Hatchery and Supplementation Program

2018 Annual Report
FINAL

Lewis River Hydroelectric Projects

FERC Project Nos. 935, 2071, 2111, 2213

PACIFICORP
A BERKSHIRE HATHAWAY ENERGY COMPANY

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1.0 INTRODUCTION

The purpose of this report is to document results from monitoring and evaluation activities associated with implementing the Hatchery and Supplementation (H&S) program in 2018. Program activities and studies are developed through a collaborative effort of the Hatchery and Supplementation (H&S) Subgroup which are documented within Annual Operating Plans (AOP). The AOP is reviewed and approved by the Aquatic Coordination Committee (ACC) each year. The following key activities were completed as part of the 2018 AOP:

- Transport of winter steelhead, spring Chinook and coho salmon upstream of Swift Dam
- Screw trapping of emigrating juveniles downstream of Merwin Dam
- Carcass and redd surveys downstream of Merwin Dam for all three transport species
- Collection of NOR broodstock to support hatchery production of late winter steelhead
- Hatchery production of trout and salmon as stipulated in Section 8 of the Lewis River Settlement Agreement.
- Evaluation of total dissolved gases and temperature in the Lewis River Hatchery rearing ponds

This report is required by Section 8.2.4 of the Lewis River Settlement Agreement that states:

"On an annual basis, the Licensees shall provide to the ACC for review and comment a report compiling all information gathered pursuant to implementation of the Hatchery and Supplementation Plan. The report also will include recommendations for ongoing management of the Hatchery and Supplementation Program. The ACC shall have 60 days to comment on the annual report. Within 60 days of the close of the comment period, the Licensees shall finalize the report after consideration of all comments. The Licensees shall also provide the comprehensive periodic review undertaken pursuant to Section 8.2.6 below to the ACC. The Licensees shall provide final annual reports and the comprehensive periodic review to the Services during the development of any required ESA permit or authorization for hatchery operations, including NOAA Fisheries' HGMP process. The report may be included as part of the detailed annual reports of the ACC activities required by Section 14.2.6."

2.0 WINTER STEELHEAD

In 2018, the North Fork Lewis River supported three stocks of winter running steelhead:

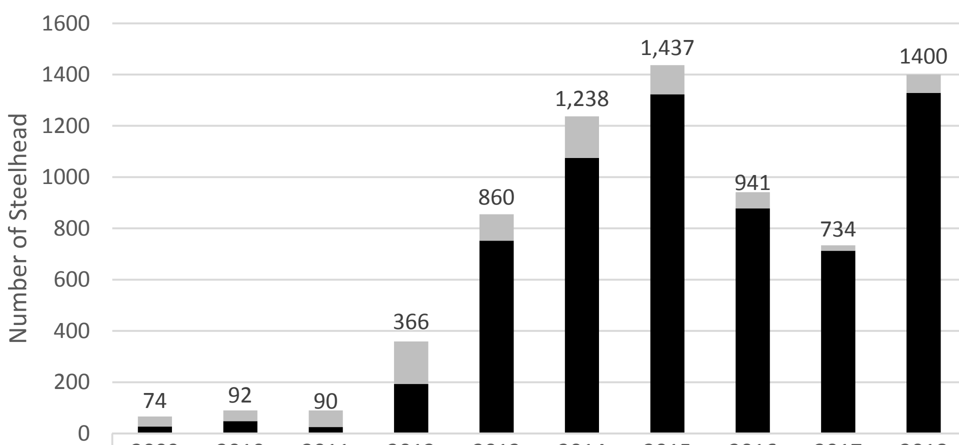
1. A hatchery produced winter steelhead stock derived from Chambers Creek (Puget Sound) with a peak spawn time of December
2. An endemic natural stock with a peak spawn time in April
3. A fully integrated stock derived from the endemic population but spawned and reared in the hatchery (program or supplementation stock).

The primary goal of the fully integrated program is to produce adult returns that are genetically identical to the late winter steelhead endemic stocks to be used for upstream supplementation.

This program has three main components:

- Collection of broodstock at traps and through in-river netting.
- Spawning and rearing at Merwin Hatchery.
- Transport of returning adults upstream of Swift Dam.

Figure 1. Total captures of NOR and BWT steelhead by method between 2009 and 2018 (excludes same year recaptures and adipose fin-clipped steelhead)



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Tangle Netting	39	42	65	166	103	162	114	63	21	72
Merwin Trap	27	48	25	193	752	1,075	1,323	878	713	1328

2.1 Broodstock Collection

Broodstock collection relies on two methods: (1) trapping at Merwin Dam and (2) in-river tangle netting. Natural origin (NOR) winter steelhead captured from the Merwin Trap and in-river netting are transported to Merwin Hatchery for genetic assignment analysis. Once results are known, these fish are either held for broodstock or released back to river depending on predetermined collection curves Data for all steelhead transported to Merwin hatchery are provided in Appendix A.

2.1.1 Merwin Trap

During the period from January 1 through June 11, 2018, a total of 118 NOR and 1210 blank wire tagged[1] (BWT) winter steelhead were captured at the Merwin trap (Table 1). The ratio of females to males was 0.78 and 1.57 for BWT and NOR, respectively. BWT steelhead represented 91 percent of all captures between BWT and NOR steelhead.

Table 1. Origin and gender of winter steelhead captured at the Merwin Trap between January 1 and June 11, 2018

Origin	Males	Females	TOTAL
NOR	46	72	118
HOR (BWT)	680	530	1210
HOR (AD Clip)	310	525	835

Figure 2 illustrates the cumulative proportion of both NOR and BWT steelhead captured during the first six months of 2018. As in previous years, BWT returns to the Merwin Trap begin earlier than NOR winter steelhead and achieve 50 percent collection earlier.

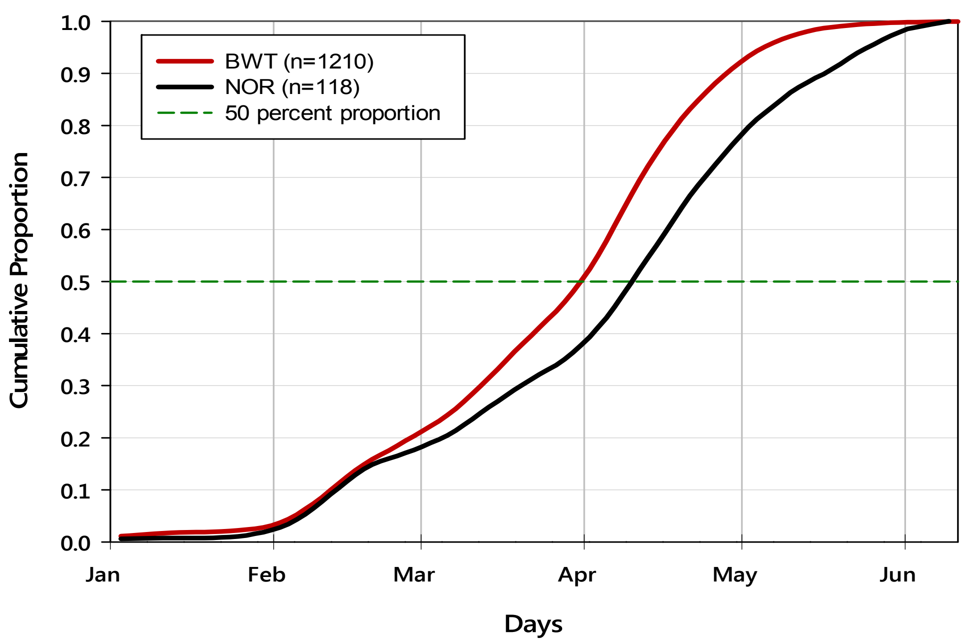


Figure 2. Cumulative proportion of NOR and BWT steelhead trapped at the Merwin Collection Facility between January 1 and June 11, 2018.

[1] Adult steelhead that possess a blank wire tag in their snout are referred to as BWT steelhead and represent returns from the hatchery supplementation program using native broodstock.

2.1.2 Tangle Netting

Tangle netting efforts began on February 22, 2018 and continued through May 2, 2018. A total of 21 netting days were conducted during this period. Table 2 provides a summary of late winter steelhead captured for the 21 days of effort.

Table 2. Origin, gender and disposition of steelhead captured through tangle netting in 2018 (excludes same year recaptures)

Distribution	Males	Females
NOR shipped to Merwin	3	0
NOR Released on site	20	18
BWT Released on site	16	14
Hatchery (AD clip)	0	3
NOR Mortality	1	0
TOTAL	40	35

In total, 75 steelhead were handled through the tangle netting program. Of these, 42 (56%) were of natural origin (Figure 3). The remaining 33 steelhead were BWT and AD clip (3) returns.

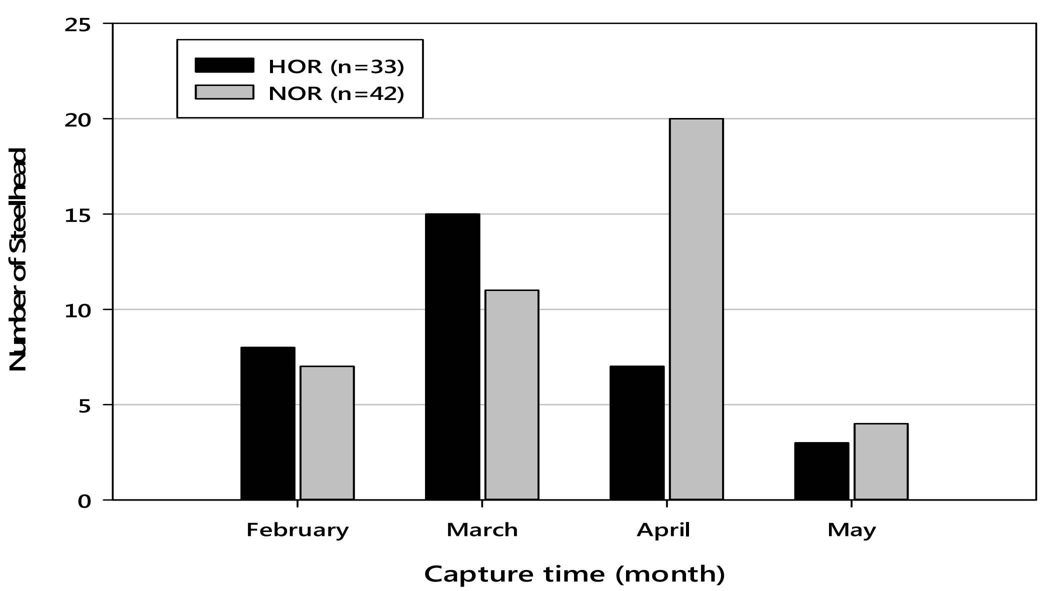


Figure 3. Composition of winter steelhead captured by month through tangle netting between February 22 and May 2, 2018 (n= 75)

2.2 Late Winter Steelhead Broodstock Collection Timing

The ability to conform to predetermined collection curves presents several difficulties in the field. Several variables continue to make broodstock collection challenging including:

- Genetic assignment results may reduce available broodstock being held.
- Spawning maturity in females is highly variable creating uncertainty when deciding to retain or release male broodstock.
- The number of kelts increases substantially from mid to late April.
- Individual fecundity is highly variable

The collection curve proposed in the annual operating plan is intended to help ensure that broodstock are collected across their spawning period. Up to 50 steelhead are spawned over the course of the run with a collection goal total of 75.

In 2018, a total of 93 NOR steelhead were transferred to Merwin Hatchery as potential broodstock. Of these, 46 were spawned and 2 died while being held. All live steelhead (including those spawned) were returned to river. Figure 4 shows the actual collection timing of broodstock held at Merwin compared to the proposed timing curve. The actual timing and number of spawners is also provided.

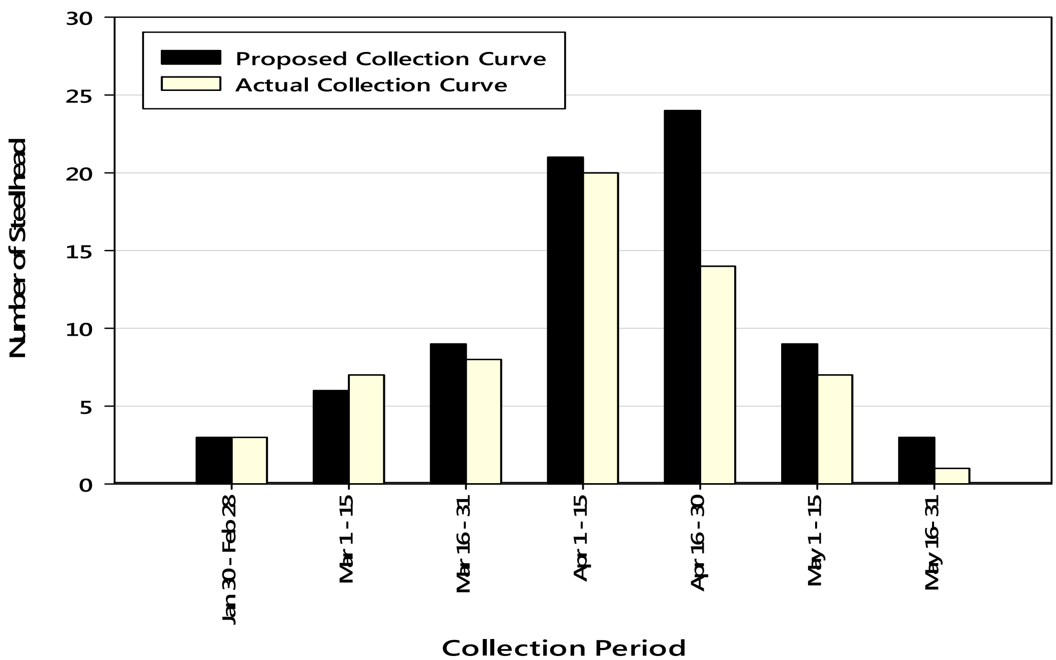


Figure 4. Actual collection timing of steelhead <u>held as broodstock</u> compared to proposed collection curve during 2018.

2.3 Genetic Analysis of Potential Broodstock

The H&S Subgroup agreed to use a primary genetic assignment target level of 50 percent or greater to the NF Lewis River or Cedar Creek stock(s) to be considered acceptable broodstock. After April 1, steelhead may be considered broodstock if assignment probability is 50 percent or greater to Cascade Strata. The only exception to these requirements is any steelhead indicating assignment probabilities to any hatchery stock of more than 5 percent will never be incorporated in the broodstock.

A total of 112 samples were taken from steelhead captured in the Merwin Trap or through in-river tangle netting. All sampled steelhead were assigned a probability percentage as to likelihood of assignment to known baselines established for Lower Columbia River tributaries including the North Fork Lewis River. Probabilities are classified as primary, secondary and tertiary to account for introgression from other basins and provide a more complete picture of diversity present within the samples. Figure 5 illustrates the results of results of sampled NOR steelhead captured and those that were spawned. Appendix B provides the tabular genetic assignments results for each individual unclipped steelhead captured at the Merwin trap and tangle netting.

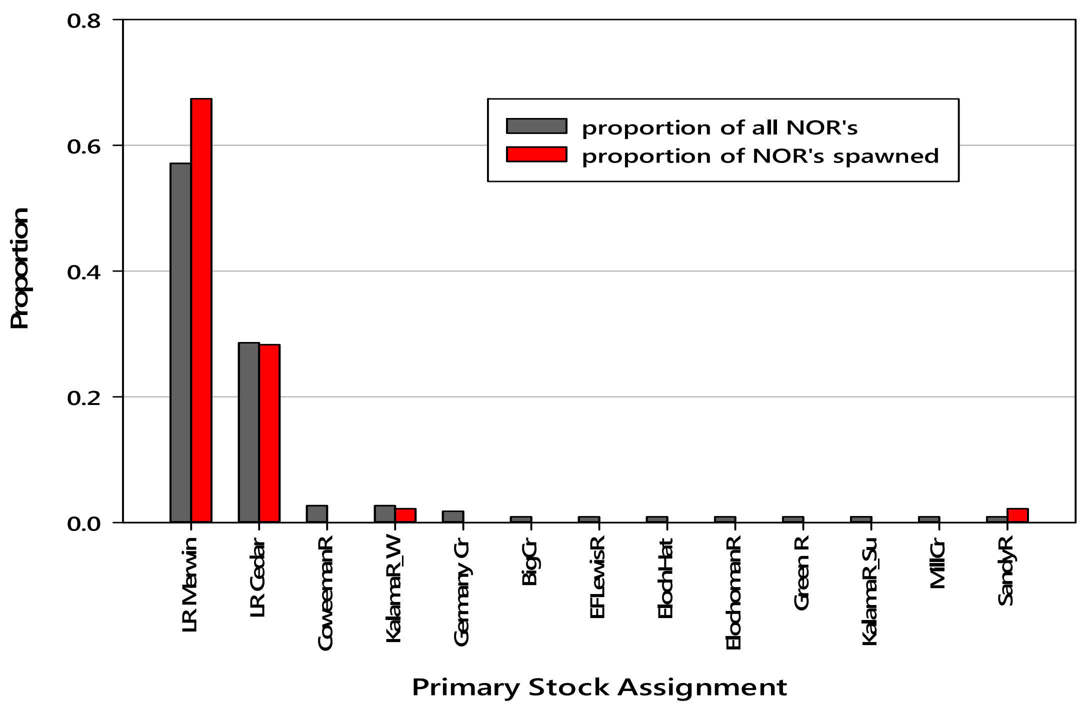


Figure 5. Proportion of primary genetic assignment of NOR late winter steelhead collected from the Merwin Trap and tangle netting (n=112) and those that were spawned (n=46) in 2018.

2.4 Spawning

A total of 45 NOR winter steelhead (22 females, 23 males) were spawned at Merwin Hatchery. A pairwise mating strategy was used over 22 crosses. A number of males were pooled across the available females (Appendix C).

Table 3. Number of spawning crosses and parents including the duration of each spawning periods for brood years between 2009 and 2018

Brood Year	Crosses	Females	Males	Potential Families	Spawn Period	Days
2009	10	12	19		Mar 2 - May 21	81
2010	22	22	24		Mar 17 - May 14	56
2011	9	16	19		Mar 30 - May 18	49
2012	12	19	23		Apr 10 - May 29	49
2013	8	8	11		Apr 10 - May 6	26
2014	26	26	25		Apr 7 - May 16	39
2015	25	25	25		Mar 26 - May 22	58
2016	10	17	20		Apr 8 - May 27	49
2017	10	25	24		Apr 7 - May 19	43
2018	22	22	23	54	Mar 23 - May 25	63

2.5 Spawn Timing

Steelhead broodstock are captured over a collection period that extends from February through the first week of May. The purpose of this protocol is to collect steelhead over the course of the run so that a representative sample of the total run is spawned to limit any bias in spawn time or other variables. Collection timing, however, does not appear to be a realistic predictor of spawn timing as most fish, regardless of collection time, spawn between April 1 and mid-April. For example, the first steelhead collected as potential broodstock and held was on February 20, 2018. This fish was held for 52 days until it was eventually spawned on April 13. Conversely, the average hold time of female broodstock collected in March and April was only 28 and 12 days, respectively (Table 4).

Table 4. Average spawn date and holding times for steelhead captured in February, March, April and May, 2018

Collection Month	Average Hold Time (days)		Sample (n)
	Females	Males	
February	52	51	2
March	26	21	13
April	16	11	27
May	12	7	3

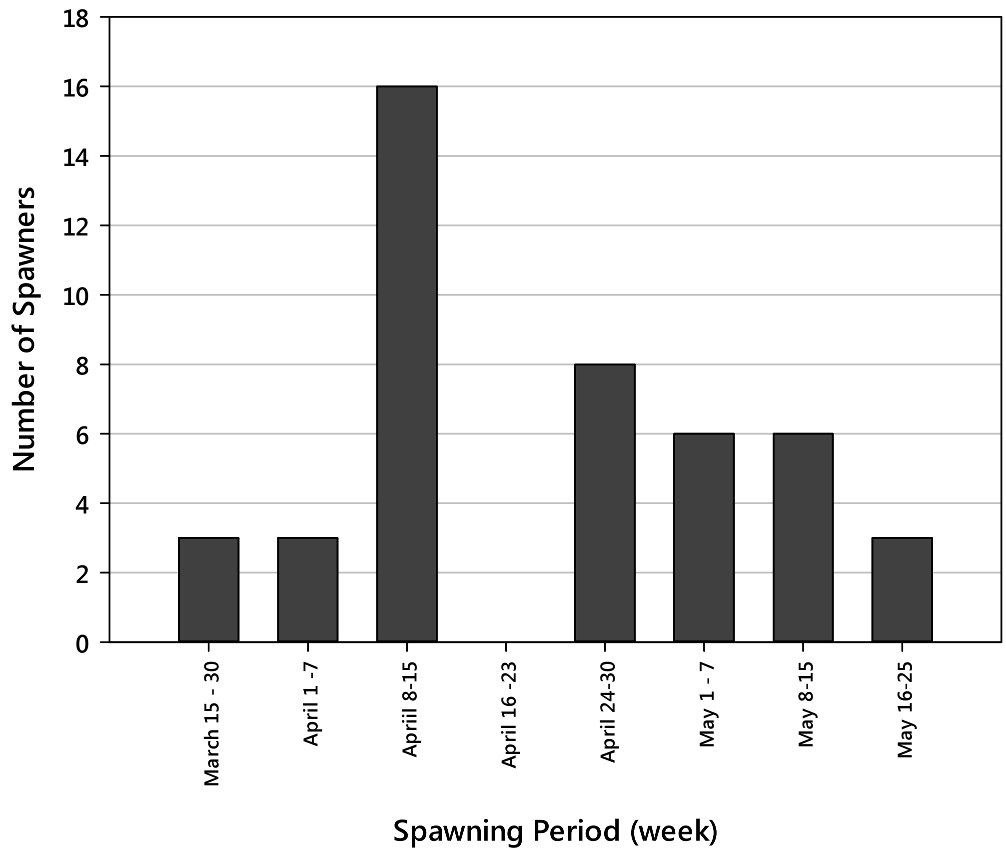


Figure 6. Spawn timing of broodstock held at the Merwin Hatchery (n=45)

2.5.1 Tagging

All subyearling steelhead were tagged with a blank wire snout tag in December 2018.

2.5.2 Release

All fish will be volitionally released on May 1, 2019 at the Merwin boat launch. Volitional release will continue until June 1, 2019. Any fish remaining in the ponds on June 1, 2019 will be forced out and released downstream at the Pekins Ferry Boat Launch (RM 3.1) near the confluence with the East Fork Lewis River. Projected average release size is 8 fish per pound. A total release number of between 40,000 and 44,000 smolts is projected. This is below the target release of 50,000 and was due to both insufficient broodstock and higher mortality rates from ichthyopthirius infections.

3.0 MONITORING AND EVALUATION

3.1 Winter Steelhead Redd Surveys (Lower River)

Redd surveys are used to estimate spawning abundance and distribution of winter steelhead in the mainstem North Fork Lewis River. Surveys are conducted weekly throughout the spawning period, which starts on March 1 and extends into mid-June.

A total of 317 individual redds were counted during redd surveys in 2018. Surveys began on February 19, when the first redd was observed, and continued through June 1. The survey reach begins at Merwin Dam and continues downstream to the lower end of Eagle Island.

3.1.1 Spawning Abundance

Spawning abundance estimates rely on new redd census data, assumed sex ratio and females per redd to calculate total spawner abundance (Freymond and Foley 1986). Females per redd follow WDFW generalized guidelines of 0.81 females per redd and sex ratio is assumed equal (Table 5). Beginning in 2013, we also calculate the spawner abundance using the observed sex ratio of late winter steelhead entering the Merwin Trap. This may be a more accurate estimate of female to male ratio in the river because of the large numbers captured in the trap and is unbiased in terms of capture efficiency for males or females.

Using Merwin Trap capture data between January 1 and June 11, 2018, a total of 2,163 winter steelhead were trapped. These include BWT (1,210) Adipose clipped (835) and NOR (118) winter steelhead. Of this total, 52 and 48 percent were female and male, respectively. Therefore, based on observed trapping proportions, we calculate that for every female on the spawning grounds there are 0.92 males – essentially a 1:1 ratio.

Table 5. Late winter steelhead abundance downstream of Merwin Dam 2008 through 2016 based on redd counts

Year	Number of Redds observed	Spawner Estimate	Observed sex ratio (females : males)	Spawner Estimate (Corrected)
2008	131	212		
2009	176	286		
2010	248	402		
2011	108	174		
2012	343	556		
2013	456	739	1:1.43	898
2014	364	590	1:0.80	531
2015	384	622	1:1.46	765
2016*	NA	NA	1:0.97	NA
2017*	NA	NA	1:1.17	NA
2018	317	514	1:0.92	493

* No data are available in 2016 and 2017 due to severe spring turbidity.

3.1.2 Distribution

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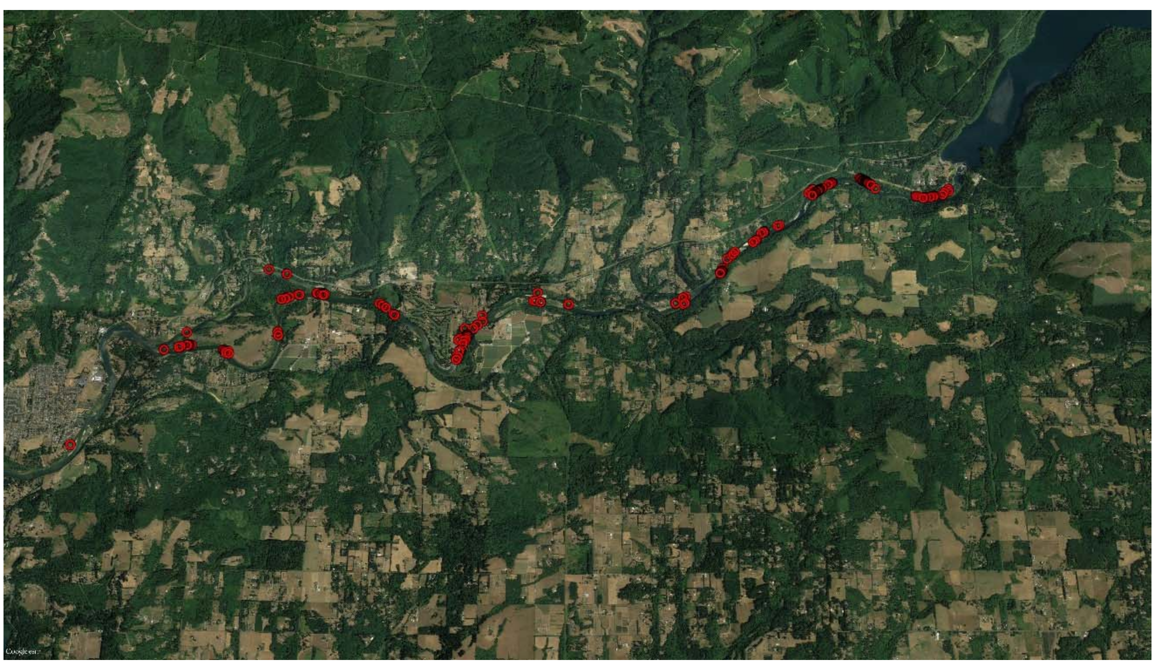

Figure 7. Distribution of late winter steelhead redds downstream of Merwin Dam - 2018

3.2 Proportion of Hatchery Origin Spawners (pHOS) on the Spawning Grounds

Program returns (BWT) are treated as hatchery origin (HOR) steelhead despite their genotype assignment to NOR stocks. This is due to the hatchery influence during mating and captive rearing conditions during their first year of life. As these program fish return as adults, there is opportunity for these (HOR) fish to spawn with NOR stocks. It has been shown that reproductive success (fitness) declines rapidly (up to 37 percent per captive reared generation) within a natural population (Araki et. al. 2007). The evolutionary mechanisms for declines in fitness are not fully understood, but hatchery protected rearing environments and controlled mating selection are suspected contributors to this decline (Araki et. al. 2007). Inbreeding between program fish is also a concern because of loss in genetic diversity or effective population size further limits fitness and adaptability of the natural spawning population.

Appendix H provides estimates of pHOS for late winter steelhead downstream of Merwin Dam during the 2016 sampling season. In 2017, there were insufficient numbers of steelhead captured for tagging due to turbidity. In 2018, steelhead captures were sufficient to generate an estimate, however, this analysis in incomplete and will be reported in the 2019 annual report.

3.3 Recaptures of Circular Pond Reared Late Winter Steelhead

Between 2013 and 2015 a small portion of the total release of BWT winter steelhead juveniles were reared in circular tanks at the hatchery. Smolts rearing in the tanks, were tagged with PIT tags in the dorsal sinus. During this period, a total of 3,181 were tagged – representing approximately 2 percent of the total release cohort in any one year.

As of February 1, 2019, a total of 416 detections (13 percent) have been recorded into PTAGIS. The majority of detections (recoveries) occurred on Sand Island for all three release groups (Figure 8).

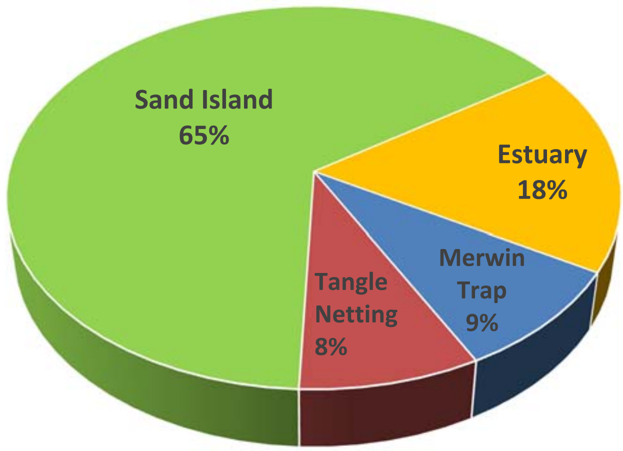

Figure 8. Proportion and last detection location of circular tank release groups (years 2013, 2014 and 2015) as of February 1, 2019.

Table 6. Number and location of detections from PIT tagged circlular tank reared steelhead as of February 1, 2019

	Release Year		
	2013	2014	2015
No. of tags released	1,206	802	1,173
Lewis River (traps, tangle netting)	18	44	10
Sand Island	62	62	145
Estuary Trawl	27	13	34
Swift Reservoir			1

3.4 Upstream Transport of Steelhead, Coho and Spring Chinook

In 2019, a total of 1,220 blank wire tagged steelhead were transported upstream of Swift Dam (Table 7). All steelhead were transported from the Merwin Trap. Seventy-eight of those transported received a gastric radio tag for distribution studies in the upper basin as part of the Aquatic Monitoring and Evaluation Plan.

This year represents the seventh year of steelhead transportation activities. The target goal of the H&S program is 500 winter steelhead transported each year. We have exceeded this target the last six years.

Table 7. Number of fish transported upstream of Swift Dam relative to transport goal

	Number Transported Upstream					
	Winter Steelhead		Coho		Spring Chinook	
Transport Goal	500		7,500		2,000	
YEAR						
2012	189	38%	206	3%	0	0%
2013	741	148%	6,962	93%	513	26%
2014	1,033	207%	9,179	122%	0	0%
2015	1,265	253%	3,754	50%	0	0%
2016	754	151%	7,346	98%	0	0%
2017	598	120%	4,878	65%	1,116	56%
2018	1,220	244%	7,060	94%	700	35%

% is portion of goal achieved

* beginning in 2015, late coho salmon were included as a transport species

3.5 2018 Lower River Screw Trapping Operations

Meridian staff operated the Golf Course traps (two rotary screw traps fished side-by-side with 8-foot diameter cones) located near the Lewis River Golf Course downstream of Merwin Dam (Figure 8) from 1-March 1 to 13-June, 2018. Traps were checked on a daily basis. Total trap captures are combined for the purposes of this summary for this time period.

The yoke cross beam, which supports the upstream end of the cone, needed replacement in early April. The left screw trap was turned off on 29-April through 8-May while waiting for a new yoke cross beam to be provided by the manufacturer. The new yoke cross beam was installed on 9-May and the trap was turned back on that day. As the field crew was checking the trap on 14-May, a log floating downstream hit the upstream end of the cone/yoke cross beam, which caused the bearing bushing sleeve on the yoke to break away, dropping the front of the cone into the river and severely damaging the trap. It was determined by the manufacturer that the replacement yoke contained incomplete welds where the bearing bushing sleeve was attached to the cross beam. During the time needed to remove the damaged trap from the river, the right trap was turned off from 14-May through 17-May. Estimates of the number of fish that may have passed the trap during times when traps were not in operation were not generated. The right screw trap was re-rigged and turned back on 18-May and was operated continuously until 13-June. At this point, trapping was ended for the season due to low flows, lack of fish captures, and heavy growth and drift of filamentous algae into the trap, which caused the cone to stop spinning on a daily basis (even with thorough daily cleaning).

The total number of fish captured by species during the monitoring period is summarized in Table 4. Fork length distributions of focal salmonid fish species are presented in Figure 9. Marked coho, Chinook, rainbow/steelhead, and cutthroat were placed upstream of the trap on a daily basis as fish were available from trap captures to estimate trap efficiency (Table 10). Fish ≥60 mm FL were marked with an alcian blue tattoo or upper caudal fin clip for mark-recapture efficiency tests. All species efficiency tests were combined to generate weekly trap efficiency estimates (Table 10). Focal salmonid fish species outmigration timing is presented in Figure 10 and was calculated by making estimates of the total number of fish that passed the trap on a weekly basis using the adjusted weekly trap efficiency values summarized in Table 10. Total estimates of fish passing the trap during the monitoring period and their associated 95 percent confidence intervals were generated using the Bootstrap Method (Thidenga et al. 1994) and are summarized in Table 11. The sum of discrete interval method for calculating total outmigration described by Volkhardt et al. (2007) for a single partial capture trap was used to make a secondary estimate (Table 11) using the measured weekly trap efficiencies (Table 10). These total outmigration estimates should only be viewed as the total fish that passed the trap during the study period.

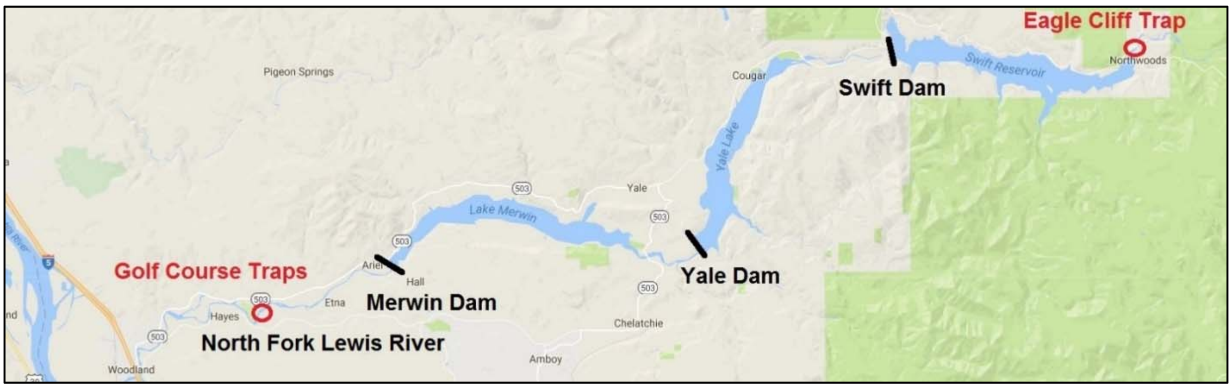

Figure 9. Location of screw trapping sites - North Fork Lewis River

Table 8. Summary of Golf Course traps total captures

Species	Total Hatchery[a] Produced ≥60 mm FL	Total Naturally Produced <60 mm FL	Total Naturally Produced ≥60 mm FL	Total Marked & Released Upstream ≥60 mm FL	Total Recaptured	Total Season Trap Efficiency
Coho	21,753	60	117	3,434	49	0.014
Chinook[b]	3	13,380	6	4	0	0.000
Rainbow/Steelhead	8	1	26	33	0	0.000
Cutthroat	0	0	12	10	0	0.000
All Salmonids Combined			161	3,481	49	0.014

Species	Total
Dace	4
Lamprey	3
Northern Pikeminnow	18
Redside Shiner	3
Sculpin	180
Sucker	1
Three-spined Stickleback	4

[a]Hatchery fish were identified by either a clipped adipose fin or presence of a coded wire tag.
[b]In addition, 1 adult hatchery Chinook was captured in the screw trap.

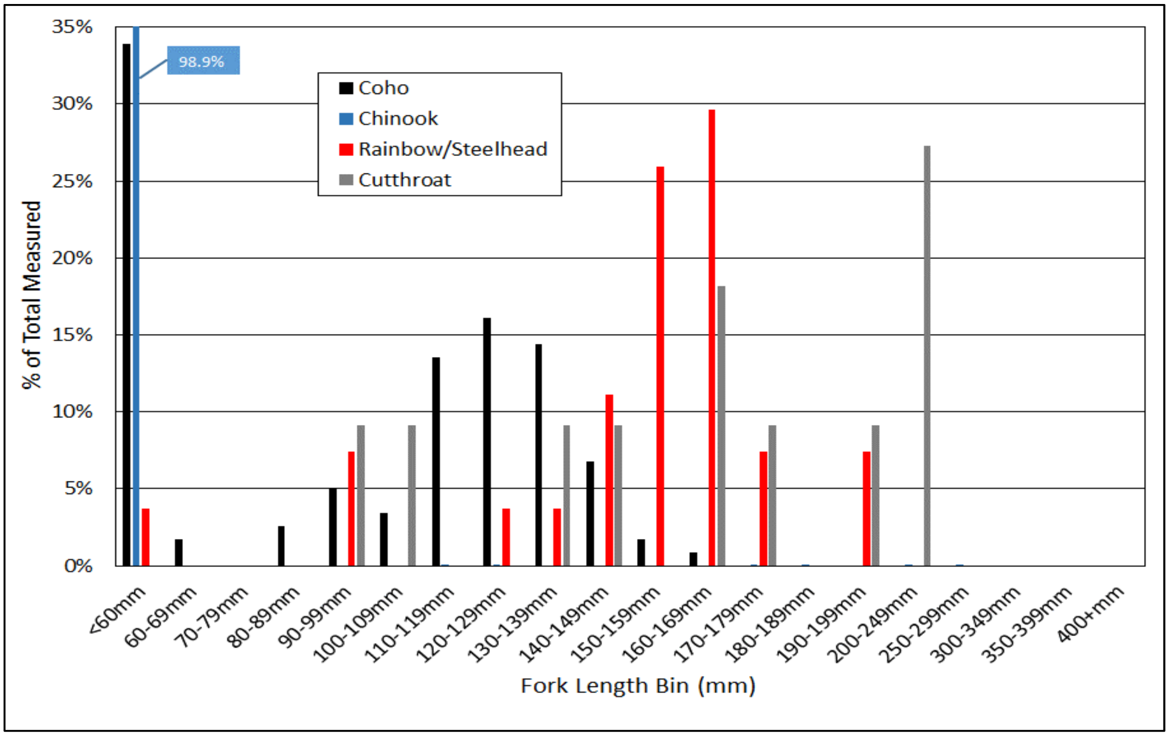

Figure 10. Length frequency of naturally produced salmonids

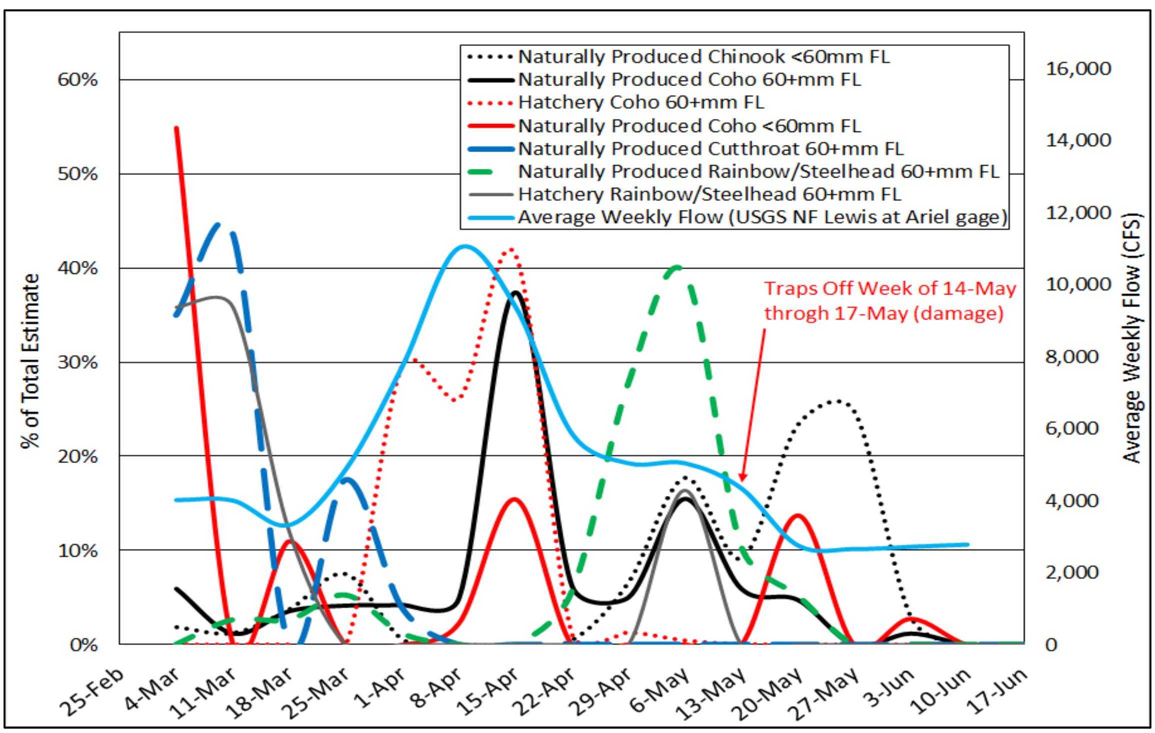

Figure 11. Salmonid migration timing based on total weekly estimates

Table 99. Summary of weekly mark-recapture tests of trap efficiency

Week (first day)	Total Caught ≥60 mm FL	Total Marked & Released Upstream ≥60 mm FL	Total Recaptured	Trap Efficiency	Average Weekly Flow (cfs)[a]	Adjusted Efficiency Based on Flow /Trap Status
2-Mar	19	18		0.000	4016	0.014[b]
11-Mar	14	11		0.000	4003	0.014[b]
18-Mar	12	12		0.000	3324	0.014[b]
25-Mar	13	12		0.000	4874	0.014[b]
1-Apr	14125	921	29	0.031	7731	0.031[c]
8-Apr	3346	1059	9	0.008	11017	0.008[c]
15-Apr	3907	964	6	0.006	9391	0.006[c]
22-Apr	227	226	3	0.013	5863	0.013[c]
29-Apr	142	140		0.000	5040	0.007[d]
6-May	98	98	1	0.010	5040	0.010[e]
13-May	13	13		0.000	4343	0.007[f]
20-May	8	7	1	0.143	2757	0.007[g]
27-May	0	0	0	NA	2656	0.007[g]
3-Jun	1	0	0	NA	2720	0.007[g]
10-June	0	0	0	NA	2780	0.007[g]
Total	21,925	3,481	49	0.014		0.011

[a]USGS Gage 14220500 Lewis River at Ariel, WA.
[b]Combined efficiency measured during weeks of 2-Mar trough 22-Apr (before left screw trap was damaged).
[c]No adjustment made to measured weekly efficiency.
[d]One trap off and one trap fishing; efficiency of the prior week (with similar average weekly flow) with 2 traps fishing was decreased by 50% and applied.
[e]Adustment made based on 1 trap not operating on 2 days.
[f]Adjustment made based on 2 traps operating on one day, and one trap operating on 2 days total.
[g]Only 1 trap operating; total season measured efficiency decreased by 50% and applied.

