	183
	0 1	0	0	–	–	3	1	4	2	10	–	29	6	47
2015	**1 0**	0	0	–	–	5	5	10	1	18	–	22	13	54
	0 0	1	1	–	–	6	19	27	3	77	–	69	32	181
	Total	1	2	–	–	68	39	110	8	149	–	230	78	465
	1 1	2	6	1	–	103	57	169	2	24	20	93	6	145
	0 1	1	0	1	–	0	0	2	1	4	8	11	2	26
2016	**1 0**	0	0	0	–	0	0	0	0	0	0	2	1	3
	0 0	0	2	2	–	13	16	33	2	23	21	51	3	100
	Total	3	8	4	–	116	73	204	5	51	49	157	12	274
	1 1	4	0	1	15	16	148	184	0	12	8	48	90	158
	0 1	3	0	0	1	0	6	10	1	1	2	2	15	21
2018	**1 0**	0	0	0	0	0	5	5	0	0	1	1	2	4
	0 0	3	0	0	5	1	93	102	4	12	6	19	43	84
	Total	10	0	1	21	17	252	301	5	25	17	70	150	267

Table E.5. Capture Histories at the Primary and Combined Downstream Arrays for Wild Surrogate Winter Steelhead (STH2) Release Group V_1 for Spring 2015, 2016, and 2018, and Hatchery Summer Steelhead (S-STH) for Spring 2018 used in Estimating Survival by High and Low Pool Elevations and Individual Route of Passage at Foster. The "Capture History" column has two numbers. The number on the left represents capture history at the Primary Array, and the number on the right represents the combined capture histories as downstream arrays. A "1" denotes detection, "0" denotes non-detection.

		Dam-Passage Survival													
		High Pool						Low Pool							
Study Year	**Capture History**	**DAM**	**PS1**	**SP2**	**SP3**	**SW4**	**Overall**	**DAM**	**PS1**	**PS2**	**SP1**	**SP2**	**SP3**	**SW4**	**Overall**
2015 STH2	**1 1**	0	1	–	3	98	102	0	8	–	0	–	19	21	48
	0 1	2	0	–	0	1	3	1	1	–	0	–	7	7	16
	1 0	0	0	–	0	4	4	1	0	–	1	–	1	2	5
	0 0	0	0	–	1	63	64	2	7	–	0	–	18	16	43
	Total	2	1	–	4	166	173	4	16	–	1	–	45	46	112
2016 STH2	**1 1**	2	–	–	3	109	114	0	4	3	–	–	10	11	28
	0 1	1	–	–	0	1	2	0	1	1	–	–	0	3	5
	1 0	0	–	–	0	1	1	0	1	0	–	–	2	0	3
	0 0	1	–	–	1	31	33	3	7	1	–	–	9	16	36
	Total	4	–	–	4	142	150	3	13	5	–	–	21	30	72
2018 STH2	**1 1**	3	0	0	0	136	139	0	1	1	1	1	9	11	24
	0 1	0	0	0	0	5	5	0	0	0	0	1	0	1	2
	1 0	0	0	0	0	0	0	0	1	1	0	0	0	0	2
	0 0	5	1	2	1	42	51	3	4	5	0	3	11	7	33
	Total	8	1	2	1	183	195	3	6	7	1	5	20	19	61
2018 S-STH	**1 1**	0	1	1	–	82	84	10	17	11	4	11	30	32	115
	0 1	0	0	0	–	3	3	1	3	5	0	1	1	2	13
	1 0	0	0	0	–	1	1	1	3	0	0	0	1	1	6
	0 0	5	1	0	–	21	27	9	16	9	0	5	24	32	95
	Total	5	2	1	–	107	115	21	39	25	4	17	56	67	229

E.2 Capture Histories of Subyearling Chinook Salmon (2015, 2016, and 2018) and Wild Surrogate Winter Steelhead (age-1; 2015 and 2016) in Fall

Table E.6. Capture Histories at the Primary and Combined Downstream Arrays for Release Group V_1 for Subyearling Chinook Salmon in Fall 2015, 2016, and 2018, and Wild Surrogate Winter Steelhead (age-1) in Fall 2015 and 2016 used in Estimating Dam-Passage Survival at Low Pool Elevation. The "Capture History" column has two numbers. The number on the left represents capture history at the Primary Array, and the number on the right represents the combined capture histories as downstream arrays. A "1" denotes detection, "0" denotes non-detection.