Table 100. Estimates of total salmonids passing the Golf Course traps by species and origin (Bootstrap and Sum of Discrete Interval Method)

Bootstrap Method (Thedinga et al. 1994)			
Species	Capture Efficiency Applied[a]	Bootstrap Mean Total Estimate	95% CI +/-
Coho (naturally produced, ≥60 mm FL)	0.011	10,893	4,072
Coho (naturally produced, <60 mm FL)	0.011	5,595	2,348
Coho (hatchery produced)	0.012	1,852,836	546,035
Chinook (naturally produced, <60 mm FL)	0.011	1,250,158	402,614
Rainbow/Steelhead (naturally produced, ≥60 mm FL)	0.012	2,212	1,084
Cutthroat (naturally produced, ≥60 mm FL)	0.017	714	466
Sum of Discrete Interval Method (Volkhardt et al. 2007)			
Species		**Total Estimate**	**95% CI +/-**
Coho (naturally produced, ≥60 mm FL)		9,648	4,645
Coho (naturally produced, <60 mm FL)		3,905	3,728
Coho (hatchery produced)		1,352,784	450,647
Chinook (naturally produced, <60 mm FL)		1,036,912	864,701
Rainbow/Steelhead (naturally produced, ≥60 mm FL)		2,001	1,761
Cutthroat (naturally produced, ≥60 mm FL)		625	854

3.5.1 Fall Screw trapping operations

The utilities operated a single 8 foot screw trap at the Golf Course site during release of spring Chinook from the Lewis River hatchery. The purpose of this trapping was to describe the outmigration patterns of spring Chinook released from the hatchery. Trap efficiency was not estimated during this period, therefore, no estimates of abundance are available. However, the data suggest that smolts released from Lewis River hatchery pass the trap within 24 to 48 hours and once all smolts were released from the hatchery catch rates at the screw trap dropped to zero.

Fall trapping began on October 17, 2018, to coincide with the start of volitional releases from the hatchery. Trapping ended on November 12, 2018. The trap was checked on a daily basis during the sampling period.

Table 111. Daily screw trap captures of fish by category and species between Oct 17, 2018 and November 12, 2018

DATE	Chinook (AD only)	Chinook (AD+CWT)	Chinook (CWT only, DIG)	Chinook (PJ Mark)	NOR Chinook	NOR Steelhead	Coho (AD)	NOR Coho	HOR Chinook	TOTAL (Chinook)	TOTAL (Steelhead)	TOTAL (Coho)	NOTES
17-Oct	45	0	0	0	3	3	0	4	45	48	3	4	
18-Oct	90	1	4	0	2	0	0	1	95	97	0	1	
19-Oct	172	3	0	0	1	1	0	0	175	176	1	0	
20-Oct	190	6	0	0	0	0	0	2	196	196	0	2	
21-Oct	129	10	8	0	1	3	0	0	147	148	3	0	
22-Oct	157	8	3	0	6	1	0	2	168	174	1	2	
23-Oct	198	12	9	0	2	0	2	0	219	221	0	2	
24-Oct	104	7	5	0	2	0	0	1	116	118	0	1	
25-Oct	157	12	10	0	0	0	2	3	179	179	0	5	
26-Oct	130	4	7	0	3	0	0	1	141	144	0	1	
27-Oct	68	1	2	0	2	0	0	4	71	73	0	4	
28-Oct	87	3	6	0	2	1	1	9	96	98	1	10	
29-Oct	5	1	1	0	1	0	0	1	7	8	0	1	
30-Oct	18	0	1	0	1	0	0	0	19	20	0	0	
31-Oct	8	0	0	0	0	0	0	0	8	8	0	0	
1-Nov	4	0	0	0	1	0	0	1	4	5	0	1	
2-Nov	88	4	5	10	3	0	0	0	107	110	0	0	
3-Nov	10	0	2	1	2	0	0	0	13	15	0	0	
4-Nov	3	0	0	0	0	0	0	2	3	3	0	2	
5-Nov	5	0	1	0	0	0	0	1	6	6	0	1	
6-Nov	2	0	0	0	1	1	0	0	2	3	1	0	
7-Nov	4	0	1	0	1	0	0	0	5	6	0	0	
8-Nov													trap not sampled
9-Nov	5	0	0	0	0	0	0	0	5	5	0	0	
10-Nov													trap not sampled
11-Nov													trap not sampled
12-Nov	4	0	0	0	0	0	0	0	4	4	0	0	
Totals	**1683**	**72**	**65**	**11**	**34**	**10**	**5**	**32**	**1831**	**1865**	**10**	**37**	**1912**

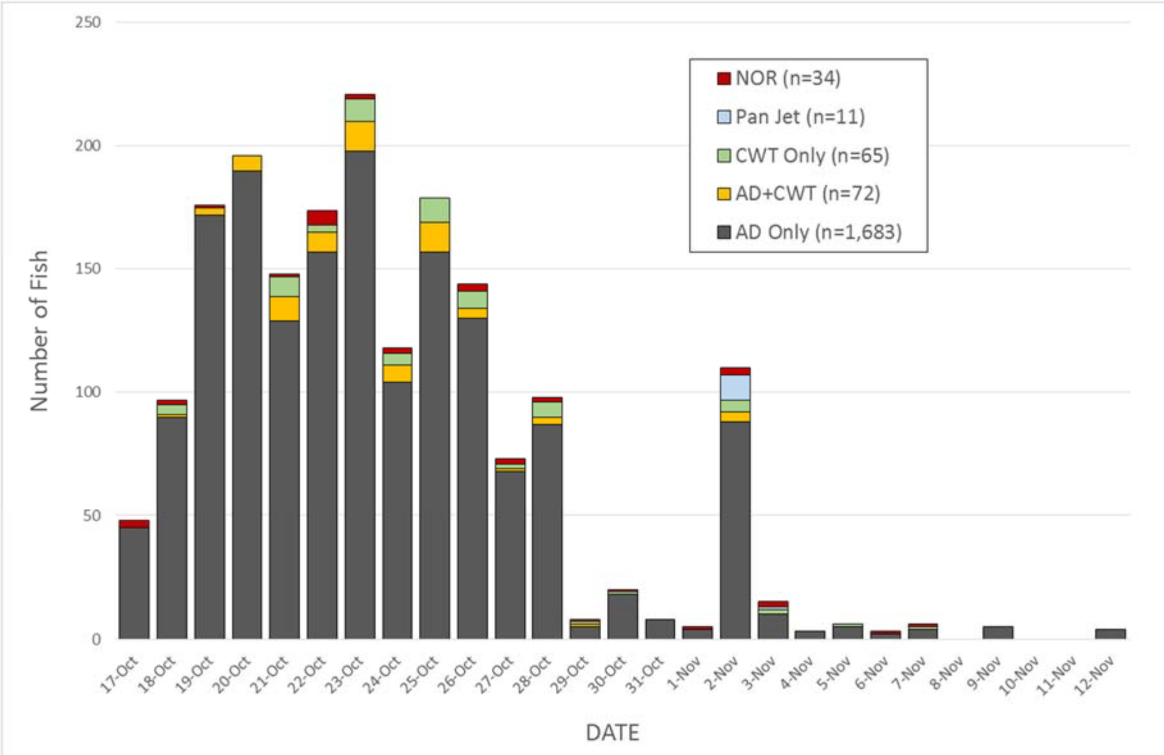

Figure 12. Daily screwtrap captures representing migration timing at the trap

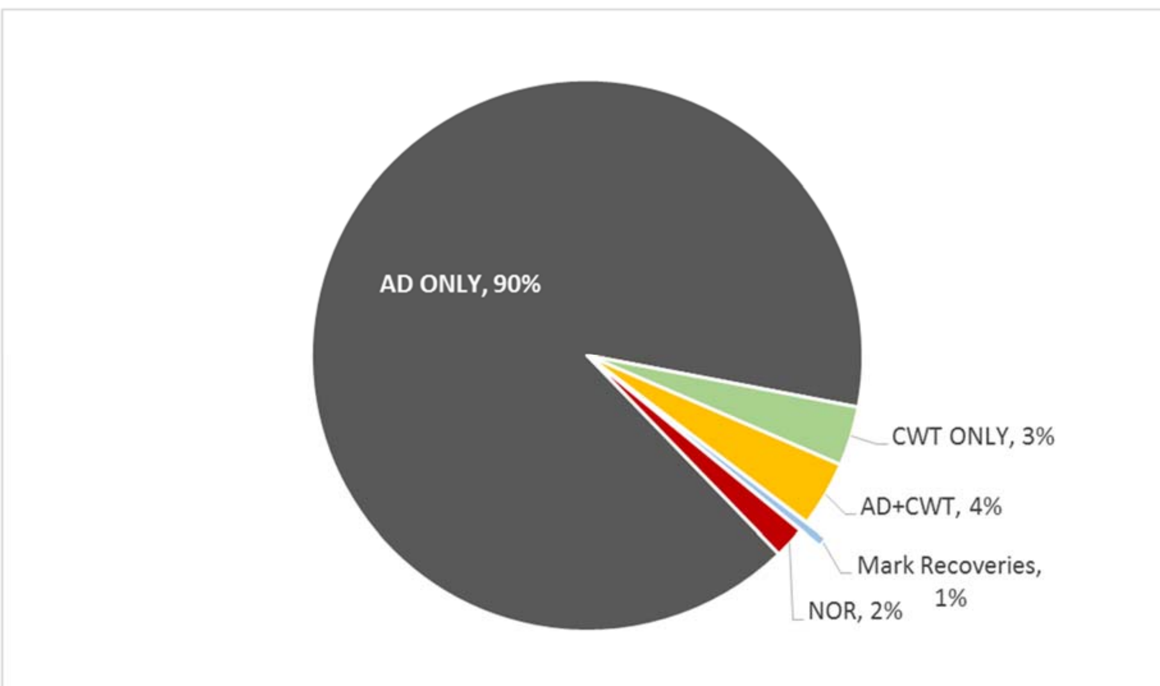

Figure 13. Proportion of screw trap captures by category

3.6 Mainstem Carcass and Redd Surveys

3.6.1 Mainstem Adult Coho Salmon Abundance Estimates – 2017

See Attachments D and E

3.6.2 Tributary Adult Coho Salmon Abundance Estimates: 2012 – 2016 (WDFW to provide)

PacifiCorp is awaiting analysis and results from tributary GRTS sampling conducted since 2012 by WDFW. All data have been provided to WDFW for analysis.

3.6.3 Fall Chinook Salmon Mainstem Surveys – 2013 to 2017

The Washington Department of Fish and Wildlife completed a detailed analysis of sampling methods in 2018. In addition, WDFW provided estimates of adult fall Chinook escapement for the North Fork Lewis River during the years 2013 to 2017. This information is provided in Appendix F.

4.0 RECOMMENDATIONS FOR ONGOING MANAGEMENT

The annual operating plan (AOP) for the Hatchery and Supplementation program continues to be updated and used as an adaptive management tool to address both ongoing and new priorities as they relate to hatchery operations, supplementation activities and development of effective monitoring designs.

In 2017 and 2018, the Hatchery and Supplementation subgroup began to add substantial detail and focus to several objectives. This work is still ongoing, but will also provide the foundation for consistent monitoring designs that will be helpful moving forward and have some application to other monitoring plans such as the Aquatic Monitoring and Evaluation Plan.

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APPENDIX A –

Late winter unmarked steelhead captured at the Merwin Trap and Tangle Netting and transported to Merwin Hatchery

Trap Date	Capture Location	Gender	Fork Length (cm)	Pit Tag #	DNA Sample # MFCF 18	Spawned	Mammal Marks	Comments
2/2/2018	Merwin Trap	M	64	3D6.001843D2F0	1	N	N	Meet Genetic Criteria. Released based on collection curve
2/3/2018	Merwin Trap	M	65	3D6.001843D309	2	N	Y	Meet Genetic Criteria. Released based on collection curve
2/8/2018	Merwin Trap	F	73	3D6.001843D329	3	N	N	Return to River 3/9 Poor condition
2/8/2018	Merwin Trap	M	66	3D6.001843D340	4	N	N	Meet Genetic Criteria. Released based on collection curve Return to FCF 2/18
2/12/2018	Merwin Trap	F	74	3DD.003C010D98	5	N	Y	Meet Genetic Criteria. Released based on collection curve
2/12/2018	Merwin Trap	F	64	3DD.003C010DDD	6	N	N	
2/12/2018	Merwin Trap	M	69	3DD.003C010DBO	7	N	N	Meet Genetic Criteria. Released based on collection curve
2/12/2018	Merwin Trap	F	60	3DD.003C010DCE	8	N	N	Meet Genetic Criteria. Released based on collection curve
2/13/2018	Merwin Trap	F	62	3DD.003C010DE8	9	N	N	Meet Genetic Criteria. Released based on collection curve
2/14/2018	Merwin Trap	M	68	3DD.003C010DB6	10	N	N	
2/15/2018	Merwin Trap	F	62	3DD.003C010DB9	11	N	N	
2/20/2018	Merwin Trap	F	68	3DD.003C0111A4	12	N	N	Meet Genetic Criteria. Released based on collection curve
2/20/2018	Merwin Trap	F	63	3DD.003C0111BA	13	Y	N	Recapture 4/5 @ FCF Held for Brood. 4/13 Spawned w/ Male FCF# 31,49
2/21/2018	Merwin Trap	M	60	3DD.003C0111AB	14	Y	N	4/13 Spawned w/ Female FCF# 29,46,57
2/26/2018	Merwin Trap	F	66	3DD.003C011194	15	N	N	Meet Genetic Criteria. Released based on collection curve
3/2/2018	Merwin Trap	M	84	3DD.003C010E31	16	Y	N	4/6 Spawned w/ Female FCF#38
3/5/2018	Merwin Trap	F	58	3DD.003C010E3E	17	Y	Y	4/13 Spawned w/ Male FCF# 37,24, TN#20
3/5/2018	Merwin Trap	F	56	3DD.003C010E18	18	N	Y	Genetic Assignment. Returned to River 4/24
3/5/2018	Merwin Trap	F	61	3DD.003C010E41	19	M	Y	Mortality 3/19
3/6/2018	Merwin Trap	F	62	3DD.003C010E04	20	N	N	
3/7/2018	Merwin Trap	M	72	3DD.003C010E0C	21	N	Y	Released due to condition and health
3/12/2018	Merwin Trap	F	66	3DD.003C01123C	22	Y	Y	4/13 Spawned w/ Male FCF# 37,24, TN#20
3/12/2018	Merwin Trap	M	68	3DD.003C010E1D	23	Y	Y	Spawned w/ Female #25
3/14/2018	Merwin Trap	M	63	3DD.003C011231	24	Y	Y	4/13 Spawned w/ Female FCF# 17,54,22
3/14/2018	Merwin Trap	F	73	3DD.003C011242	25	Y	Y	3/23 Spawned w/ Male #23 & #27
3/15/2018	Merwin Trap	F	67	3DD.003C011223	26	N	Y	Genetic Assignment. Returned to River
3/16/2018	Merwin Trap	M	64	3DD.003C95FAE	27	Y	Y	3/23 Spawned w/ Female #25
3/16/2018	Merwin Trap	F	68	3DD.003C01127	28	N	Y	Poor Condition. 4/13 Return to River
3/19/2018	Merwin Trap	F	72	3DD.003C010E98	29	Y	Y	4/13 Spawned w/ Male FCF# 47,41,14
3/19/2018	Merwin Trap	F	71	3DD.003C010EB3	30	N	Y	Genetic Assignment. Returned to River
3/19/2018	Merwin Trap	M	59	3DD.003C010E7B	31	Y	Y	4/13 Spawned w/ Female FCF# 40,13
3/21/2018	Merwin Trap	F	68	3DD.003C010E5B	32	Y	Y	4/24 Spawned w/ Male FCF# 48,62
3/22/2018	Merwin Trap	F	67	3DD.003C010E92	33	N	N	
3/26/2018	Merwin Trap	F	64	3DD.003C010E99	34	N	Y	Genetic Assignment. Returned to River
3/27/2018	Merwin Trap	F	76	3DD.003C010E8F	35	N	N	
3/29/2018	Merwin Trap	F	78	3DD.003C010ED2	36	Y	N	5/1 Spawned w/ Male FCF #73,74,77
3/29/2018	Tangle Net	M	80	3DD.003C0115C5	37	Y	Y	Tangle Net used MFCF 18-37 genetic vial. 4/13 Spawned w/ Female FCF# 17,54,22
3/30/2018	Merwin Trap	F	78	3DD.003C010EEC	38	Y	N	4/6 Spawned w/ Male FCF#16 & TN19

Trap Date	Capture Location	Gender	Fork Length (cm)	Pit Tag #	DNA Sample # MFCF 18	Spawned	Mammal Marks	Comments
4/2/2018	Merwin Trap	F	56	3DD.003C010EFC	39	N	Y	Genetic Assignment. Returned to River
4/2/2018	Merwin Trap	F	51	3D6.001843D301	40	Y	N	4/13 Spawned w/ Male FCF# 31,49
4/2/2018	Merwin Trap	M	82	3DD.003C010ECF	41	Y	N	4/13 Spawned w/ Female FCF# 29,46,57
4/2/2018	Merwin Trap	F	60	3DD.003C010EE6	42	N	Y	Returned to River 4/24, Ripe NO Male to Spawn
4/2/2018	Merwin Trap	F	56	3DD.003C010F18	43	Y	Y	4/24 Spawned w/ Male FCF# 67,50
4/2/2018	Merwin Trap	F	58	3DD.003C010ED1	44	N	Y	
4/2/2018	Merwin Trap	F	73	3DD.003C010EE0	45	Y	Y	5/8 Spawned w/ Male FCF #82,80,78
4/2/2018	Tangle Net	M	79	3DD.003C0115B5	TN 19	Y		4/6 Spawned w/ Female FCF#38
4/3/2018	Merwin Trap	F	63	3DD.003C010EDF	46	Y	N	4/13 Spawned w/ Male FCF# 47,41,14
4/3/2018	Merwin Trap	M	64	3DD.003C010EF0	47	Y	Y	4/13 Spawned w/ Female FCF# 29,46,57
4/4/2018	Merwin Trap	M	60	3DD.003C011264	48	Y	Y	4/24 spawned w/ Female #66, 32
4/4/2018	Merwin Trap	M	70	3DD.003C011250	49	Y	Y	4/13 Spawned w/ Female FCF# 40,13
4/4/2018	Tangle Net	M	69	3DD.003C0115A0	TN-20	Y		4/13 Spawned w/ Female FCF# 17,54,22
4/5/2018	Merwin Trap	M	52	3DD.003C01127E	50	Y	Y	4/24 Spawned w/ Female FCF# 56,43
4/5/2018	Merwin Trap	F	53	3DD.003C011279	51	N	Y	
4/6/2018	Merwin Trap	F	60	3DD.003C01129B	52	N	Y	Returned to River 5/8, Ripe NO Male to Spawn
4/6/2018	Merwin Trap	M	72	3DD.003C011256	53	N	Y	
4/9/2018	Merwin Trap	F	63	3DD.003C011072	54	Y	Y	4/13 Spawned w/ Male FCF# 37,24, TN#20
4/9/2018	Merwin Trap	F	81	3DD.003C011680	55	N	Y	Genetic Assignment. Returned to River 4/24
4/10/2018	Merwin Trap	F	71	3DD.003C01163D	56	Y	N	4/24 Spawned w/ Male FCF# 67,50
4/10/2018	Merwin Trap	F	63	3DD.003C011687	57	Y	Y	4/13 Spawned w/ Male FCF# 47,41,14
4/11/2018	Merwin Trap	F	61	3DD.003C011670	58	N	Y	Returned to River 4/24, Ripe NO Male to Spawn
4/11/2018	Merwin Trap	F	76	3DD.003C0115E2	59	N	Y	Returned to River Ripe
4/13/2018	Merwin Trap	F	61	3DD.003C0115DC	60	N	N	
4/13/2018	Merwin Trap	F	70	3DD.003C01160E	61	Y	N	5/1 Spawned w/ Male FCF #73,74,77
4/13/2018	Merwin Trap	M	57	3DD.003C01160B	62	Y	Y	4/24 spawned w/ Female #66, 32
4/16/2018	Merwin Trap	M	72	3DD.003C0115D1	63	N		5/8 Returned to River. Attempted to Spawn three weeks.
4/16/2018	Merwin Trap	F	70	3DD.003C010BEE	64	N		Genetic Assignment. Returned to River 4/24
4/16/2018	Merwin Trap	F	72	3DD.003C010DBD	65	N		Genetic Assignment. Returned to River 4/24
4/16/2018	Merwin Trap	F	73	3DD.003C0115D9	66	Y		4/24 Spawned w/ Male FCF# 48,62
4/16/2018	Merwin Trap	M	64	3DD.003C011609	67	Y		4/24 Spawned w/ Female FCF# 56,43
4/16/2018	Merwin Trap	F	69	3DD.003C010BCF	68	N	Y	Poor Condition Return to River
4/16/2018	Merwin Trap	F	68	3DD.003C011619	69	Y		5/25 Spawned w/ Male FCF #90
4/18/2018	Merwin Trap	F	62	3DD.003C010BEF	70	Y	N	5/8 Spawned w/ Male FCF #82,80,78
4/19/2018	Merwin Trap	F	60	3DD.003C010BDD	71	Y	Y	5/1 Spawned w/ Male FCF #73,74,77
4/19/2018	Merwin Trap	F	53	3DD.003C010BC3	72	N	N	Returned to River 5/21, Ripe NO Male to Spawn
4/20/2018	Merwin Trap	M	73	3DD.003C010BE9	73	Y	Y	5/1 Spawned w/ Female FCF #71,36,61
4/23/2018	Merwin Trap	M	68	3DD.003C010C16	74	Y	Y	5/1 Spawned w/ Female FCF #71,36,61
4/23/2018	Merwin Trap	F	62	3DD.003C010BD8	75	Y	Y	5/8 Spawned w/ Male FCF #82,80,78

Trap Date	Capture Location	Gender	Fork Length (cm)	Pit Tag #	DNA Sample # MFCF 18	Spawned	Mammal Marks	Comments
4/24/2018	Merwin Trap	F	65	3DD.003C010C2F	76	N	Y	Returned to River 5/1, Ripe NO Male to Spawn
4/24/2018	Merwin Trap	M	58	3DD.003C010C63	77	Y	N	5/1 Spawned w/ Female FCF #71,36,61
4/26/2018	Merwin Trap	M	58	3DD.003C010C4E	78	Y	N	5/8 Spawned w/ Female FCF #45,70,75
4/27/2018	Merwin Trap	F	66	3DD.003C010C64	79	N	Y	
4/30/2018	Merwin Trap	M	77	3DD.003C010C3B	80	Y	Y	5/8 Spawned w/ Female FCF #45,70,75
4/30/2018	Merwin Trap	F	70	3DD.003C010C17	81	N	Y	Returned to River 5/1, Ripe NO Male to Spawn
5/1/2018	Merwin Trap	M	62	3DD.003C010FD9	82	Y	Y	5/8 Spawned w/ Female FCF #45,70,75
5/2/2018	Merwin Trap	M	75	3DD.003C010FE7	83	M	N	5/11 Mortality
5/2/2018	Merwin Trap	F	58	3DD.003C010FD1	84	N	N	Returned to River 5/21, Ripe NO Male to Spawn
5/3/2018	Merwin Trap	F	71	3DD.003C010F9D	85	N	Y	Returned to River 5/11, Ripe NO Male to Spawn
5/4/2018	Merwin Trap	F	63	3DD.003C010F87	86	N	N	Returned to River 5/11, Ripe NO Male to Spawn
5/7/2018	Merwin Trap	F	63	3DD.003C0115AA	87	N	Y	Returned to River End of Season
5/9/2018	Merwin Trap	F	67	3DD.003C010F96	88	Y	Y	5/21 Spawned w/ Male FCF #89
5/15/2018	Merwin Trap	M	67	3DD.003C010F88	89	Y	Y	5/21 Spawned w/ Female FCF #88
5/16/2018	Merwin Trap	M	71	3DD.003C010FA6	90	Y	Y	5/25 Spawned w/ Female FCF #69
5/21/2018	Merwin Trap	F		3DD.003C010FFA	91	N	Y	Returned to River 5/21, Ripe NO Male to Spawn

APPENDIX B –

Genetic Assignment Results from Late Winter Steelhead Captures at Merwin Trap (MFCF) and Tangle Netting (TN) – 2018

	Date	Vial Label	Assignment Probability: Primary	*p*	Secondary	*p*	Tertiary	*p*	Spawned
1	2/9/2018	MFCF18-001	EFLewisR	0.57	**LR Cedar**	0.37	SandyR	0.04	
2	2/9/2018	MFCF18-002	**LR Cedar**	0.55	GreenR	0.40	KalamaR_W	0.03	
3	2/16/2018	MFCF18-003	**LR Cedar**	0.64	**LR Merwin**	0.32	CoweemanR	0.03	
4	2/16/2018	MFCF18-004	**LR Merwin**	0.82	KalamaR_W	0.06	CoweemanR	0.05	
5	2/16/2018	MFCF18-005	**LR Merwin**	0.42	CoweemanR	0.38	**LR Cedar**	0.09	
6	2/16/2018	MFCF18-006	Germany Cr	0.60	GreenR	0.17	**LR Cedar**	0.09	
7	2/16/2018	MFCF18-007	**LR Merwin**	0.52	EFLewisR	0.15	**LR Cedar**	0.14	
8	2/16/2018	MFCF18-008	**LR Merwin**	0.68	**LR Cedar**	0.23	CoweemanR	0.06	
9	2/16/2018	MFCF18-009	**LR Merwin**	0.66	KalamaR_Su	0.20	GermanyCr	0.06	
10	2/23/2018	MFCF18-010	Germany Cr	0.95	BigCr	0.02	GreenR	0.02	
11	2/23/2018	MFCF18-011	CoweemanR	0.49	**LR Merwin**	0.37	GermanyCr	0.10	
12	2/23/2018	MFCF18-012	**LR Merwin**	0.83	**LR Cedar**	0.12	MillCr	0.01	
13	2/23/2018	MFCF18-013	**LR Merwin**	0.72	**LR Cedar**	0.23	SandyR	0.01	✓
14	3/2/2018	MFCF18-014	**LR Cedar**	0.64	**LR Merwin**	0.30	KalamaR_W	0.03	✓
15	3/2/2018	MFCF18-015	**LR Merwin**	0.72	ElochomanR	0.13	**LR Cedar**	0.12	
16	3/9/2018	MFCF18-016	**LR Merwin**	0.78	ElochomanR	0.08	**LR Cedar**	0.06	✓
17	3/9/2018	MFCF18-017	**LR Merwin**	0.76	**LR Cedar**	0.20	ClackamasR	0.02	✓
18	3/9/2018	MFCF18-018	**LR Merwin**	0.49	**LR Cedar**	0.30	CoweemanR	0.11	
19	3/9/2018	MFCF18-019	**LR Cedar**	0.60	**LR Merwin**	0.37	KalamaR_W	0.03	
20	3/9/2018	MFCF18-020	Green R	0.66	**LR Cedar**	0.28	KalamaR_Su	0.04	
21	3/16/2018	MFCF18-021	**LR Merwin**	0.99					
22	3/16/2018	MFCF18-022	**LR Cedar**	0.50	**LR Merwin**	0.16	GraysR	0.09	✓
23	3/16/2018	MFCF18-023	KalamaR_W	0.30	**LR Merwin**	0.26	GermanyCr	0.14	✓
24	3/23/2018	MFCF18-024	**LR Cedar**	0.76	**LR Merwin**	0.20	BigCr	0.02	✓
25	3/23/2018	MFCF18-025	**LR Cedar**	0.66	CoweemanR	0.23	**LR Merwin**	0.07	✓
26	3/23/2018	MFCF18-026	CoweemanR	0.59	**LR Merwin**	0.21	**LR Cedar**	0.19	
27	3/23/2018	MFCF18-027	**LR Merwin**	0.94	**LR Cedar**	0.04	CoweemanR	0.00	✓
28	3/23/2018	MFCF18-028	**LR Merwin**	0.87	CoweemanR	0.10	**LR Cedar**	0.02	
29	3/23/2018	MFCF18-029	**LR Merwin**	0.95	**LR Cedar**	0.04	ElochomanR	0.01	✓
30	3/23/2018	MFCF18-030	CoweemanR	0.35	**LR Cedar**	0.13	KalamaR_W	0.13	
31	3/23/2018	MFCF18-031	**LR Merwin**	0.83	**LR Cedar**	0.04	GermanyCr	0.03	✓
32	3/30/2018	MFCF18-032	**LR Merwin**	0.92	**LR Cedar**	0.05	CoweemanR	0.02	✓
33	3/30/2018	MFCF18-033	ElochomanR	0.91	**LR Merwin**	0.06	**LR Cedar**	0.02	
34	3/30/2018	MFCF18-034	KalamaR_W	0.57	**LR Cedar**	0.37	EFLewisR	0.02	
35	3/30/2018	MFCF18-035	KalamaR_Su	0.30	CoweemanR	0.27	KalamaR_W	0.14	
36	4/6/2018	MFCF18-036	**LR Merwin**	0.55	**LR Cedar**	0.42	GermanyCr	0.01	✓
37	4/6/2018	MFCF18-037	**LR Merwin**	0.75	GermanyCr	0.16	KalamaR_W	0.05	✓
38	4/6/2018	MFCF18-038	**LR Merwin**	0.87	**LR Cedar**	0.06	KalamaR_W	0.03	✓
39	4/6/2018	MFCF18-039	**LR Cedar**	0.49	CoweemanR	0.22	GermanyCr	0.11	
40	4/6/2018	MFCF18-040	**LR Cedar**	0.37	**LR Merwin**	0.30	GermanyCr	0.11	✓

	Date	Vial Label	Assignment Probability						Spawned
			Primary	*p*	Secondary	*p*	Tertiary	*p*	
41	4/6/2018	MFCF18-041	**LR Merwin**	0.85	**LR Cedar**	0.09	ElochomanR	0.03	✓
42	4/6/2018	MFCF18-042	**LR Cedar**	0.58	**LR Merwin**	0.23	GermanyCr	0.14	
43	4/6/2018	MFCF18-043	**LR Merwin**	0.98	GreenR	0.01			✓
44	4/6/2018	MFCF18-044	BigCr	0.98	GermanyCr	0.01			
45	4/6/2018	MFCF18-045	**LR Merwin**	0.89	**LR Cedar**	0.04	ElochomanR	0.04	✓
46	4/6/2018	MFCF18-046	**LR Merwin**	0.44	**LR Cedar**	0.43	GermanyCr	0.06	✓
47	4/6/2018	MFCF18-047	**LR Cedar**	0.71	**LR Merwin**	0.24	GreenR	0.03	✓
48	4/2/2018	TN18-019	**LR Cedar**	0.48	**LR Merwin**	0.45	CoweemanR	0.05	✓
49	2/26/2018	TN18-001	**LR Cedar**	0.77	**LRhat_W**	0.18	**LR Merwin**	0.03	
50	2/26/2018	TN18-002	**LR Cedar**	0.45	**LR Merwin**	0.34	GreenR	0.10	
51	2/26/2018	TN18-003	**LR Cedar**	0.53	KalamaR_W	0.18	EFLewisR	0.17	
52	2/26/2018	TN18-004	**LR Merwin**	0.98	**LR Cedar**	0.02			
53	2/26/2018	TN18-005	**LR Cedar**	0.44	**LR Merwin**	0.40	ElochomanR	0.06	
54	2/26/2018	TN18-006	**LR Merwin**	0.57	**LR Cedar**	0.40	CoweemanR	0.02	
55	3/7/2018	TN18-007	**LR Merwin**	0.56	GermanyCr	0.36	MillCr	0.03	
56	3/7/2018	TN18-008	**LR Merwin**	0.40	CoweemanR	0.25	**LR Cedar**	0.13	
57	3/12/2018	TN18-009	**LR Merwin**	0.38	**LR Cedar**	0.34	KalamaR_W	0.16	
58	3/12/2018	TN18-010	**LR Merwin**	0.97	**LR Cedar**	0.01	ClackamasR	0.01	
59	3/19/2018	TN18-011	**LR Cedar**	0.96	**LR Merwin**	0.02	GermanyCr	0.01	
60	3/19/2018	TN18-012	**LR Merwin**	0.44	KalamaR_W	0.27	ElochomanR	0.21	
61	3/29/2018	TN18-013	**LR Merwin**	0.59	**LR Cedar**	0.34	GermanyCr	0.05	
62	4/2/2018	TN18-014	**LR Cedar**	0.67	ElochomanR	0.14	KalamaR_W	0.10	
63	4/2/2018	TN18-015	**LR Cedar**	0.63	**LR Merwin**	0.21	MillCr	0.09	
64	4/2/2018	TN18-016	**LR Merwin**	0.99	KalamaR_W	0.00			
65	4/2/2018	TN18-017	**LR Cedar**	0.74	KalamaR_W	0.13	**LR Merwin**	0.11	
66	4/2/2018	TN18-018	**LR Merwin**	0.59	CoweemanR	0.21	**LR Cedar**	0.09	
67	4/13/2018	MFCF18-048	SandyR	0.98	**LR Merwin**	0.01			✓
68	4/13/2018	MFCF18-049	**LR Merwin**	0.88	**LR Cedar**	0.10	CowlitzR	0.01	✓
69	4/13/2018	MFCF18-050	**LR Merwin**	0.59	**LR Cedar**	0.41			✓
70	4/13/2018	MFCF18-051	MillCr	0.50	**LR Cedar**	0.43	KalamaR_W	0.04	
71	4/13/2018	MFCF18-052	**LR Merwin**	0.59	**LR Cedar**	0.25	CoweemanR	0.08	
72	4/13/2018	MFCF18-053	**LR Merwin**	0.26	EFLewisR	0.25	**LR Cedar**	0.12	
73	4/13/2018	MFCF18-054	**LR Merwin**	0.81	**LR Cedar**	0.07	KalamaR_W	0.06	✓
74	4/13/2018	MFCF18-055	**LR Merwin**	0.41	CoweemanR	0.30	**LR Cedar**	0.28	
75	4/13/2018	MFCF18-056	**LR Merwin**	0.60	**LR Cedar**	0.35	CoweemanR	0.04	✓
76	4/13/2018	MFCF18-057	**LR Merwin**	0.68	**LR Cedar**	0.20	CoweemanR	0.07	✓
77	4/13/2018	TN18-020	**LR Merwin**	1.00					✓
78	4/23/2018	MFCF18-058	**LR Merwin**	0.95	**LR Cedar**	0.03	CoweemanR	0.01	
79	4/23/2018	MFCF18-059	**LR Merwin**	0.97	MillCr	0.01	**LR Cedar**	0.01	
80	4/23/2018	MFCF18-060	**LR Cedar**	0.40	GermanyCr	0.28	EFLewisR	0.15	

	Date	Vial Label	Assignment Probability						Spawned
			Primary	*p*	Secondary	*p*	Tertiary	*p*	
81	4/23/2018	MFCF18-061	**LR Cedar**	0.88	**LR Merwin**	0.11			✓
82	4/23/2018	MFCF18-062	**LR Merwin**	0.60	**LR Cedar**	0.19	ElochomanR	0.09	✓
83	4/23/2018	MFCF18-063	**LR Merwin**	0.46	**LR Cedar**	0.34	GreenR	0.12	
84	4/23/2018	MFCF18-064	**LR Cedar**	0.45	CoweemanR	0.36	**LR Merwin**	0.17	
85	4/23/2018	MFCF18-065	**LR Cedar**	0.46	**LR Merwin**	0.28	CoweemanR	0.26	
86	4/23/2018	MFCF18-066	**LR Merwin**	0.95	CoweemanR	0.03	**LR Cedar**	0.02	✓
87	4/23/2018	MFCF18-067	**LR Merwin**	0.60	**LR Cedar**	0.36	GermanyCr	0.01	✓
88	4/23/2018	MFCF18-068	**LR Merwin**	0.88	CoweemanR	0.11	**LR Cedar**	0.01	
89	4/23/2018	MFCF18-069	**LR Merwin**	0.74	**LR Cedar**	0.09	KalamaR_W	0.08	✓
90	4/23/2018	TN18-022	**LR Merwin**	0.60	**LR Cedar**	0.39			
91	4/30/2018	MFCF18-070	**LR Merwin**	0.59	**LR Cedar**	0.34	EFLewisR	0.04	✓
92	4/30/2018	MFCF18-071	**LR Cedar**	0.70	**LR Merwin**	0.28	GermanyCr	0.01	✓
93	4/30/2018	MFCF18-072	**LR Merwin**	0.92	**LR Cedar**	0.07	KalamaR_W	0.01	
94	4/30/2018	MFCF18-073	**LR Merwin**	0.61	**LR Cedar**	0.13	CoweemanR	0.08	✓
95	4/30/2018	MFCF18-074	**LR Cedar**	0.48	**LR Merwin**	0.44	CoweemanR	0.04	✓
96	4/30/2018	MFCF18-075	**LR Merwin**	0.63	**LR Cedar**	0.37			✓
97	4/30/2018	MFCF18-076	**LR Cedar**	0.51	**LR Merwin**	0.37	MillCr	0.03	
98	4/30/2018	MFCF18-077	**LR Cedar**	0.49	**LR Merwin**	0.45	KalamaR_W	0.06	✓
99	5/7/2018	MFCF18-078	**LR Merwin**	0.90	**LR Cedar**	0.08	CoweemanR	0.00	✓
100	5/7/2018	MFCF18-079	**ElochHat**	0.32	GermanyCr	0.29	CoweemanR	0.13	
101	5/7/2018	MFCF18-080	**LR Cedar**	0.49	**LR Merwin**	0.47	KalamaR_W	0.03	✓
102	5/7/2018	MFCF18-081	**LR Merwin**	0.44	**LR Cedar**	0.37	GreenR	0.08	
103	5/7/2018	MFCF18-082	**LR Merwin**	0.60	**LR Cedar**	0.23	CoweemanR	0.06	✓
104	5/10/2018	MFCF18-083	**LR Cedar**	0.79	KalamaR_W	0.07	**LR Merwin**	0.05	
105	5/10/2018	MFCF18-084	**LR Cedar**	0.63	**LR Merwin**	0.28	KalamaR_W	0.05	
106	5/10/2018	MFCF18-085	**LR Merwin**	0.96	**LR Cedar**	0.02	KalamaR_Su	0.01	
107	5/10/2018	MFCF18-086	**LR Merwin**	0.85	**LR Cedar**	0.11	GermanyCr	0.04	
108	5/10/2018	MFCF18-087	**LR Merwin**	0.60	CoweemanR	0.20	**LR Cedar**	0.09	
109	5/17/2018	MFCF18-088	**LR Merwin**	0.66	**LR Cedar**	0.32	GermanyCr	0.02	✓
110	5/17/2018	MFCF18-089	**LR Cedar**	0.44	**LR Merwin**	0.24	KalamaR_W	0.18	✓
111	5/25/2018	MFCF18-090	**LR Merwin**	0.92	**LR Cedar**	0.06	KalamaR_W	0.01	✓
112	5/25/2018	MFCF18-091	kalamaR_W	0.42	**LR Cedar**	0.27	GermanyCr	0.17	

APPENDIX C –

NOR Late Winter Steelhead Spawning Crosses -2018

Spawn Date	Cross	Genetic Vial Label FEMALES	MALES			Potential Families
3/23/2018	**1**	25	23	27		2
4/6/2018	**2**	38	16	TN19		2
4/13/2018	**3**	22	37	24	TN20	9
		54	37	24	TN20	
		17	37	24	TN20	
	4	40	31	49		4
		13	31	49		
	5	57	47	41	14	9
		46	47	41	14	
		29	47	41	14	
4/24/2018	**6**	56	67	50		4
		43	67	50		
	7	32	48	62		4
		66	48	62		
5/1/2018	**8**	36	73	74	77	9
		71	73	74	77	
		61	73	74	77	
5/8/2018	**9**	45	82	80	78	9
		70	82	80	78	
		75	82	80	78	
5/21/2018	**10**	88	89			1
5/25/2018	**11**	69	90			1
						54

APPENDIX D –

North Fork Lewis River *Downstream* of Merwin Dam – 2017 Coho Salmon Spawning Survey Results (October 2017 through January 2018)

Environmental Sciences
Regulatory Planning
Project Management

To: Erik Lesko, PacifiCorp

From: Jason Shappart, Meridian Environmental, Inc.

Date: June 26, 2018

Re: North Fork Lewis River Downstream of Merwin Dam – 2017 Coho Salmon Spawning Survey Results (October 2017 through January 2018)

Introduction

As a component of its existing FERC license, PacifiCorp conducts annual coho salmon spawning surveys from mid-October through January to facilitate estimating coho salmon spawning escapement in the North Fork Lewis River downstream of Merwin Dam (PacifiCorp 2017). Meridian Environmental, Inc. (Meridian) has performed these surveys under a contract with PacifiCorp since 2013. The mainstem North Fork Lewis River spawning survey area is divided into five index reaches as defined by the Washington Department of Fish and Wildlife (WDFW), extending from the boat barrier downstream of Merwin Dam to the downstream end of Eagle Island (Figure 1), encompassing 10.84 river miles (mainstem channel and Eagle Island side channel). The North Fork Lewis River tributary spawning survey reaches are defined annually by WDFW using a GRTS sample design. In 2017, WDFW designated two survey reaches within the Hayes Creek drainage, and one reach each in Robinson and Ross creeks (Figure 1). All surveys were conducted on a weekly basis as environmental conditions allowed (flow, turbidity, etc.) following methods described in PacifiCorp's revised Monitoring and Evaluation Plan (PacifiCorp 2017 and WDFW 2017 Stream Survey Manual). This memorandum summarizes the results of the coho salmon spawning surveys from mid-October 2017 through January 2018.

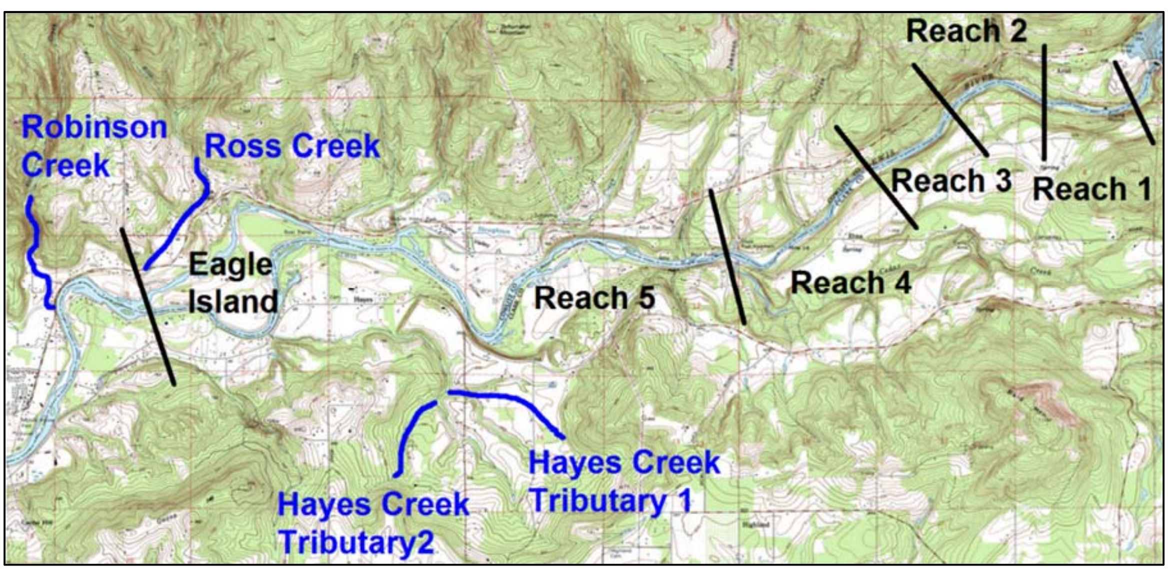

Figure 1. 2017 NF Lewis River coho spawning survey reaches below Merwin Dam.

Survey Conditions

In 2017, North Fork Lewis River flows below Merwin Dam were variable. They were high from mid-November through mid-December, yet conditions were surveyable for mainstem North Fork Lewis River and tributary survey reaches during every week of the survey period (Figure 2). On each survey occasion, all five mainstem North Fork Lewis River reaches were surveyed via jet boat during a single day. All tributary surveys were conducted on foot (walking surveys). In prior years, PacifiCorp conducted river drawdowns, generally on Wednesdays during the coho and fall Chinook spawning survey season, at the request of WDFW to facilitate WDFW's ability to recover fall Chinook carcasses. From 2013 to 2015, Meridian purposefully avoided conducting coho surveys during the Wednesday drawdowns at the request of WDFW. However, additional data analyses suggested that coho carcass recovery rates may be improved during lower flows. As a result, starting in 2016, Meridian conducted coho surveys during drawdown days to improve carcass detection probability and increase carcass resight probability. However, weekly spawning survey drawdowns generally did not occur during the 2017 survey season (Figure 2).

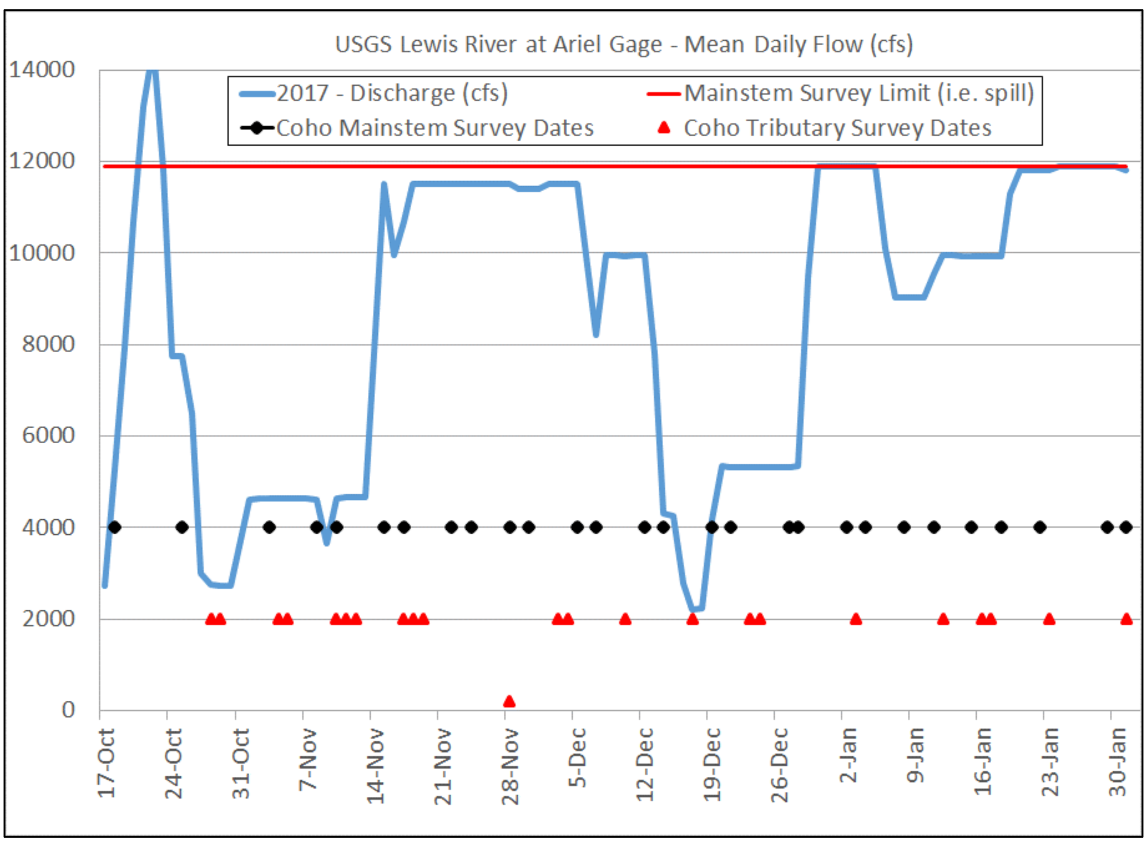

Figure 2. USGS Lewis River at Ariel gage – mean daily flow (cfs) during the 2017 coho spawning survey season and survey day timing.

Results

Tributary Surveys

Meridian biologists counted a total of 30 coho redds, 20 live coho spawners, and 11 coho carcasses in the Ross Creek survey reach. A total of 15 redds, 16 live coho spawners, and 2 carcasses were counted in the Robinson Creek reach. Two redds were counted in Hayes Creek Tributary 1, but no live coho or carcasses were observed. No redds, live coho, or carcasses were observed in Hayes Creek Tributary 2. No carcasses with coded wire tags were found.

Table 1. Summary of tributary coho salmon spawning surveys downstream of Merwin Dam (mid-October 2017 through January 2018).

Stream	Reach Length (miles)	Total Weeks (mid-Oct to Jan 31)	Total Weeks Surveyable	Total New Redds	Total Live Holders	Total Live Spawners	Hatchery Male Carcass	Hatchery Female Carcass	Unmarked Male Carcass	Unmarked Female Carcass	Total Carcass	% Pre-spawn Mortality (Females)	Carcass Wanded for CWT	CWT Positive Carcass
Hayes Trib 1	1.0	16	16	2	0	0	0	0	0	0	0	NA	0	0
Hayes Trib 2	0.5	16	16	0	0	0	0	0	0	0	0	NA	0	0
Robinson Creek	1.0	16	16	15	0	16	0	0	1	1	2	0%	2	0
Ross Creek	1.0	16	16	30	0	20	0	3	5	3	11	0%	11	0

The same tributary reaches were surveyed in some or all prior years from 2013 to 2016. Ross Creek continues to be a tributary with relatively high coho spawning activity. Of note is that coho redds were observed in Hayes Creek Tributary 1 for the first time since 2013 (Table 2). Coho spawning activity has not been observed in Hayes Creek Tributary 2 since Meridian began surveys in 2013 (Table 2).

Table 2. Tributary spawning survey count summary (2013-2017)

Year	Total Weeks Surveyable	Total Live Spawners	Total Carcasses	Total Redds
Ross Creek				
2013	13	44	20	18
2014	14	14	68	33
2015	10	10	5	2
2016	15	49	10	33
2017	16	20	11	30
Robinson Creek				
2013	not surveyed	NA	NA	NA
2014	10	28	3	4
2015	not surveyed	NA	NA	NA
2016	not surveyed	NA	NA	NA
2017	16	16	2	15
Hayes Creek Tributary 1				
2013	13	0	0	0
2014	4	0	0	0
2015	not surveyed	NA	NA	NA
2016	not surveyed	NA	NA	NA
2017	16	0	0	2
Hayes Creek Tributary 2				
2013	14	0	0	0
2014	2	0	0	0
2015	not surveyed	NA	NA	NA
2016	9	0	0	0
2017	16	0	0	0

North Fork Lewis River Surveys

As in prior years, Meridian biologists conducting coho redd surveys in the mainstem North Fork Lewis River found it difficult to differentiate coho redds from fall Chinook redds due to the very large number of fall Chinook spawning in the mainstem North Fork Lewis River. Only 24 coho carcasses were observed in the entire mainstem North Fork Lewis River survey area over the 28 survey occasions in the 16-week survey period (Table 3). No carcasses with coded-wire tags were found. A total of 58 percent of the carcasses were of hatchery origin. All carcasses were tagged and released to complete the mark-resight estimate of total carcasses. A total of 8 (33 percent) of the tagged carcasses were resighted at least once over the 28 sampling occasions. Carcass tagging results were used to make estimates of spawner escapement (i.e., total carcasses); see report from Leigh Ann Starcevich, PhD, Biometrician, West Inc., 2018. Coho spawning escapement to the North Fork Lewis River mainstem between the downstream end of Eagle Island and the boat barrier downstream of Merwin Dam was estimated to be 44, bootstrap 95 percent-CI: 33 to 55 (Starcevich 2018). The coefficient of variation for estimated escapement was 0.11.

Table 3. Summary of North Fork Lewis River mainstem coho salmon spawning surveys downstream of Merwin Dam (mid-October 2017 through January 2018).

NF Lewis River	Reach Length (miles)	Total Weeks (mid-Oct to Jan 31)	Total Weeks Surveyable	Total Live Holders	Total Live Spawners	Hatchery Male Carcass	Hatchery Female Carcass	Unmarked Male Carcass	Unmarked Female Carcass	Total Carcass	Total Carcass Tagged	Total Carcass Recoveries	% Pre-spawn Mortality (Females)	Carcass Wanded for CWT	CWT Positive Carcass
Reach 1	0.57	16	16	6	4	0	0	0	0	0	0	0	NA	0	0
Reach 2	0.68	16	16	4	14	0	1	1	0	2	2	1	0%	2	0
Reach 3	0.97	16	16	0	8	0	0	0	0	0	0	0	NA	0	0
Reach 4	1.32	16	16	20	25	1	3	1	3	8	8	3	0%	8	0
Reach 5	7.3	16	15	20	12	7	2	3	2	14	14	4	25%	14	0
Total	10.84	16	16	50	63	8	6	5	5	24	24	8	9%	24	0

Discussion and Conclusions

Incorporating surveys on drawdown days in 2016 nearly doubled the proportion of tagged carcasses that were resighted compared to the highest resight proportion in previous years (2013 to 2015) when surveys were conducted on non-drawdown days (Table 4). It is important to note that the same crew conducted all surveys during all four years covering the same reaches and season. These data suggest that conducting coho surveys on drawdown days increases detection probability of coho carcasses, which ultimately increases precision and confidence in estimates of coho spawning escapement. Drawdown operation for spawning surveys generally did not occur during the 2017 coho spawning survey season and average daily flow on survey days and average daily flow during the survey season was the highest since 2013 (Table 4). However, the coho carcass resight rate was the highest since 2013, which could be due to random chance due to low sample size. Therefore, we recommend to continue conducting coho spawning surveys during drawdown days in the future as possible.

Over the long term, these data suggest that as the upstream passage program has been implemented and refined (beginning in 2012) to transport coho upstream of the Lewis River Hydroelectric Projects, returning coho are electing to travel further upstream to spawn, and continue to spawn in lower North Fork Lewis River tributaries, rather than spawn in the lower mainstem NF Lewis River. The primary evidence of this effect is that thousands of adult coho have been captured at the fish passage facilities each year since 2013, while the number of coho carcasses encountered in the lower North Fork Lewis River downstream of the fish passage facilities appears to be declining. Over the same time, redd counts in important spawning tributaries, such as Ross Creek, have remained relatively similar.

Table 4. 2013 to 2017 total coho redd estimates.

Year	Total Carcasses Tagged	Total Carcasses Resighted	% Carcasses Resighted	Total Weeks Surveyable	Average Daily Flow during Surveys (cfs)	Average Daily Flow Oct 16-Jan-31
2013	328	41	13%	15	4,700	4,804
2014	431	18	4%	15	7,765	7,876
2015	12	2	17%	12	5,632	8,429
2016	65	20	31%	16	4,587	6,721
2017	24	8	33%	16	8,817	8,587

References

PacifiCorp and Cowlitz PUD. 2017. Aquatic monitoring and evaluation plan for the Lewis River – first revision, objective 15 - determine spawner abundance, timing and distribution of transported anadromous adults, dated February 28, 2017. Prepared by PacifiCorp and Public Utility District No. 1 of Cowlitz County.

Starcevich, L.A. 2017. Estimates of 2017 Coho Adult Escapement from Tagged Carcass Surveys in the Lower North Fork Lewis River downstream of Merwin Dam, dated May 31, 2018. Prepared for Meridian Environmental, Inc. by Leigh Ann Starcevich, PhD, Biometrician, West Inc., Environmental & Statistical Consultants, Corvallis, Oregon.

Appendix E –

Abundance estimate of 2017 coho escapement from carcass surveys in the lower Lewis River mainstem

ENVIRONMENTAL & STATISTICAL CONSULTANTS
456 SW Monroe Ave, Suite 106, Corvallis, OR 97333
Phone: 541-738-6198 ◆ www.west-inc.com

Date: May 31, 2018
To: Jason Shappart (Meridian Environmental, Inc.)
From: Leigh Ann Starcevich (WEST, Inc.)
Re: Estimates of 2017 Coho Adult Escapement from Tagged Carcass Surveys in the Lower North Fork Lewis River downstream of Merwin Dam

Introduction

Coho salmon spawning surveys (including carcass tagging) are conducted annually by Meridian Environmental, Inc. (Meridian) for PacifiCorp to provide the basis for estimating escapement in the mainstem North Fork Lewis River downstream of Merwin Dam to the downstream end of Eagle Island. The area of interest is divided into 5 reaches ranging from 0.57 to 7.30 miles long, previously defined by Washington Department of Fish and Wildlife (WDFW).

Coho carcass surveys were conducted on 28 occasions between October 18, 2017 and January 30, 2017. All observed coho carcasses in sufficient condition were identified and tagged with a uniquely-numbered plastic disk behind the gills (two tags per carcass) so that re-sighting probabilities of tagged carcasses do not differ from untagged carcasses. The tagged carcasses were returned to the river in the same location where found as suggested by WDFW. On successive survey occasions, carcasses were counted by reach. In previous years, after tagging, carcasses were placed in the current to re-distribute, and tails and tags from resighted tagged carcasses were removed and carcasses deposited adjacent to the river to prevent subsequent sightings. This year, resighted tagged carcasses were recorded but not destroyed so that carcasses were available for multiple resightings. After each resight, the tagged carcass was returned to the river in the same location where found.

Statistical Methods

Analysis tools developed for a similar analysis used by California Department of Fish and Wildlife (Bergman et al. 2012) were applied to the carcass data from the Lower Lewis River surveys. In the R statistical environment (2014), the *rma* package (McDonald 2015) was used to apply the super-population parameterization (Schwarz and Arnason 1996) of the Jolly-Seber model to estimate the total escapement in the population while accounting for subsampling of coho for marking. Escapement is quantified by Schwarz and Arnason (1996) as the total number of gross "births" in the area of interest, which includes coho present at the beginning of the study, those that move into the study area during the monitoring period, and those that do not survive to the end of the monitoring period.

Intercept-only models were used for capture and survival probabilities because preliminary modeling indicated that the 2017 data were too sparse for time-dependent

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models. A nonparametric bootstrap (Manly 2007) was used to obtain the standard error and 95%-confidence intervals on total escapement.

Results

The results of the 2017 carcass survey are provided in Table 1. A total of 26 carcasses were observed and 24 carcasses were in sufficient condition to mark. Of the 24 marked carcasses, 7 were re-sighted once and one carcass was resighted 5 times over 28 sampling occasions. Escapement (i.e. the total number of carcasses) was estimated in 2017 as 44 (bootstrap 95%-CI: 33, 55) individuals. However, the model results indicated poor convergence as demonstrated by near-zero estimates of the standard error of the capture probability, so model results may not be reliable. Analysis with the Cormack-Jolly-Seber model also resulted in poor convergence, which is likely due in both cases to the small sample size of 24 marked carcasses.

Table 1. Estimated 2017 coho spawner escapement by year to the mainstem North Fork Lewis River from Merwin Dam to the downstream end of Eagle Island, with 95%-confidence intervals.

Year	Number of marked carcasses	Number (%) of captured carcasses	Est. Gross Population Size	Bootstrap SE	95%-Confidence Interval	CV
2016	24	8 (33.3%)	44	5	(33, 55)	0.11

Literature Cited

Bergman, J. M., R. M. Nielson, and A. Low. 2012. Central Valley in-river Chinook salmon escapement monitoring plan. Fisheries Branch Administrative Report Number: 2012-1. California Department of Fish and Wildlife. Sacramento, CA.

Manly, B. 2007. *Randomization, Bootstrap, and Monte Carlo Methods in Biology, 3rd edition*. Chapman and Hall, Boca Raton, Florida, USA.

McDonald T. 2015. mra: Analysis of Mark-Recapture Data. R package version 2.16.4. http://CRAN.R-project.org/package=mra.

R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Schwarz, C.J., and A.N. Arnason. 1996. A general method for analysis of capture-recapture experiments in open populations. *Biometrics* 52:860-

APPENDIX F

North Fork Lewis River Fall Chinook Escapement Estimates: 2013 - 2017

STATE OF WASHINGTON **June 2018**

Estimates of Escapement and an Evaluation of Abundance Methods for North Fork Lewis River Fall-run Chinook Salmon, 2013 – 2017

by Kale Bentley, Dan Rawding, Shane Hawkins, Josua Holowatz, Scott Nelsen, Julie Grobelny & Thomas Buehrens

Photo credit: Tim Grams

Washington Department of FISH and WILDLIFE

FPT 18-03

Estimates of Escapement and an Evaluation of Abundance Methods for North Fork Lewis River Fall-run Chinook Salmon, 2013 – 2017

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June 2018

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Executive Summary

The Washington Department of Fish and Wildlife (WDFW) has estimated the abundance of fall-run Chinook salmon spawners in the North Fork (NF) Lewis River for more than five decades. Over this time period, the methods used to collect spawner data and generate estimates of abundance have varied. Specifically, estimates from 1964 – 1999 were calculated using a peak count expansion (PCE) factor of 5.27 that was derived using the relationship between the peak count (797) and total abundance (4,199) in a single year (1976). In the early-2000s, WDFW re-evaluated the PCE estimator and from this work developed a new expansion estimator known as the Bright-eye method (BEM). The BEM estimates annual abundance for NF Lewis River Chinook salmon using weekly carcass counts and average age-specific recovery rates observed during two years of data collection (2001 and 2002). Although the BEM was thought to be an improved estimator relative to the historical PCE factor, the main assumptions of the BEM (i.e., constant within and among year age-specific carcass recovery rates) have never been evaluated and thus it is unknown if estimates derived using the BEM are unbiased. Additionally, the BEM does not generate an estimate of uncertainty around the point estimate. Therefore, the current BEM estimator does not meet the monitoring recommendations for ESA-listed salmon and steelhead populations that have been outlined by NOAA Fisheries and local watershed management plans.

In an effort to evaluate the BEM and gather additional years of the PCE ratios, WDFW conducted mark-recapture spawning ground surveys for five years (2013 – 2017). The objectives of the mark-recapture carcass tagging surveys were to (1) generate independent and unbiased estimates of spawner abundance and composition with estimates of uncertainty, (2) evaluate whether or not the BEM and PCE can generate unbiased estimates of abundance, and (3) provide recommendations for future surveys and analyses based on the results. Using a mark-recapture Jolly-Seber (JS) model, we generated estimates of abundance for NF Lewis River Chinook by stock (tule, bright), origin (hatchery, wild), sex (jack, female, male), and total age (2 – 6). Across the five years of surveys, estimates of total fall-run Chinook salmon abundance (i.e., tules and brights combined) generated with the JS estimator ranged from approximately 10,000 to 27,000 spawners per year (CV of 2 – 13%) of which approximately 66 – 85% were late-run (“bright” stock) Chinook salmon.

Using the JS estimates, which were assumed to be unbiased, we evaluated the accuracy and precision of abundance estimates derived with the BEM and three different PCE estimators. Among years, the absolute percent error for estimates of abundance derived with the BEM estimator ranged from 3 – 55% (mean absolute percent error: 13 – 24%) while the absolute percent error for estimates of abundance derived with the PCE estimators ranged from <1 – 65% (mean absolute percent error: 7 – 28%). Therefore, in general, the accuracy of abundance estimates derived with the BEM and PCE estimators were quite similar. However, one advantage of the PCE estimators is that abundance estimates are derived with uncertainty, albeit relatively imprecise (CV 28 – 49%). Overall, the main assumptions of the BEM and PCE estimators were not consistently met, which led to inaccurate estimates of abundance in some years. Based on these results, we recommend the continuation of annual mark-recapture surveys (JS method) to estimate the abundance of NF Lewis Chinook salmon until a more cost-effective, alternative method has been developed that can generate abundance estimates by stock, origin, sex, and age with comparable uncertainty and robustness to model assumptions.

Introduction

The Lower Columbia River (LCR) Chinook salmon (*Oncorhynchus tshawytcha*) Evolutionarily Significant Unit (ESU) consists of 32 historical independent populations that are distributed from the mouth of the Columbia River upstream to Hood River in Oregon (NMFS 2013). LCR Chinook salmon exhibit two dominant adult migration patterns based on when individuals return to freshwater to spawn. These two dominant life-history strategies have been used to categorize populations as either spring-run or fall-run Chinook (Myers et al. 2006). Fall-run Chinook populations have been further separated into two groups (i.e., stocks) based on run-timing– "fall-run" and "late fall-run" – and are referred to as "tule" and "bright" Chinook salmon, respectively. Hereafter, the term "fall-run" Chinook will be used in reference to the combination of these two stocks while the terms tule and bright will be used to identify the specific fall-run stock.

In 1999, Chinook salmon in the LCR ESU were listed for protection under the Endangered Species Act (ESA) and have been designated as Threatened ever since. Following listing, the Washington Department of Fish and Wildlife (WDFW) initiated an extensive monitoring program for Chinook salmon (hereafter referred to as just Chinook) throughout Washington's portion of the LCR ESU. This monitoring program focused on estimating Viable Salmonid Population (VSP) parameters (McElhany et al. 2000) and other specific indicators (Rawding and Rodgers 2013, Rawding et al. 2014) with the purpose of assessing the status, trend, and long-term viability of LCR Chinook. While this relatively recent monitoring program marked the beginning of data collection for many LCR Chinook populations, Chinook in the Lewis River have a much longer monitoring history.

WDFW, formerly the Washington Department of Fisheries, has been conducting spawning ground surveys for Chinook in the Lewis River since the mid-1950s. In the early years, surveys were focused on fall-run Chinook in the North Fork (NF) Lewis River and consisted of live and dead counts in index sections during peak spawning for the purpose of estimating relative abundance. In the mid-1970s, managers commenced several studies to better understand why the numbers of Lewis River Chinook had remained relatively abundant while numbers of most other LCR populations had dwindled. One of the studies was a mark-recapture carcass tagging evaluation. The goal of the study was to estimate the total spawning population of fall-run Chinook in the NF Lewis River for a single year that would allow the generation of a peak count expansion (PCE) factor (McIssac 1976). For the following two and a half decades, WDFW continued to conduct peak count surveys and generated estimates of total Chinook abundance using the PCE factor established in 1976.

In the early 2000s, WDFW revisited the methods that were being used to estimate the abundance of Lewis River Chinook due to several management changes that had occurred over the previous decades. First, the fall Chinook hatchery program on the Lewis River had been discontinued in the mid-1980s and there was evidence that the peak spawning timing had shifted later in the season thereby questioning the accuracy of the 1976 PCE factor. This change in peak spawning also corresponds with environmental conditions (i.e., increased flows, decreased visibility) that make counts of fish much more difficult and in some years impossible. Second, mass-marking (i.e., adipose fin-clipping) of hatchery-origin Chinook had been implemented in the mid-2000s, which now allowed hatchery- and wild-origin stocks to be monitored independently. Third, monitoring standards and guidelines had been refined and specifically, the Chinook Technical Committee recommended that escapement estimates derived from index expansion factors be regularly evaluated (Hawkins et al. 2003a). Therefore, WDFW conducted a mark-recapture carcass tagging study in three consecutive years (2000 – 2002) to estimate total escapement and establish updated expansion factors for Lewis River fall-run Chinook.

From this work, WDFW developed a new expansion method to estimate total fall-run Chinook abundance in the Lewis River. This new abundance estimator was termed the "Bright-eye method" (BEM) and has been used as the primary estimator since 2000 (e.g., Hawkins 2013; see methods section below for further description). Although the BEM was likely an improvement from the earlier PCE factor, it is not known if BEM estimates of Chinook abundance are accurate (i.e., unbiased). Additionally, the current form of the estimator does not derive estimates of uncertainty (i.e., precision) which means that we are unable to evaluate confidence in the resulting estimate. Therefore, the BEM does not meet the monitoring recommendations for ESA-listed salmon and steelhead populations (Crawford and Rumsey 2011) and monitoring guidelines established by the Lewis River Hatchery and Supplementation Annual Operating Plan (H&S Subgroup 2015). These limitations of the BEM are the impetus for the work contained in this report.

In 2013, WDFW reinitiated mark-recapture carcass surveys of Lewis River Chinook and has continued to use these methods in all subsequent years. The objectives of these mark-recapture carcass tagging surveys were three-fold:

(1) Generate independent and unbiased estimates of spawner abundance (i.e., escapement) for NF Lewis fall-run Chinook salmon
- Describe and evaluate the Jolly-Seber (JS) open population mark-recapture abundance estimator and its corresponding assumptions
- Estimate abundance using the JS estimator for populations of fall-run Chinook downstream of Merwin Dam from return years 2013 - 2017
- Report estimates in a manner that is consistent with Chinook populations listed in the Recovery Plan for the Lower Columbia River Evolutionary Significant Unit (NMFS 2013)

(2) Evaluate the Bright-eye method (BEM) and peak count expansion (PCE) estimators
- Describe and evaluate the BEM estimator and its corresponding assumptions
- Report the estimates of abundance that have been generated using the BEM from 2013 - 2017
- Develop updated PCE factors, evaluate model assumptions, and derive estimates of abundance
- Calculate the absolute difference and absolute percent error in abundance estimates derived with the BEM and PCE estimators relative to the JS estimator

(3) Provide recommendations for future fall-run Chinook monitoring methods and analyses in the Lewis River Basin

Methods

Study System

The Lewis River is located in southwest Washington and enters the Columbia River approximately 85 miles upstream from the Pacific Ocean (Figure 1). The Lewis River drains a basin of approximately 730 square miles and receives water from snowmelt from Mt. St. Helens and Mt. Adams, spring water, and rainfall. Historically, the diversity of habitats and associated hydrology and water temperatures in the watershed supported a great deal of run timing diversity in Chinook salmon, with earlier returning (e.g., spring and summer) Chinook salmon generally spawning higher in the watershed, and later returning fall spawners using the lower reaches of the watershed. In 1931, Merwin (Ariel) Dam was built at river mile (RM) 19.5 and has blocked natural upstream migration of Chinook and other fishes thereby forcing all Chinook, regardless of run timing to spawn in approximately nine miles of river. Three hatcheries (Lewis River, Merwin, and Speelyai) have been constructed and currently raise coho salmon, spring-run Chinook, kokanee, and steelhead. Hatchery fall-run Chinook were historically released into the Lewis River, but this program was discontinued after 1984 and the last of hatchery releases returned in 1991. However, many other LCR basins still receive releases of hatchery tule juveniles and some of these hatchery tule Chinook return (i.e., stray) to the Lewis River.

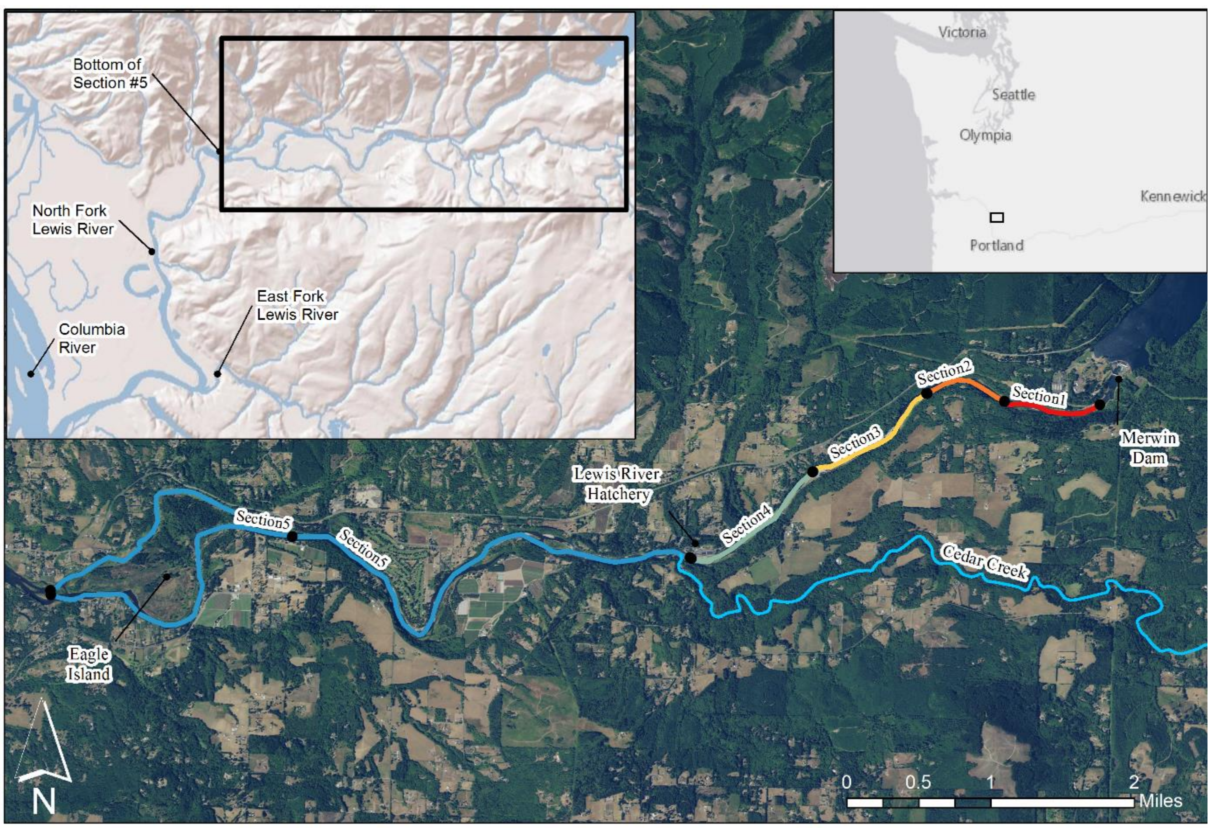

Figure 1. Map of fall-run Chinook salmon carcass survey sections on the NF Lewis River.

The Lewis River watershed contains three of the 32 LCR Chinook populations and together display each of the three unique run-types (spring, fall, and late-fall). The majority of Lewis River fall-run Chinook spawning occurs between the Lewis River Salmon Hatchery (RM 15.7) and the base of Merwin Dam (RM19.5). Additional spawning occurs in the mainstem Lewis River between the bottom of Eagle Island (RM10.0) and Lewis River Salmon Hatchery as well as in two major tributaries: Cedar Creek and the East Fork (EF) Lewis River, which enter the Lewis River at RM 15.7 and 3.5, respectively (Figure 1). The section of the Lewis River upstream from the mouth of the EF Lewis River is often referred to as the North Fork (NF) Lewis River.

The mark-recapture carcass tagging surveys completed in 2000 – 2002 and 2013 – 2017 were conducted in the NF Lewis River from the bottom of Eagle Island upstream to just below Merwin Dam. This total survey area has been delineated into five survey sections (Table 1, Figure 1). These survey sections have remained constant since the original 1976 carcass tagging study. Sections 1 – 4 are each approximately one mile in length and together make up the index count section dating back to the mid-1950s. Section 5 consists of a split channel surrounding Eagle Island. Historically, the 1976 PCE factor included Cedar Creek escapement, but for this evaluation, Cedar Creek and East Fork Lewis River Chinook data were analyzed separately. Therefore, these two data sets were not incorporated into this current evaluation. However, in the future, WDFW will make an effort to generate "total" Lewis River tule and bright abundance estimates that incorporate all major spawning areas (see "Recommendations").

Table 1 – Description of fall-run Chinook carcass survey sections on the NF Lewis River, 2013 – 2017.

Reach Code	Length (miles)	Description
NFL-1	0.7	Top: Pool Below Merwin Dam (RM 19.1) Bottom: Rocky bluff/Bottom of Sec #1 (RM 18.4)
NFL-2	0.8	Top: Rocky bluff/Bottom of Sec #1 (RM 18.4) Bottom: Waterfall below Hagedorns (RM 17.8)
NFL-3	1.0	Top: Waterfall below Hagedorns (RM 17.8) Bottom: Top of Big Bar (RM 16.8)
NFL-4	1.1	Top: Top of Big Bar (RM 16.8) Bottom: Lewis R. Hatchery Boat Ramp (RM 15.7)
NFL-5	7.7*	Top: Lewis R. Hatchery Boat Ramp (RM 15.7) Bottom: Bottom of Eagle Island (RM 10)

*Length includes both north and south channel around Eagle Island

Data Collection – Mark-recapture carcass surveys

From 2000 – 2002 and 2013 – 2017, mark-recapture carcass surveys were conducted on the NF Lewis River. Each year, surveys began in mid- to late-September and continued through mid-January to mid-February. This time period encompassed the large majority of fall-run Chinook spawn timing in the NF Lewis River. Surveys were conducted weekly given that river conditions were conducive to staff safety and fish visibility. Carcass surveys typically occurred on a single day per week and were aligned with when river flows were the lowest. One to four jet boats were used to navigate the river and sample Chinook carcasses. During the peak fall-run Chinook spawning timeframe (November through early December), PacifiCorp normally provided five "drawdowns" where river discharge at Merwin Dam was reduced in an effort to facilitate increased carcass recovery rates and improve observer efficiency for live and redd counts. Occasionally, a second survey day in a week was required due to large numbers of carcasses. When multiple surveys occurred in a single week, the data sets were pooled and treated as a single sampling period for mark-recapture analyses. Additionally, when a second survey day occurred in a single week, surveys proceeded upstream starting with the lowest reach first in order to prevent carcasses from being sampled more than once in a single week (e.g., by drifting into a current survey reach from a previously surveyed reach on consecutive days).

During each survey, recovered carcasses were sorted and processed in a sequential manner (Figure 2). First, carcasses were sorted based on their recovery status (i.e., recovered vs. not recovered) and several external features of the carcass. Carcasses that could not be recovered (e.g., too deep, pinned in a log jam) were enumerated and recorded as a Carcass Category 5 (Figure 3; Appendix A). If the carcass could be recovered (i.e., handled), it was initially examined for the presence of a tail. A carcass with a severed (i.e., missing) tail was indicative of a previously sampled fish and was subsequently ignored. Carcasses with intact tails were then sorted based on whether or not a surveyor could determine if the carcass had been previously tagged. Previously tagged carcasses would have a tag on the inside of one or both opercula (see below). Therefore, if a carcass was missing its head and/or opercula its previous tag status could not be determined. These carcasses were enumerated, denoted as either a Carcass Category 1 or 2 and had their tail severed. Carcasses recovered with a slit belly were assumed to not have died naturally (e.g., harvest mortalities) and were enumerated and denoted as a Carcass Category 6.

Second, carcasses with intact heads and/or opercula were sorted as either taggable or untaggable based on its qualitative Carcass Condition (CC) score (Table 2). The purpose of the CC score was to describe the carcass' state of decomposition. In 2001 – 2002, taggable carcasses typically had a numeric carcass condition score of 2 while untaggable carcasses were classified as either 3 – 6. The exception to this general rule was that early in the survey season when carcass recovery numbers were generally low and carcass persistence was short, carcasses with a score of 3 and sometimes 4 were also tagged. In 2013 – 2017, taggable carcasses had a numeric score of 2, 3, or 4 while untaggable carcasses were classified as either 5 or 6. Carcasses that were in a degraded condition (i.e., CC 5 or 6) were not tagged to reduce the dissimilarity in "survival" (i.e., persistence as a recoverable carcass) among tagged carcasses as older, more decomposed carcasses typically have lower probabilities of surviving to subsequent periods relative to newer carcasses (Sykes and Botsford 1986). Therefore, in all years, untaggable carcasses were designated as "mark sample only", classified as either a "jack" or an "adult" group carcass (see below), had their adipose-fin status recorded (see below) and Carcass Category recorded, examined for a coded-wire tag (CWT), had their tail severed to signify the carcass had been sampled (i.e., denoted as a "loss on capture" in Jolly-Seber model), and returned to the river.

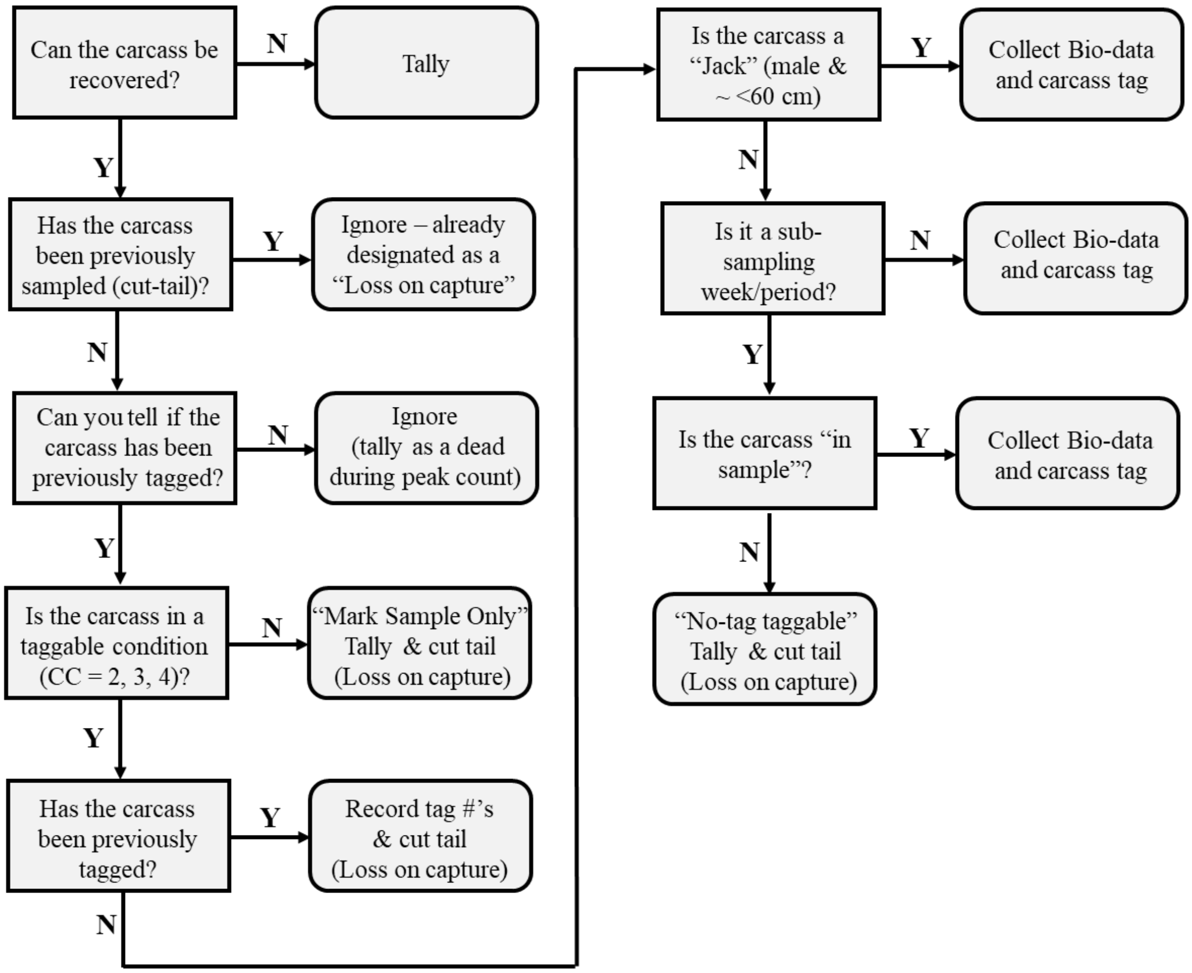

Figure 2. Sampling procedure for Fall Chinook carcass surveys on the NF Lewis River, 2013 – 2017.

Third, carcasses that were in taggable condition were then processed based on their capture history and size/age. Carcasses were sorted into maiden and recapture recoveries. A recaptured carcass would have had a uniquely numbered plastic tag stapled to the inside of one or both opercula while a carcass with no opercal tags was classified as a maiden. Recaptured carcasses had their tag number(s) recorded, tag(s) removed, tail severed to denote the carcass was sampled, and returned to the river. Maiden captures were sorted into two groups based on their sex and fork length. The first group were classified as "jacks/group 1" fish and consisted of small(er) males whose fork length was approximately < 60 cm. The second group were classified as "adults/group 2" fish and consisted of females and large(r) males whose fork length was approximately ≥60 cm. It should be noted that these group classifications were largely based on visual assessment of fish length upon collection. Therefore, a portion of the "jack" group carcasses consisted of small "adult" males and vice versa due to both inaccuracies in visually classifying carcasses by length (e.g., a 62 cm carcass placed into the <60 cm "jack" group) and variability in length-at-age (e.g., a 62 cm carcass classified as an "adult" was, in fact, a true, age-2 jack) based on scale analysis. Regardless, this slight variation in the group classification of each carcass (i.e., "jacks" vs. "adults") did not have any impact on the accuracy of abundance estimates as age-distribution was apportioned using weekly scale samples (see below).