		Dam-Passage Survival	
Study Year	**Capture History**	**Chinook Salmon**	**Steelhead (age-1)**
2015	**1 1**	708	0
	0 1	29	0
	1 0	25	1
	0 0	109	3
	Total	871	4
2016	**1 1**	714	0
	0 1	22	0
	1 0	35	0
	0 0	241	11
	Total	1012	11
2018	**1 1**	327	N/A
	0 1	9	
	1 0	1	
	0 0	73	
	Total	410	

Table E.7. Capture Histories at the Primary and Combined Downstream Arrays for Release Group V_1 for Subyearling Chinook Salmon in Fall 2015, 2016, and 2018, and Wild Surrogate Winter Steelhead (age-1) in Fall 2015 and 2016 used in Estimating Dam-Passage Survival at Low Pool Elevation by Day and Night. The “Capture History” column has two numbers. The number on the left represents capture history at the Primary Array, and the number on the right represents the combined capture histories as downstream arrays. A "1" denotes detection, "0" denotes non-detection.

Study Year	Capture History	Dam-Passage Survival					
		Chinook Salmon			Steelhead (age-1)		
		Day	Night	Overall	Day	Night	Overall
2015	**1 1**	22	682	704	0	0	0
	0 1	4	11	15	0	0	0
	1 0	1	24	25	0	1	1
	0 0	5	104	109	1	2	3
	Total	32	821	853	1	3	4
2016	**1 1**	46	668	714	0	0	0
	0 1	1	21	22	0	0	0
	1 0	3	32	35	0	0	0
	0 0	28	213	241	7	4	11
	Total	78	934	1012	7	4	11
2018	**1 1**	4	323	327	N/A		
	0 1	0	9	9			
	1 0	0	1	1			
	0 0	3	70	73			
	Total	7	403	410			

Table E.8. Capture Histories at the Primary and Combined Downstream Arrays for Subyearling Chinook Salmon Release Group V_1 for Fall 2015, 2016, and 2018 used in Estimating Survival by Individual Route of Passage at Foster at Low Pool Elevation. The “Capture History” column has two numbers. The number on the left represents capture history at the Primary Array, and the number on the right represents the combined capture histories as downstream arrays. A "1" denotes detection, "0" denotes non-detection.

Study Year	Capture History	Dam-Passage Survival							
		DAM	**PS1**	**PS2**	**SP1**	**SP2**	**SP3**	**SW4**	**Overall**
2015	**1 1**	4	82	17	1	14	507	83	708
	0 1	14	6	1	0	1	7	0	29
	1 0	0	10	8	0	2	5	0	25
	0 0	0	26	11	1	3	57	11	109
	Total	18	124	37	2	20	576	94	871
2016	**1 1**	20	106	84	2	112	359	31	714
	0 1	2	4	2	1	2	11	0	22
	1 0	1	8	3	1	4	16	2	35
	0 0	8	47	28	0	44	104	10	241
	Total	31	165	117	4	162	490	43	1012
2018	**1 1**	11	104	4	–	4	12	192	327
	0 1	2	4	0	–	0	1	2	9
	1 0	0	0	0	–	0	0	1	1
	0 0	4	27	0	–	0	1	41	73
	Total	17	135	4	–	4	14	236	410

Table E.9. Capture Histories at the Primary and Combined Downstream Arrays for Wild Surrogate Winter Steelhead (age-1) Release Group V_1 for Fall 2015 and 2016 used in Estimating Survival by Individual Route of Passage at Foster at Low Pool Elevation. The “Capture History” column has two numbers. The number on the left represents capture history at the Primary Array, and the number on the right represents the combined capture histories as downstream arrays. A "1" denotes detection, "0" denotes non-detection.