Fourth, carcasses were then processed based on the weekly sampling rate. Specifically, carcasses were sorted into two groups ("in-sample" or "out-of-sample") based on the sampling rate for a particular week. In all weeks, "jack" group carcasses were sampled at a 1:1 rate due to the low overall recoveries of carcasses in this category. In most weeks, "adult" group carcasses were sampled at a 1:1 rate. However, sub-sampling occurred in most years during peak weeks when the number of recovered carcasses was too high to sample at a 1:1 rate. Sub-sampling rates were predetermined based on the anticipated number of recoveries for a particular week and varied from 1:2 to 1:10 among weeks and years. Out-of-sample carcasses were enumerated, had their tail severed to denote the carcass was sampled, and returned to the river. All carcasses (in and out of sample) with a missing adipose fin were scanned for a CWT (see below).

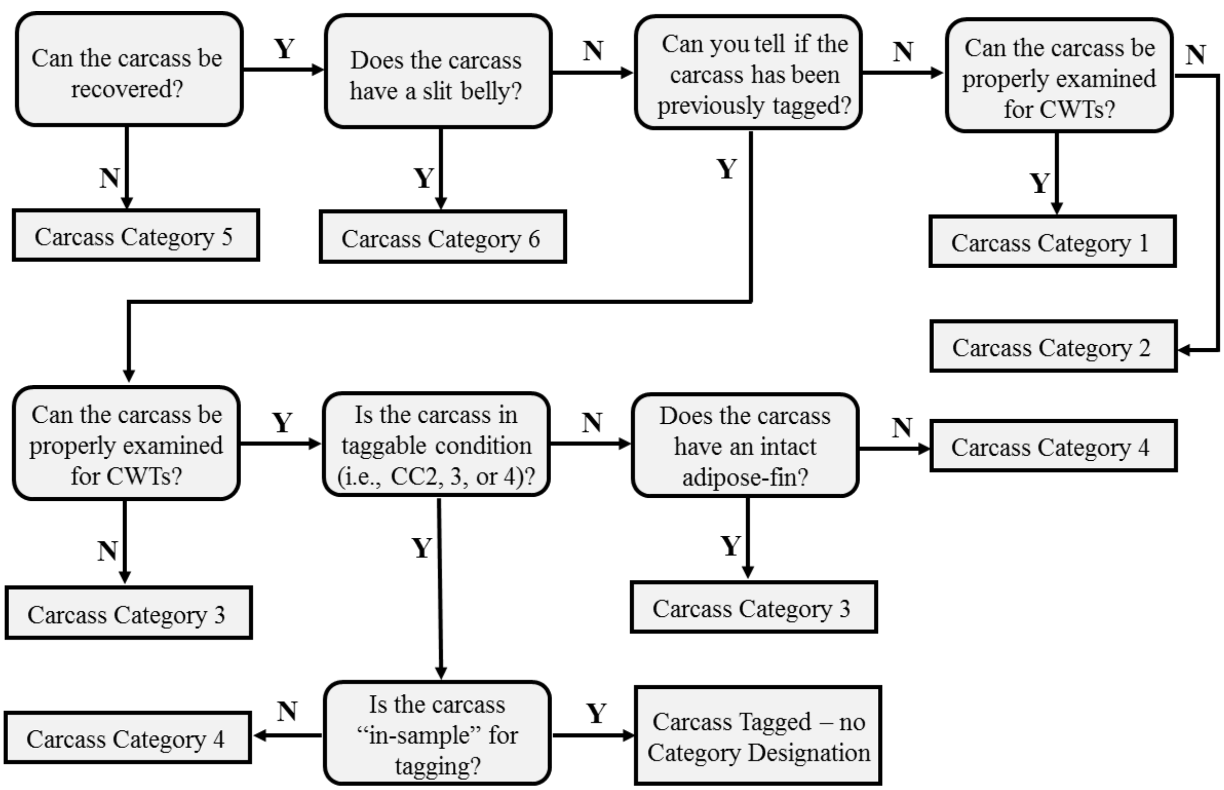

Figure 3. Diagram of Carcass Category designation for carcass surveys conducted on the NF Lewis River. Carcass Categories were only assigned to maiden (i.e., previously unsampled) carcasses that were not carcass tagged.

Lastly, in-sample (taggable, maiden) carcasses were bio-sampled and tagged. Carcasses were examined for the presence or absence of an adipose fin and CWTs. Prior to mid-November, all maiden recovered carcasses were scanned for a CWT using a handheld wand regardless of adipose status due to the possible presence of double-index tagged (DIT) spring run Chinook. After mid-November, only carcasses with missing adipose fins were scanned for CWTs. Carcasses that wanded positive for a CWT had their snouts removed and collected. All carcasses then had their sex, fork length (FL), and CC score (Table 2) recorded, scales collected for aging, and were tagged. Carcasses were tagged by stapling a uniquely numbered plastic tag on the inside of both opercles. Tagged carcasses were then returned to moving water in the river section they were collected from (Table 1) to facilitate mixing with untagged carcasses.

Table 2. Carcass condition (CC) categories codes and the associated description of a carcass. Categories and definitions are based on criteria developed by Sykes and Botsford (1986).

Category (Numeric)	Category (Alpha)	Description of Carcass Condition
1	L	Live, still gilling or moving*
2	F	Fresh, both eyes clear, firm flesh, gills bright red
3	D-	Slightly decayed, eyes cloudy, firm flesh
4	D	Decayed, eyes cloudy, soft flesh
5	D+	More decayed, eyes cloudy, very soft flesh
6	S	Skeleton, losing flesh

*Note: live fish were not tagged

Data Collection – Bright-eye method (BEM)

"Bright-eye" data collection methods were identical to the mark-recapture methods described above in years when mark-recapture tagging surveys were conducted. In years when mark-recapture carcass surveys were not conducted (i.e., years 2003 – 2012), "bright-eye" data collection methods were similar to the mark-recapture methods with a few exceptions. The major exceptions during these years were that (1) there were only two CC score designations ("fresh" or "mark-sample only"), and (2) the definition of a "fresh" carcass for the BEM is slightly different than the term for mark-recapture surveys (Table 2). Specifically, the term fresh for the BEM is meant to characterize a fish that had died in the same week of the survey (based on professional opinion) as opposed to just the external characteristics of the fish. This slight difference in the definition of a "fresh" carcass mainly impacts how carcasses are categorized during earlier survey periods (i.e., September and October) when water temperatures are higher and thus carcasses degrade faster. Therefore, a CC2 carcass would be classified as a "fresh" fish for both methods regardless of the survey time period. However, under the "bright eye" method a carcass with a CC of 3 or 4 may have been considered fresh depending on when it was recovered. In general, "bright eye" data collection methods considered carcasses to be fresh in September if they had a CC score of 2 – 4, in October if they had a CC score of 2 or 3, and in November to February if they had a CC score of 2. Also, jacks recovered with a CC score of 2 or 3 from October to February were considered fresh due to low sample sizes. Similar to "taggable carcasses" during mark-recapture data collection methods, biological data (i.e., FLs, scales) were only collected from "fresh" carcasses during Bright-eye surveys.

Data Collection – Peak count surveys

In addition to carcass surveys, visual surveys were conducted to count the number of live spawning Chinook in the NF Lewis. Counts coincided with the presumed peak spawn time period for both tule and bright fall-run Chinook. From 2013 - 2017, two to three counts were conducted for tules in October (generally the 2nd, 3rd, and 4th week of October) and brights in late November to early December (generally 3rd and 4th week of November and 1st week of December) for a total of four to six counts annually. Counts were performed by surveyors in boats and all five sections were surveyed during each count (Table 1). During the early (tule) counts when abundance was low, live fish were typically enumerated at the same time carcasses were being recovered and both live counts and carcass sampling was completed with one boat. During the late (bright) counts when abundance was high, live fish were enumerated separately from carcass surveys. For the bright counts, surveys began in the morning at the top of section #1 and two boats simultaneously counted live Chinook and redds while slowly motoring downstream to the bottom of section #5 (Figure 1). Counts of live fish were separated into jacks and adults by section based on a visual approximation of lengths greater or less than ~60 cm FL. Crews also collected waypoints of spawning aggregations to document spawning distribution. During the bright surveys, counts and carcass surveys were generally conducted on the same day. Therefore, the live count surveys corresponded with the drawdown from Merwin Dam that reduced flows in the lower river and increased visibility.

Data Management

Field data were recorded on a combination of scale cards and a whiteboard. Individual carcasses that were bio-sampled and/or tagged had their corresponding data (collection area, tag number, fork length, carcass condition, scales, etc.) recorded on the front of a scale card. Each column represented one carcass and each card held approximately 20 samples. Information regarding survey date, section number, sample rate, and the number of carcasses sampled was recorded on the back of the scale card. Tag numbers from carcass recoveries and the number of non-taggable ("mark sample only") carcasses were recorded on the whiteboard. Specific details on field data recording methods and terminology can be found in the WDFW's "Stream Survey Manual" (WDFW 2018). At the end of each survey day, the number of non-taggable carcasses was tallied and recorded by survey reach in the "plus count" field on the back of a single scale card. Field data were entered into WDFW's Traps, Weirs, and Surveys (TWS) Access database as well as a separate Excel spreadsheet throughout the survey season. Entered data were QA/QC at the end of the season and any errors or missing information were corrected. Fish scales and CWT samples/recoveries are processed by WDFW laboratories in Olympia, WA. Specific details describing how scales and CWTs are processed can be found in Rawding et al. (2014: page 12).

Data Analysis – Mark-recapture Jolly-Seber (JS) abundance estimates

The abundance of fall-run Chinook adult spawners (i.e., escapement) in 2013 – 2017 was estimated using a Jolly-Seber (JS) open population estimator (Seber 1982, Pollock et al. 1990) using a Bayesian modeling approach. Specifically, we used the "super-population" JS model that was developed by Schwarz et al. (1993) for estimating salmon spawning escapement using mark-capture methods. The super-population JS model built upon previous mark-recapture modeling work by Crosbie & Manly (1985) and Sykes & Botsford (1986). A conceptual diagram of the super-population model and its main components is shown in Figure 4 and detailed summary statistics and equations for the JS model can be found in Appendix B.

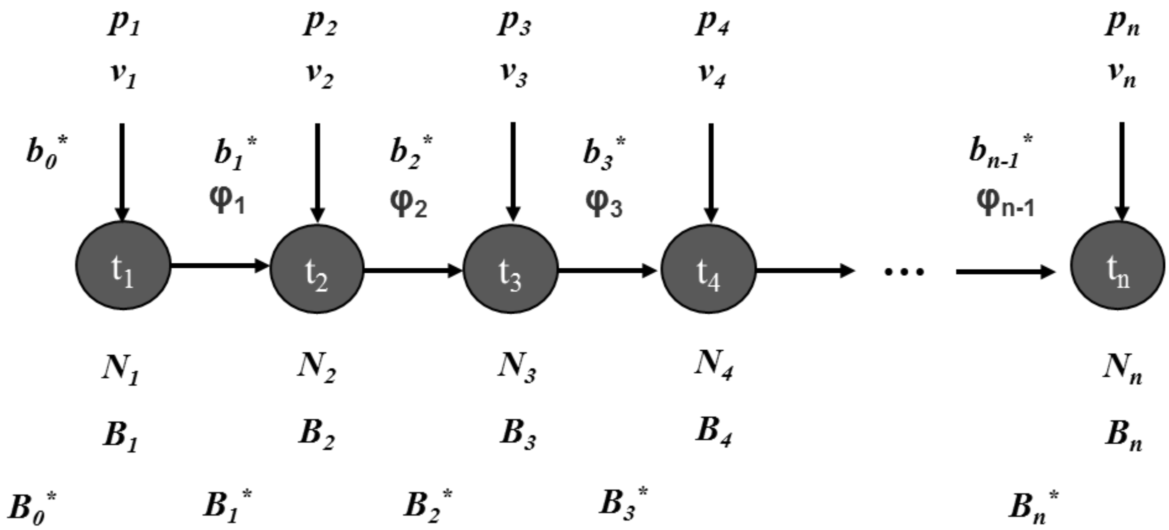

Figure 4**.** Conceptual diagram of "super population" Jolly-Seber abundance model developed by Schwarz et al. (1993) – diagram adapted from Schwarz and Arnason (2006). Fundamental parameters of the model include: sample period *i* ($\mathbf{t_i}$), probability of capture at sample period *i* ($\boldsymbol{p_i}$), probability that a carcass captured at time *i* will be released, opposite of a loss-on-capture ($\boldsymbol{v_i}$), probability that a carcass enters the population between sample periods *i* and *i+1*, which is referred to as probability of entry ($\mathbf{b_i^*}$), and the probability of a carcass persisting between sample periods *i* and *i+1* ($\boldsymbol{\varphi_i}$). Derived parameters of the model include: population size at sample period *i* ($\mathbf{N_i}$), number of fish that enter after sample period i and survive to sample period *i +1* ($\boldsymbol{B_i}$), and number of fish that enter between sampling period i-1 and i, these are referred to as gross births ($\boldsymbol{B_i^*}$). Total abundance is calculated as the sum of $\boldsymbol{B^*}$ over all sample periods.

The super-population JS model has been previously implemented by Rawding et al. (2014) to estimate the abundance of fall-run Chinook in the lower Columbia River. Rawding et al. (2014) provide a comprehensive description of the super population JS model, including summary statistics, fundamental parameters, derived parameters, and likelihoods is provided in Rawding et al. (2014). Overall, our analytical methods mirrored those used by Rawding et al. (2014) except in how we estimated the composition of the run (i.e., total abundance stratified by stock, origin, sex, and age) – see below. Briefly, the super-population JS model estimates total spawner escapement by summing "newly arrived" carcasses (i.e., gross births – B^*) that enter the study system over the entire survey period. This estimate of new carcasses includes both the number of carcasses that were present (i.e., available to sample) during each sampling period as well as the number of carcasses that arrived after a particular sampling period but were lost/removed (e.g., washed out) before the subsequent sample period.

The number of new carcasses (B^*) is a derived parameter from the JS model, which is based on a three-part likelihood equation:

$$\textit{Likelihood} = \textit{Pr (first capture)} \times \textit{Pr(loss on capture)} \times \textit{Pr (subsequent recaptures)}$$

where (1) the first component is the probability of first capture based on a super population (N) that enter the population (b_i^*) following a multinomial distribution, (2) the second component is the probability of release on capture (v_i) from a binomial distribution using total fish sampled (n_i)

and the number of n_i that are released (R_i) versus removed (i.e., loss-on-capture), and (3) the last component is the probability of recapture which is the product two binomial distributions to estimate the probability of survival (i.e., carcass remains available to sample) and probability of capture (i.e., catchability based on sampling conditions and characteristics of carcass).

Each year, we summarized the carcass survey data, tested model assumptions, and generated estimates of abundance following a serial approach. First, carcass data for an individual survey year were queried from the TWS Access database and ran through a standardized set of summarizations based on field sampled biological data. These summarizations first classified each sampled carcass by stock (tule, bright) using CWT recoveries, origin (hatchery, wild) using adipose-fin status and CWT recovery, and age (ages 2 – 6) using scale-pattern analysis. These bio-data were then summarized by sample period and these summaries were subsequently used to apportion the JS abundance estimates (see below). Second, we evaluated annual recapture probabilities by sex and size using logistic regression (Link and Barker 2006). The results of these tests influenced how carcass data were stratified (i.e., grouped; see below). Third, capture histories were generated for each individual carcass and JS summary statistics were generated by survey period using the *RMark* package (Laake 2013) implemented through the program R (R Development Core Team 2011). Only tagged individuals or carcasses with a Carcass Category of 3 or 4 were used in the analysis. Fourth, we evaluated the fit of four potential abundance models using Bayesian Goodness-of-Fit (GOF) tests using posterior predictive checks (Gelman et al. 1996). The four JS models that were evaluated included a combination of static (s) or time-varying (t) probabilities of capture (p), persistence/survival (φ), and entry (b^*) among survey periods/weeks (i.e., *ttt*, *stt*, *tst*, *sst*). Note that the third "*t*" is for the probability of entry, which was always modeled as a time-varying parameter due to intra-annual variation in spawn timing among individuals. Inputs for the JS models are listed in Appendix C.

Based on the results of the logistic regression and GOF tests within and among years, we chose to standardize our modeling procedure across years. First, we stratified the carcass data into three groups – jacks (i.e., small males), females, and males (i.e., larger males) – and generated <u>period-specific</u> estimates of abundance (B^*) for each of the three groupings using the completely time-varying JS estimator (i.e., *ttt* model). Second, we partitioned the period-specific B^* estimates by stock (tule, bright), origin (wild, hatchery), sex (jack, female, male), and age using <u>period-specific</u> summarized bio-data. Specifically, we partitioned stock using the ratio of CWT recoveries from out-of-basin hatchery tules to Lewis River wild brights, origin using adipose-fin status (clipped, unclipped) from all sampled carcasses, and age using scale-age reads from sampled carcasses. Combinations of stock, origin, and sex were estimated by multiplying probabilities based on binomial distributions while age was estimated with a multinomial distribution. Third, total estimates for a specific compositional grouping (e.g., hatchery tules) were generated by summing all of the period-specific estimates across the three groups.

Again, our overall modeling approach was the same as in Rawding et al. (2014) except in how we partitioned the B^* estimates. Specifically, Rawding et al. (2014) would have summed the all of the B^* estimates for each group and then partitioned the total estimate (N) using the "pooled" bio-data (i.e., bio-data summed across the entire run) for that group. The approach used by Rawding et al. (2014) assumes there is no run-timing variation in the composition of the overall population whereas our approach allows for run-timing variation and essentially weights the bio-data by the relative proportion of the run. If there is no variability in the composition of the population based on run-timing and/or variability in capture probabilities among sample periods, the two approaches will produce the same results. However, if there is variability in the composition of the population based on run-timing and/or variability in capture probabilities then the "pooled" bio-data partitioning approach may produce biased estimates. Ultimately, the appropriate approach will depend on partially on bio-data sample sizes. Because the NF Lewis bio-data sets were generally large, we were able to partition the bio-data by individual sample periods. This may not be the case for other (smaller) populations.

The Jolly-Seber (JS) models were parameterized using a Bayesian framework. Parameters were estimated from the posterior distribution, which was calculated as the product of the prior distribution and the probability of the data given the model or likelihood (Gelman et al. 2004). A vague "Bayes-LaPlace" uniform prior was used for the probability of capture (ρ), the probability of persistence (φ), the probability that a carcass was released (v), and the JS abundance calculations. A Dirichlet prior, with values of 1, was used for the probability of entry (b^*). The weekly proportions of race and origin were estimated based on a Binomial distribution with a Haldane prior (Beta[0.01,0.01]). The weekly age proportions were estimated based on a Multinomial distribution with a Dirichlet prior set to 0.01. The Haldane prior places most of its weight near 0 or 1 and provides a more robust estimate when proportions are near 0 or 1, which occurred for race, origin, and age in our analysis. Samples from the posterior distribution were obtained using Markov chain Monte Carlo (MCMC) simulations (Gilks 2005) in WinBUGS (Lunn et al. 2000) using the *R2WinBUGS* package (Sturtz et al. 2005). WinBUGS implements MCMC simulations using a Metropolis Gibbs sampling algorithm (Spiegelhalter et al. 2003). We ran two chains with the Gibbs sampler with an appropriate number of iterations and burn-in period so that the number of independent samples, as measured by effective sample size (ESS), was approximately 4,000 for each parameter of interest. An ESS of 4,000 provides a 95% credible interval (CI) that has posterior probabilities between 0.94 and 0.96 (Lunn et al. 2012). Initial values for each chain were automatically generated within the WinBUGS package. Modeled converged was based on visual assessment of traceplots for chain mixing and evaluation of the Brook-Gelman-Rubin (BGR) statistic (Su et al. 2001; Rhat < 1.05). For each of our reported estimates, we ensured that convergence was achieved and therefore assumed that our reported posterior distributions were accurate and represent the underlying stationary distributions of the estimated parameters.

When the assumptions of a super-population JS model are met, this estimator produces unbiased estimates of escapement with known levels of precision and is robust to minor assumption violations (Schwarz et al. 1993). Within the JS model, there are specific assumptions as to how recruitment (i.e., newly arrived carcasses) is modeled, but overall there are a total of four critical assumptions for open population models that must be met to obtain unbiased estimates (Seber 1982):

1. *Equal Catchability*: Each carcass that is present in the study system during a specific sample event, whether tagged or untagged, has the same probability of being sampled

2. *Equal Persistence*: Each carcass that is present in the study system during a specific sample event, whether tagged or untagged, has the same probability of survival (i.e., persisting in the study area to following sample period)
3. *Tag Loss and Recovery*: Tagged carcasses do not lose their marks and all marks are recognized and read properly on recovery
4. *Instantaneous Sampling*: All samples are instantaneous, i.e., the sampling time is negligible and each release is made immediately after the sample

Data Analysis – Bright-eye method (BEM) abundance estimates

Since 2002, the Bright-eye method (BEM) has been used to estimate the annual abundance of fall-run Chinook spawners. The BEM is similar in concept to the "sequential" estimator that was developed and implemented in Hawkins et al. (2003a, 2003b, 2004) in that abundance estimates are based on weekly carcass recoveries and a pooled expansion factor. However, the BEM is an age-stratified estimator that estimates annual abundance using (1) an adjusted count of weekly carcass recoveries from each survey year, and (2) a constant set of recovery and sample rates that were derived from the mark-recapture carcass tagging surveys conducted in 2001 and 2002 (Table 3).

Estimates of total abundance and composition for NF Lewis River fall-run Chinook were generated using the BEM in four sequential steps. First, the total number of recovered carcasses were summarized by survey week based on the presumed spawn week of each individual fish. This process was done separately for carcasses based on their carcass condition (fresh vs. mark sample - "MS" - only). Because "MS only" carcasses are recovered in a more deteriorated condition, these fish were presumed to have been recovered more than one week after spawning. Therefore, MS only carcasses were adjusted (i.e., assigned back) back to their presumed spawn week based on an average recovery rate of carcasses post-death. For example, during September and October surveys, approximately 80% of fresh carcasses are recovered one-week post tagging and 20% are recovered after two weeks post tagging. Therefore, if 100 MS only carcasses were recovered in survey period #3, 80 carcasses were assigned back to survey period #2 and 20 were assigned back to survey period #1. Based on their definition, fresh carcasses were assumed to have spawned and died in the same week they were recovered and therefore no adjustment was needed. Additionally, if sub-sampling occurred in a particular survey week, the number of fresh carcasses sampled was expanded by the weekly sub-sampling rate.

Second, carcass recoveries were apportioned by age class based on a weekly derived age-distribution separated by sex using scale samples collected from fresh carcasses. This process was done separately for carcasses based on their carcass condition (fresh vs. MS only). Fresh carcasses were directly apportioned based on the weekly sampled age-distribution. For example, if 100 fresh carcasses recovered in a week and age-distribution based on scale-age read from fresh carcasses was 10% age-2, 20% age-3, 40% age-4, and 30% age-5 then the estimated number of age-specific recoveries would have been 10, 20, 40, and 30, respectively. The MS only carcasses were also apportioned based on the weekly age-distribution from fresh carcasses. However, because MS only carcasses were older and thus had been subject to age-specific selectivity longer, the number of MS only recoveries were also "adjusted" by the age-specific recovery rate (Table 3). For example, if 100 MS only carcasses were recovered in a week and the estimated age-distribution of fresh carcasses was 10% age-2, 20% age-3, 40% age-4, and 30% age-5 then the “adjusted” age-specific MS only recoveries would have been approximately 4, 19, 40, and 37, respectively. Specifically, the number of age-2 MS only carcasses was calculated by: 100 (sampled MS carcasses) × 10% (age-distribution of age-2s) × 13% (recovery rate of age-2s) × 100 (sampled MS carcasses) ÷ 31.8 (total number of relative carcass recoveries across all ages). Weekly carcass recoveries for each group (fresh, MS only) were summed to get a total number of recovered carcasses by age across the entire survey year.

Table 3. Average age-stratified carcass tag recovery and sample rates used for the Bright-eye method (BEM) that were derived from mark-recapture carcass tagging surveys conducted in 2001 and 2002 (see Hawkins 2012).

Parameter	Age-2	Age-3	Age-4	Age-5	Age-6
Recovery Rate	0.13	0.30	0.32	0.39	0.54
Sample Rate	0.2290	0.5037	0.5837	0.7083	0.8263

Third, total escapement estimates were derived by age for each survey year. The total number of recovered carcasses were expanded to an escapement estimate using a constant set of age-specific sample rates that were derived from the carcass tagging surveys in 2001 and 2002 (Table 3). The age-specific sample rates are based on the age-specific recovery rates, but in essence account for the open population characteristics of the carcasses in the NF Lewis River (i.e., carcass immigration, persist/survive, and then emigrate). For instance, if the estimated recovery rate for age-2 Chinook was 0.13 then the estimated sample rate would have been approximately 0.24. This can be illustrated by the following example: across the entire survey season, a total of 100 carcasses were tagged and 13 were recovered, the calculated recovery rate would be estimated to be 0.13. Therefore, the total estimated number of carcasses (in the NF Lewis) would have been approximately 769 (100 ÷ 0.13) and over the entire survey season a total of 87 untagged carcasses would have been sampled (769 – 100 tagged = 669 untagged * 0.13 = 87 sampled). Thus, over the entire survey season, a total of 187 carcasses would have been sampled or rather 0.24 of the true total of 769. Age-specific sample rates can be calculated for any given recovery rate using this same logic. The age-specific sample rates were slightly modified when the BEM estimator was originally “calibrated”. For example, this slight calibration is why the sample rate for age-2 carcasses was 0.229 as opposed to 0.24 for a recovery rate of 0.13 (Table 3).

Lastly, total estimates of abundance were stratified by stock (tule, bright) and origin (wild, hatchery). Estimates of abundance by stock were based on the general timing of wild CWTs recoveries (i.e., wild Chinook that were tagged with a CWT as a juvenile, assumed to be bright-run Chinook, and subsequently recoveries on the spawning ground 2 – 6 years later). In general, carcasses recovered before the second week of November were assigned as tules while carcasses recovered after the second week of November were assigned as brights. Origin was based on both the timing (i.e., survey week) of recovery and the adipose fin-clip status (AD intact = wild, AD removed = hatchery) of recovered carcasses. Carcasses recovered prior to the second week of

November were assigned an origin based on their adipose fin-clip status while carcasses recovered after the second week of November were assumed to be all wild.

Abundance estimates derived using the BEM require two stringent set of assumptions:

1. *Equal Catchability*: Each carcass has a constant probability of capture (i.e., probability that a carcass is sampled given that it is present in the study system) for a given age-class across all survey periods within a year AND that probability is equal to the average capture probability estimated from mark-recapture data collected in 2001 and 2002.
2. *Equal Persistence*: Each carcass has a constant probability of survival (i.e., persisting in the study area to following sample periods) for a given age-class across all survey periods within a year AND that probability is equal to the average survival probability estimated from mark-recapture data collected in 2001 and 2002.

Data Analysis – Peak count expansion (PCE) estimates

We developed a hierarchical Bayesian model to derive peak count expansion (PCE) factors by stock (tule, bright) using our JS estimates of abundance and peak count (PC) carcass survey data collected from 2013 – 2017. These PCE factors were then used to subsequently generate PCE estimates of abundance for NF Lewis River tule-, bright-, and total fall-run Chinook.

Since 2000, carcass surveys have been completed almost every single week from early Sept through late December each year while the collection of live spawner count data has been more sporadic. In general, from 2000 – 2012, live counts have only been conducted for bright-run Chinook and the counts were typically conducted in early November. From 2013 – 2017, live counts were generally conducted 2 – 3 times per year for both tules and brights for a total of 4 – 6 surveys per years. However, live count surveys were not always completed due to adverse sampling conditions. For example, in 2015, live count surveys were not completed for brights and, in 2016, live counts did not correspond with the anticipated peak for tules.

Therefore, based on the historical live and dead count data, we decided to summarize PC data, and thus calculate PCE factors and estimates of abundance, three separate ways. First, we calculated the "peak lives + deads", which corresponded to the highest weekly count of carcasses and live spawners combined (i.e., the summation of lives and deads in the same week). Second, we calculated the "peak deads", which corresponded to the maximum weekly count of carcasses. Third, we calculated the "top 3 deads", which corresponded to the summation of the three highest weekly counts of carcasses across the sample periods of interest. Across all years, we only used peak count data that were collected during the same anticipated 5 – 6 week peak spawning time period, which corresponded from the first week in October through the first week in November for tules and from the second week in November through the second week in December for brights. We chose to use the "top 3" counts instead of summation of counts across all 5 – 6 periods (per stock) in order to facilitate computation in years when counts were not conducted across all weeks (e.g., missed survey due to poor conditions). Inputs for the PCE estimators are listed in Appendix D.

To fit our PCE model, we started by visually examining the posterior distribution of the JS abundance estimates and fitting a normal, log-normal, and gamma distributions to the draws of the posteriors. Based on these plots and the fits of each distribution, the log-normal distribution provided the best fit. Therefore, before fitting the PCE model, we converted the mean and standard deviation of the posterior of each observed JS abundance estimate into a log-normal mean and standard deviation using:

$$\mu_{logn_{i,j}} = \log\left(\mu_{n_{i,j}}\right) - \frac{1}{2}\,log\left(\frac{{\mu_n}^2{}_{i,j} - {\sigma_n}^2{}_{i,j}}{{\mu_n}^2{}_{i,j}}\right) \tag{1}$$

$$\sigma_{logn_{i,j}} = \sqrt{log\left(\frac{{\mu_n}^2{}_{i,j} - {\sigma_n}^2{}_{i,j}}{{\mu_n}^2{}_{i,j}}\right)} \tag{2}$$

where μ_n was the mean and σ_n was the standard deviation of the posterior draws of JS abundance estimate *n* for stock *i* and year *j* (Hobbs and Hooten 2015). The observed JS abundance estimates were then used in the following observation model (likelihood):

$$\mu_{logn_{i,j}} \sim Normal\left(log\left(N_{i,j}\right), \sigma_{logn_{i,j}}\right) \tag{3}$$

where the log-normal posterior mean of the JS abundance estimate $\mu_{logn_{i,j}}$ was normally distributed around the log of the predicted abundance *N* based on a hierarchical peak count expansion. The predicted abundance based on a hierarchical peak count expansion that was defined by:

$$N_{i,j} = PCE_{i,j} * PC_{i,j} \tag{4}$$

where *PCE* was the estimated peak count expansion factor and the *PC* was the peak count of carcasses. The PCE expansion factors were estimated by:

$$PCE_{i,j} = \frac{1}{PCP_{i,j}} \tag{5}$$

Where *PCP* was the proportion of the total abundance that was counted as part of the peak count. Each peak count expansion factor was estimated based on a hierarchical prior:

$$\text{logit}\left(PCP_{i,j}\right) \sim \text{Normal}\left(\mu_{logitPCP_i}, \sigma_{logitPCP_i}\right) \tag{6}$$

where the logit of each PCP was modeled as a random variable that was normally distributed around a hierarchical mean $\mu_{logitPCP}$ with standard deviation $\sigma_{logitPCP}$. The parameters of the hierarchical prior were then given hyper priors:

$$\mu_{logitPCP_i} \sim \text{Normal } (-0.75, 0.75) \tag{7}$$

$$\sigma_{logitPCP_i} \sim \text{Normal } (0, 0.5) \text{ Truncated}[0,] \tag{8}$$

Finally, we generated predictive distributions for the PCE and PCP factors in an unknown year using equations (5) and (6), respectively, and abundances estimates for each year peak counts were available based on these predictive PCEs using equation (4).

The peak count expansion (PCE) model was estimated using a Bayesian framework. Samples from the posterior distribution were obtained using Markov chain Monte Carlo (MCMC) simulations (Gilks 2005) in JAGS (Plummer 2003) using the *R2jags* package (Su and Yajima 2009). We ran four chains with 500,000 iterations, a burn-in period of 250,000, and a thinning rate of 250 so that the number of independent samples, as measured by effective sample size (ESS), was approximately 4,000 for each parameter of interest. Initial values for each chain were automatically generated within the JAGS package. Modeled convergence was assessed in the same manner as the JS models (i.e., assessment of ESS and BGR statistics).

The following is a list of the critical assumptions for the PCE method (Rawding and Rodgers 2013):

1. The entire spawning distribution is surveyed, or if the entire spawning distribution is not surveyed, the proportion of fish using the index area is the same as it was in the years used to develop the peak count expansion factor
2. The proportion of spawners available for counting as lives or carcasses on the peak survey date(s) is the same as it was in the years used to develop the peak count expansion factor
3. Observer efficiency is similar in all years

Comparison of abundance estimators

We evaluated the estimates of tule, bright, and total fall-run (tule and bright combined) Chinook abundance generated from the Bright-eye method (BEM) and peak count expansion (PCE) estimators by calculating the absolute difference, absolute percent (%) error, mean absolute percent error (MAPE) relative to the Jolly-Seber (JS) estimates using the following formulas:

$$Absolute\ Difference = X - JS \tag{9}$$

$$Absolute\ \%\ Error = \frac{|X - JS|}{JS} \times 100 \tag{10}$$

$$Mean\ Absolute\ \%\ Error = \left(\frac{1}{n}\sum \frac{|X - JS|}{JS}\right) \times 100 \tag{11}$$

Where X is an abundance estimate derived using either the BEM or PCE estimator, | | denotes that absolute difference between the BEM or PCE abundance estimate and the JS estimate, and n is the total number of paired estimates.

Results

Mark-recapture Jolly-Seber (JS) abundance estimates

Mark-recapture carcass tagging surveys were conducted for fall-run Chinook in the North Fork (NF) Lewis River for return years 2013 – 2017. Among years, fall-run Chinook surveys began in mid- to late September and continued for 15 to 21 weeks through mid-January to early February. Within a survey year, approximately 7,000 to 15,000 carcasses were recovered (i.e., sampled) of which approximately 2,000 to 3,000, or rather 20 – 40%, were tagged to evaluate seasonal recovery rates (Table 4). Across all years, the total (i.e., pooled) recovery rate of carcasses was estimated to be 41%, but recovery rates varied among years (Table 5). For instance, recovery rates in 2015 were approximately half of those in all other years. Recovery rates also varied among carcass grouping (Table 5). Specifically, the recovery rate of the jack-group carcasses (males <60 cm), which included a mixture of age-2 and age-3 males, was approximately half of that for females and males (≥60 cm).

Table 4. Summary of fall-run Chinook mark-recapture carcass surveys conducted in the NF Lewis River, 2013 - 2017. The survey start date reflects the week when the first fall-run Chinook was sampled.

Year	Start Date	End Date	Number of Survey Weeks	# of Carcasses Tagged	# of Carcasses Sampled	% of Sampled Carcasses Tagged
2013	9/12/2013	2/4/2014	21	3,417	11,984	29%
2014	9/11/2014	1/13/2015	19	2,954	14,680	20%
2015	9/23/2015	1/7/2016	15	2,060	9,957	21%
2016	9/22/2016	1/10/2017	17	2,839	7,170	40%
2017	9/27/2017	1/10/2018	16	2,109	4,712	45%

Mark-recapture data were analyzed using a Jolly-Seber (JS) open population mark-recapture estimator. Assumptions of this model were tested prior to generating abundance estimates to ensure unbiased results. The first two (of four) assumptions regarding equal catchability and survival of carcasses were evaluated using logistic regression and Bayesian Goodness-of-Fit (GOF) tests within and among years. Logistic regression tests generally concluded that jacks (males <60 cm), females, and males (≥ 60 cm) carcasses had statistically different recapture rates among years due to differences in body size. The Bayesian GOF tests concluded that while simpler JS models (*tst*, *stt*, *sst*) sometimes provided adequate fit for a particular carcass group (jacks, females, males) within a year, the completely time-varying (*ttt*) model always provided an adequate fit (i.e., $0.025 <$ Bayesian p-value < 0.975) for all groups among all years. Therefore, we standardized our modeling approach by generating separate estimates of abundance for the three carcass groups (jack, female, and male) within the same model using a JS estimator with a time-varying probability of capture (p), survival (φ), and entry (b^*) among survey periods/weeks. The third assumption regarding tag loss was assessed through double tagging of carcasses. Across all years, >97% of carcasses were recaptured with both tags meaning that <0.1% of carcasses would have lost both tags assuming individual tag loss is independent. Therefore, tag loss had a negligible effect on the final estimates and was not adjusted for. Proper reporting of recovered tags was not directly measured in the field, but careful training, use of experienced staff, development of data collection protocols, and standardized datasheets minimized concern that this assumption was violated. The final assumption, regarding instantaneous sampling, was meet by sampling almost every week throughout the survey season and by minimizing the survey duration (1-2 days) relative to the duration between surveys (5-6 days).

Across the five survey years, total mean estimates of fall-run Chinook salmon abundance in the NF Lewis River ranged approximately from 10,000 to 27,000 with tule- and bright-run estimates ranging approximately from 2,700 to 6,300 and 7,600 to 22,000, respectively (Table 6 – Table 10; Figure 5). The total fall-run and bright-run Chinook estimates of abundance had derived coefficient of variations (CV) ranging from 2 – 6% among years. Abundance estimates for tule-run Chinook had CVs ranging from 10 – 24%. Among years, the tule portion of the overall fall-run comprised on average 23% (range 18 – 31%) of the total abundance. In general, tule carcasses were recovered on the spawning grounds from late September through the first week in November with a peak in abundance in mid-October while bright carcasses were recovered from late October through January with the main peak in mid-November to early December and a second, smaller peak in mid- to late December (Appendix E). The second peak during the bright run-timing period corresponds to a sub-stock of brights referred to as “late-brights” by WDFW biologists but is not a formally recognized as a distinct stock of fall-run Chinook. Although there are no fall-run Chinook hatchery plants in the Lewis River, 30 – 64% of recovered tules were of hatchery-origin that had strayed from other lower Columbia River watersheds (Table 11).

Fall-run Chinook return back to the NF Lewis River to spawn between the age of 2 and 6, but the majority of the run in any given year is made up of age 3, 5, and 5-year-olds. The distribution of jacks (age-2 males), females, and males (age-3 to age-6) was relatively similar among tules and brights and across years with typically 1 – 4% of the run comprised of jacks, 40 – 50% males, and 50 – 60% females. The relative age-distribution of tules versus brights was similar among years, but the absolute age-composition was quite variable (Figure 6). Specifically, tules typically had higher proportions of age-3s, similar proportions of age-4s, and lower proportions of age-5s relative to brights for a particular return year. However, Chinook from brood-year 2010 returned at high rates resulting in higher proportions of age-3s in 2013, age-4s in 2014, and age-5s in 2015 relative to most other years for both tules and brights. For instance, approximately 80% of the 2014 run was comprised of age-4s while in all other years age-4s made up approximately 40 – 60%.

Table 5. Summary of mark-recapture recovery data for fall-run Chinook carcass surveys conducted in the NF Lewis River in years 2013 - 2017.

Year	Group	# of Carcasses Tagged	# of Tagged Carcasses Recovered	Average Recovery Rate
2013	Jack	667	206	31%
	Female	1,410	691	49%
	Male	1,339	611	46%
	Total	3,416	1,508	44%
2014	Jack	435	120	28%
	Female	1,610	763	47%
	Male	909	397	44%
	Total	2,954	1,280	43%
2015	Jack	156	13	8%
	Female	1,135	270	24%
	Male	769	220	29%
	Total	2,060	503	24%
2016	Jack	136	26	19%
	Female	1,650	762	46%
	Male	1,053	479	45%
	Total	2,839	1,267	45%
2017	Jack	53	10	19%
	Female	1,444	705	49%
	Male	612	268	44%
	Total	2,109	983	47%
Total	-	13,378	5,541	41%

Table 6. Estimates of abundance (i.e., escapement) and composition for return-year **2013** fall-run Chinook in the NF Lewis River by stock (tule, bright), origin (hatchery, wild), and age.

Stock	Origin	Age	Mean	SD	L.95%	Median	U.95%	CV
Tule			3,511	462	2,642	3,495	4,533	13%
	Hatchery		1,156	171	898	1,133	1,553	15%
		2	47	35	13	36	141	76%
		3	323	67	227	312	484	21%
		4	680	100	525	667	918	15%
		5	100	27	62	95	167	27%
		6	7	5	2	6	20	70%
	Wild		2,355	348	1,665	2,355	3,066	15%
		2	124	65	47	108	290	53%
		3	711	130	485	702	1,007	18%
		4	1,314	200	910	1,321	1,704	15%
		5	193	45	119	188	292	23%
		6	12	7	4	11	29	54%
	Prop. Hatchery		0.33	0.03	0.28	0.33	0.40	
	Prop. Wild		0.67	0.03	0.60	0.67	0.73	
	Prop. Jack		0.05	0.03	0.02	0.04	0.11	
	Prop. Female		0.43	0.05	0.34	0.43	0.51	
	Prop. Male		0.52	0.04	0.44	0.52	0.62	
Bright			17,351	450	16,500	17,340	18,300	3%
	Hatchery†		328	49	255	322	435	15%
		2	15	4	10	15	24	25%
		3	105	16	81	104	137	15%
		4	158	29	117	154	222	18%
		5	47	7	35	46	63	16%
		6	3	1	1	2	5	42%
	Wild		17,022	428	16,220	17,010	17,910	3%
		2	697	94	540	687	909	14%
		3	5,205	259	4,716	5,197	5,740	5%
		4	7,993	315	7,374	7,986	8,619	4%
		5	2,953	187	2,601	2,950	3,337	6%
		6	172	46	100	166	277	27%
	Prop. Hatchery†		0.02	0.00	0.02	0.02	0.02	
	Prop. Wild		0.98	0.00	0.98	0.98	0.99	
	Prop. Jack		0.04	0.01	0.03	0.04	0.05	
	Prop. Female		0.42	0.01	0.40	0.42	0.44	
	Prop. Male		0.54	0.01	0.52	0.54	0.56	
Total			20,862	496	19,990	20,830	21,940	2%

† There are no hatchery brights in NF Lewis River. This result is a minor side effect of apportioning JS abundance estimates with raw biological data collected from carcasses (see methods and discussion).

Table 7. Estimates of abundance (i.e., escapement) and composition for return-year **2014** fall-run Chinook in the NF Lewis River by stock (tule, bright), origin (hatchery, wild), and age.

Stock	Origin	Age	Mean	SD	L.95%	Median	U.95%	CV
Tule			4,055	409	3,326	4,027	4,902	10%
	Hatchery		2,051	173	1,757	2,034	2,438	8%
		2	72	47	22	60	196	65%
		3	241	37	177	237	322	15%
		4	1,557	141	1,320	1,541	1,873	9%
		5	178	29	125	175	242	17%
		6	0	2	-	0	4	361%
	Wild		2,005	320	1,449	1,978	2,674	16%
		2	102	55	36	89	241	54%
		3	189	35	130	186	266	18%
		4	1,570	271	1,105	1,547	2,145	17%
		5	143	29	94	141	206	20%
		6	0	1	-	0	3	335%
	Prop. Hatchery		0.51	0.04	0.43	0.51	0.58	
	Prop. Wild		0.49	0.04	0.42	0.49	0.57	
	Prop. Jack		0.04	0.02	0.02	0.04	0.10	
	Prop. Female		0.55	0.05	0.46	0.56	0.65	
	Prop. Male		0.40	0.05	0.32	0.40	0.50	
Bright			20,803	620	19,670	20,780	22,050	3%
	Hatchery†		314	58	215	310	438	18%
		2	14	7	7	13	32	47%
		3	27	6	17	26	43	24%
		4	249	48	168	246	352	19%
		5	24	6	13	23	37	27%
		6	0	0	0	0	0	146%
	Wild		20,489	604	19,380	20,460	21,690	3%
		2	837	101	677	824	1,079	12%
		3	1,832	197	1,479	1,821	2,261	11%
		4	16,321	580	15,230	16,300	17,520	4%
		5	1,481	163	1,186	1,473	1,825	11%
		6	12	11	1	9	38	95%
	Prop. Hatchery†		0.01	0.00	0.01	0.02	0.02	
	Prop. Wild		0.99	0.00	0.98	0.99	0.99	
	Prop. Jack		0.04	0.01	0.03	0.04	0.05	
	Prop. Female		0.59	0.02	0.56	0.59	0.62	
	Prop. Male		0.37	0.01	0.34	0.37	0.40	
Total			24,859	588	23,790	24,830	26,100	2%

† There are no hatchery brights in NF Lewis River. This result is a minor side effect of apportioning JS abundance estimates with raw biological data collected from carcasses (see methods and discussion).

Table 8. Estimates of abundance (i.e., escapement) and composition for return-year **2015** fall-run Chinook in the NF Lewis River by stock (tule, bright), origin (hatchery, wild), and age.

Stock	Origin	Age	Mean	SD	L.95%	Median	U.95%	CV
Tule			5,449	381	4,759	5,440	6,265	7%
	Hatchery		3,437	228	3,031	3,428	3,917	7%
		2	103	48	46	92	224	47%
		3	998	83	845	996	1,179	8%
		4	1,619	133	1,389	1,609	1,898	8%
		5	716	74	581	712	873	10%
		6	1	2	-	0	5	291%
	Wild		2,012	235	1,636	1,985	2,535	12%
		2	61	28	27	54	135	46%
		3	520	63	415	515	659	12%
		4	927	113	745	915	1,184	12%
		5	503	100	361	487	743	20%
		6	1	7	-	0	6	700%
	Prop. Hatchery		0.63	0.03	0.58	0.63	0.68	
	Prop. Wild		0.37	0.03	0.33	0.37	0.43	
	Prop. Jack		0.03	0.01	0.01	0.03	0.06	
	Prop. Female		0.56	0.03	0.49	0.56	0.62	
	Prop. Male		0.41	0.03	0.35	0.41	0.48	
Bright			18,915	992	17,120	18,850	21,080	5%
	Hatchery†		280	74	206	264	481	26%
		2	7	5	3	6	19	68%
		3	39	22	23	34	96	57%
		4	118	37	83	110	209	32%
		5	116	23	85	112	165	19%
		6	0	0	-	0	2	229%
	Wild		18,635	979	16,850	18,580	20,740	5%
		2	347	126	185	320	659	36%
		3	1,869	309	1,388	1,825	2,597	17%
		4	7,888	639	6,741	7,842	9,287	8%
		5	8,440	618	7,291	8,420	9,726	7%
		6	88	91	6	55	335	104%
	Prop. Hatchery†		0.01	0.00	0.01	0.01	0.03	
	Prop. Wild		0.99	0.00	0.98	0.99	0.99	
	Prop. Jack		0.02	0.01	0.01	0.02	0.04	
	Prop. Female		0.60	0.03	0.54	0.60	0.65	
	Prop. Male		0.38	0.03	0.33	0.38	0.45	
Total			24,364	981	22,550	24,310	26,431	4%

† There are no hatchery brights in NF Lewis River. This result is a minor side effect of apportioning JS abundance estimates with raw biological data collected from carcasses (see methods and discussion).

Table 9. Estimates of abundance (i.e., escapement) and composition for return-year **2016** fall-run Chinook in the NF Lewis River by stock (tule, bright), origin (hatchery, wild), and age.

Stock	Origin	Age	Mean	SD	L.95%	Median	U.95%	CV
Tule			4,127	482	3,329	4,073	5,225	12%
	Hatchery		2,469	310	1,952	2,435	3,178	13%
		2	49	30	13	41	122	62%
		3	484	84	348	473	675	17%
		4	1,595	208	1,248	1,570	2,067	13%
		5	325	93	193	309	557	29%
		6	12	20	0	5	67	166%
	Wild		1,658	231	1,284	1,627	2,183	14%
		2	33	20	9	28	82	61%
		3	386	87	256	372	601	23%
		4	1,009	140	785	993	1,326	14%
		5	221	66	132	208	381	30%
		6	7	11	0	3	33	160%
	Prop. Hatchery		0.60	0.03	0.53	0.60	0.65	
	Prop. Wild		0.40	0.03	0.35	0.40	0.47	
	Prop. Jack		0.02	0.01	0.01	0.02	0.05	
	Prop. Female		0.60	0.05	0.49	0.60	0.70	
	Prop. Male		0.38	0.05	0.28	0.38	0.49	
Bright			9,360	243	8,912	9,357	9,863	3%
	Hatchery†		48	51	23	35	181	106%
		2	2	1	1	2	6	55%
		3	8	12	3	5	38	163%
		4	29	32	13	21	117	111%
		5	9	11	4	6	29	128%
		6	0	1	0	0	1	250%
	Wild		9,311	229	8,873	9,313	9,763	2%
		2	232	61	135	223	382	26%
		3	1,073	75	931	1,070	1,227	7%
		4	5,481	170	5,146	5,477	5,834	3%
		5	2,320	110	2,112	2,319	2,543	5%
		6	203	37	139	200	282	18%
	Prop. Hatchery†		0.00	0.01	0.00	0.00	0.02	
	Prop. Wild		1.00	0.01	0.98	1.00	1.00	
	Prop. Jack		0.03	0.01	0.02	0.02	0.04	
	Prop. Female		0.59	0.01	0.57	0.59	0.62	
	Prop. Male		0.38	0.01	0.36	0.38	0.41	
Total			13,487	496	12,660	13,440	14,600	4%

† There are no hatchery brights in NF Lewis River. This result is a minor side effect of apportioning JS abundance estimates with raw biological data collected from carcasses (see methods and discussion).

Table 10. Estimates of abundance (i.e., escapement) and composition for return-year **2017** fall-run Chinook in the NF Lewis River by stock (tule, bright), origin (hatchery, wild), and age.

Stock	Origin	Age	Mean	SD	L.95%	Median	U.95%	CV
Tule			2,255	450	1,560	2,203	3,258	20%
	Hatchery		1,310	266	910	1,273	1,944	20%
		2	7	5	2	6	21	74%
		3	628	139	414	608	955	22%
		4	466	114	293	450	739	24%
		5	209	59	121	200	349	28%
		6	1	2	-	0	6	396%
	Wild		944	231	603	908	1,508	24%
		2	17	12	4	13	50	73%
		3	410	102	257	395	651	25%
		4	356	112	198	337	635	31%
		5	160	57	78	151	302	36%
		6	1	3	-	0	6	429%
	Prop. Hatchery		0.58	0.04	0.48	0.59	0.66	
	Prop. Wild		0.42	0.04	0.35	0.41	0.52	
	Prop. Jack		0.01	0.01	0.00	0.01	0.03	
	Prop. Female		0.53	0.09	0.36	0.53	0.71	
	Prop. Male		0.46	0.09	0.28	0.46	0.63	
Bright			7,268	355	6,664	7,240	8,084	5%
	Hatchery†		118	62	56	106	250	52%
		2	4	3	1	3	14	80%
		3	29	26	10	23	79	90%
		4	57	27	26	50	116	48%
		5	29	13	15	26	58	44%
		6	0	0	0	0	0	-
	Wild		7,149	323	6,579	7,130	7,869	5%
		2	94	28	55	89	163	30%
		3	825	99	646	818	1,041	12%
		4	3,461	196	3,127	3,446	3,889	6%
		5	2,743	135	2,491	2,739	3,022	5%
		6	25	13	8	23	59	52%
	Prop. Hatchery†		0.02	0.01	0.01	0.02	0.03	
	Prop. Wild		0.98	0.01	0.97	0.99	0.99	
	Prop. Jack		0.01	0.00	0.01	0.01	0.02	
	Prop. Female		0.68	0.03	0.63	0.68	0.73	
	Prop. Male		0.31	0.03	0.26	0.31	0.36	
Total			9,523	536	8,632	9,470	10,720	6%

† There are no hatchery brights in NF Lewis River. This result is a minor side effect of apportioning JS abundance estimates with raw biological data collected from carcasses (see methods and discussion).

Table 11. Summary of unexpanded coded-wire tag (CWT) recoveries in the NF Lewis River by origin (hatchery, wild), release location, and return year along with the percent composition of hatchery recoveries by release location.

Origin	Release Location	2013	2014	2015	2016	2017	% Comp. Average	% Comp. Range
Hatchery	Cowlitz	1	2	3	1	0	11%	0 - 25%
	Kalama	4	13	6	5	1	42%	20 - 48%
	Fallert (Kalama)	3	9	3	1	3	32%	9 - 60%
	Toutle	0	1	0	0	0	1%	0 - 3%
	Washougal	1	1	0	1	0	5%	0 - 11%
	Big Creek (Oregon)	0	0	0	0	1	4%	0 - 20%
	Upper Columbia	0	1	0	1	0	3%	0 - 10%
	California	0	0	0	2	0	4%	0 - 18%
	Total – Low.Colum.	9	26	12	8	5	-	-
	Total - Hatchery	9	27	12	11	5	-	-
Wild	Lewis River	52	84	69	37	29	-	-
Total		61	111	81	48	34	-	-

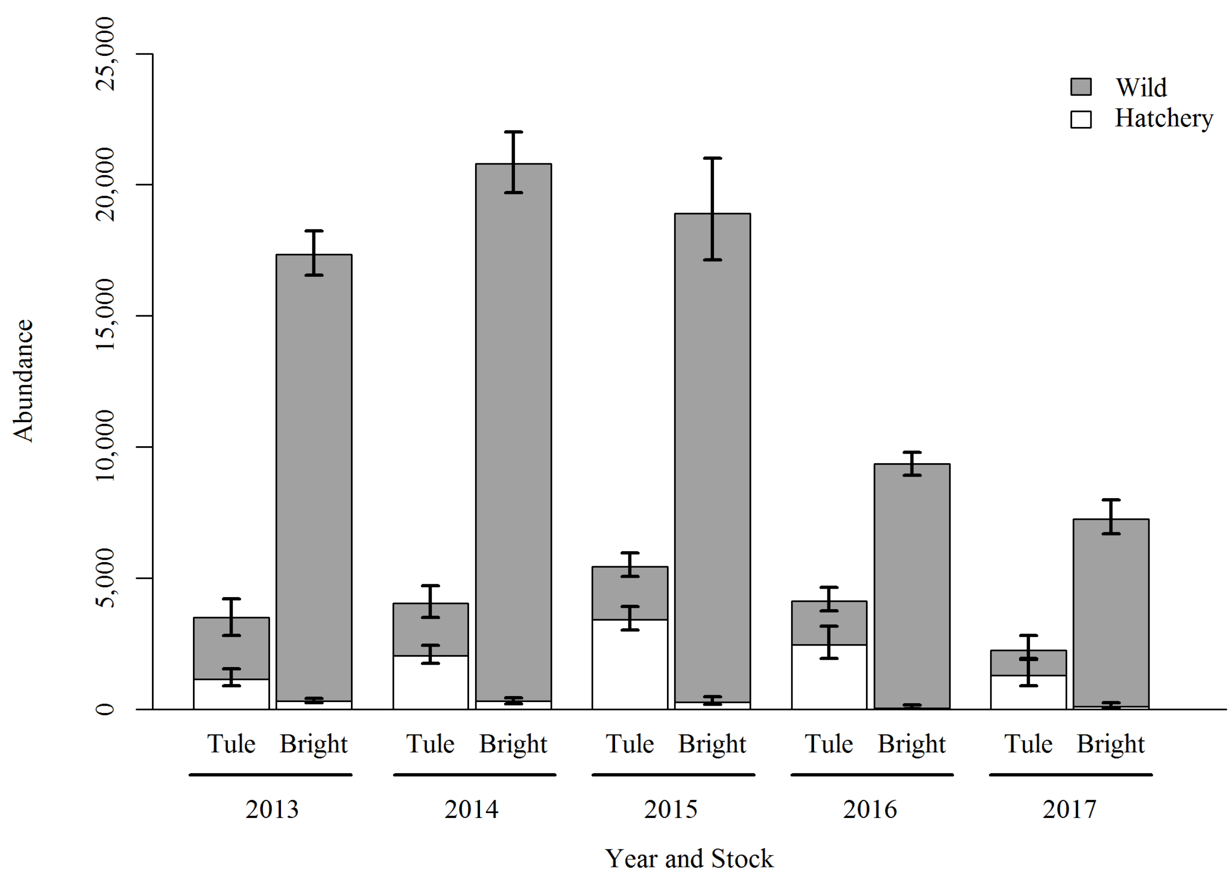

Figure 5. Abundance estimates of NF Lewis River fall-run Chinook salmon by stock (tule, bright) and origin (hatchery, wild) for survey years 2013 – 2017. Bar height is the mean of the posterior distribution from the JS analysis and error bars represent the 95% credible intervals for each stock.

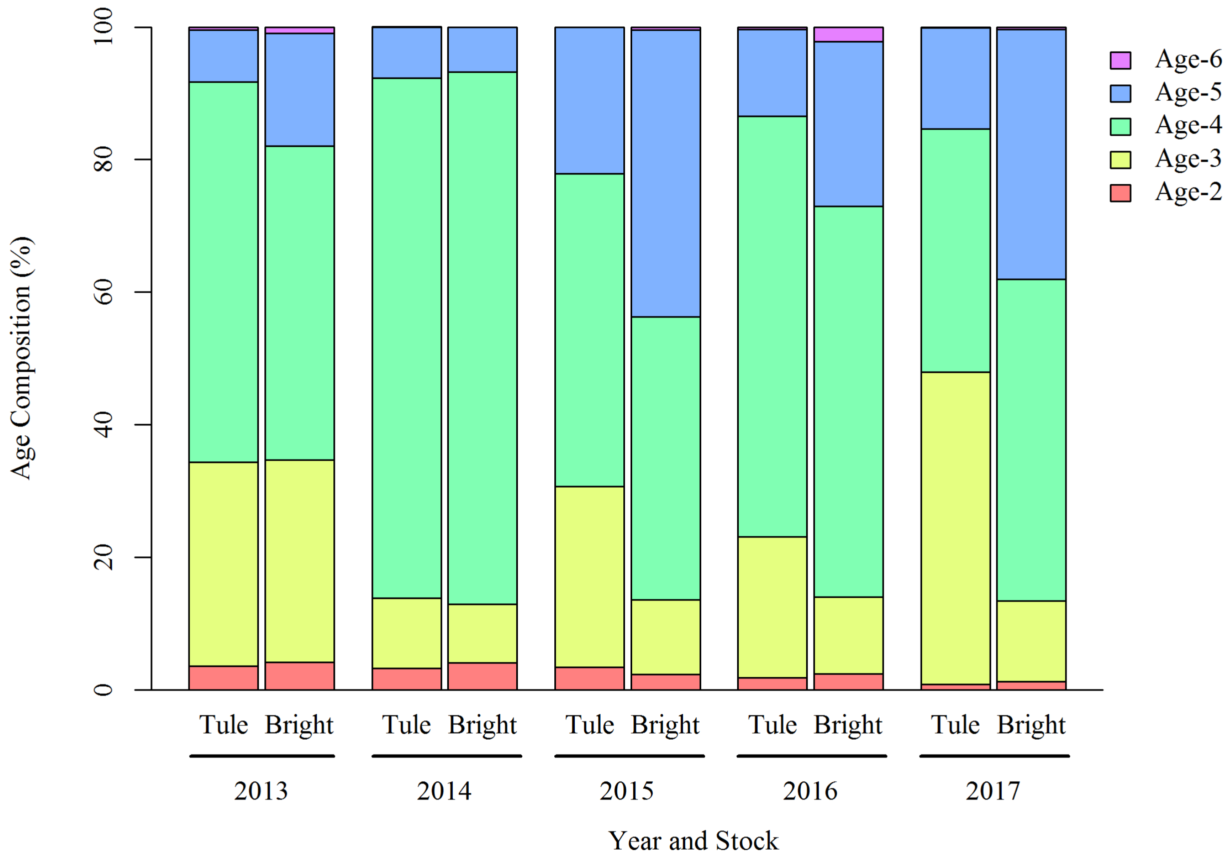

Figure 6. Relative age composition of NF Lewis River fall-run Chinook by stock (tule, bright) and return year.

Evaluation of the Bright-eye method (BEM) estimator

The Bright-eye method (BEM) estimator was developed to estimate annual fall-run Chinook abundance in the NF Lewis River. Estimate of abundance have been derived with the BEM since 2000 and reported in annual reports (e.g., Hawkins 2012). The BEM estimator expands "raw" carcass recoveries to estimates of total abundance using constant age-specific carcass recovery rates (of "fresh" carcasses) that were estimated from a mark-recapture carcass study conducted in the early 2000s. In order for the BEM estimator to generate unbiased estimates of abundance, each recovered carcasses must have the same (i.e., constant) probability of recovery within and among years by age-class. Put another way, the BEM estimator assumes that the recovery rate of carcasses in each weekly survey across all years is always exactly equal to the recovery rates that were estimated in 2001 and 2002 despite potential differences in survey conditions. This assumption was tested by estimating recovery rates within and among years using mark-recapture carcass survey data collected from 2013 – 2017 and comparing these rates with the set of constant BEM recovery rates that were developed with carcass survey data collected in the early 2000s.

First, we calculated the average annual recovery rate by age-class across all years when carcass mark-recapture surveys were conducted (Table 12). Here, the average annual recovery rate was simply the total number of carcass recaptures divided by the total number of carcasses tagged. Overall, the average annual recovery rates by age-class from 2013 – 2017 were relatively similar to the averaged recovery rates used for the BEM estimator. Specifically, approximately half (13 out of 23) of the age-specific recovery rates from 2013 – 2017 were within ~1 – 5% of the absolute difference in BEM recovery rates. However, there were substantial differences in average annual recovery rates in some years. For example, in 2015, there was a 9 – 18% difference in the absolute recovery rates for the three most dominate age-classes (age-3, 4, and 5). Because recovery rates serve as expansions, the relative difference in recovery rates matter more than absolute recovery rates for the final results. Similar to absolute differences, approximately half (12 out of 23) of the age-specific recovery rates were within 0 – 15% of the relative difference in BEM recovery rates. However, again in 2015, the relative recovery rates were approximately 20 – 90% lower compared to the BEM rates. Therefore, the assumption that recovery rates were constant among years was not meet.

Table 12. Age-stratified carcass recovery rates for "fresh" (i.e., bio-sampled) carcasses in 2001, 2002, and 2013 - 2017. The "Bright-eye" row of data represents the carcass tag recovery rates used for the Bright-eye method (BEM), which was based on data from 2001 and 2002. The "Average" row of data represents "the averaged of the average" recovery rates from 2013 - 2017. Recovery rates were omitted when <10 carcasses were recovered across the entire survey season for a particular age-class.

Year	Age-2	Age-3	Age-4	Age-5	Age-6
2001	0.16	0.34	0.36	0.38	-
2002	0.12	0.25	0.39	0.41	0.75
2013	0.18	0.28	0.32	0.31	0.30
2014	0.19	0.30	0.31	0.29	-
2015	0.11	0.18	0.23	0.21	-
2016	0.11	0.29	0.30	0.34	0.28
2017	0.15	0.23	0.32	0.34	-
Bright-Eye	0.13	0.30	0.32	0.39	0.54
Average ('13 – '17)	0.15	0.26	0.30	0.30	0.29

Second, recovery rates were estimated for each survey period using the estimates of capture and survival probability that were generated from the timing varying (*ttt*) JS model. Specifically, recovery rates were calculated as the product of capture (p) and survival probability (φ) for each survey period. Across all five survey years, recovery rates varied throughout the survey season for each of the three estimate groupings (jacks, females, and males). For example, the absolute recovery rates for the male abundance group ranged from 0.07 – 0.31 in 2015 compared to 0.07 – 0.57 in 2016 (Figure 7a). In general, recovery rates within a given year were lower in September, October, and January and were higher in November and December. This seasonal pattern in recovery rates is important given that carcass tags were not deployed uniformly throughout the season (Figure 7b). Rather, the majority of carcass tags were released in November and December, which would result in the overall average recovery rate being weighted towards recovery rates during this time period. Therefore, the BEM assumption that recovery rates are constant within a given survey year was not met.

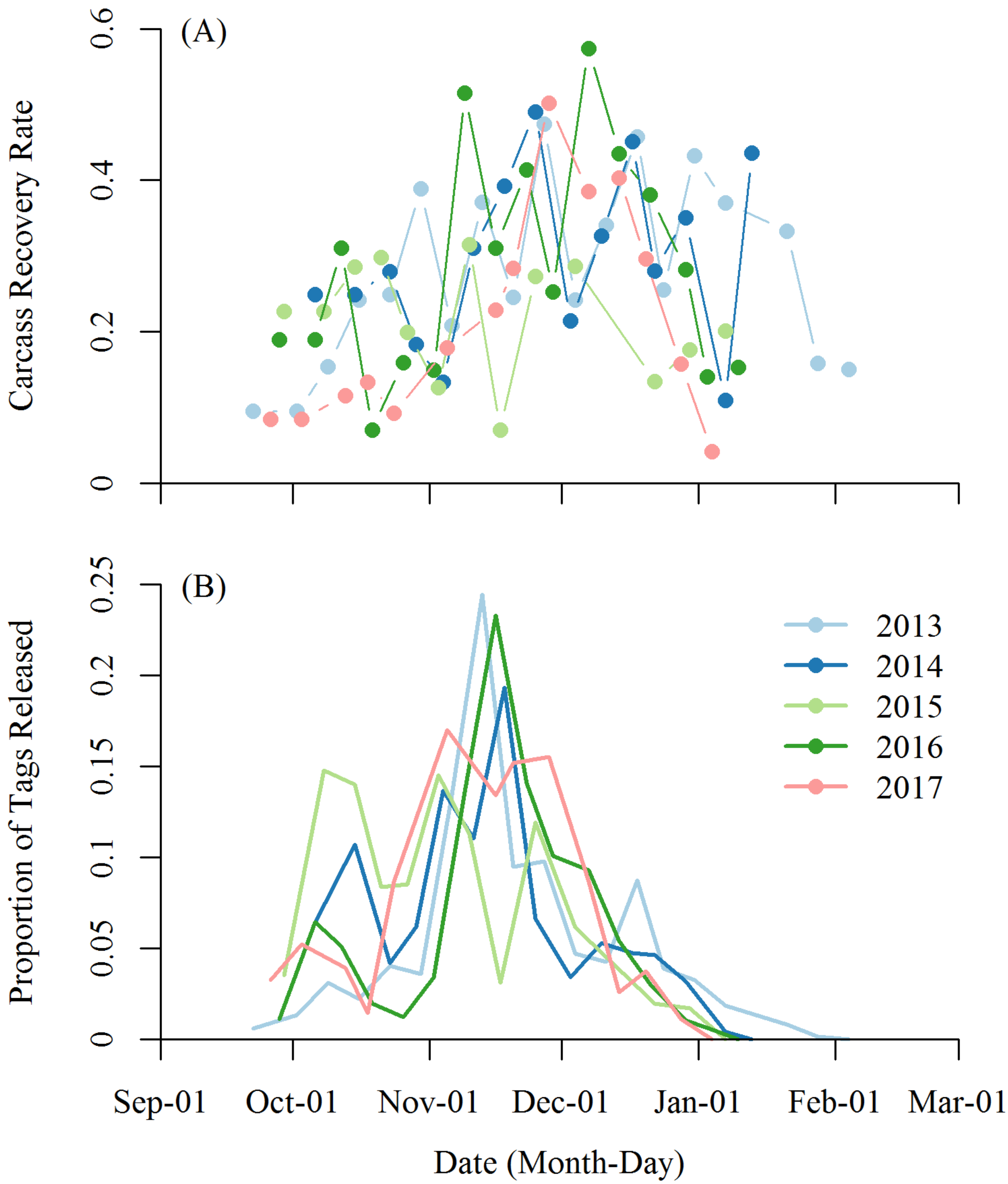

Figure 7. Estimated (A) mean recovery rates and (B) proportion of carcass tags for NF Lewis River fall-run Chinook salmon released by week for males (≥ 60 cm) among years 2013 – 2017.

Evaluation of the peak count expansion (PCE) estimator

Three critical assumptions must be met in order for the peak count expansion (PCE) estimator to generate unbiased abundance estimates. The first assumption was that the spatial distribution of spawners among years was similar to the years used to develop the PCE. This assumption was met given that all five sections (Table 1) were surveyed each year and almost all fall-run Chinook spawning occurs in these five sections.

The second assumption of a PCE estimator was that the proportion of spawners available to sample as either lives or carcasses on the peak survey date(s) was the same as it was in the years used to develop the PCE factor. This assumption was meet for the "peak dead" and "top 3 dead" PCE estimators because carcass surveys were completed every week throughout the entire spawn time period and thus all five years of carcass data were used to calculate the PCE factor and derived estimates of abundance. However, this was not always the case with live count data. Specifically, in 2015 and 2016, live counts were not completed during the known peak spawn time period for bright- and tule-run Chinook, respectively. Knowing that the count data from these years did not correspond to the same peak time period in the other years, and thus would knowingly bias our hierarchical PCE factor, we calculated the "live + dead peak" PCE factor excluding these two years of data. Therefore, our "live + dead peak" PCE factor was unbiased but this assumption was violated in 2015 and 2016 for brights and tules, respectively

The third assumption of a PCE estimator was that observer efficiency during carcass and live counts was similar across all surveys. As discussed above, we know that recovery rates of carcasses (i.e., observer efficiency) were not constant within and among years. Although we did not measure observer efficiencies for live counts, we would expect that weekly live count observer efficacies would track carcass recovery rates due to similar impacts of environmental conditions. Therefore, the third assumption of similar recovery rates within and among years was not met.

Comparison of abundance estimators

In addition to evaluating assumptions of the BEM and PCE estimators, we were ultimately interested in knowing whether or not the two estimators were capable of generating unbiased estimates of fall-run Chinook abundance. Therefore, we calculated the absolute difference, absolute percent (%) error, and mean absolute percent error (MAPE) of the abundance estimates generated with the BEM and PCE estimators relative to the Jolly-Seber (JS) for tule-, bright-, and total fall-run Chinook (Figure 8, Figure 9, Appendix F).

In three of the five survey years (2013, 2014, 2016), the BEM estimator generated a total fall-run Chinook abundance estimate that was within 1,500 fish, or 1 – 7%, of the JS estimates. In the two other years (2015 and 2017), the BEM estimator generated estimates that were approximately 1,500 (16%) and 7,900 (32%) less fish than the JS estimates. Across all years, estimates of tule abundance generated from the two estimators varied by approximately 100 (3%) to 1,900 (55%) fish while estimates of bright abundance varied by approximately 300 (4%) to 8,000 (42%) fish. Overall, the mean absolute percent error (MAPE) was 24% for tules, 14% for brights, and 13% for total fall-run Chinook (Figure 9). In total, 47% (7 of the 15) of the abundance estimates generated with the BEM estimator did not fall within the 95% credible intervals for the corresponding JS estimate (Figure 8). Therefore, almost half of the abundance estimates generated over the past five years using the BEM estimator were potentially biased due to a violation of the estimator's main assumption of constant recovery rates within and among years. Based on our comparison with the JS estimates, BEM estimates were more likely to be biased low than high.

Updated peak count expansion (PCE) estimators were developed for tule- and bright-run Chinook using three different peak count (PC) groupings: "peak live + dead", "peak dead", and "top 3 dead" (Table 13). Using the PCE factors and PC data, we derived estimates of abundance by stock for 2013 - 2017 (Figure 8, Appendix F). Similar to estimates generated with the BEM estimator, the PCE factors generated some abundance estimates that were relatively accurate in some years while in other years the estimates were highly inaccurate. In general, the accuracy of the estimates derived with the three PCE estimators were relatively similar to one another with mean absolute percentage errors (MAPE) ranging from 26 – 28% for tules, 13 – 18% for brights, and 7 – 10% for total fall-run Chinook (Figure 9), which was similar to the MAPE for BEM estimates. In total, 42% (19 of the 45) of the abundance estimates generated with the BEM estimator did not fall within the 95% credible intervals for the corresponding JS estimate (Figure 8). However, out of the total 45 PCE generated abundance estimates, only two were technically biased (i.e., their 95% prediction interval did not include the "true" JS mean estimate) and these two estimates corresponded to the two years (2015, 2016) when the peak live count did not occur during the anticipated peak time frame. Overall, the PCE derived abundance estimates were mostly unbiased but this was in large part due to the estimates being relatively imprecise. Specifically, the coefficient of variation (CV) of the PCE estimators ranged from 28 – 49% (Table 13).

Table 13. Hierarchical peak count expansion (PCE) factor estimates for tule- and bright-run NF Lewis River Chinook salmon. PCEs were generated using the three peak count data summarizations: the peak lives + deads count, the peak dead only, and the summation of the three largest dead counts per year.

Stock	PCE	Mean	SD	L.95%	Median	U.95%	CV
Tule	Lives + Deads	3.15	1.09	1.91	2.94	5.65	35%
	Deads only	8.86	4.33	3.42	8.15	19.24	49%
	Top 3 Deads	3.81	1.84	1.85	3.44	8.01	48%
Bright	Lives + Deads	4.11	1.22	2.28	3.94	7.21	30%
	Deads only	6.49	2.27	3.33	6.17	11.60	35%
	Top 3 Deads	2.78	0.77	1.82	2.64	4.54	28%

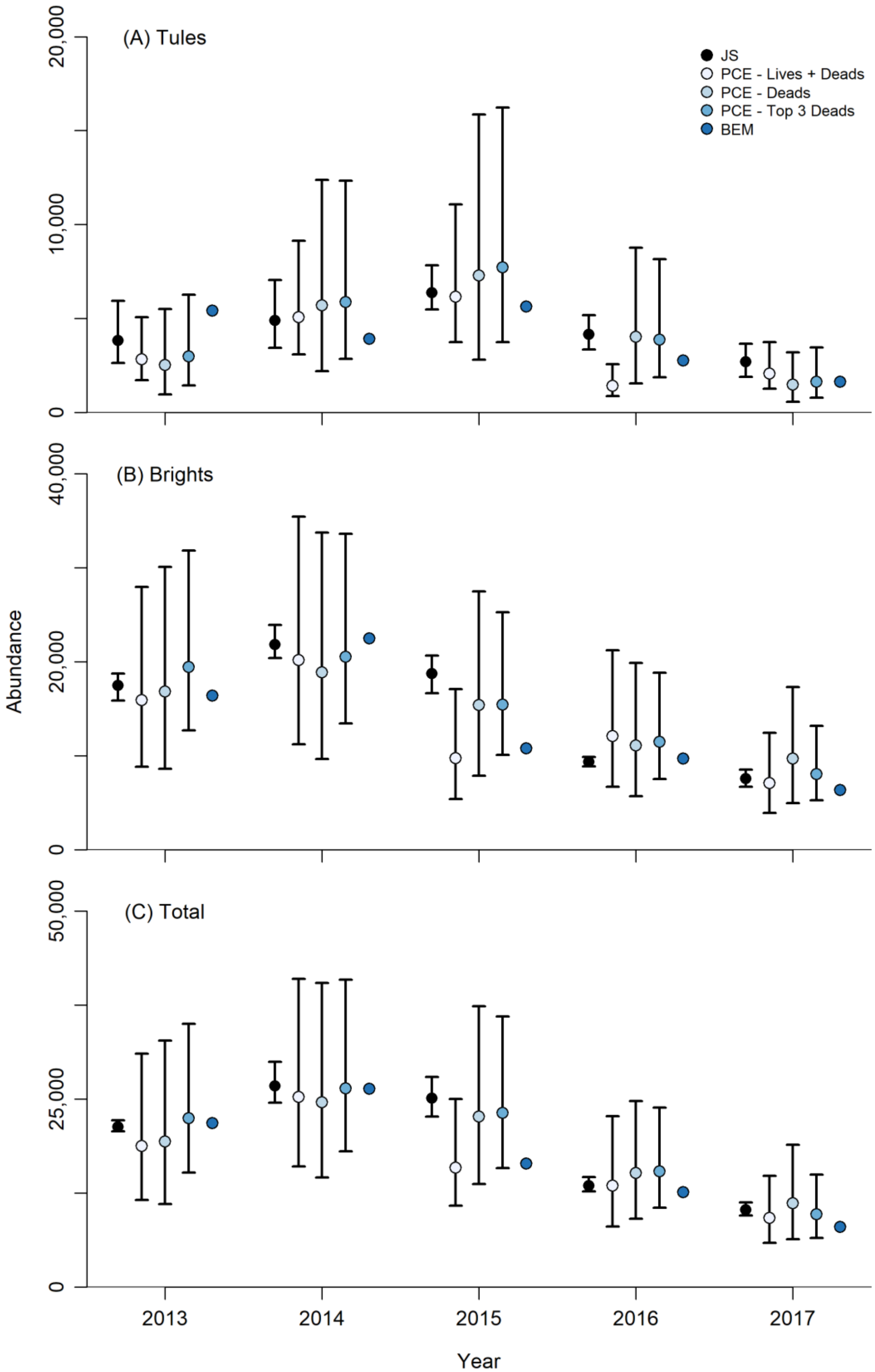

Figure 8. Comparison of estimates of spawner abundance for (A) tules, (B) brights, and (C) the total fall-run Chinook (i.e., tules and bright combined) in the NF Lewis River from 2013 - 2017 using the Jolly-Seber (JS), Bright-eye method (BEM), and the peak count expansion (PCE) estimators. Points are the mean of the posterior distribution (for JS and PCE) and error bars on the estimates represent the 95% prediction interval.

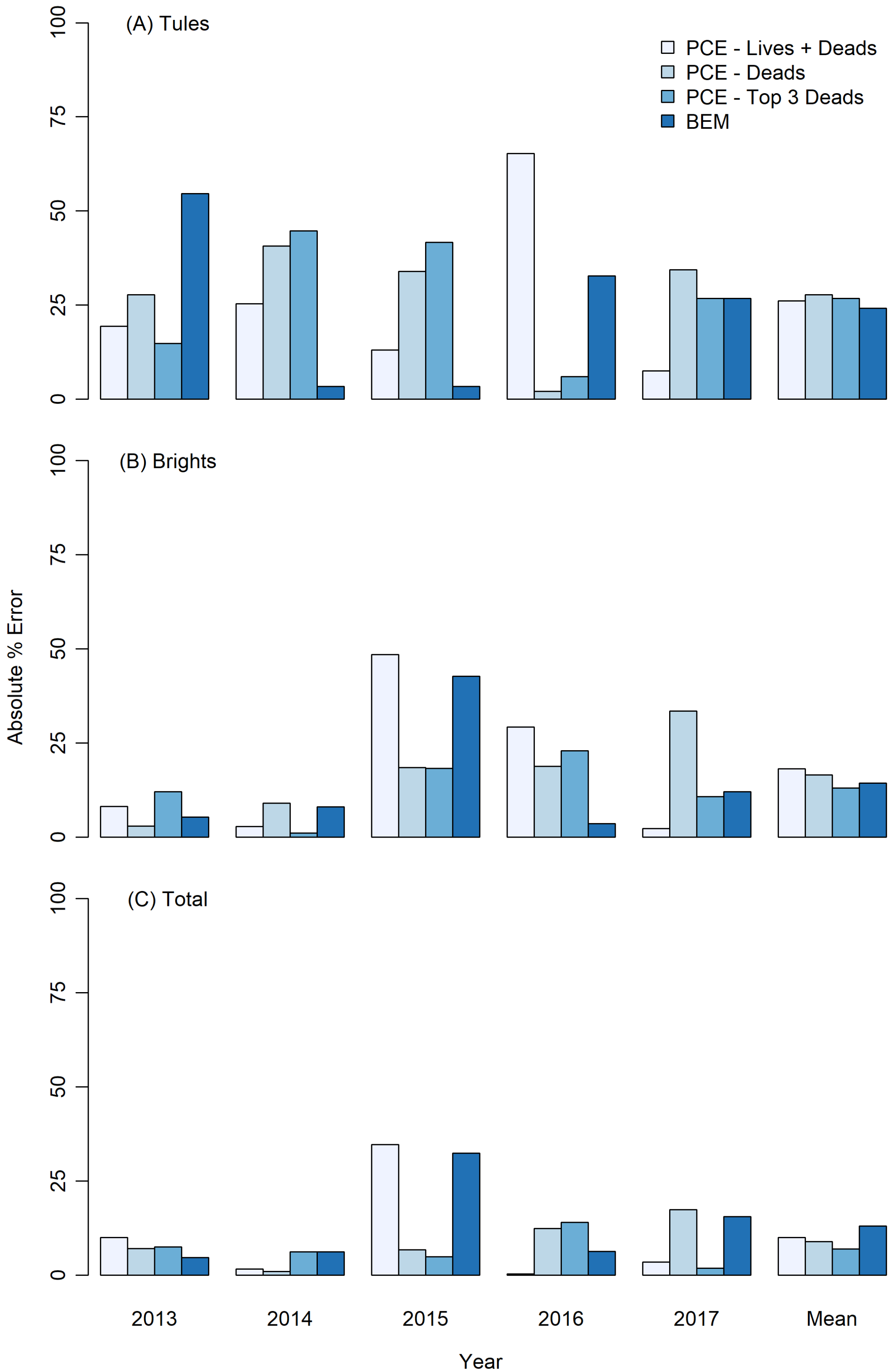

Figure 9. Absolute percent (%) error of spawner abundance estimates generated using the Bright-eye method (BEM) and the peak count expansion (PCE) estimators relative to Jolly-Seber (JS) estimates for (A) tules, (B) brights, and (C) the total fall-run Chinook (i.e., tules and bright combined) in the NF Lewis River from 2013 – 2017.

Discussion

Mark-recapture Jolly-Seber (JS) abundance estimates

The primary goal of our mark-recapture analysis was to derive unbiased estimates of adult spawner abundance and composition along with estimates of uncertainty for North Fork (NF) Lewis River fall-run Chinook for return years 2013 – 2017. We used a Jolly-Seber (JS) open population estimator applied to carcass recovery data with a Bayesian modeling approach. Our analytical methods were developed specifically for estimating salmon spawning escapement using mark-recapture data (Schwarz et al. 1993) and has been successfully implemented to estimate spawner escapement for salmon populations throughout the Lower Columbia River (Rawding et al. 2014). A thorough discussion of our analytical methods can be found in Rawding et al. (2014; pg. 62-63, 66-68) but in short the JS estimator will produce unbiased estimates when the assumptions of the model are met. Although the JS estimator requires multiple assumptions, the assumption that is of greatest importance, and thus requires thorough evaluation, is that every surviving carcass in the population whether tagged or untagged must have the same probability of recovery during each sampling event (Seber 1982). Therefore, prior to generating estimates of abundance each year, we evaluated the variation in recovery rates among carcasses using logistic regression and Bayesian GOF tests.

Previous studies have shown that recovery rates of Chinook salmon carcasses on spawning grounds can be influenced by size and sex (Zhou 2002, Murdoch et al. 2010). The logic is that smaller carcasses are likely easier for scavengers to remove, more difficult for surveyors to detect, and perhaps more readily washed away (Zhou 2002). Therefore, we used a logistic regression analysis to test if carcass recoveries were sex and/or length dependent. Across years, there were slight variations in the regression results, but overall there was always strong support for models with size- and sex-based recovery rates. Depending on the observed recovery rates and the number of carcasses sampled, the regression results typically suggested that a total of 2 – 6 strata were necessary to obtain "apparent" homogeneous groupings that would satisfy the equal probability of capture and persistence assumptions for a given year. However, it was important to consider that the regression tests were evaluating the overall recovery rates (i.e., survey season average) while our JS estimator modeled recovery rates by period. For instance, while there may be a statistically significant difference in overall recovery rates among two groups, stratifying the estimates can result in a low number (<5 – 10) of carcass recoveries per sample period which can lead to biased estimates (Seber 1982). Additionally, stratifying a single group (e.g., "jacks") into two (e.g., jacks 40 – 50 cm and jacks 50 – 60 cm) can decrease the precision of each individual estimate resulting in the cumulative sum of the two estimates being statistically similar to the single estimate. Based on these results and previous literature, we chose to standardize our carcass stratifications into three groups (jacks, females, males) across all years. Although this standardization may have resulted in fewer or a greater number of groupings for a given year as opposed to those based solely on the regression results, these groupings provide a parsimonious approach for generating unbiased estimates of abundance and composition.

Recovery rates of carcasses can also vary throughout a survey season. This variation can be due to several independent or correlated variables such as flow, weather, visibility, survey effort, and surveyor experience. Regardless of the mechanism, the JS open population estimator estimates the probability of recovery as a function (i.e., joint likelihood) of the probability of capture (p) and the probability of persistence/survival (φ). These two probabilities can be modeled as either timing varying (t) or constant (s) parameters for each survey period throughout a survey season resulting in four candidate JS models (*ttt, stt, tst, sst*). Prior to running the JS estimates, we tested the fit of each of the four models to the three groups of carcass data (jacks, females, males) using Bayesian GOF tests. Across years, generally all four JS models provided an adequate fit for the "jack" data set (i.e., $0.025 <$ Bayesian p-value < 0.975) while only the completely time-varying (*ttt*) model provided an adequate fit for the female and male groupings. Put another way, the GOF tests suggested that JS estimators that assumed either constant or varying probabilities of recovery and survival were adequate models for jacks, but only the JS estimator that assumed varying probabilities of recovery and survival across all sample periods was an adequate model for females and males. Based on these results, we chose to standardize our JS modeling approach and use the completely timing-varying JS model for each carcass grouping across all years. However, prior to running the final estimates as a single model, we would run independent estimates for each carcass group with each of the JS models that provided an adequate fit based on the GOF tests. Across all years and groups, the "*ttt*" JS model provided either the best or a "similarly" good fit based on deviance information criterion (DIC) and all abundance estimates were within a couple hundred fish of one another. Therefore, while it is possible that the "*ttt*" model may have overfit the mark-recapture dataset for a couple of the jack groupings among all years, it likely had little to no influence on our final estimates.