		Dam-Passage Survival					
		Winter Steelhead (age-1)					
Study Year	**Capture History**	**PS1**	**PS2**	**SP2**	**SP3**	**SW4**	**Overall**
2015	**1 1**	0	–	–	–	0	0
	0 1	0	–	–	–	0	0
	1 0	0	–	–	–	1	1
	0 0	1	–	–	–	2	3
	Total	1	–	–	–	3	4
2016	**1 1**	0	0	0	0	0	0
	0 1	0	0	0	0	0	0
	1 0	0	0	0	0	0	0
	0 0	3	1	1	5	1	11
	Total	3	1	1	5	1	11

E.3 PIT Recaptures Post-Study Periods for 2015, 2016 and 2018

In spring 2015, a total of 705 CH1 and 796 STH2 were released into the Foster reservoir during the low and high pool study periods. Of these, 7 CH1 and 4 STH2 were detected at a downstream in-stream passive integrated transponder (PIT) antenna after the spring study period had concluded on June 25, 2015 (Table E.10). In fall 2015, a total of 1,256 CH0 and 98 juvenile wild surrogate winter steelhead age-1 (STH1) were released. Of these, no CH0 and 3 STH1 were captured at a PIT antenna after the fall study period had concluded on December 31, 2015 and up to the current time of reporting (Table E.10).

Table E.10. PIT Detections Post-Study Periods for Spring and Fall 2015

Species	Release Date	Recapture Date	Recapture Site	Days from Release to Recapture
CH1	5/11/2015	10/26/2015	LD1 - Lebanon Dam South Ladder	169
CH1	5/12/2015	10/19/2015	SUJ - Sullivan Dam Juvenile	160
CH1	5/13/2015	10/23/2015	LD1 - Lebanon Dam South Ladder	163
CH1	5/14/2015	11/13/2015	SUJ - Sullivan Dam Juvenile	183
CH1	5/14/2015	11/6/2015	LD1 - Lebanon Dam South Ladder	176
CH1	5/14/2015	11/6/2015	LD4 - Lebanon Dam Spillway	176
CH1	5/14/2015	10/13/2015	LD1 - Lebanon Dam South Ladder	153
STH2	3/30/2015	4/5/2016	LD2 - Lebanon Dam North Ladder	373
STH2	5/11/2015	7/22/2015	FOS - Foster Dam Weir	73
STH2	5/14/2015	9/15/2015	FOS - Foster Dam Weir	124
STH2	5/14/2015	11/19/2015	FOS - Foster Dam Weir	189
STH1	10/6/2015	1/23/2016	FOS - Foster Dam Weir	110
STH1	10/8/2015	4/20/2016	LD1 - Lebanon Dam South Ladder	196
STH1	10/8/2015	4/18/2016	SUJ - Sullivan Dam Juvenile	194

In spring 2016 a total of 745 CH1 and 801 STH2 were released into the Foster reservoir during the low and high pool study periods. Of these, 1 CH1 and 1 STH2 were detected at a downstream in-stream PIT antenna after the spring study period had concluded on July 13, 2016 (Table E.11). In fall 2016, a total of 1,371 CH0 and 149 STH1 were released. Of these, no CH0 or STH1 were detected at a PIT antenna after the fall study period had concluded on December 20, 2016 and up to the current time of reporting (Table E**.11**).

Table E.11. PIT Detections Post-Study Periods for Spring and Fall 2016

Species	Release Date	Recapture Date	Recapture Site	Days from Release to Recapture
CH1	5/14/2016	10/9/2016	SUJ - Sullivan Dam Juvenile	149
STH2	5/13/2016	10/23/2016	FOL - Foster Dam Ladder S. Santiam R	163
STH2	5/13/2016	4/23/2018	FOL - Foster Dam Ladder S Santiam R	710
STH2	5/13/2016	4/26/2018	FOL - Foster Dam Ladder S Santiam R	713
STH2	5/13/2016	5/2/2018	LD4 - Lebanon Dam Spillway	719

In spring 2018 a total of 757 CH1, 1,016 STH2, and 683 S-STH were released into the Foster reservoir during the low and high pool study periods. Of these, 1 CH1, 7 STH2, and 4 S-STH were detected at a downstream in-stream PIT antenna after the spring study period had concluded on August 14, 2018 (Table E.12). In fall 2018, a total of 749 CH0 were released. Of these, none were detected at a PIT antenna after the fall study period had concluded on February 4, 2019, and up to the time of reporting.

Table E.12. PIT Detections Post-Study Periods for Spring and Fall 2018

Species	Release Date	Recapture Date	Recapture Site	Days from Release to Recapture
STH2	5/10/2018	4/3/2019	FOL - Foster Dam Ladder S Santiam R	328
STH2	5/10/2018	4/5/2019	FOL - Foster Dam Ladder S Santiam R	330
STH2	5/10/2018	4/7/2019	FOL - Foster Dam Ladder S Santiam R	332
STH2	5/10/2018	4/10/2019	FOL - Foster Dam Ladder S Santiam R	335
S-STH	5/24/2018	10/26/2018	FOL - Foster Dam Ladder S Santiam R	155
S-STH	5/24/2018	10/27/2018	FOL - Foster Dam Ladder S Santiam R	156
S-STH	5/24/2018	12/19/2018	FOL - Foster Dam Ladder S Santiam R	209
S-STH	5/24/2018	12/21/2018	FOL - Foster Dam Ladder S Santiam R	211
S-STH	5/24/2018	12/22/2018	FOL - Foster Dam Ladder S Santiam R	212
S-STH	5/24/2018	12/23/2018	FOL - Foster Dam Ladder S Santiam R	213
S-STH	5/24/2018	12/31/2018	FOL - Foster Dam Ladder S Santiam R	221

Appendix F

Fish Approach vs. Passage

Appendix F

Approach vs. Passage

This appendix describes the array on which the fish was first detected was compared to the final route of passage. This was then compared between years, to see if fish behavior in the near forebay of the dam was broadly affected by the new weir installation. STH2 and S-STH were also compared, to see if they behaved similarly enough to be functionally interchangeable.

For CH1, it appears that the proportions of fish approaching dam from the powerhouse side vs. the proportion approaching from the spillway side has not changed substantially between years. However, a greater proportion of both fish that approach the powerhouse first and those that approach the spillway first ultimately pass through the weir, instead of through other spillway routes. This difference is particularly dramatic at high pool (Figure F.1).

Approach vs. passage proportions for STH2 were not significantly affected by installation of the new weir. In addition, the near-forebay approach behaviors and passage proportions of S-STH resembled those of the STH2 to a sufficient degree (Figure F.2).

Similarly to the CH1 released in the spring, the CH0 released in the fall did not differ substantially in initial approach as a result of the new weir installation, but much greater proportions passed through the weir instead of other non-weir spillway routes (Figure F.3).