After abundance estimates were generated for the three carcass groupings, we estimated spawner composition by stock (tule, bright), origin (hatchery, wild), sex, and age using biological data collected from recovered carcasses. Specifically, in regards to estimating stock composition, we chose to use the weekly ratio of "raw" (i.e., unadjusted) CWT recoveries to partition the overall abundance estimates as either tules or brights. Although the CWT recoveries allow for a direct estimate of race composition, their use requires several assumptions. First, it assumes that the total "pool" of CWTs that were available to sample was equal among tule- and bright-run Chinook. For example, if two tule and two bright CWTs were recovered in a given week, we would have estimated approximately a 50:50 composition. However, there may have actually been twice as many bright CWTs available to sample, which means the actual ratio was 66:33 tule vs. bright. While we were aware of the potential violation of this assumption, it is difficult to actually calculate the relative sample pools given that all tule recoveries were hatchery strays from multiple basins that (likely) had varying tag rates, release sizes, stray rates, marine survival, harvest rates, and run-timing. Regardless, there was little to no overlap in CWT recoveries for tules and brights across years, which alleviates the concern over violation of this assumption. Second, using CWTs to assign race composition assumes that the actual CWT origin is accurate. Wild fall-run Chinook are CWT tagged as juveniles and the assumption is that all of these juveniles are bright-run Chinook based on their capture location, size, and timing. However, this assumption has not been thoroughly evaluated and there is evidence that there may be a group of fall-run Chinook that are tagged as juveniles but ultimately display phenotypic characteristics of both tules and brights. Third, the use of CWTs assumes that the run-timing of stray hatchery tules is the same as wild tules. For example, if NF Lewis wild tules have a later run-timing than stray hatchery tules, then at least a portion of the wild tules, which have no CWTs, would have been classified as wild brights. In general, wild tules exhibit a later run-timing relative to hatchery tules in the LCR but these patterns are variable among watersheds (*Jeremy Wilson, personal communication, WDFW*). Lastly, the use of CWTs assumes that the timing of carcass recoveries is representative of the relative run-timing of each stock. Because a carcass is recovered after the fish has died it is possible to recover a CWT carcass weeks after death. This phenomenon is not unique to CWT recoveries and applies to all composition data based on carcass recoveries. For instance, this characteristic of carcass data may explain why a portion (0-2%) of the bright-run fish were also classified as hatchery-origin (i.e., a handful of clipped, non-CWT tules were recovered during the bright-run time period).

An alternative method that could be used for stock assignment with available data would be to use adipose-clip status. Here, we would have to assume that all clipped carcasses without a bright CWT were a tule. This assumption is likely true aside from the relatively small number of bright juveniles that were adipose fin-clipped but too small to CWT or that were clipped and lost their CWT tag. Based on our results, there were unclipped (i.e., wild) fall-run Chinook sampled during the tule time-frame and these individuals are either mis-clipped strays, a naturally occurring population of tules in the mainstem Lewis, stray (out-of-basin) tules, or in-basin tules that originated from Cedar Creek or EF Lewis. Nonetheless, if any portion of the tule-run were indeed wild, then using adipose-clip status would require the same run-timing assumption that is required for CWTs. Overall, the use of CWT recoveries and/or adipose fin-clip status allows us to generate an estimate of stock composition but both rely on some untested assumptions. Therefore, it may be worth exploring alternative methods (e.g., genetic-based analysis) to assign stock composition in future years.

We apportioned the estimates of abundance by origin (hatchery, wild) using the weekly ratio of carcass recoveries and their corresponding adipose fin-clip status. Specifically, we assumed that any carcass with a missing adipose-fin without a Lewis bright CWT was of hatchery-origin while any carcass with an intact adipose-fin was wild. These assumptions meant that our assignment of origin did not account for any possible “mis-clips” whether those were hatchery-origin Chinook that accidentally did not have their adipose fin removed prior to release or wild-origin Chinook that were clipped but were either too small to CWT or lost their CWT. The effect of unclipped hatchery Chinook would impact our tule estimates and potentially result in an underestimate of pHOS for tules while the effect of clipped wild Chinook would impact our bright estimates and potentially result in an overestimate of pHOS for brights. In general, mis-clip rates for LCR hatchery Chinook vary between 1 – 3% (*WDFW unpublished data*). Therefore, while ignoring mis-clip rates may bias our run-specific estimates of abundance, because mis-clip rates are so low, accounting for them here would have had a negligible effect on our estimates. Nonetheless, mis-clip rates could be incorporated into future estimates.

Lastly, we apportioned the estimates of abundance by age using the weekly ratio of carcass recoveries based on scale-age reads. As mentioned earlier, recovery rates of Chinook salmon carcasses on spawning grounds can be influenced by size and sex (Zhou 2002, Murdoch et al. 2010) and therefore apportioning estimates by “raw” ratios of carcasses can lead to biased estimates. However, this potential effect was alleviated by stratifying our estimates into groupings that had relatively homogeneous recovery rates. In regards to the accuracy of age assignment, a previous analysis has noted that the age-distribution of Chinook can be biased low when using scales to assign ages. Specifically, Wilson (2016) compared Chinook ages based on read scale ages and CWTs collected from the same fish and found that older fish (age 5 and 6) were regularly misread as younger fish. This disparity impacted bright-run Chinook more so than tule-run Chinook due to their generally older age-distributions. Claiborne et al. (2016) attributed the misidentifications to scale resorption, which occurs in all species of Pacific salmon during the anadromous migration and can reduce the number of winter annuli visible on the scale. Currently, our analysis does not account for any potential bias due to scale age mis-reads but should be evaluated in the future to better understand the possible impact on the age distribution.

Evaluation of the Bright-eye method (BEM) estimator

Estimates of fall-run Chinook abundance in the NF Lewis River have been generated using the Bright-eye method (BEM) since the early 2000s. The BEM was developed as an alternative to the peak count expansion (PCE) estimator, which was developed in the mid-1970s and had been used as the sole estimator of Chinook abundance for approximately three decades. Despite the limitations of the BEM (see below), it has several advantages over the PCE estimator. First, the BEM accounts for some sampling variation (i.e., variable age composition and recovery rates) while the PCE estimator relies on a single, constant expansion factor that is also dependent on the peak spawn date being known. Second, the BEM requires carcasses to be bio-sampled, which allows the total estimate to be stratified by stock, origin, sex, and age while the PCE estimator can only generate estimates by stock. Third, the BEM implements weekly surveys throughout the entire spawning time-frame, which allows for a representative estimate of run-timing. Based on this information, it was assumed that estimates derived using the BEM were more robust than the PCE estimator, and thus, has been the preferred estimator over the past 15 years. However, the robustness of BEM estimates was never formally evaluated prior to our analysis.

The BEM generates estimates of abundance for NF Lewis Chinook by expanding "raw" carcass recoveries by age-specific recovery rates. This method is essentially the same as the Jolly-Seber (JS) estimator except that the BEM assumes that the recovery rates for a given age-class of carcasses are constant both within and among years. Based on our analysis, the assumptions of the BEM estimator (i.e., constant recovery rates, see pg. 17) was often violated (see Figure 7) and led to biased estimates of abundance (Figure 8, Figure 9). Interestingly, BEM abundance estimates were not always biased and in some cases were very similar to JS derived estimates. Congruence in some of the abundance estimates can be attributed to relatively consistent overall (i.e., pooled) recovery rates among years (Table 12). This among year consistency in recovery rates is likely a result of some consistency in both sampling effort and environmental conditions. Over the past 15 years, carcass surveys have largely been conducted by the same WDFW crew of individuals resulting in relatively consistent sampling effort within and among years. Environmental conditions on the NF Lewis are heavily influenced by the management of flow through the series of three upriver dams, which are operated by PacifiCorp but mitigated as a part of a Federal Energy Regulatory Commission (FERC) licensing agreement. Specifically, minimum flows are maintained early in the survey season and drawdowns are provided during peak surveys to facilitate carcass recovery and improve conditions for live and redd counts. The peak survey drawdowns also provide flow ramping which redistribute tagged and untagged carcasses and help to satisfy the assumptions of equal mixing and equal catchability. Despite these efforts to standardize survey effort, recovery rates were still quite variable within and among years leading to biased abundance estimates.

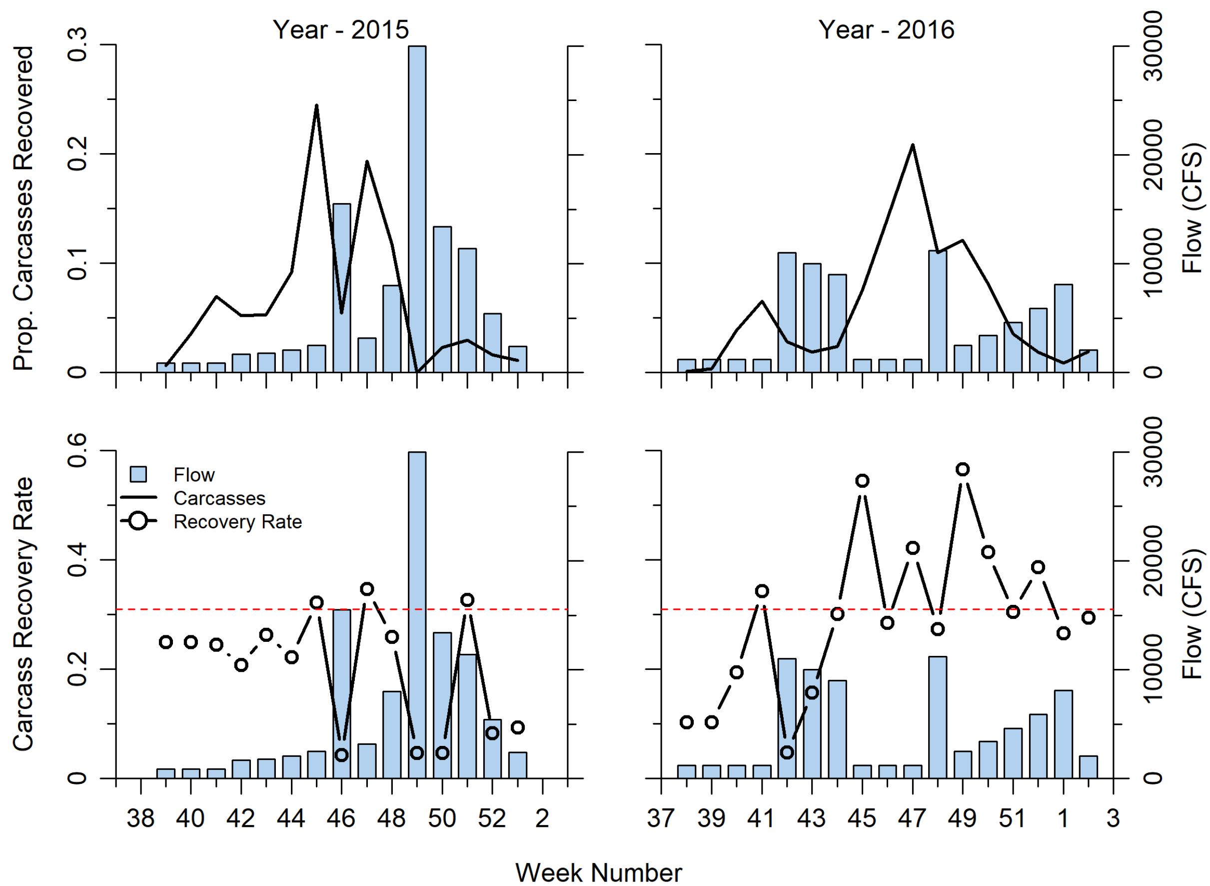

Figure 10. Relative recoveries (top panes – solid lines) and estimated recovery rates (bottom panes – dotted line) of female fall-run Chinook salmon carcasses and peak discharge of the NF Lewis River (blue bars) on the survey date by week for the year 2013 (left) and 2015 (right). The horizontal dashed red line represents the approximate average recovery rate of female carcasses used in the Bright-eye method (BEM) estimator.

Although recovery rates can again be influenced by a suite of factors, it is likely that flow rates in the NF Lewis, which can be correlated with turbidity and visibility, have a large impact on relative recovery rates. This can clearly be seen in two years of mark-recapture data. For instance, in 2016, the average year-specific recovery rates were almost exactly the same as the BEM recovery rates that were calculated from 2001 and 2002 data (Table 12), which lead to similar estimates of total fall-run Chinook between the two estimators (Figure 8). However, upon closer examination of within-year recovery rates and flows, we can see that JS derived recovery rate estimates early in the survey season (weeks 37 – 44) were below the average BEM recovery rates and this corresponded with three weeks when flows were ~10,000 CFS while JS recovery rates later in the season (weeks 45 – 50) were above the BEM average and this corresponded to relatively low flows (Figure 10). This seasonal shift from below-average recovery rates early in the season to above-average recovery rates later in the season lead to a substantial underestimate in tule abundance and a slight overestimate of bright abundance.

On the other hand, in 2015, almost every weekly calculated recovery rate was lower than the overall average BEM recovery rate leading to underestimates of abundance for tules, brights, and total fall-run Chinook. Specifically, substantially high flows in week 46 lead to extremely low recovery rates and flows were so high in week 49 that the carcass surveys were canceled. In theory, a lower than average or even zero percent capture probability in one week can be offset by higher than average capture probability in subsequent weeks if the persistence (i.e., survival) of carcasses is not affected by the high flow event. However, it appears as though the high flow events affected both capture probability and persistence of carcasses meaning that BEM estimates of abundance will likely be biased low if any carcass surveys are missed throughout the survey period. It should be noted, however, that even though flow clearly influences recovery rates, it is not the only influential variable. For example, recovery rates in early 2015 were lower than average despite flows being at or below the typical minimum allowable rate for that time period (Figure 10).

Evaluation of the peak count expansion (PCE) estimator

Estimates of abundance for fall-run Chinook in NF Lewis River were generated for over 25 years with a peak count expansion (PCE) estimator that was developed back in the 1970s (McIssac 1976). In the early 2000s, multiple years of mark-recapture surveys were conducted that would have allowed the development of an updated PCE estimator. However, the PCE model update was never completed. Instead, the Bright-eye method (BEM) was developed and has been used to generate estimates of fall-run Chinook abundance since 2000. Regardless, there was never a formal evaluation of the PCE (or the BEM) model and whether or not this estimator could generate unbiased estimates of abundance.

Typically, the peak count (PC) refers to an enumeration of fish that corresponds to the largest count of either live spawners, carcasses, or a combination of the two. A peak count expansion (PCE) factor is then calculated as the ratio of the peak count relative to the (estimated) total abundance of spawners (Parsons and Skalski 2009). However, the PCE factor is just one specific form of an expansion factor and a countless number of expansion factors could hypothetically be developed to derive an abundance estimator given the existing data. Hence, we chose to evaluate three different PCE estimators: "peak lives + deads", "peak deads only", and "top 3 deads" (see methods). In theory, a PCE estimator that incorporates more data should be more accurate and precise. Therefore, all other things being equal, we hypothesized that the "peak lives + deads" and the "top 3 deads" PCE estimates of abundance should have been better. However, the underlying assumptions of the estimator (see pg. 19) are still of utmost importance. For instance, if incorporating more data leads to greater variability in detection rates of spawners and/or carcasses then the PCE estimator may not be improved. Ultimately, we were interested in the performance of all three estimators based on past data collection efforts and consideration for future surveys. Specifically, peak live counts for tule-run Chinook were not consistently conducted prior to 2013 but carcass (i.e., dead) surveys were completed almost every week. Thus, we would need a PCE estimator that used exclusively carcass data to generate estimates prior to 2013 but we still wanted to know if incorporating live count data (when available) improved the accuracy and precision of the abundance estimates.

Using the five years of paired Jolly-Seber and PCE estimates of abundance, we evaluated the accuracy and precision of our three different PCE estimators. Based on our analysis, estimates of abundance that were generated with the PCE estimators had mean absolute percent errors (MAPEs) of 7 – 28% but were statistically similar to the JS estimates (i.e., unbiased) for 43 out of the 45 (95%) generated estimates. The uncertainty associated with the abundance estimates as measured with the coefficient of variation (CV) was estimated to be between 28 – 49%, which is well above the recommended precision goal of 15% that have been developed for ESA-listed salmon and steelhead populations by NOAA Fisheries (Crawford and Rumsey 2011) and the Lewis River Hatchery and Supplementation Annual Operating Plan (H&S Subgroup 2015). Still, it is important to highlight that the estimates of uncertainty we generated are underestimated because uncertainty in live and deads counts was not incorporated in the estimate of PCE (see Parsons and Skalski 2009). Hypothetically, we could have potentially incorporated uncertainty in the dead (carcass) counts into our PCE model, which would have increased the estimates of CV. However, this could not have been done for live count data as observer efficiencies have never been measured. Nonetheless, estimates of precision for the PCE estimator were substantially higher than those generated with the JS model.

It should be noted that we used "weakly" informative priors in the development of the PCE estimators. Specifically, the mean and median PCE estimates were not sensitive to the hyper-prior we used for $\mu_{logitPCP_i}$ and $\sigma_{logitPCP_i}$, but the estimate of uncertainty in our PCE estimators was semi-sensitive. We ended up choosing a prior for $\mu_{logitPCP_i}$ of *Normal (-0.75, 0.75)*, which corresponds to a prior on PCE that has it 95% distribution between approximately 1.5 and 10, which based on the existing data made biological sense. One thing to remember is that we generated a hierarchical estimate with only 4 – 5 data points. Therefore, the estimate is going to naturally be somewhat uncertain due to low sample size. However, the estimates of uncertainty for our PCE estimators may potentially become more precise as additional years of data are added.

It is important to highlight a detail in how we calculated our PCE estimators. We used carcass recovery data and calibrated those recoveries relative to estimates derived with a mark-recapture model. During the mark-recapture surveys, carcasses that were either recaptured or sampled but not tagged were chopped in half and denoted as "loss-on-capture. Assuming chopped carcass had lower recovery rates, which they almost certainly would, the total number of carcasses surveyed during the following week(s) would be less than if carcasses were not chopped. Therefore, in future years, if we were to only conduct peak carcass counts (i.e., not chop carcasses throughout the entire spawn time period), we would overestimate abundance using the PCE factors that were derived in this study. This bias would likely be relatively small given that the large majority of carcasses are recovered in the first several weeks post-death, but nonetheless the estimate would still be biased. A few solutions to this potential issue would be to (1) develop a PCE estimator that only used counts of live spawners, (2) only enumerate "fresh" carcasses, (3) enumerate and include the recovery of chopped carcasses in the dead count, or (4) develop a weekly estimate of chopped carcasses that would have survived and been recovered as part of the JS model. This issue does not affect any historical data and derived estimates as recovered carcasses have always been chopped. Nonetheless, this would be an important consideration if there was ever a shift to only conducting peak carcass surveys.

Overall, the assumptions of the PCE model were not consistently met. Although the violation of assumptions did not lead to biased estimates in most years, all of the estimates were highly imprecise and in some years the mean of the estimate was inaccurate (Figure 8, Figure 9, Appendix E). The main issue with the PCE estimator in the NF Lewis was that in several years the peak count survey was not conducted during the peak time frame. When this occurred, the peak count was underestimated and thus the estimate of abundance was biased low or incomputable. In general, though, the main issue with the PCE estimator is that the observer efficiencies for live counts and recovery rates for carcasses must remain constant among surveys. If this assumption is not met, the PCE will not reflect the actual relationship between the count and total abundance, the peak date can be misidentified, and ultimately the abundance estimate will be biased. This issue is similar to the main issue with the BEM. Despite these limitations, our PCE estimators generated estimates of abundance that were unbiased in most years, albeit relatively imprecise, so long as the peak count data were collected during the peak spawn time period.

Recommendations

Based on the results of our analysis and the goals of the North Fork (NF) Lewis River fall-run Chinook surveys salmon, we have developed a list of recommended actions. The list is prioritized in the order that items should be addressed to improve the accuracy and precision of spawner abundance estimates for fall-run Chinook salmon in the NF Lewis River.

(1) **Continue implementation of mark-recapture surveys for abundance estimation.** One of the main objectives of the NF Lewis River fall-run Chinook salmon surveys is to generate unbiased estimates of spawner abundance with specified uncertainty by stock (tule, bright), origin (hatchery, wild), sex (male, female), and age. Therefore, it is necessary to use an abundance estimator that generates unbiased estimates when the assumptions of the model are met. The Jolly-Seber (JS) open population mark-recapture model we used to estimate Chinook abundance was developed specifically for salmon, has been thoroughly evaluated over the past several decades, and successfully used for other lower Columbia River salmon populations. Our JS modeling approach not only allowed us to directly test the assumptions of the model but also account for heterogeneity in the data and structure it so that unbiased estimates could be generated. Hence, the abundance estimates generated using the JS mark-recapture estimator should be viewed as unbiased.

    Conversely, the use of the Bright-eye method (BEM) and peak count expansion (PCE) estimators can lead to biased estimates due to a violation of the model assumptions. Specifically, for the BEM and PCE estimators to generate an unbiased estimate, recovery rates, which are a function of both environmental conditions and sampling effort, have to be constant within and among years. Although averaged age-specific recovery rates of

Chinook in the NF Lewis were relatively constant among the five years of data we analyzed, they are quite variable within a year, which can lead to biased estimates of abundance by stock (tule, bright) and can vary substantially from the averaged recovery rates (e.g., 2015 estimates). In theory, the BEM and PCE estimators could be modified in a manner that allows recovery rates to be estimated as a function of multiple variables and thus vary within and among years (see recommendation #5). However, the feasibility of this model has not been explored and may or may not produce a better estimator.

Therefore, given the limitations of the BEM and PCE estimators, we recommend conducting mark-recapture surveys throughout the entire spawning time frame to estimate the abundance of Chinook salmon in the NF Lewis River until an alternative, more cost-effective method has been developed that can generate an unbiased estimate with a specified level of uncertainty. We want to emphasize that our recommendation for weekly mark-recapture surveys is to meet NOAA viable salmon population (VSP) monitoring guidelines for accuracy and precision of abundance estimates as well as diversity metrics such as spawning time and age structure (Crawford and Rumsey 2011). Unbiased estimates of spawning time (Appendix E: Figures E1 – E5) and age structure (Figure 6) can only be accomplished by weekly surveys.

(2) **Continue implementation of peak count surveys.** Despite the current limitation of the PCE estimators, we recommend the continuation of peak counts, which include counts of live spawners. Peak live counts are attempted annually for almost all lower Columbia River fall-run Chinook populations in Washington State. Peak counts not only provide VSP data on the spatial structure of a population, they can also be used to generate PCE factors, and thus estimates of abundance with uncertainty. Specifically regarding NF Lewis fall-run Chinook data collection, future peak count data can be used to update the current PCE models, which may provide improved estimates with additional years of data.

Moving forward, we recommend a minimum of three peak count surveys per stock (tule, bright) for a total of at least six counts per year. Counts should be conducted during the peak spawning time frame for each stock, which corresponds to generally the 2nd, 3rd, and 4th week of October for tule-run Chinook and generally the 3rd and 4th week of November and 1st week of December for bright-run Chinook. During each survey, both live and dead (i.e., carcasses) Chinook should be enumerated. However, live counts and carcass surveys should not be conduct simultaneously by the same crew/boat. If possible, peak live counts should be separated by holders (i.e., fish sighted in areas where spawnable habitat is not present and spawning does not occur) and spawners (fish sighted in an area with spawnable habitat). Peak dead counts should be separated by maiden carcasses, recaptured carcasses, previously sampled carcasses (i.e., chopped), and non-sampled carcasses (i.e., Carcass Category 5 and 6 – see Figure 3 and Appendix A).

(3) **Improve understanding and estimates of population structure.** The NF Lewis River consists of two ESA-listed distinct independent populations (DIPs; a.k.a., stocks) of fall-run Chinook salmon (i.e., tules and brights). Currently, population-specific estimates of abundance are generated using recoveries of CWTs collected on the spawning grounds

during weekly carcass surveys. Although there is coherence between the population-specific estimates of abundance and run-timing distributions (Appendix E), these CWT-based estimations are based on several untested assumptions. Therefore, it may be worth exploring alternative methods to assign stock composition in future years.

Genetic methods have proven useful in distinguishing populations/stocks; however, existing genetic marker panels (i.e., the GAPS microsatellite baseline and the Columbia Basin SNP panels) are limited in scope regarding tules and brights and may not be powerful enough to distinguish them. Therefore, we propose an additional exploration of genetic techniques to better partition the fall-run Chinook abundance estimate by stock. First, a more detailed investigation of existing SNP panels may be useful (e.g., Meek et al. 2016). Second, new distinguishing SNP markers may be discovered using genomic methods. The first step for either of these methods will require tissue collections from groups of known tules and known brights. Therefore, we recommend (1) identifying sample time frames and locations in the NF Lewis River that minimize spawning overlap between tules, brights, and spring-run Chinook, (2) determining necessary tissue collection sample sizes, and (3) collecting genetic samples during the fall of 2018.

(4) **Generate basin-wide estimates of abundance.** Historically, estimates of abundance for Lewis River fall-run Chinook salmon have been generated independently for four individual "sub-populations": tules in the NF Lewis River, Cedar Creek, and EF Lewis River and brights in the NF Lewis. However, these individual sub-populations of tules and brights each correspond to a larger geographic DIP that encompasses the entire Lewis River basin. Specifically, the Willamette-Lower Columbia Technical Recovery Team (WLC-TRT) identifies early-run (tules) and late-run (brights) Chinook consisting of fish from both the NF Lewis River (including Cedar Creek) and EF Lewis River (Myers et al. 2006). Currently, WDFW does not generate an estimate of bright-run Chinook in the EF Lewis and, interestingly, LCR Recovery Plan does not list the EF Lewis as a bright-run sub-population (LCFRB 2010). Nonetheless, we recommend the development of analytical methods that would allow the generation of annual abundance estimates for tule- and bright-run Chinook salmon at the Lewis River basin-wide geographic scale, which would correspond to the how Lewis River Chinook are listed under ESA.

(5) **Explore the development of a model-assisted abundance estimator.** WDFW has used other methods to estimate abundance for other Lower Columbia River Chinook populations (Rawding et al. 2014). Specifically, closed population models based on the tagging of live adults and recovery of carcasses have been effective for some populations but not for the Chinook salmon spawners in the Lewis due to violations of key assumptions (Hawkins et al. 2003a). Genetic methods have been successful on the Coweeman River but depend on the assumption of equal catchability of fish in the first sample with respect to their reproductive success (Rawding et al. 2013). This is likely difficult to achieve especially given the variability in adult capture probabilities discussed above and the prolonged outmigration of juvenile Chinook in the Lewis River. Redd based estimates are also likely problematic due to the challenge of obtaining individual redd counts due to mass spawning and superimposition because of high Chinook salmon densities (i.e., over 1,000 fish per

kilometer). If alternate methods are to be considered, we believe that AUC methods based on counts of "spawners" have the highest chance for success (Parken et al. 2011, Rawding et al. 2014). This approach would require the development of observer efficiency models based on environmental and surveyor experience covariates as well as estimates of apparent residence time. However, development of the additional parameters needed for the AUC approach may not be more cost-effective than the JS approach based on carcass tagging.

The results from the 2013-17 JS model assessment indicated that survival and capture probabilities varied by time. Graphical inspection of Figure 10 suggests that recovery probabilities may be related to flow. In addition, logistic regression also indicated that annual recovery probabilities were related to size. A complementary approach to recommendations #1 and #3 would be to explore a model-assisted JS estimator, which is likely to be a more successful approach than other approaches described in the above paragraph. For example, covariates such as flow, temperature, visibility, survey effort, surveyor experience, sex, and size could be incorporated into weekly estimates of capture and survival probabilities (Kery and Schaub 2012). In addition, the probability of entry parameter could be modeled as a parametric curve (Sethi and Bradley 2015). If this hypothetical model can be shown to consistently generate unbiased estimates, it may be possible to reduce the frequency and/or intensity of mark-recapture surveys or modify the current BEM method.

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Appendix A – Carcass category definitions

Table A1. Carcass categories codes and their associated definitions.

Carcass Category	Definition
-	Any carcass that you **can CWT sample** and **can tell** if it had been previously carcass tagged (both opercules intact). No carcass tags present and in condition to be tagged.
1	Any carcass that you **can CWT sample** but you **cannot tell** if it had been previously carcass tagged (i.e., missing portions of the head, missing one or both opercules).
2	Any carcass that you **cannot CWT sample** and you **cannot tell** if it had been previously carcass tagged (missing portions of the head, missing one or both opercules).
3	Any carcass that you **cannot CWT sample** but you **can tell** if it had been previously carcass tagged (both opercules present).
4	Any carcass that you **can CWT sample** and **can tell** if it had been previously carcass tagged (both opercules intact) BUT you do not want to tag it (e.g., carcass too old, sub-sampling).
5	Any carcass you are unable to examine but can ID species (e.g., too deep to recover)
6	Any carcass with a slit belly

Appendix B – Jolly-Seber Mark-Recapture Open Population Model Notation

Table B1. Summary statistics used in the Jolly-Seber model

Statistic	Definition/Equation
m_i	Number of fish captured at sample time i that were previously marked.
u_i	Number of fish captured at sample time i that were unmarked.
n_i	Number of fish captured at sample time i. $n_i = m_i + u_i$.
l_i	Number of fish lost on capture at time i.
R_i	Number of fish that were released after the ith sample. R_i need not equal n_i if there were losses on capture or injections of new fish at sample time i.
r_i	Number of R_i fish released at sample time i that were recaptured at one or more future sample times.
z_i	Number of fish captured before time i, not captured at time i, and captured after time i.
T_i	Number of fish captured at before time i and captured at or after time i. $T_i = m_i + z_i$.

Table B2. Fundamental parameters for the Jolly-Seber model under the salmon escapement super population model (Schwarz et al. 1993).

Parameter	Definition/Equation
s, tm	Number of sample times and length of interval between samples
p_i	Probability of capture at sample time i, $i = 1,\ldots, s$.
φ_i	Probability of a fish surviving and remaining in the population between sample time i and sample time $i + 1$, given it was alive and in the population at sample time i, $i = 1,\ldots, s\text{-}1$.
b^*_i	Probability that a fish enters the population between sample times i and $i +1$, $i = 0,\ldots, s\text{-}1$ under the constrain that $\sum b^*_i = 1$. These are referred to as entry probabilities.
v_i	Probability that a fish captured at time i will be released, $i = 1,\ldots, s\text{-}1$.
N	Total number of fish that enter the system before the last sample time or the escapement. This is referred to as the super population.

Table B3. Derived parameters for the Jolly-Seber model under the salmon escapement super population model (Schwarz et al. 1993).

Parameter	Definition/Equation
λ_i	Probability that a fish is seen again after sample time i, $i = 1,\ldots, s$. $\lambda_i = \varphi_i\, p_{i+1} + \varphi_i\, (1 - p_{i+1})\, \lambda_{i+1}$, $i = 1,\ldots, s\text{-}1$; $\lambda_s = 0$.
τ_i	Conditional probability that a fish is seen at sample time i given that it was seen at or after sample time i, $i = 1,\ldots, s$. $\tau_i = p_i/(p_i + (1\text{-}p_{i+1})\, \lambda_i)$.
ψ_i	Probability that a fish enters the population between sample time i-1 and i and survives to the next sampling occasion. $\psi_i = b^*_0$, $\psi_{i+1} = \psi_i\,(1 - p_i)\varphi_i + b^*_i(\varphi_i - 1)/\log(\varphi_i)$
B^*_i	Number of fish that enter between sampling occasion i-1 and i, $i = 0,\ldots, s\text{-}1$. These are referred to as gross births. $B^*_i = N\,(b^*_i)$

Table B4. The likelihoods for the Schwarz et al. (1993) model

Description	Likelihood
Pr(first capture part a)	$u.$ ~ Binomial($\sum\psi_i p_i$,N), i = 0,…, s-1. $u. = \sum u_i$
Pr(first capture part b)	u_i ~ Multinomial ($\psi_i p_i/\sum\psi_i p_i$,$u.$)), i = 0,…, s-1.
Pr(release on capture)	R_i ~ Binomial(v_i,n_i), i = 1,…, s-1.
Pr(recapture part a)	m_i~Binomial(τ_i,T_i), i = 2,…, s-1.
Pr(recapture part b)	r_i ~ Binomial(λ_i,R_i), i = 1,…, s-1.

Appendix C – Jolly-Seber Mark-Recapture Model Inputs, 2013 – 2017

Table C1. 2013 mark-recapture summary statistics used to estimate the abundance of mainstem North Fork Lewis River fall-run Chinook spawners using a Jolly-Seber open population model. Estimates were derived for three groups – jacks (males <60 cm), females, and males (≥60 cm). "j.date" was formatted as the day of year. Periods "-1" and "+1" only apply to "j.date" data where an additional date was needed before the first period and after the last period to run the model.

		Period																				
Statistic	Group	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	+1
j.date	Jack	273	280	297	310	317	324	331	338	345	352	358	365	372	393	400	-	-	-	-	-	-
	Female	261	268	275	282	289	296	303	310	317	324	331	338	345	352	358	365	372	386	393	400	407
	Male	258	265	275	282	289	296	303	310	317	324	331	338	345	352	358	365	372	386	393	400	407
n	Jack		4	21	57	115	135	335	110	116	89	26	23	14	1	NA	NA	NA	NA	NA	NA	
	Female		15	39	129	84	103	140	377	837	1005	1126	711	542	421	170	227	165	85	30	15	
	Male		11	26	84	89	129	116	343	1031	1209	1196	577	585	370	147	127	109	39	11	10	
R	Jack		4	20	54	104	119	202	55	53	34	8	11	3	0	NA	NA	NA	NA	NA	NA	
	Female		13	26	66	26	40	67	191	256	105	126	79	52	139	56	96	39	21	5	0	
	Male		8	18	42	30	54	48	180	327	127	131	63	57	117	52	44	25	11	2	0	
u	Jack		4	20	55	104	126	290	73	72	58	16	18	4	0	NA	NA	NA	NA	NA	NA	
	Female		15	36	124	65	88	124	346	750	923	1041	656	485	382	123	171	118	57	20	10	
	Male		11	25	81	78	118	90	326	955	1124	1080	533	540	325	115	80	75	30	8	5	
z	Jack		0	0	0	2	10	9	33	15	8	9	6	0	0	NA	NA	NA	NA	NA	NA	
	Female		0	0	3	4	3	4	8	14	37	11	24	25	15	49	26	17	7	4	0	
	Male		0	0	0	5	3	3	3	15	69	23	31	19	10	33	19	2	5	5	0	
r	Jack		1	2	13	17	44	61	26	24	11	2	4	1	0	NA	NA	NA	NA	NA	NA	
	Female		3	8	20	14	17	35	93	105	59	68	58	29	81	33	38	18	7	1	0	
	Male		1	3	16	9	26	17	88	139	70	52	33	36	55	33	17	12	3	0	0	
m	Jack		0	1	2	11	9	45	37	44	31	10	5	10	1	NA	NA	NA	NA	NA	NA	
	Female		0	3	5	19	15	16	31	87	82	85	55	57	39	47	56	47	28	10	5	
	Male		0	1	3	11	11	26	17	76	85	116	44	45	45	32	47	34	9	3	5	

Table C2. 2013 biological data summary data used to apportion the abundance estimates of mainstem North Fork Lewis River fall-run Chinook spawners that were derived for three groups – jacks (males <60 cm), females, and males (≥60 cm) – into reporting groups by stock (tule, brights), origin (hatchery, wild), sex, and age.

			Period																		
Group	Variable	Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Jack	Stock	Tule	1	4	3	0	0	0	0	0	0	0	0	0	0						
		Total	1	4	4	10	12	14	5	6	3	1	1	1	1						
	Origin	Hatchery	169	207	61	41	31	14	7	7	1	0	2	2	0						
		Total	299	590	727	1809	1247	1383	694	661	764	254	269	197	130						
	Age	Age-2	2	13	21	47	56	60	13	12	6	1	1	1	0						
		Age-3	2	7	32	57	60	129	35	38	24	6	10	2	0						
		Age-4	0	0	0	0	0	0	0	1	0	0	0	0	0						
		Age-5	0	0	0	0	0	0	0	0	0	0	0	0	0						
		Age-6	0	0	0	0	0	0	0	0	0	0	0	0	0						
Female	Stock	Tule	1	1	1	1	2	1	3	0	0	0	0	0	0	0	0	0	0	0	0
		Total	1	1	1	1	2	1	4	10	12	14	5	6	3	1	1	1	1	1	1
	Origin	Hatchery	16	29	124	89	69	49	61	41	31	14	7	7	1	0	2	2	0	0	0
		Total	29	62	208	149	210	231	727	1809	1247	1383	694	661	764	254	269	197	87	28	15
	Age	Age-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Age-3	0	1	7	2	3	9	21	20	8	9	4	3	5	1	1	0	0	0	0
		Age-4	11	19	64	21	32	44	138	183	63	80	54	27	78	21	38	17	7	1	0
		Age-5	3	6	15	0	4	5	24	44	25	26	16	17	47	26	43	14	10	2	4
		Age-6	1	0	0	2	0	1	1	3	1	1	1	0	0	1	5	4	2	0	2
Male	Stock	Tule	1	1	1	1	2	1	3	0	0	0	0	0	0	0	0	0	0	0	0
		Total	1	1	1	1	2	1	4	10	12	14	5	6	3	1	1	1	1	1	1
	Origin	Hatchery	16	29	124	89	69	49	61	41	31	14	7	7	1	0	2	2	0	0	0
		Total	29	62	208	149	210	231	727	1809	1247	1383	694	661	764	254	269	197	87	28	15
	Age	Age-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Age-3	2	7	23	13	29	13	79	146	54	63	32	17	43	10	5	3	1	1	0
		Age-4	6	8	31	15	21	27	88	140	50	50	21	22	41	22	13	9	1	1	1
		Age-5	1	1	3	0	0	4	10	34	14	5	5	13	28	17	21	11	6	0	1
		Age-6	0	0	0	0	0	1	0	1	1	1	0	1	0	0	2	1	2	0	0

Table C3. 2014 mark-recapture summary statistics used to estimate the abundance of mainstem North Fork Lewis River fall-run Chinook spawners using a Jolly-Seber open population model. Estimates were derived for three groups – jacks (males <60 cm), females, and males (≥60 cm). "j.date" was formatted as the day of year. Periods "-1" and "+1" only apply to "j.date" data where an additional date was needed before the first period and after the last period to run the model.

		Period																		
Statistic	Group	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	+1
j.date	Jack	281	288	300	308	315	322	329	337	344	351	356	363	370	NA	NA	NA	NA	NA	NA
	Female	260	267	276	281	288	296	302	308	315	322	329	337	344	351	356	363	372	378	385
	Male	272	279	288	296	302	308	315	322	329	337	344	351	356	363	372	378	385	NA	NA
n	Jack		7	15	15	48	184	187	65	31	21	3	3	NA	NA	NA	NA	NA	NA	
	Female		16	54	109	237	414	272	404	884	1396	1833	934	990	1195	360	438	92	118	
	Male		95	193	278	115	275	623	1265	1051	531	404	543	108	116	17	19	NA	NA	
R	Jack		7	14	14	47	166	122	38	17	8	2	0	NA	NA	NA	NA	NA	NA	
	Female		5	25	73	118	63	131	175	136	182	111	54	127	100	147	103	30	0	
	Male		58	97	38	56	124	100	175	60	31	48	43	42	29	4	0	NA	NA	
u	Jack		7	14	14	47	167	126	52	21	8	2	1	NA	NA	NA	NA	NA	NA	
	Female		16	53	99	215	360	246	371	814	1294	1738	905	967	1090	329	330	73	84	
	Male		95	177	244	105	261	583	1194	956	518	384	508	95	93	12	11	NA	NA	
z	Jack		0	0	0	1	1	3	4	7	2	2	0	NA	NA	NA	NA	NA	NA	
	Female		0	0	3	6	1	1	6	28	17	16	22	30	13	32	8	16	0	
	Male		0	3	3	2	1	24	8	13	17	13	4	10	4	4	0	NA	NA	
r	Jack		1	1	2	17	63	14	13	8	1	0	0	NA	NA	NA	NA	NA	NA	
	Female		1	13	25	49	26	38	92	91	94	35	31	88	50	84	27	18	0	
	Male		19	34	9	13	63	55	100	17	16	26	19	17	5	4	0	NA	NA	
m	Jack		0	1	1	1	17	61	13	10	13	1	2	NA	NA	NA	NA	NA	NA	
	Female		0	1	10	22	54	26	33	70	102	95	29	23	105	31	108	19	34	
	Male		0	16	34	10	14	40	71	95	13	20	35	13	23	5	8	NA	NA	

Table C4. 2014 biological data summary data used to apportion the abundance estimates of mainstem North Fork Lewis River fall-run Chinook spawners that were derived for three groups – jacks (males <60 cm), females, and males (≥60 cm) – into reporting groups by stock (tule, brights), origin (hatchery, wild), sex, and age.

			Period																
Group	Variable	Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Jack	Stock	Tule	12	9	4	1	0	0	0	0	0	0	0						
		Total	12	10	8	9	17	19	6	13	12	3	1						
	Origin	Hatchery	540	492	39	10	14	8	1	5	5	3	0						
		Total	660	969	646	500	1227	1290	712	674	1037	426	604						
	Age	Age-2	5	14	13	35	143	103	26	13	6	2	1						
		Age-3	2	0	1	12	19	16	10	4	2	0	0						
		Age-4	0	0	0	0	1	0	0	0	0	0	0						
		Age-5	0	0	0	0	0	0	0	0	0	0	0						
		Age-6	0	0	0	0	0	0	0	0	0	0	0						
Female	Stock	Tule	2	1	2	8	8	1	4	1	0	0	0	0	0	0	0	0	0
		Total	2	1	2	8	8	2	8	9	17	19	6	13	12	3	1	1	1
	Origin	Hatchery	14	58	153	315	387	105	39	10	14	8	1	5	5	3	0	0	0
		Total	21	75	167	397	609	360	646	500	1227	1290	712	674	1037	426	424	85	95
	Age	Age-2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Age-3	1	1	2	2	3	4	10	2	7	6	0	3	4	2	0	2	0
		Age-4	11	36	61	101	47	105	152	117	156	89	50	102	82	120	74	17	22
		Age-5	2	3	6	12	11	17	9	13	11	10	3	18	8	18	24	8	8
		Age-6	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
Male	Stock	Tule	4	8	8	1	4	1	0	0	0	0	0	0	0	0	0		
		Total	4	8	8	2	8	9	17	19	6	13	12	3	1	1	1		
	Origin	Hatchery	225	315	387	105	39	10	14	8	1	5	5	3	0	0	0		
		Total	263	397	609	360	646	500	1227	1290	712	674	1037	426	424	85	95		
	Age	Age-2	2	0	0	0	0	0	0	1	0	0	0	0	2	0	0		
		Age-3	16	20	12	8	13	10	37	16	4	8	8	5	1	1	0		
		Age-4	45	71	27	44	100	81	122	35	27	37	32	30	21	3	3		
		Age-5	5	4	2	2	4	4	7	3	0	3	3	5	4	1	1		
		Age-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		

Table C5. 2015 mark-recapture summary statistics used to estimate the abundance of mainstem North Fork Lewis River fall-run Chinook spawners using a Jolly-Seber open population model. Estimates were derived for three groups – jacks (males <60 cm), females, and males (≥60 cm). "j.date" was formatted as day of year. Periods "-1" and "+1" only apply to "j.date" data where an additional date was needed before the first period and after the last period to run the model.

		Period															
Statistic	Group	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	+1
j.date	Jack	274	281	288	294	300	307	315	329	336	361	368	NA	NA	NA	NA	NA
	Female	266	273	281	288	294	300	307	314	321	329	336	350	356	364	372	379
	Male	265	272	281	288	294	300	307	314	321	329	338	356	364	372	379	NA
n	Jack		4	13	8	8	14	49	39	31	3	NA	NA	NA	NA	NA	
	Female		39	216	443	340	337	568	1520	325	1160	726	138	188	100	71	
	Male		34	204	360	323	215	293	902	259	930	394	77	65	62	NA	
R	Jack		4	12	7	7	13	48	34	29	0	NA	NA	NA	NA	NA	
	Female		30	121	136	70	103	213	142	29	115	85	22	37	20	0	
	Male		27	113	107	64	65	111	86	24	91	47	15	13	0	NA	
u	Jack		4	12	7	7	13	48	34	29	2	NA	NA	NA	NA	NA	
	Female		39	208	412	309	313	543	1446	321	1142	694	136	175	96	67	
	Male		34	195	323	287	198	281	859	254	917	363	69	63	57	NA	
z	Jack		0	0	0	0	0	0	0	0	0	NA	NA	NA	NA	NA	
	Female		0	1	3	6	3	7	1	11	3	0	6	3	2	0	
	Male		0	0	0	4	4	4	0	9	2	1	1	2	0	NA	
r	Jack		1	1	1	1	1	5	2	1	0	NA	NA	NA	NA	NA	
	Female		9	33	34	21	29	68	14	10	29	8	10	3	2	0	
	Male		9	37	40	17	12	39	14	6	30	8	3	3	0	NA	
m	Jack		0	1	1	1	1	1	5	2	1	NA	NA	NA	NA	NA	
	Female		0	8	31	31	24	25	74	4	18	32	2	13	4	4	
	Male		0	9	37	36	17	12	43	5	13	31	8	2	5	NA	

Table C6. 2015 biological data summary data used to apportion the abundance estimates of mainstem North Fork Lewis River fall-run Chinook spawners that were derived for three groups – jacks (males <60 cm), females, and males (≥60 cm) – into reporting groups by stock (tule, brights), origin (hatchery, wild), sex, and age.

			Period													
Group	Variable	Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Jack	Stock	Tule	3	1	3	4	0	1	0	0	0					
		Total	3	1	3	4	7	23	21	16	3					
	Origin	Hatchery	413	567	398	193	63	24	2	4	0					
		Total	480	747	603	518	837	1813	1275	745	529					
	Age	Age-2	4	11	6	6	10	36	29	0	2					
		Age-3	0	1	1	1	3	12	3	0	0					
		Age-4	0	0	0	0	0	0	0	0	0					
		Age-5	0	0	0	0	0	0	0	0	0					
		Age-6	0	0	0	0	0	0	0	0	0					
Female	Stock	Tule	1	2	1	3	4	0	1	0	0	0	0	0	0	0
		Total	1	2	1	3	4	7	16	7	21	14	2	2	1	1
	Origin	Hatchery	62	351	567	398	193	63	24	0	2	4	0	0	0	0
		Total	73	407	747	603	518	837	1440	373	1275	547	198	245	159	125
	Age	Age-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Age-3	2	17	23	10	13	14	10	0	8	6	0	2	0	0
		Age-4	17	62	69	39	51	78	55	9	47	31	6	17	10	8
		Age-5	4	34	34	16	31	113	64	18	51	42	12	15	9	3
		Age-6	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Male	Stock	Tule	1	2	1	3	4	0	1	0	0	0	0	0	0	
		Total	1	2	1	3	4	7	16	7	21	16	2	1	1	
	Origin	Hatchery	62	351	567	398	193	63	24	0	2	4	0	0	0	
		Total	73	407	747	603	518	837	1440	373	1275	745	245	159	125	
	Age	Age-2	0	0	0	2	0	1	0	0	0	0	0	0	0	
		Age-3	9	51	59	29	23	20	24	5	10	7	1	1	0	
		Age-4	12	44	28	25	25	52	40	12	40	21	7	6	4	
		Age-5	4	10	11	8	14	32	18	7	33	15	5	4	6	
		Age-6	0	0	0	0	0	0	0	0	0	0	0	1	0	

Table C7. 2016 mark-recapture summary statistics used to estimate the abundance of mainstem North Fork Lewis River fall-run Chinook spawners using a Jolly-Seber open population model. Estimates were derived for three groups – jacks (males <60 cm), females, and males (≥60 cm). "j.date" was formatted as the number of day of year. Periods "-1" and "+1" only apply to "j.date" data where an additional date was needed before the first period and after the last period to run the model.

		Period																		
Statistic	Group	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	+1
j.date	Jack	281	288	313	320	327	333	341	353	360	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Female	259	266	271	279	285	292	299	306	313	320	327	333	341	348	355	363	369	376	383
	Male	264	271	279	285	292	299	306	313	320	327	333	341	348	355	363	369	376	383	NA
n	Jack		18	28	47	35	13	18	3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
	Female		5	16	170	313	126	89	115	363	655	1027	549	685	452	208	123	60	116	
	Male		14	131	179	75	43	64	318	582	719	287	413	203	98	38	20	18	NA	
R	Jack		18	27	41	28	11	10	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
	Female		5	15	88	96	36	27	61	158	279	220	213	163	139	71	50	15	0	
	Male		12	68	54	21	13	36	143	245	148	106	98	57	32	11	7	0	NA	
u	Jack		18	27	41	28	11	10	1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
	Female		5	15	167	283	122	82	104	325	607	899	474	522	349	153	81	38	84	
	Male		14	129	158	71	39	61	295	537	607	238	318	142	68	20	17	10	NA	
z	Jack		0	1	1	0	6	1	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
	Female		0	0	1	1	2	3	4	3	12	24	52	41	17	23	26	26	0	
	Male		0	1	1	1	3	4	1	13	21	41	21	12	11	8	7	0	NA	
r	Jack		2	6	6	8	3	1	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
	Female		1	4	30	5	8	12	37	57	140	103	152	79	61	45	22	6	0	
	Male		3	21	4	6	4	20	57	120	69	75	52	29	15	2	1	0	NA	
m	Jack		0	1	6	7	2	8	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
	Female		0	1	3	30	4	7	11	38	48	128	75	163	103	55	42	22	32	
	Male		0	2	21	4	4	3	23	45	112	49	95	61	30	18	3	8	NA	

Table C8. 2016 biological data summary data used to apportion the abundance estimates of mainstem North Fork Lewis River fall-run Chinook spawners that were derived for three groups – jacks (males <60 cm), females, and males (≥60 cm) – into reporting groups by stock (tule, brights), origin (hatchery, wild), sex, and age.

			Period																
Group	Variable	Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Jack	Stock	Tule	8	0	0	0	0	0	0										
		Total	8	4	6	12	8	3	4										
	Origin	Hatchery	762	12	4	1	0	2	3										
		Total	1268	647	1185	1167	723	850	963										
	Age	Age-2	17	22	30	11	3	6	1										
		Age-3	1	4	8	17	6	2	0										
		Age-4	0	0	1	0	1	0	0										
		Age-5	0	0	0	0	0	0	0										
		Age-6	0	0	0	0	0	0	0										
Female	Stock	Tule	1	1	3	3	1	1	1	0	0	0	0	0	0	0	0	0	0
		Total	1	1	3	3	1	1	1	4	6	12	8	3	1	3	1	1	1
	Origin	Hatchery	2	19	222	323	129	51	16	12	4	1	0	2	3	0	0	0	0
		Total	6	28	304	446	193	121	170	647	1185	1167	723	850	492	221	101	55	94
	Age	Age-2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Age-3	0	0	6	10	7	7	6	14	12	11	11	6	7	1	0	0	0
		Age-4	3	7	61	75	21	15	41	113	193	139	116	91	63	40	29	9	4
		Age-5	2	5	13	7	7	4	11	23	54	57	71	47	56	21	16	5	9
		Age-6	0	1	0	0	0	0	0	1	2	5	7	2	3	4	3	0	2
Male	Stock	Tule	1	3	3	1	1	1	0	0	0	0	0	0	0	0	0	0	
		Total	1	3	3	1	1	1	4	6	12	8	3	1	3	1	1	1	
	Origin	Hatchery	21	222	323	129	51	16	12	4	1	0	2	3	0	0	0	0	
		Total	34	304	446	193	121	170	647	1185	1167	723	850	492	221	101	55	94	
	Age	Age-2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	
		Age-3	2	21	15	6	5	17	35	43	34	20	23	8	5	2	0	0	
		Age-4	5	40	35	13	6	17	79	151	77	58	45	25	21	5	2	1	
		Age-5	1	3	3	1	1	1	21	41	31	20	23	17	4	4	3	1	
		Age-6	0	0	0	0	0	0	2	4	2	2	0	0	0	1	1	0	

Table C9. 2017 mark-recapture summary statistics used to estimate the abundance of mainstem North Fork Lewis River fall-run Chinook spawners using a Jolly-Seber open population model. Estimates were derived for three groups – jacks (males <60 cm), females, and males (≥60 cm). "j.date" was formatted the day of year. Periods "-1" and "+1" only apply to "j.date" data where an additional date was needed before the first period and after the last period to run the model.

		Period																
Statistic	Group	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	+1
j.date	Jack	309	316	324	332	343	357	375	382	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Female	271	278	286	291	297	304	311	320	324	332	341	348	354	362	369	375	382
	Male	269	276	286	291	297	309	320	324	332	341	348	354	362	369	375	382	NA
n	Jack		19	11	15	9	8	1	3	NA	NA	NA	NA	NA	NA	NA	NA	
	Female		41	84	100	57	21	89	274	293	481	1118	577	454	234	126	51	
	Male		36	70	65	55	127	202	148	210	329	143	130	75	36	6	NA	
R	Jack		19	10	13	7	4	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	
	Female		29	38	36	9	3	46	140	168	220	363	231	57	64	26	0	
	Male		20	32	24	9	53	104	82	93	95	53	16	23	7	0	NA	
u	Jack		19	10	13	7	4	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	
	Female		41	83	93	51	19	88	261	248	428	961	415	301	169	99	38	
	Male		36	68	60	51	126	192	121	179	254	99	83	61	29	5	NA	
z	Jack		0	0	1	1	0	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	
	Female		0	0	0	1	0	1	0	24	43	37	81	56	17	9	0	
	Male		0	0	2	1	0	3	16	32	12	35	12	5	1	0	NA	
r	Jack		1	3	2	3	1	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	
	Female		1	7	7	1	2	12	69	72	151	206	128	26	19	4	0	
	Male		2	7	3	0	13	40	47	55	67	24	7	3	0	0	NA	
m	Jack		0	1	2	2	4	1	NA	NA	NA	NA	NA	NA	NA	NA	NA	
	Female		0	1	7	6	2	1	13	45	53	157	162	153	65	27	13	
	Male		0	2	5	4	1	10	27	31	75	44	47	14	7	1	NA	

Table C10. 2017 biological data summary data used to apportion the abundance estimates of mainstem North Fork Lewis River fall-run Chinook spawners that were derived for three groups – jacks (males <60 cm), females, and males (≥60 cm) – into reporting groups by stock (tule, brights), origin (hatchery, wild), sex, and age.

			Period														
Group	Variable	Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Jack	Stock	Tule	5	0	0	0	0	0									
		Total	8	6	4	11	5	1									
	Origin	Hatchery	348	0	3	5	1	0									
		Total	1188	379	620	1736	746	43									
	Age	Age-2	16	8	12	6	2	0									
		Age-3	2	2	1	1	0	0									
		Age-4	1	0	0	0	0	0									
		Age-5	0	0	0	0	0	0									
		Age-6	0	0	0	0	0	0									
Female	Stock	Tule	2	1	2	1	1	0	0	0	0	0	0	0	0	0	0
		Total	2	1	2	1	1	2	1	6	4	7	4	1	2	2	1
	Origin	Hatchery	48	108	109	45	17	14	7	0	3	4	1	0	1	0	0
		Total	77	153	153	102	51	184	468	379	620	1220	516	386	231	129	43
	Age	Age-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Age-3	9	17	11	4	1	7	11	17	16	5	9	2	1	2	0
		Age-4	17	14	13	2	2	27	76	96	103	162	96	18	28	7	6
		Age-5	12	6	7	2	0	11	42	46	87	163	93	23	29	16	5
		Age-6	0	0	0	0	0	0	0	0	1	1	2	0	0	1	0
Male	Stock	Tule	2	1	2	1	1	0	0	0	0	0	0	0	0	0	
		Total	2	1	2	1	3	1	6	4	7	4	1	2	2	1	
	Origin	Hatchery	48	108	109	45	31	7	0	3	4	1	0	1	0	0	
		Total	77	153	153	102	235	468	379	620	1220	516	386	231	129	43	
	Age	Age-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		Age-3	17	21	12	5	16	38	20	16	9	3	1	1	1	0	
		Age-4	12	8	8	3	25	37	42	37	43	21	1	11	3	2	
		Age-5	3	2	4	1	12	21	16	32	31	22	3	9	3	0	
		Age-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Appendix D – Peak Count Expansion (PCE) Model Inputs, 2013 – 2017

Table D1. Summary of NF Lewis fall-run Chinook data used to develop the peak count expansion (PCE) estimators, 2013 - 2017. The estimated mean and standard deviation (SD) of NF Lewis River fall-run Chinook abundance was generated using a Jolly-Seber (JS) open population mark-recapture model. Peak count (PC) data were summarized three ways: (1) "peak lives + deads" = maximum weekly count of carcasses and live spawners combined, (2) "peak deads" = maximum weekly count of carcasses, and (3) "top 3 deads" = summation of the three highest weekly counts of carcasses. Note: we did not use the "peak lives + dead" count data for brights in 2015 and tules in 2016 to develop the hierarchical PCE as the live count in those two years was not conducted during the known peak time period based on all other years of data.

		Year				
Stock	Parameter	2013	2014	2015	2016	2017
Tule	JS Abundance - mean	3511	4055	5449	4127	2225
	JS Abundance - SD	462	409	381	482	450
	PC – Peak Live + Dead	900	1616	2190	939	663
	PC – Peak Dead	286	644	824	456	167
	PC – Top 3 Dead	784	1540	2026	1018	433
Bright	JS Abundance - mean	17351	20803	18915	9360	7268
	JS Abundance - SD	450	620	992	243	355
	PC – Peak Live + Dead	3878	4945	2372	3209	1832
	PC – Peak Dead	2594	2912	2372	1714	1495
	PC – Top 3 Dead	7010	7406	5564	4147	2901

Appendix E – Plots of Run-Timing by Stock and Origin

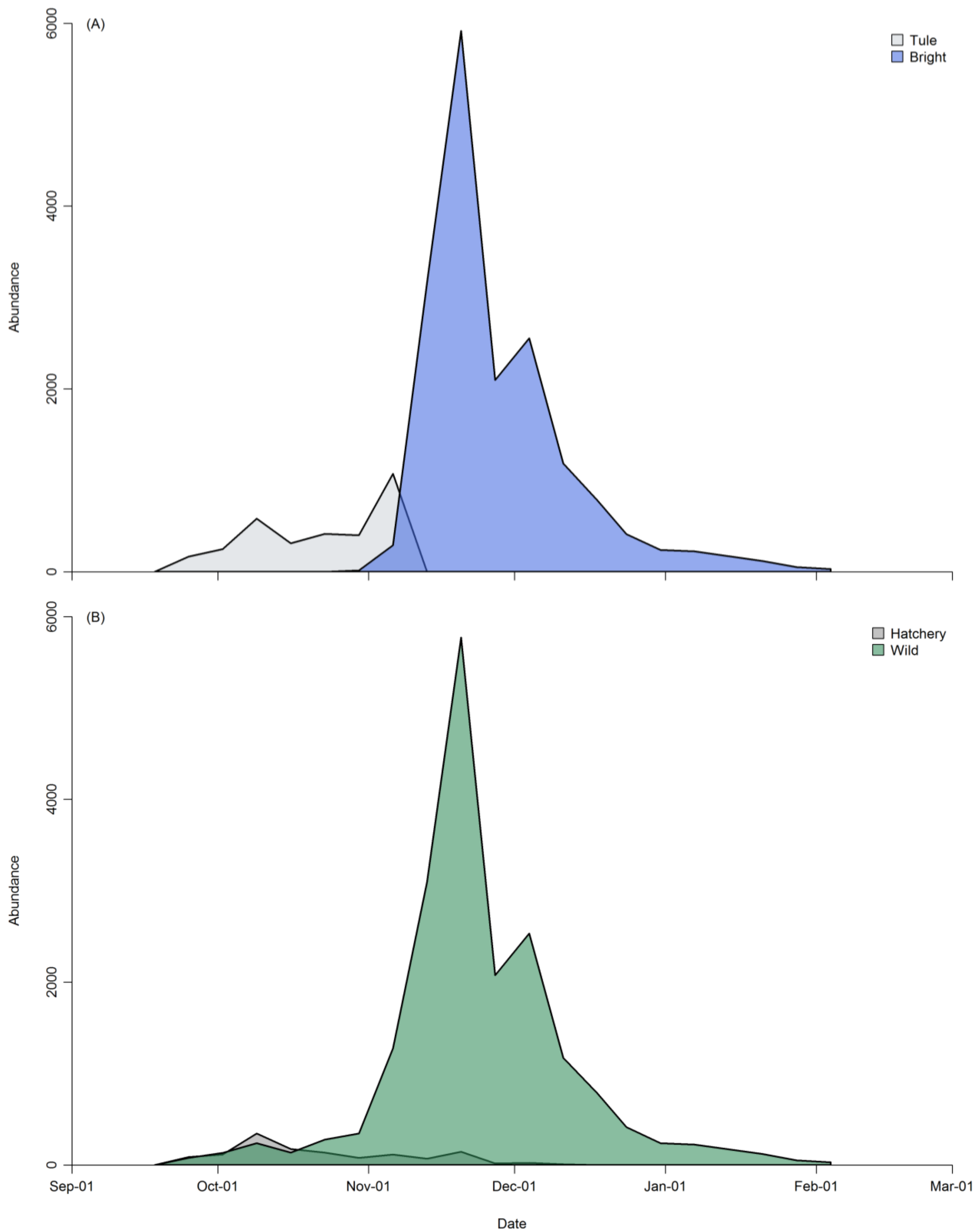

Figure E1. 2013 weekly abundance of fall-run Chinook by (A) stock (tule, bright) and (B) origin (hatchery, wild) in the NF Lewis. Estimates of abundance were derived using an open Jolly-Seber estimator applied to mark-recapture carcasses recovery data.

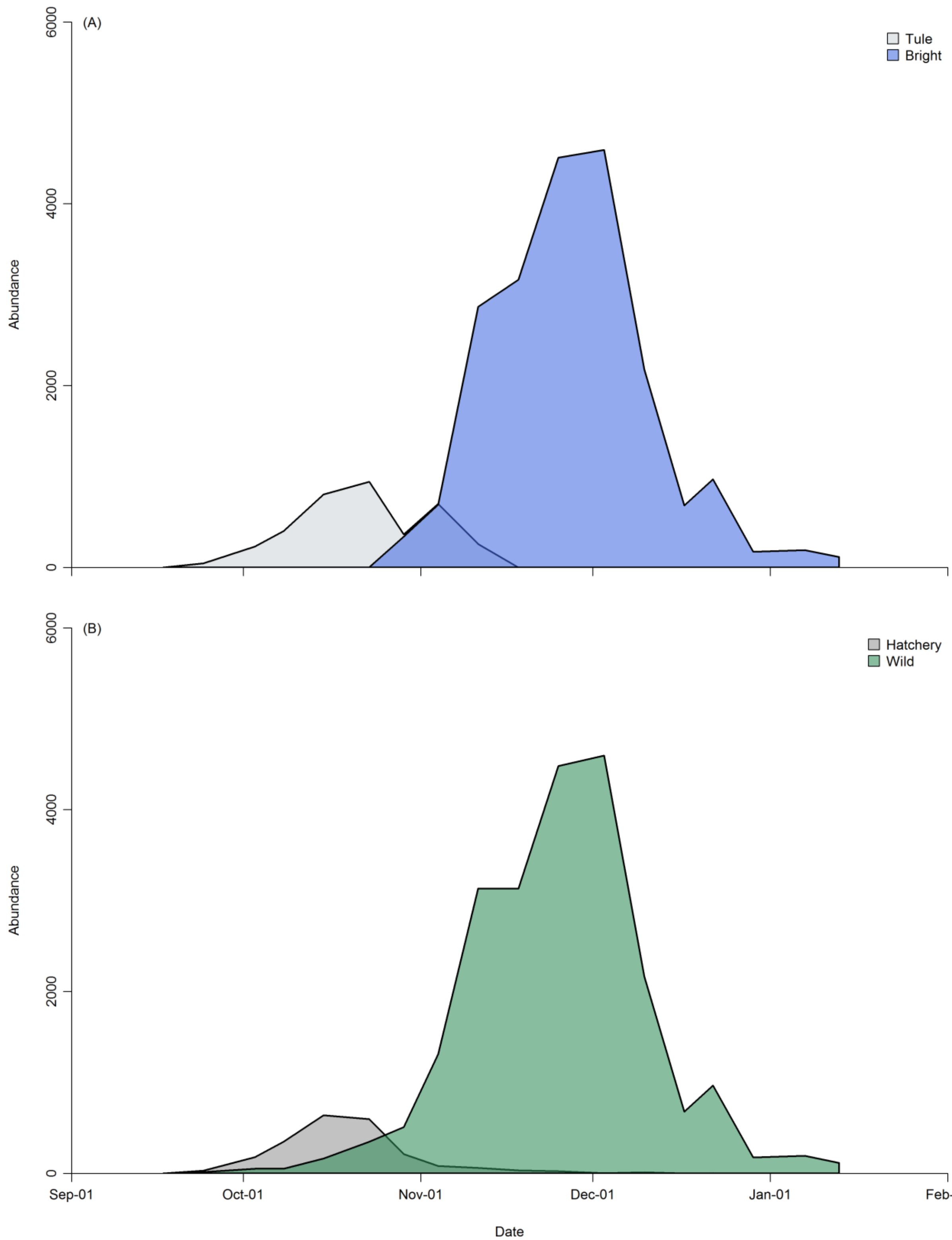

Figure E2. 2014 weekly abundance of fall-run Chinook by (A) stock (tule, bright) and (B) origin (hatchery, wild) in the NF Lewis. Estimates of abundance were derived using an open Jolly-Seber estimator applied to mark-recapture carcasses recovery data.

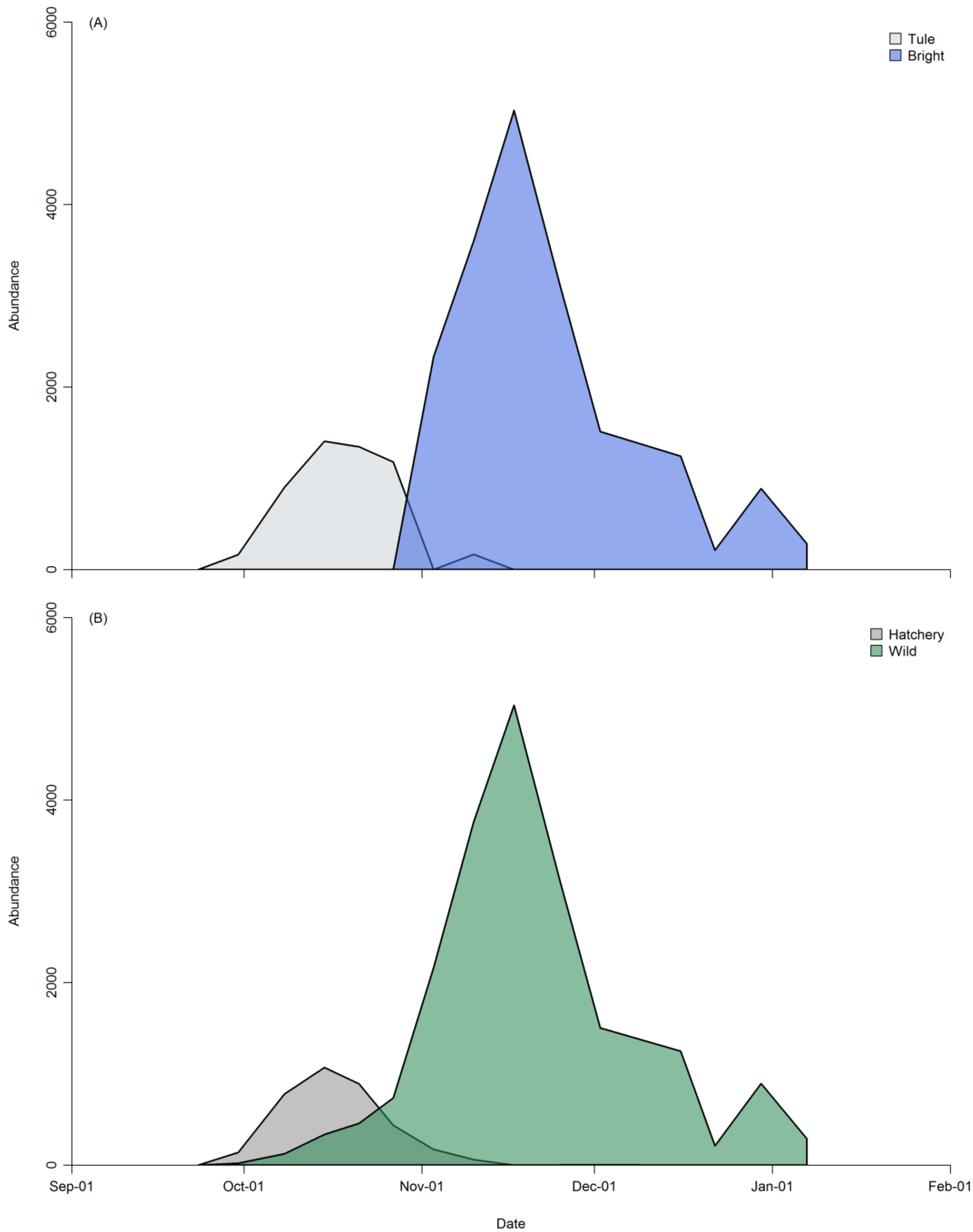

Figure E3. 2015 weekly abundance of fall-run Chinook by (A) stock (tule, bright) and (B) origin (hatchery, wild) in the NF Lewis. Estimates of abundance were derived using an open Jolly-Seber estimator applied to mark-recapture carcasses recovery data.

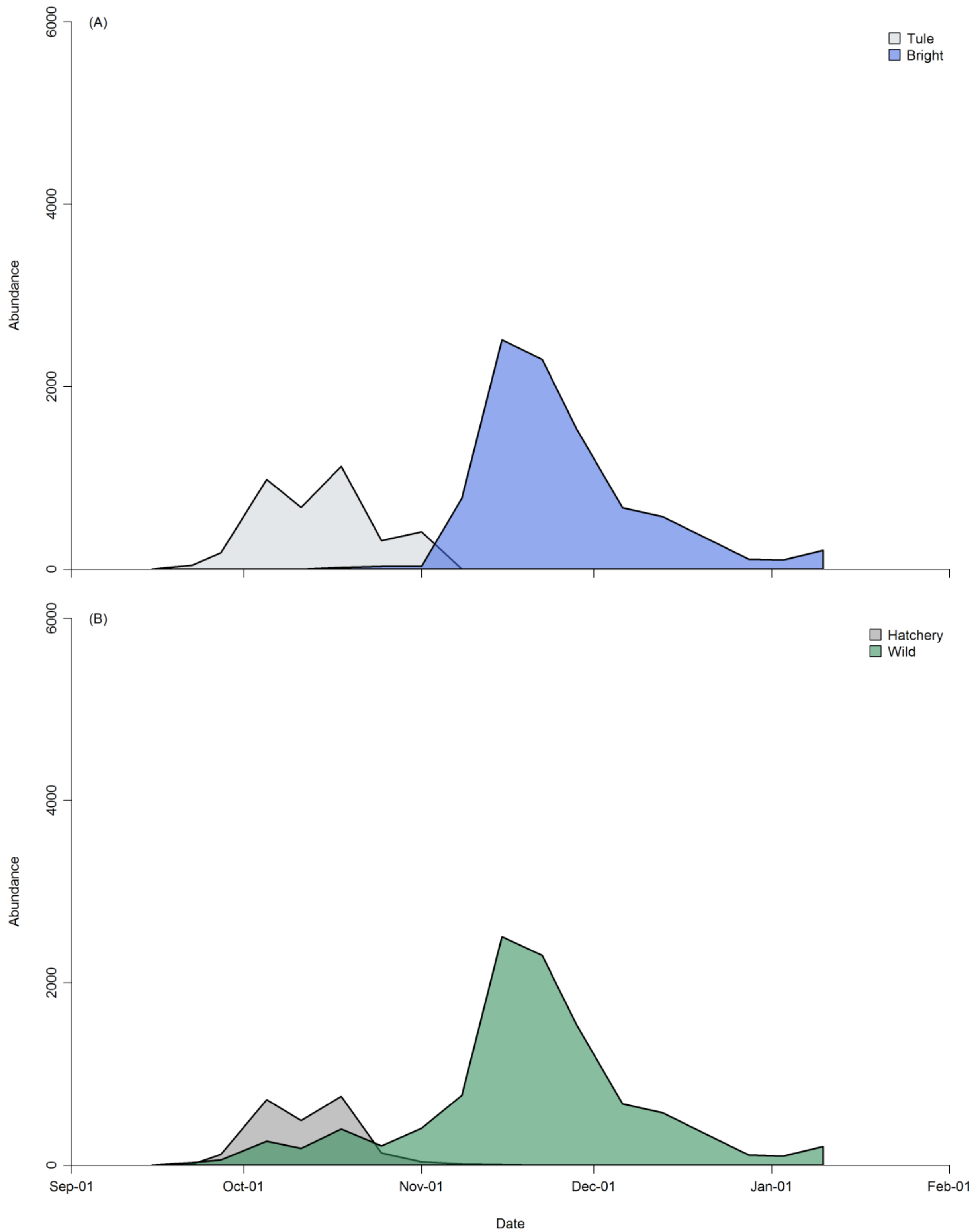

Figure E4. 2016 weekly abundance of fall-run Chinook by (A) stock (tule, bright) and (B) origin (hatchery, wild) in the NF Lewis. Estimates of abundance were derived using an open Jolly-Seber estimator applied to mark-recapture carcasses recovery data.

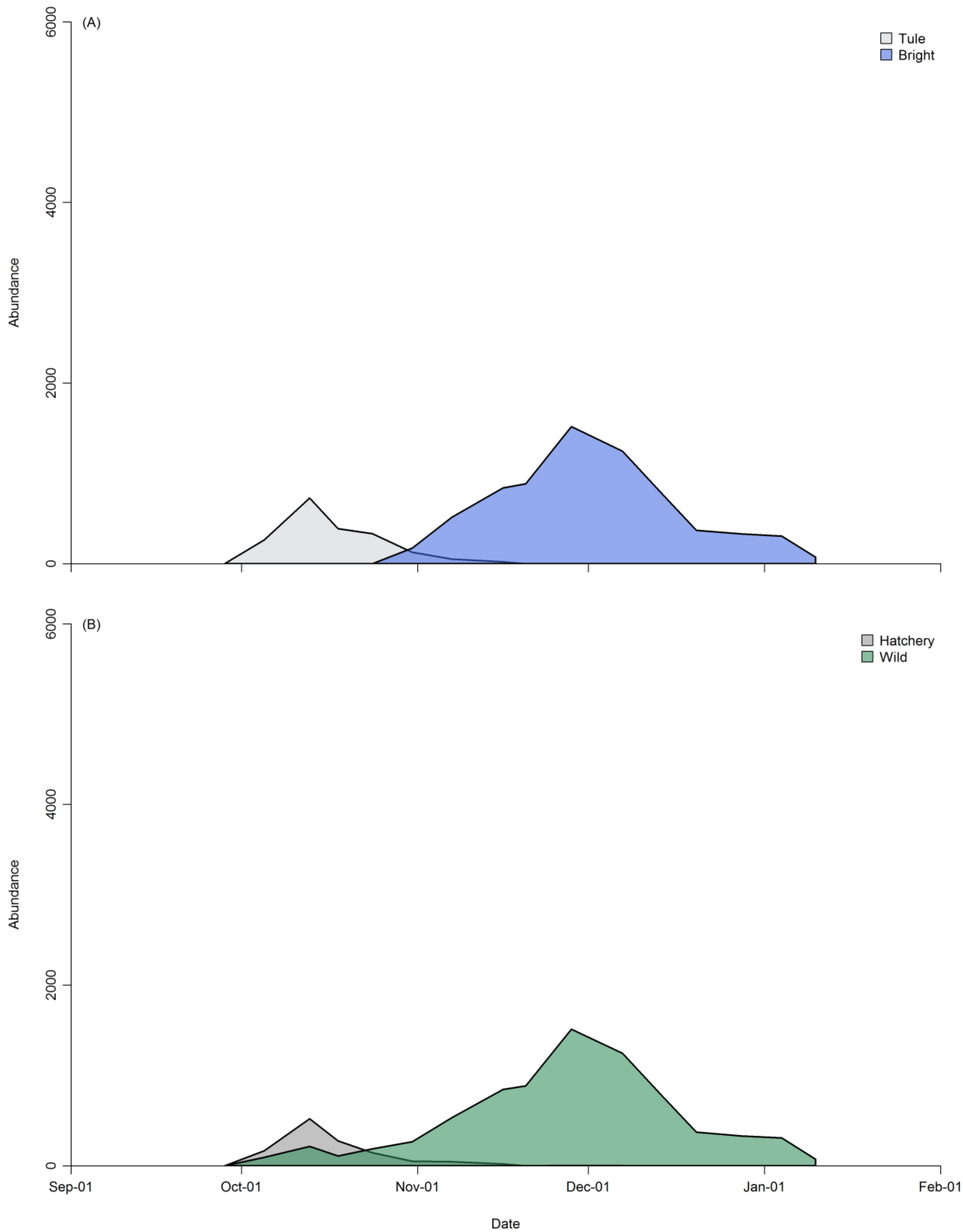

Figure E5. 2017 weekly abundance of fall-run Chinook by (A) stock (tule, bright) and (B) origin (hatchery, wild) in the NF Lewis. Estimates of abundance were derived using an open Jolly-Seber estimator applied to mark-recapture carcasses recovery data.

Appendix F – Comparison of abundance estimates

Table F1. Comparison of abundance estimates derived for North Fork Lewis River fall-run Chinook salmon, 2013 - 2017, using the Jolly-Seber (JS), Bright-eye method (BEM), and peak count expansion (PCE) estimators. Absolute difference and absolute percent (%) error in abundance were calculated for the BEM and PCE estimates relative to the JS estimates.

		Abundance Estimator												
		J-S	BEM			PCE - Peak Live + Dead			PCE - Peak Dead			PCE - Top 3 Dead		
Year	Group	Estimate (mean)	Estimate (mean)	Abs. Diff.	Abs. % Error	Estimate (mean)	Abs. Diff.	Abs. % Error	Estimate (mean)	Abs. Diff.	Abs. % Error	Estimate (mean)	Abs. Diff.	Abs. % Error
2013	Tules	3,511	5,427	1,916	55%	2,831	680	19%	2,535	976	28%	2,988	523	15%
	Brights	17,351	16,421	930	5%	15,925	1,426	8%	16,842	509	3%	19,457	2,106	12%
	Total	20,862	21,847	985	5%	18,756	2,106	10%	19,376	1,486	7%	22,446	1,584	8%
2014	Tules	4,055	3,917	138	3%	5,083	1,028	25%	5,708	1,653	41%	5,870	1,815	45%
	Brights	20,803	22,493	1,690	8%	20,204	599	3%	18,906	1,897	9%	20,556	247	1%
	Total	24,859	26,410	1,551	6%	25,287	428	2%	24,614	245	1%	26,426	1,567	6%
2015	Tules	5,449	5,633	184	3%	6,162	713	13%	7,303	1,854	34%	7,722	2,273	42%
	Brights	18,915	10,826	8,089	43%	9,741	9,174	49%	15,400	3,515	19%	15,444	3,471	18%
	Total	24,364	16,459	7,905	32%	15,903	8,461	35%	22,703	1,661	7%	23,166	1,198	5%
2016	Tules	4,127	2,776	1,351	33%	1,434	2,693	65%	4,041	86	2%	3,880	247	6%
	Brights	9,360	9,699	339	4%	12,098	2,738	29%	11,128	1,768	19%	11,511	2,151	23%
	Total	13,487	12,631	856	6%	13,532	45	0%	15,170	1,683	12%	15,391	1,904	14%
2017	Tules	2,255	1,651	604	27%	2,085	170	8%	1,480	775	34%	1,650	605	27%
	Brights	7,268	6,387	881	12%	7,100	168	2%	9,706	2,438	34%	8,052	784	11%
	Total	9,523	8,038	1,485	16%	9,186	337	4%	11,186	1,663	17%	9,703	180	2%

APPENDIX G –

Protocol for estimating pHOS of late winter steelhead downstream of Merwin Dam: 2016 model estimates of pHOS

MEMORANDUM

To: Larissa Rohrbach, Anchor QEA
From: Dalton Hance, USGS
Date: May 2, 2018
Subject: **Mark-Recapture Modelling of Lewis River Steelhead Proportion of Hatchery-Origin Spawners**

BACKGROUND

The proportion of hatchery-origin spawners, or pHOS, is a metric used to monitor the genetic influence that hatchery-produced fish may have on a naturally spawning population. Estimating pHOS for steelhead is particularly challenging due to their iteroparous spawning strategy. The number of fish of each origin cannot be confirmed through post-spawning carcass surveys, which are routine for semelparous Pacific salmon species. Instead estimates must be made based on observations of live steelhead.

In late 2016, a draft multistate mark-recapture model was developed by Anchor QEA for PacifiCorp to estimate pHOS in the population of winter-run steelhead that spawn in the North Fork Lewis River, below Merwin Dam (the pHOS model). The model is based upon a study design that takes advantage of existing field efforts to collect broodstock by tangle-netting, and the capture of all fish that migrate upstream to the Merwin Trap and Lewis Hatchery Ladder. The draft pHOS model was documented in Objective 2 of the Draft Annual Operating Plan for the North Fork Lewis Hatchery and Supplementation Program (AOP). In 2017, the draft pHOS model was reviewed by the Lewis River Hatchery and Supplementation Subgroup which made recommendations to modify the pHOS model and test the model-fit. In 2018, in response to these recommendations and in consulation between USGS and Anchor QEA, the pHOS model was revised to account for residuals (non-anadramous individuals) observed either through tangle-netting or capture at the Merwin Trap. A fuller description of the model is included in revised Objective 2 of the Draft AOP, but we briefly review the key concepts here.

The pHOS model is based on the capture by tangle-netting and marking of live steelhead on spawning grounds and capture or recapture of marked and unmarked individuals in subsequent tangle-net sampling events or at the Merwin Trap. Multiple tangle-net sampling events occur at approximately weekly intervals during the early Spring of each year, while the Merwin trap is operated continuously. Each fish captured by either mode is classified by sex, origin, and anadramous status based on physical appearance and/or the precense of marks. Origin can be determined by the presence of a blank wire tag (BWT) or stubby dorsal fin. Anadromy is determined primarily based on the size of the individuals. Natural origin anadramous fish captured during tangle-netting may be removed for broodstock, otherwise most hatchery origin fish and some natural origin fish are marked with a PIT tag and released and are available for recapture. The pHOS model utilizes this study design to identifying the relative proportion of four groups in the Lewis River steelhead population: 1) natural origin anadramous fish, 2) hatchery origin anadramous fish, 3) natural origin residual fish, and 4) hatchery origin residuals fish. Each of these groups are presumed to have separate probabilities of transitioning to Merwin trap or remaining on the spawning grounds as either potential or known spawners in the interval between each tangle-net sampling event. Each tangle-net event is assumed to have capture efficiency, defined as the probability that a fish that is present on the spawning grounds will be captured. Capture efficiency is allowed to vary among tangle-net sampling events, but a single capture efficiency is assumed for all tangle-net locations and for each group of fish present on the spawning grounds during a given event. After the final tangle-net sampling event, the model assumes that all fish remaining on the spawning grounds contribute to the spawning population. The pHOS is calculated as the proportion of fish in this spawning population that are of hatchery origin.

Because the model relies on simplifying assumptions (e.g. common capture efficiency for all fish per event), Anchor QEA requested that, as part of fitting the model to 2016 data, we assess the adequacy of the model fit. Therefore, we produced a posterior predictive check to identify any discrepancy between the data generating process assumed by the pHOS model and the observed data.

This document summarises the fitting of the revised model to data from 2016. In the following sections, we 1) describe data processing required to apply the statistical model to the data; 2) describe assessments of the adequacy of model fit through posterior predictive checks; 3) summarise the results of 2016 PHOS and associated parameters.

DATA PROCESSING

The data provided by Anchor QEA and PacifiCorp consisted of Excel files containing records of tangle-net sampling efforts and daily counts of fish captured and recaptured at the Merwin Trap broken down by sex and origin status of fish. Tangle-net data consisted of a row in the table for each fish captured or recaptured during a given tangle-net sampling event with data entries including the date of capture, life stage (smolt, adult, residual), presence of BWT, presence of stubby dorsal fin, sexual maturity (green, ripe, or kelt), sex, length, retention status (marked/released, removed for broodstock, removed due to mortality), and, if PIT-tagged, a PIT-ID. A total of 10 approximately weekly tangle-net events were represented in the data, with the first event occuring on March 8, 2016 and the final event occuring on May 10, 2016. Merwin trap records covered the time period from January 1, 2016 to June 27, 2016.

The data was restructured to facilitate modelling the hypothesized data generating process. The observed data matrix was structured to contain a row for each fish with a set of columns for identifying information (PIT-ID, Origin, Sex, and Anadromy), a column for the observed state of the fish at each tangle-netting event including an extra psuedo-event for fish captured at the Merwin Trap after the last tangle-net event, plus a dummy column for the initial state. The observed data matrix was constructed in three steps. First, all fish observed during tangle-net efforts were processed resulting in 66 records of fish captured or recaptured. Second, all fish observed at the Merwin trap were processed resulting in 791 additional records. Lastly, the data was padded out with an abitrary large number of dummy records to account for fish that were never observed but could potentially have been present on the spawning grounds. This data augmentation step is described further in Kéry and Schaub (Chapter 10)[1]. During initial runs of the model we used 2000 dummy records, but reduced this number to 1000 after examining initial model fits. Because these fish were never observed, NAs were recorded for Origin, Sex, and Anadromy. As part of the modelling, we imputed origin, sex and anadromy for unobserved individuals based off rate parameters to be estimated for each characteristic. We allowed the rate of anadromy to vary based on sex.