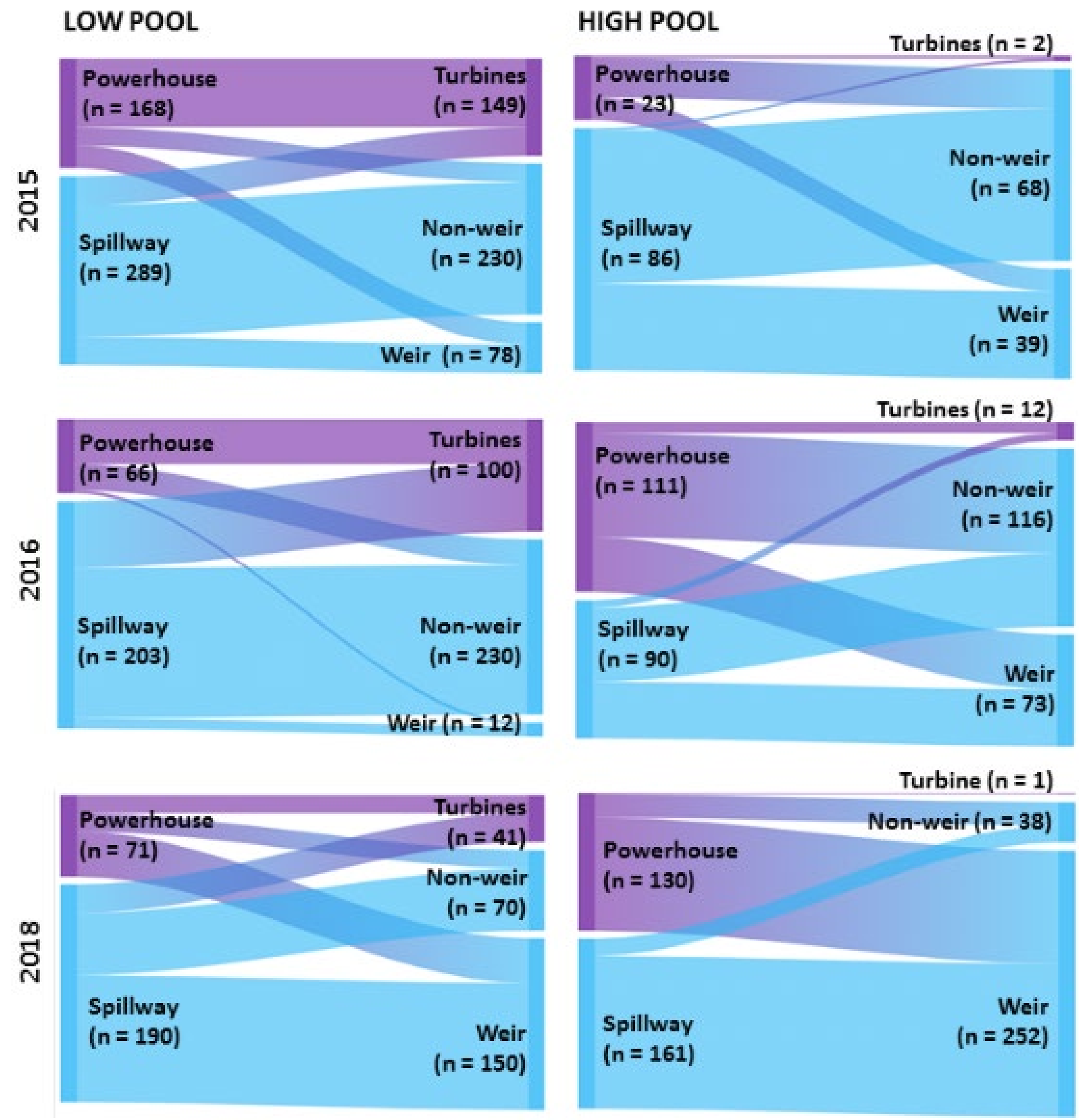

Figure F.1. Yearling Chinook Salmon Approach vs. Passage for Low and High Pool Elevations during Spring 2015, 2016, and 2018

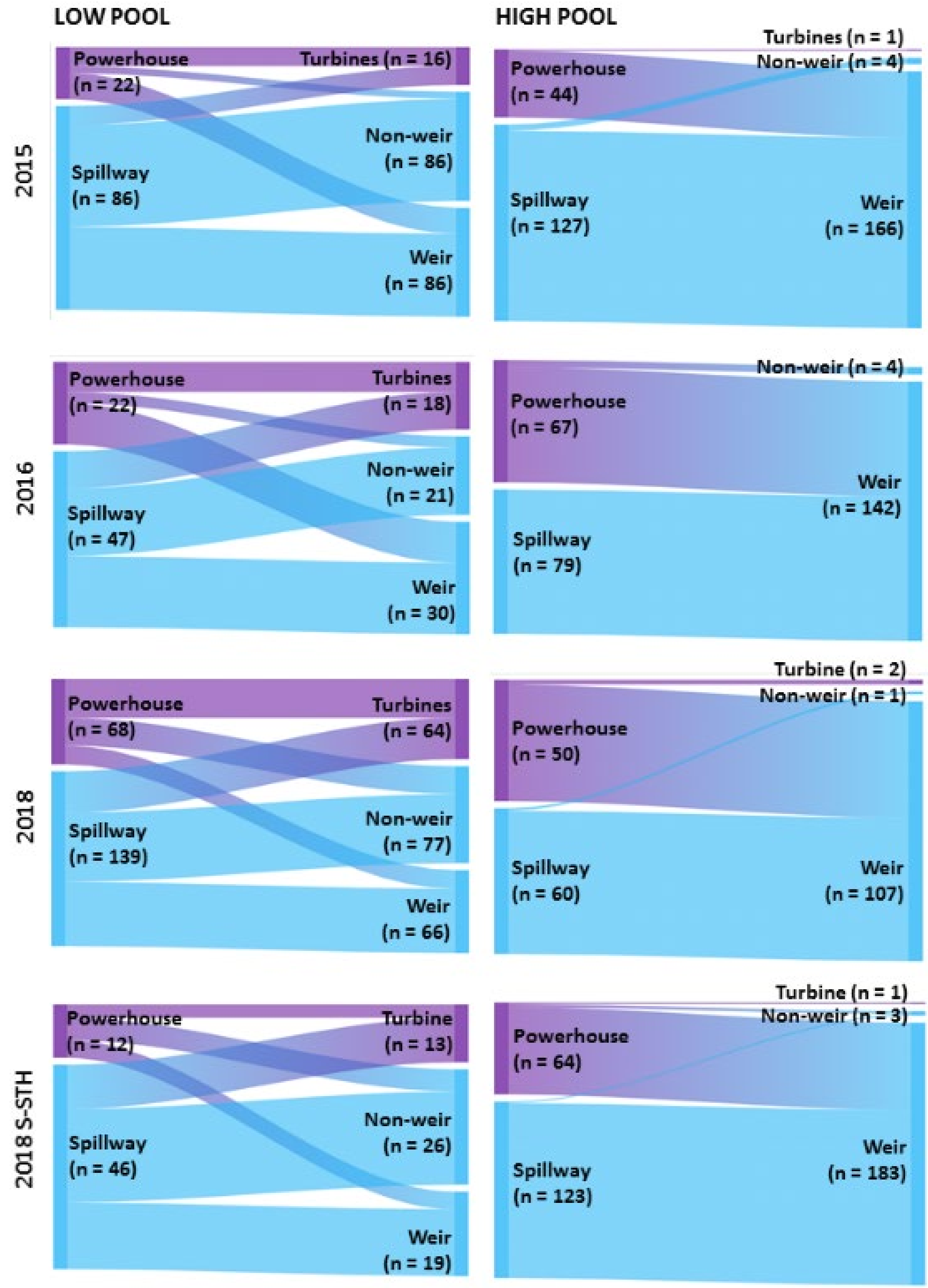

Figure F.2. Wild Surrogate Winter Steelhead Approach vs. Passage for Low and High Pool Elevation during Spring 2015, 2016, and 2018, and Hatchery Summer Steelhead (S-STH) Approach vs. Passage for Low and High Pool Elevations during Spring 2018

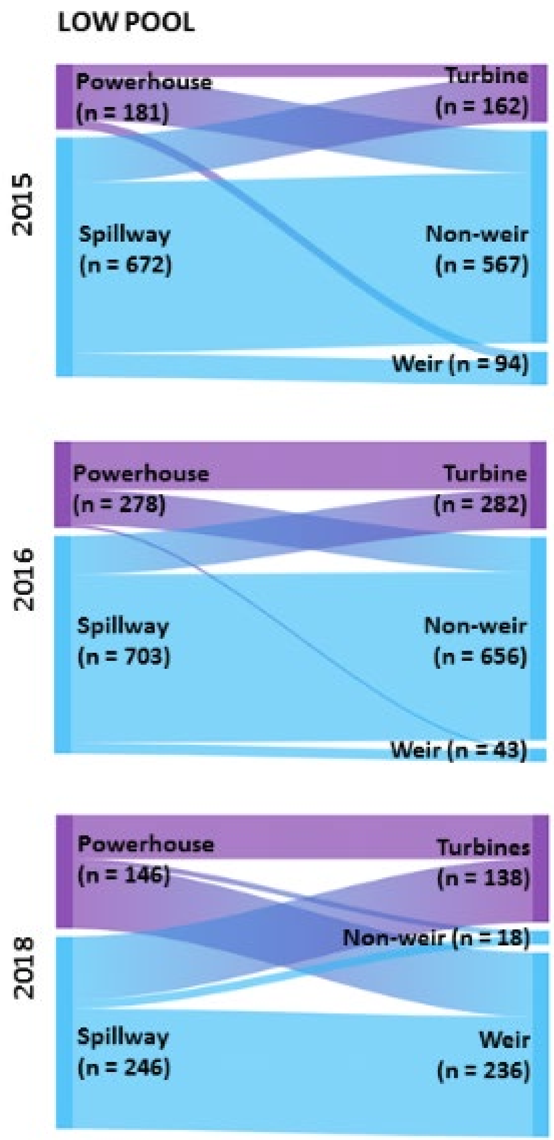

Figure F.3. Subyearling Chinook Salmon Approach vs. Passage for Low Pool Elevation During Fall 2015, 2016, and 2018

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