As described in the Objective 2 text, the model allows fish to undertake one-way transitions to different states. The model is initialized with all fish in the same state as members of the “potential” population. This state is signified with the integer 1. Fish from the “potential” state that enter the Lewis River take the “returning” state and are signified with the integer 2. Fish can then transition from the “returning”" state to either the “spawners” state or “up-river migrant” state, signified with the integers 3 and 4 respectively. Fish that were unobserved during a given tangle-net event were also identified with the integer 1 in the observed data matrix. Thus the dummy column consisted entirely of a vector of 1’s. Green or ripe fish that were observed during a given tangle-net sampling event where assigned to the “returning”" state and a 2 was entered in the respective column. Kelt observed during tangle-netting were assigned to the “spawner” state and a 3 was entered. Fish observed at the trap were assigned to the “up-river migrant” state and a 4 was entered in the column for a given sampling event if a fish was observed at any time in the interval between the focal sampling event and the prior event. For example, all fish captured at Merwin Trap after March 8 and before or on March 15 had a 4 entered for their Event 2 observed state. Any

[1]Kéry, M. & Schaub, M. (2012). *Bayesian population analysis using WinBUGS : a hierarchical perspective.* Waltham, MA: Academic Press.

fish captured at the Merwin Trap on or before March 8 were ignored because these fish were never subject to tangle-netting and so provide no information on capture efficiency or conversion rates.

As a final step, an indicator matrix was constructed to signify which fish were unavailable for recapture during any sampling event. Fish were assigned as unavailable for recapture for all events after the event in which they were captured and removed. A total of 24 fish become unavailable for further tangle-net capture either because they were removed for broodstock or died. All fish captured at the Merwin Trap were also considered unavailable for recapture after initially being captured at the Merwin trap.

Examples of the processed data are provided in Appendix A1.

The model does not allow fish to transition from "returning"" back to "potential", from "spawner" back to "returning" or "up-river migrant", nor from "up-river migrant" back to "returning" or to "spawner". Additionally we assume that the origin, sex, and residual status are identified correctly in the field and that once fish become unavailable for recapture they do not become available again. Some data records appears to violate these assumptions and required further processing. Those records and adjustments made to them are as follows:

1. PIT-ID 770E4EC: captured on March 23 and identified as an anadramous hatchery origin male (both BWT and stubby dorsal present), but then recaptured on April 19 and identified as an anadramous natural origin male. This individual was initially captured and PIT tagged in 2014 and identified as a residual hathcery origin male. Based on the original record, the individual classified as hatchery origin.
2. PIT-ID 3DD003BE8CB09: initially captured on April 12 and identified as a kelt, recaptured on April 26th and classified as ripe. Both captures were coded as a 2 (returning fish).
3. PIT-ID 3DD003BE8CB1E: initially captured on April 5 and identified as a kelt, recaptured on April 26th and classified as ripe. Both captures were coded as a 2 (returning fish).
4. PIT-ID 3DD003BE8CB18: captured on April 19 and removed for broodstock, later captured at the Merwin Trap on May 12. Because this fish was spawned in the hatchery and was unavailable for either tangle-net recapture or Merwin trap capture until after it was released from the hatchery, the capture record at the Merwin trap was ignored.

POSTERIOR PREDICTIVE CHECK

In order to check the adequacy of the model fit, we conducted a graphical posterior predictive check. A posterior predictive check relies on the premise that if a given model for a data generating process is adequate then new data simulated under that model should be similar to the observed data.[2] A posterior predictive check consists of generating a large number of replicated datasets using parameter estimates from the fit model and comparing some summary statistic of the observed data to the same summary statistic in the replicated data. Especially for complicated data generating processes, there are many possible characteristics of the data one might be interested in and so many choices of possible summary statistics. In this case, we chose to use the total number of fish captured during each tangle-net event and the total number captured at the Merwin Trap in the interval between each tangle-net event to determine whether the model provides an adequate description of the data generating process. To generate the replicated data, we randomly sampled 1000 draws from the joint posterior of the parameters and for each draw we simulated new data using a custom fuction written in R (Appendix C). We then plotted the observed count by each mode of capture for each event against the average and 10th and 90th percentiles of the replicated data (Figure 1). The observed data was wholly contained between the the 10th and 90th percentiles of the replicated data. Thus, the posterior predictive check demonstrated that the model describes a plausible data generating process for the observed data.

[2] Gelman, A., Carlin, J. B., Stern, H. S., Dunson, D. B., Vehtari, A., & Rubin, D. B. (2015). *Bayesian data analysis.* Boca Raton: CRC Press.

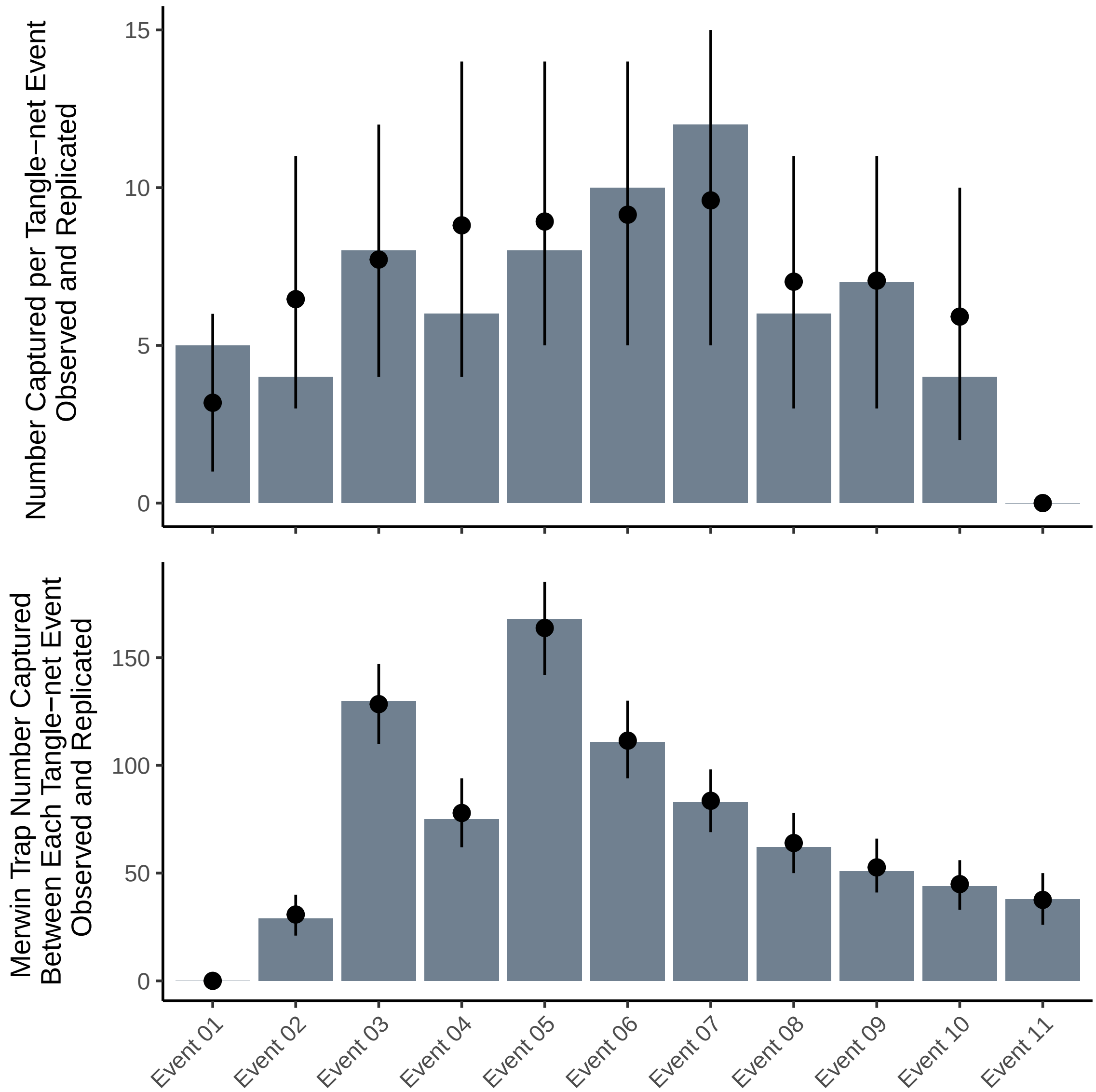

Figure 1: Posterior predictive check for Lewis River pHOS. Bars represent the total counts of fish captured during each tangle-netting event (top panel) or captured at the Merwin Trap during the interval between each tangle-netting event (bottom panel). Points and error lines represent the mean, 10th and 90th percentile of the number of fish captured by each mode among 1000 iterations of replicated data.

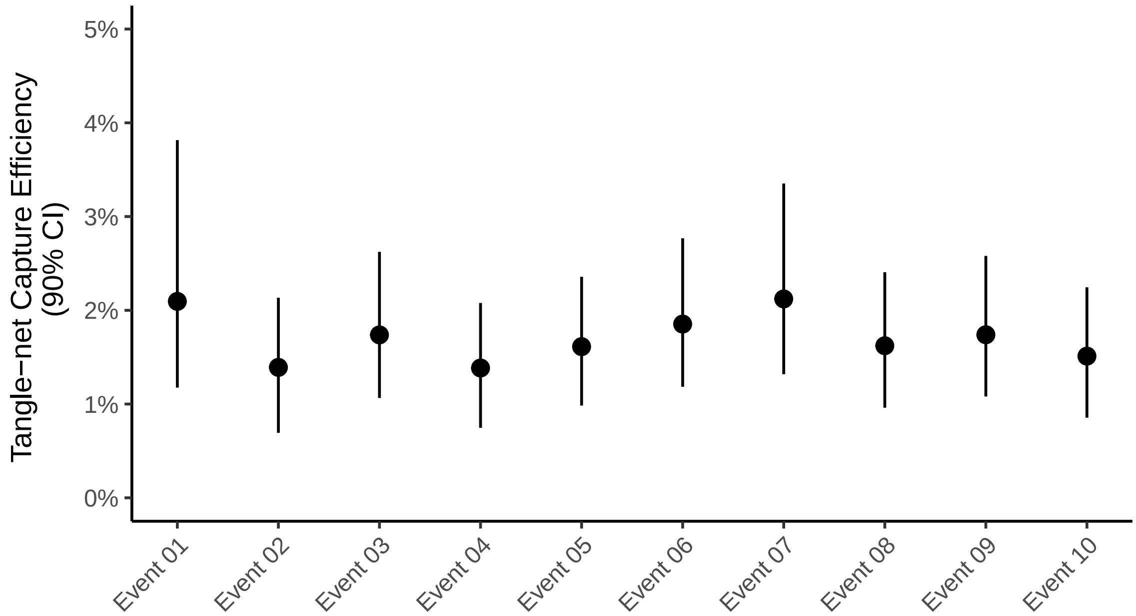

Figure 2: Tangle-net capture efficiency for each sampling event. Capture efficiency refers to the probability that a fish that is present on spawning grounds will be captured during tangle-netting efforts. Capture efficiency is pooled among all tangle-net locations and is common among all groups of fish.

RESULTS

Here we summarise results from fitting the multistate mark-recapture model to estimate the proportion of hatchery origin spawners among Lewis River Steelhead to data collected in 2016. The proportion of hatchery origin spawners was estimated to be 51% [90% CI: 41.3%, 60.4%]. This is based on an estimate of 175 [135, 218] natural origin steelhead and 182 [143, 224] hatchery origin steelhead remaining on the spawning ground after the conclusion of tangle-net and trapping efforts.

Additional parameter estimates of potential interest include capture efficiency and rate of residualism. The rate of residualism was estimated to differ between males and females, with 7.7% [4.2%, 12%] of males taking a residual life history, compared to 0.7% [0%, 2.2%] of females. A common tangle-net capture efficiency was estimated for all groups of fish present on the spawning grounds during a given tangle-net event, but was allowed to vary among tangle-net events. Even so, capture efficiency was fairly consistent among events averaging between 1% - 2% (Figure 2).

CONCLUSION

Based on this analysis, the study design of combined tangle-net and trap mark-recapture efforts and proposed mark-recapture model is sufficient to estimate the proportion of hatchery origin spawners. Inference from the model is contigent upon the assumptions of the model being satisified. The most critical element of the proposed model is that capture efficiency at the Merwin Trap is 100%. Our analysis did not find any evidence to indicate that that assumption was violated, however we emphasize that care should be taken to ensure that all fish are correctly identified and recorded (e.g. noting residuals that migrate to the Merwin Trap). Additionally, while this model does not address all possible contigencies (e.g. capture efficiency varying among groups, or different rates of residualism among hatchery and natural populations), the posterior predictive check demonstrates that the model is adequate for the main goal of estimating the proportion of hatchery origin spawners. However, the possibility for extensions or variations of the model to be evaluated in future with more formal model comparison techniques remains.

APPENDIX A: STRUCTURE OF PROCESSED DATA

Table 1: Example processed observed data. BE8CAC6 was tangle-net captured during Event 3 and subsequently captured at Merwin Trap between Event 4 and Event 5. BE8CAE2 was tangle-net captured during Event 6 and recaptured at Event 7, both times identified as kelt. Two “No PIT” individuals were mortalities or euthanized and so were not PIT tagged, but are recorded as unique individuals. Individuals with “Trap” suffix represent unique individuals encountered at the Merwin trap, but without unique PIT tags. Individuals with the “Pad” suffix represent fish that were never encountered, but which could potentially be present on the spawning grounds for which pseudo-records are required for data augmentation step of the multi-state model.

Origin	Sex	LifeHist	ID	Evnt 0	Evnt 1	Evnt 2	Evnt 3	Evnt 4	Evnt 5	Evnt 6	Evnt 7	Evnt 8	Evnt 9	Evnt 10	Evnt 11
HOR	F	A	BE8CAC6	1	1	1	2	1	4	1	1	1	1	1	1
HOR	F	A	BE8CAE2	1	1	1	1	1	1	3	3	1	1	1	1
HOR	F	A	BE8CB21	1	1	2	1	1	1	1	4	1	1	1	1
HOR	F	A	No PIT	1	2	1	1	1	1	1	1	1	1	1	1
HOR	M	R	569A080	1	1	1	1	1	2	1	1	1	1	1	4
NOR	F	A	BE8CB0D	1	1	1	1	2	1	1	1	1	1	1	1
NOR	M	A	BE8CAF6	1	1	1	1	3	1	1	1	1	1	1	1
NOR	M	A	No PIT	1	1	1	2	1	1	1	1	1	1	1	1
NOR	M	R	BE8CB09	1	1	1	1	1	1	2	1	2	1	1	1
HOR	F	A	Trap_564	1	1	1	1	1	1	4	1	1	1	1	1
HOR	M	A	Trap_10	1	1	4	1	1	1	1	1	1	1	1	1
HOR	M	A	Trap_323	1	1	1	1	1	1	1	1	1	1	4	1
NOR	M	A	Trap_770	1	1	1	1	1	1	1	1	1	1	1	4
NA	NA	NA	Pad_1	1	1	1	1	1	1	1	1	1	1	1	1
NA	NA	NA	Pad_1000	1	1	1	1	1	1	1	1	1	1	1	1

Table 2: Example processed availability data. BE8CAC6 was captured at Merwin Trap between Event 4 and Event 5 and became unavailable for capture after Event 5. Similarly BE8CB21 was captured at Merwin Trap between Event 7 and 8 and is unavailable after Event 8. BE8CB0D was removed for broodstock upon capture during Event 4 and is made unavailable for recapture. Two “No PIT” individuals were mortalities or euthanized also became unavailable for recapture. Individuals with “Trap” suffix represent unique individuals encountered at the Merwin trap, but without unique PIT tags and become unavailable for recapture after being trapped. Individuals with the “Pad” suffix represent fish that were never encountered, but which could potentially be present on the spawning grounds and so are always available. These pseudo-records are required for data augmentation step of the multi-state model.

Origin	Sex	LifeHist	ID	Evnt 0	Evnt 1	Evnt 2	Evnt 3	Evnt 4	Evnt 5	Evnt 6	Evnt 7	Evnt 8	Evnt 9	Evnt 10	Evnt 11
HOR	F	A	BE8CAC6	1	1	1	1	1	1	0	0	0	0	0	0
HOR	F	A	BE8CAE2	1	1	1	1	1	1	1	1	1	1	1	1
HOR	F	A	BE8CB21	1	1	1	1	1	1	1	1	0	0	0	0
HOR	F	A	No PIT	1	1	0	0	0	0	0	0	0	0	0	0
HOR	M	R	569A080	1	1	1	1	1	1	1	1	1	1	1	1
NOR	F	A	BE8CB0D	1	1	1	1	1	0	0	0	0	0	0	0
NOR	M	A	BE8CAF6	1	1	1	1	1	1	1	1	1	1	1	1
NOR	M	A	No PIT	1	1	1	1	0	0	0	0	0	0	0	0
NOR	M	R	BE8CB09	1	1	1	1	1	1	1	1	1	1	1	1
HOR	F	A	Trap_564	1	1	1	1	1	1	1	0	0	0	0	0
HOR	M	A	Trap_10	1	1	1	0	0	0	0	0	0	0	0	0
HOR	M	A	Trap_323	1	1	1	1	1	1	1	1	1	1	1	0
NOR	M	A	Trap_770	1	1	1	1	1	1	1	1	1	1	1	1
NA	NA	NA	Pad_1	1	1	1	1	1	1	1	1	1	1	1	1
NA	NA	NA	Pad_1000	1	1	1	1	1	1	1	1	1	1	1	1

APPENDIX B: MODEL CODE

```
model {
  #-----------------------------------------------
  #~~~~DATA:
  # M: number of fish in augmented data
  # K: number of capture events
  # origin: [M] vector taking values 0 or 1
  # sex: [M] vector taking values 0 or 1
  # resid: [M] vector taking values 0 or 1
  # z: [M x K] matrix taking values NA, 1, 2, 3, or 4
  # y: [M x K] matrix taking values 1, 2, 3, or 4
  # avail: [M x K] matrix taking values 0 or 1

  #-----------------------------------------------
  #~~~~STATES:
  # Ecological States: 1 - Potential Population
  #                    2 - Returning Fish
  #                    3 - Kelt/Spawner
  #                    4 - Trap

  # Observed States:   1 - Not Observed
  #                    2 - tangle-net trapped
  #                    3 - tangle-net trapped Kelt
  #                    4 - Trapped

  #~~~~PARAMETERS:
  #beta: origin ratio
  #sex_ratio: male-female ratio
  #resid_ratio: residual ratio
  #gamma: entry probability
  #delta: probability of becoming a spawner
  #phi: probability of moving to trap
  #p: tangle-net capture probability

  #~~~~PRIORS AND CONSTRAINTS:

  mean.p  ~ dnorm(-1.5, 1)
  # prior on tangle-net detetion efficiency which we expect to be low
  sigma.p ~ dnorm(0, 0.5) T(0,)
  # prior on standard deviation for detection efficieny random effect
  tau.p   <- pow(sigma.p, -2)
  # JAGS operates on precision rather than variance

  mean.gamma  ~ dt(0, .1, 7)
  # mean entry probability
  sigma.gamma ~ dnorm(0, 0.5) T(0,)
```

```
# standard deviation for entry probability random effects (per event)
tau.gamma   <- pow(sigma.gamma, -2)

beta_delta[1] ~ dt(0, .1, 7)
#intercept term for probability of becoming spawner
beta_delta[2] ~ dt(0, .25, 7)
# offset for natural origin
beta_delta[3] ~ dt(0, .25, 7)
# offest for residuals
beta_delta[4] ~ dt(0, .25, 7)
# interaction of origin and residual status

sigma.delta ~ dnorm(0, 0.5) T(0,)
#standard deviation for probability of becoming spawner random effect
tau.delta   <- pow(sigma.delta, -2)

beta_phi[1] ~ dt(0, .1, 7)
#intercept term for probability of moving to trap
beta_phi[2] ~ dt(0, .25, 7)
beta_phi[3] ~ dt(0, .25, 7)
beta_phi[4] ~ dt(0, .25, 7)
sigma.phi   ~ dnorm(0, .5) T(0,)
#standard deviation for probability of moving to trap random effect
tau.phi     <- pow(sigma.phi, -2)

beta          ~ dbeta(1, 1)
# uniform prior on proportion of hatchery fish in population
sex_ratio     ~ dbeta(5, 5)
# more informative prior on sex ratio since it should be close to 50%
resid_ratio[1] ~ dbeta(1, 9)
# % of male population that residualize
# expect this to be low, this prior has a mean of 10%
resid_ratio[2] ~ dbeta(1, 9)
# % of female population that residualize

# gamma: probability of entering from potential population
# Event 0 through Event K - 2
for (t in 1:(K - 2)) {
  e.gamma[t] ~ dnorm(0, tau.gamma)

  logit(gamma[t]) <- mean.gamma + e.gamma[t]
}

# delta: probability of remaining in returning state
# Event 1 through Event K - 2
for (t in 1:(K - 3)) {
  e.delta[1, t] ~ dnorm(0, tau.delta)
```

```
    e.delta[2, t] ~ dnorm(0, tau.delta)
    e.delta[3, t] ~ dnorm(0, tau.delta)
    e.delta[4, t] ~ dnorm(0, tau.delta)
    # Draw different random effect for each category of fish
    # (More flexible than single shared random effect)

    logit(delta[t, 1]) <- beta_delta[1] + e.delta[1, t]
    # probability of transitioning to kelt for hatchery anadramous
    logit(delta[t, 2]) <- beta_delta[1] + beta_delta[2] + e.delta[2, t]
    # probability of transitioning to spawner for natural anadramous
    logit(delta[t, 3]) <- beta_delta[1] + beta_delta[3] + e.delta[3, t]
    # probability of transitioning to spawner for hatchery residuals
    logit(delta[t, 4]) <- beta_delta[1] + beta_delta[2] + beta_delta[3] +
                          beta_delta[4] + e.delta[4, t]
    # probability of transitioning to spawner for natural residuals
  }

  # phi: probability of moving to trap
  # Event 1 through Event K - 1
  for (t in 1:(K - 2)) {
    e.phi[1, t] ~ dnorm(0, tau.phi)
    e.phi[2, t] ~ dnorm(0, tau.phi)
    e.phi[3, t] ~ dnorm(0, tau.phi)
    e.phi[4, t] ~ dnorm(0, tau.phi)
    # Draw different random effect for each category of fish
    # (More flexible than single shared random effect)

    logit(phi[t, 1]) <- beta_phi[1] + e.phi[1, t]
    # probability of transitioning to the trap for hatchery anadramous
    logit(phi[t, 2]) <- beta_phi[1] + beta_phi[2] + e.phi[2, t]
    # probability of transitioning to the trap for natural anadramous
    logit(phi[t, 3]) <- beta_phi[1] + beta_phi[3] + e.phi[3, t]
    # probability of transitioning to the trap for hatchery residuals
    logit(phi[t, 4]) <- beta_phi[1] + beta_phi[2] + beta_phi[3] +
                        beta_phi[4] + e.phi[4, t]
    # probability of transitioning to the trap for natural residuals

  }

  # p: detection probability
  # Event 1 through Event K - 1
  for (t in 1:(K - 2)) {
    e.p[t] ~ dnorm(0, tau.p)

    logit(p[t]) <- mean.p + e.p[t]
    # Detection efficiency varies among capture events around a common mean
  }
```

```
#~~~~TRANSITION & OBSERVATION MATRICES

for (i in 1:M){
  origin[i] ~ dbern(beta) # 0: HOR, 1: NOR
  sex[i]    ~ dbern(sex_ratio) # 0: M, 1: F
  resid[i]  ~ dbern(resid_ratio[1 + sex[i]]) # 0: anadramous, 1: residual

  g[i] <- 1 + 1 * origin[i] + 2 * resid[i]


  #~~         TRANSITION         ~~#
  #~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~#

  # Indices as follows:
  # [time, individual, current state, next state]
  # Initial entry to Lewis River, k = 1
  # Event 0 -> Event 1

  ps[1, i, 1, 1] <- 1 - gamma[t]
  ps[1, i, 1, 2] <- gamma[t]
  ps[1, i, 1, 3] <- 0
  ps[1, i, 1, 4] <- 0

  ps[1, i, 2, 1] <- 0
  ps[1, i, 2, 2] <- 1
  ps[1, i, 2, 3] <- 0
  ps[1, i, 2, 4] <- 0

  ps[1, i, 3, 1] <- 0
  ps[1, i, 3, 2] <- 0
  ps[1, i, 3, 3] <- 1
  ps[1, i, 3, 4] <- 0

  ps[1, i, 4, 1] <- 0
  ps[1, i, 4, 2] <- 0
  ps[1, i, 4, 3] <- 0
  ps[1, i, 4, 4] <- 1
  #~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~#

  #~~         OBSERVATION        ~~#
  #~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~#
  # [time, individual, actual state, observed state]
  # Event 1, k = 1

  po[1, i, 1, 1] <- 1
  po[1, i, 1, 2] <- 0
```

```
  po[1, i, 1, 3] <- 0
  po[1, i, 1, 4] <- 0

  po[1, i, 2, 1] <- 1 - p[t] * avail[i, 2]
  po[1, i, 2, 2] <- p[t] * avail[i, 2]
  po[1, i, 2, 3] <- 0
  po[1, i, 2, 4] <- 0

  po[1, i, 3, 1] <- 1 - p[t] * avail[i, 2]
  po[1, i, 3, 2] <- 0
  po[1, i, 3, 3] <- p[t] * avail[i, 2]
  po[1, i, 3, 4] <- 0

  po[1, i, 4, 1] <- 1 - avail[i, 2]
  po[1, i, 4, 2] <- 0
  po[1, i, 4, 3] <- 0
  po[1, i, 4, 4] <- avail[i, 2]
  #~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~#

  for (k in 2:(K - 2)) {
    #~~          TRANSITION         ~~#
    #~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~#
    # Event 1 -> Event 2, ..., Event K - 2 -> Event K - 1

    ps[k, i, 1, 1] <- 1 - gamma[k]
    ps[k, i, 1, 2] <- gamma[k]
    ps[k, i, 1, 3] <- 0
    ps[k, i, 1, 4] <- 0

    ps[k, i, 2, 1] <- 0
    ps[k, i, 2, 2] <- (delta[k - 1, g[i]] * avail[i, k]) +
                      (1 - avail[i, k])
    ps[k, i, 2, 3] <- (1 - delta[k - 1, g[i]]) *
                      (1 - phi[k - 1, g[i]]) *
                      (avail[k, t])
    ps[k, i, 2, 4] <- (1 - delta[k - 1, g[i]]) *
                      (phi[k - 1, g[i]]) *
                      (avail[k, t])

    ps[k, i, 3, 1] <- 0
    ps[k, i, 3, 2] <- 0
    ps[k, i, 3, 3] <- 1
    ps[k, i, 3, 4] <- 0

    ps[k, i, 4, 1] <- 0
    ps[k, i, 4, 2] <- 0
    ps[k, i, 4, 3] <- 0
```

```
    ps[k, i, 4, 4] <- 1
    #~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~#

    #~~         OBSERVATION        ~~#
    #~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~#
    # Event 2, ..., Event K - 1
    po[k, i, 1, 1] <- 1
    po[k, i, 1, 2] <- 0
    po[k, i, 1, 3] <- 0
    po[k, i, 1, 4] <- 0

    po[k, i, 2, 1] <- 1 - p[t] * avail[i, k + 1]
    po[k, i, 2, 2] <- p[t] * avail[i, k + 1]
    po[k, i, 2, 3] <- 0
    po[k, i, 2, 4] <- 0

    po[k, i, 3, 1] <- 1 - p[t] * avail[i, k + 1]
    po[k, i, 3, 2] <- 0
    po[k, i, 3, 3] <- p[t] * avail[i, k + 1]
    po[k, i, 3, 4] <- 0

    po[k, i, 4, 1] <- 1 - avail[i, k + 1]
    po[k, i, 4, 2] <- 0
    po[k, i, 4, 3] <- 0
    po[k, i, 4, 4] <- avail[i, k + 1]
    #~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~#
  }

  #~~         TRANSITION         ~~#
  #~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~#
  # Event K - 1 -> Event K
  # Turn all fish remaining on spawning grounds into spawners
  ps[K - 1, i, 1, 1] <- 1
  ps[K - 1, i, 1, 2] <- 0
  ps[K - 1, i, 1, 3] <- 0
  ps[K - 1, i, 1, 4] <- 0

  ps[K - 1, i, 2, 1] <- 0
  ps[K - 1, i, 2, 2] <- 1 - avail[i, K - 1]
  ps[K - 1, i, 2, 3] <- (1 - phi[K - 2, g[i]]) * avail[i, K - 1]
  ps[K - 1, i, 2, 4] <- phi[K - 2, g[i]] * avail[i, K - 1]

  ps[K - 1, i, 3, 1] <- 0
  ps[K - 1, i, 3, 2] <- 0
  ps[K - 1, i, 3, 3] <- 1
  ps[K - 1, i, 3, 4] <- 0
```

```
  ps[K - 1, i, 4, 1] <- 0
  ps[K - 1, i, 4, 2] <- 0
  ps[K - 1, i, 4, 3] <- 0
  ps[K - 1, i, 4, 4] <- 1
  #~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~#


  #~~         OBSERVATION        ~~#
  #~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~#
  # Event K
  # Only trap observations after last tangle-net event.
  po[K - 1, i, 1, 1] <- 1
  po[K - 1, i, 1, 2] <- 0
  po[K - 1, i, 1, 3] <- 0
  po[K - 1, i, 1, 4] <- 0

  po[K - 1, i, 2, 1] <- 1
  po[K - 1, i, 2, 2] <- 0
  po[K - 1, i, 2, 3] <- 0
  po[K - 1, i, 2, 4] <- 0

  po[K - 1, i, 3, 1] <- 1
  po[K - 1, i, 3, 2] <- 0
  po[K - 1, i, 3, 3] <- 0
  po[K - 1, i, 3, 4] <- 0

  po[K - 1, i, 4, 1] <- 1 - avail[i, K]
  po[K - 1, i, 4, 2] <- 0
  po[K - 1, i, 4, 3] <- 0
  po[K - 1, i, 4, 4] <- avail[i, K]
  #~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~#
}

#~~~ LIKELIHOOD:
for (i in 1:M){
  for (k in 2:K){
    z[i, k] ~ dcat(ps[k - 1, i, z[i, k - 1], ])
    y[i, k] ~ dcat(po[k - 1, i, z[i, k],     ])
  }
}

#~~~ DERIVED PARAMETERS:
for (i in 1:M){
  NOR_entered[i] <- (1 - equals(z[i, K], 1)) * equals(origin[i], 1)
  # If latent state is not equal to 1 at last event,
  # and latent origin state is equal to 1
  # count as natural origin fish returning to Lewis River
```

```
    HOR_entered[i] <- (1 - equals(z[i, K], 1)) * equals(origin[i], 0)
    # If latent state is not equal to 1 at last event,
    # and latent origin state is equal to 0
    # count as hatchery origin fish returning to Lewis River
    NOR_spawn[i]    <- equals(z[i, K], 3) * equals(origin[i], 1)
    # If latent state is equal to 3 at last event,
    # and latent origin state is equal to 0
    # count as natural origin spawner
    HOR_spawn[i]    <- equals(z[i, K], 3) * equals(origin[i], 0)
    # If latent state is equal to 3 at last event,
    # and latent origin state is equal to 0
    # count as hatchery origin spawner
  }

  N_NOR_entered <- sum(NOR_entered[])
  N_HOR_entered <- sum(HOR_entered[])

  N_NOR_spawn <- sum(NOR_spawn[])
  N_HOR_spawn <- sum(HOR_spawn[])

  pHOS <- N_HOR_spawn/(N_HOR_spawn + N_NOR_spawn)
}
```

APPENDIX C: Posterior Predictive Check Function

Note: this function relies on the `tidyverse` library. Expected input is a row from the parameter matrix produced by the JAGS model in Appendix B.

```
post_pred_pHOS <- function(N, draws_row){
  params <- draws_row %>%
    gather(Parameter, Value)

  sex_ratio <- params %>%
    filter(Parameter == "sex_ratio") %>%
    pull()

  beta <- params %>%
    filter(Parameter == "beta") %>%
    pull()

  resid_ratio <- params %>%
    filter(grepl("resid_ratio", Parameter)) %>%
    pull()

  gamma <-  params %>%
    filter(grepl("gamma", Parameter)) %>%
    pull()
```

```r
p <-  params %>%
  filter(Parameter %in% c("p[1]", "p[2]",
                          "p[3]", "p[4]",
                          "p[5]", "p[6]",
                          "p[7]", "p[8]",
                          "p[9]", "p[10]")) %>%
  pull()

delta <- matrix(ncol = 4, params %>%
          filter(grepl("delta", Parameter)) %>%
                     pull())

phi <- matrix(ncol = 4, params %>%
                  filter(grepl("phi", Parameter)) %>%
                  pull())

trans_array <- array(NA, c(10, 4, 3))

trans_array[, , 1] <- rbind(delta,
                            c(0,0,0,0)) # 2 -> 2
trans_array[, , 2] <- rbind((1 - delta),
                            c(1, 1, 1,1)) * (1 - phi) # 2 -> 3
trans_array[, , 3] <- rbind((1 - delta),
                            c(1, 1, 1,1)) * (phi) # 2 -> 4

eco_sim <- data_frame(origin_state = rbinom(n = N,
                                            size = 1,
                                            prob = beta),
                      #0 - HOR, 1 - NOR,
                      sex_state    = rbinom(n = N,
                                            size = 1,
                                            prob = sex_ratio),
                      #0 - M, 1 - F,
                      resid_state  = if_else(sex_state == 0,
                                             rbinom(N,
                                                    size = 1,
                                                    prob = resid_ratio[1]),
                                             rbinom(N,
                                                    size = 1,
                                                    prob = resid_ratio[2])
                                             )
                      # 0 - anadramous, 1 - residual
                      ) %>%
  mutate(state_trait = 1 + 1 * origin_state + 2 * resid_state ,
         Event_01     =  1 + rbinom(N, size = 1, prob = gamma[1]),
         Event_02     =
          case_when(
```

```
            Event_01 == 1 ~
              Event_01 + rbinom(N,
                                size = 1,
                                prob = gamma[2]),
            Event_01 == 2 & state_trait == 1 ~
              Event_01 + sample(c(0, 1, 2),
                                size = N,
                                replace = T,
                                prob = trans_array[1, 1, ]),
            Event_01 == 2 & state_trait == 2 ~
              Event_01 + sample(c(0, 1, 2),
                                size = N,
                                replace = T,
                                prob = trans_array[1, 2, ]),
            Event_01 == 2 & state_trait == 3 ~
              Event_01 + sample(c(0, 1, 2),
                                size = N,
                                replace = T,
                                prob = trans_array[1, 3, ]),
            Event_01 == 2 & state_trait == 4 ~
              Event_01 + sample(c(0, 1, 2),
                                size = N,
                                replace = T,
                                prob = trans_array[1, 4, ])),
         Event_03    =
           case_when(
             Event_02 == 1 ~
               Event_02 + rbinom(N, size = 1, prob = gamma[3]),
             Event_02 == 2 & state_trait == 1 ~
               Event_02 + sample(c(0, 1, 2),
                                 size = N,
                                 replace = T,
                                 prob = trans_array[2, 1, ]),
             Event_02 == 2 & state_trait == 2 ~
               Event_02 + sample(c(0, 1, 2),
                                 size = N,
                                 replace = T,
                                 prob = trans_array[2, 2, ]),
             Event_02 == 2 & state_trait == 3 ~
               Event_02 + sample(c(0, 1, 2),
                                 size = N,
                                 replace = T,
                                 prob = trans_array[2, 3, ]),
             Event_02 == 2 & state_trait == 4 ~
               Event_02 + sample(c(0, 1, 2),
                                 size = N,
                                 replace = T,
```

```
                        prob = trans_array[2, 4, ]),
    Event_02 == 3 ~ Event_02,
    Event_02 == 4 ~ Event_02),

Event_04    =
  case_when(
    Event_03 == 1 ~
      Event_03 + rbinom(N, size = 1, prob = gamma[4]),
    Event_03 == 2 & state_trait == 1 ~
      Event_03 + sample(c(0, 1, 2),
                        size = N,
                        replace = T,
                        prob = trans_array[3, 1, ]),
    Event_03 == 2 & state_trait == 2 ~
      Event_03 + sample(c(0, 1, 2),
                        size = N,
                        replace = T,
                        prob = trans_array[3, 2, ]),
    Event_03 == 2 & state_trait == 3 ~
      Event_03 + sample(c(0, 1, 2),
                        size = N,
                        replace = T,
                        prob = trans_array[3, 3, ]),
    Event_03 == 2 & state_trait == 4 ~
      Event_03 + sample(c(0, 1, 2),
                        size = N,
                        replace = T,
                        prob = trans_array[3, 4, ]),
    Event_03 == 3 ~ Event_03,
    Event_03 == 4 ~ Event_03),

Event_05    =
  case_when(
    Event_04 == 1 ~
      Event_04 + rbinom(N, size = 1, prob = gamma[5]),
    Event_04 == 2 & state_trait == 1 ~
      Event_04 + sample(c(0, 1, 2),
                        size = N,
                        replace = T,
                        prob = trans_array[4, 1, ]),
    Event_04 == 2 & state_trait == 2 ~
      Event_04 + sample(c(0, 1, 2),
                        size = N,
                        replace = T,
                        prob = trans_array[4, 2, ]),
    Event_04 == 2 & state_trait == 3 ~
      Event_04 + sample(c(0, 1, 2),
```

```
                            size = N,
                            replace = T,
                            prob = trans_array[4, 3, ]),
      Event_04 == 2 & state_trait == 4 ~
        Event_04 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[4, 4, ]),
      Event_04 == 3 ~ Event_04,
      Event_04 == 4 ~ Event_04),

  Event_06    =
    case_when(
      Event_05 == 1 ~
        Event_05 + rbinom(N, size = 1, prob = gamma[6]),
      Event_05 == 2 & state_trait == 1 ~
        Event_05 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[5, 1, ]),
      Event_05 == 2 & state_trait == 2 ~
        Event_05 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[5, 2, ]),
      Event_05 == 2 & state_trait == 3 ~
        Event_05 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[5, 3, ]),
      Event_05 == 2 & state_trait == 4 ~
        Event_05 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[5, 4, ]),
      Event_05 == 3 ~ Event_05,
      Event_05 == 4 ~ Event_05),

  Event_07    =
    case_when(
      Event_06 == 1  ~
        Event_06 + rbinom(N, size = 1, prob = gamma[7]),
      Event_06 == 2 & state_trait == 1 ~
        Event_06 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[6, 1, ]),
```

```r
        Event_06 == 2 & state_trait == 2 ~
          Event_06 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[6, 2, ]),
        Event_06 == 2 & state_trait == 3 ~
          Event_06 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[6, 3, ]),
        Event_06 == 2 & state_trait == 4 ~
          Event_06 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[6, 4, ]),
        Event_06 == 3 ~ Event_06,
        Event_06 == 4 ~ Event_06),

    Event_08    =
      case_when(
        Event_07 == 1 ~
          Event_07 + rbinom(N, size = 1, prob = gamma[8]),
        Event_07 == 2 & state_trait == 1 ~
          Event_07 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[7, 1, ]),
        Event_07 == 2 & state_trait == 2 ~
          Event_07 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[7, 2, ]),
        Event_07 == 2 & state_trait == 3 ~
          Event_07 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[7, 3, ]),
        Event_07 == 2 & state_trait == 4 ~
          Event_07 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[7, 4, ]),
        Event_07 == 3  ~ Event_07,
        Event_07 == 4  ~ Event_07),

    Event_09    =
      case_when(
```

```r
        Event_08 == 1 ~
          Event_08 + rbinom(N, size = 1, prob = gamma[9]),
        Event_08 == 2 & state_trait == 1 ~
          Event_08 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[8, 1, ]),
        Event_08 == 2 & state_trait == 2 ~
          Event_08 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[8, 2, ]),
        Event_08 == 2 & state_trait == 3 ~
          Event_08 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[8, 3, ]),
        Event_08 == 2 & state_trait == 4 ~
          Event_08 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[8, 4, ]),
        Event_08 == 3  ~ Event_08,
        Event_08 == 4  ~ Event_08),

    Event_10    =
      case_when(
        Event_09 == 1 ~
          Event_09 + rbinom(N, size = 1, prob = gamma[10]),
        Event_09 == 2 & state_trait == 1 ~
          Event_09 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[9, 1, ]),
        Event_09 == 2 & state_trait == 2 ~
          Event_09 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[9, 2, ]),
        Event_09 == 2 & state_trait == 3 ~
          Event_09 + sample(c(0, 1, 2),
                            size = N,
                            replace = T,
                            prob = trans_array[9, 3, ]),
        Event_09 == 2 & state_trait == 4 ~
          Event_09 + sample(c(0, 1, 2),
                            size = N,
```

```
                                replace = T,
                                prob = trans_array[9, 4, ]),
               Event_09 == 3 ~ Event_09,
               Event_09 == 4 ~ Event_09),

            Event_11    =
             case_when(
               Event_10 == 1 ~ Event_10,
               Event_10 == 2 & state_trait == 1
               ~ Event_09 + sample(c(0, 1, 2), size = N, replace = T,
                                prob = trans_array[10, 1, ]),
               Event_10 == 2 & state_trait == 2 ~
                 Event_09 + sample(c(0, 1, 2), size = N, replace = T,
                                prob = trans_array[10, 2, ]),
               Event_10 == 2 & state_trait == 3 ~
                 Event_09 + sample(c(0, 1, 2), size = N, replace = T,
                                prob = trans_array[10, 3, ]),
               Event_10 == 2 & state_trait == 4 ~
                 Event_09 + sample(c(0, 1, 2), size = N, replace = T,
                                prob = trans_array[10, 4, ]),
               Event_10 == 3 ~ Event_10,
               Event_10 == 4 ~ Event_10)) %>%
  mutate(Event_11 = if_else(Event_10 == 4, 0, Event_11),
         Event_10 = if_else(Event_09 == 4, 0, Event_10),
         Event_09 = if_else(Event_08 == 4, 0, Event_09),
         Event_08 = if_else(Event_07 == 4, 0, Event_08),
         Event_07 = if_else(Event_06 == 4, 0, Event_07),
         Event_06 = if_else(Event_05 == 4, 0, Event_06),
         Event_05 = if_else(Event_04 == 4, 0, Event_05),
         Event_04 = if_else(Event_03 == 4, 0, Event_04),
         Event_03 = if_else(Event_02 == 4, 0, Event_03),
         Event_02 = if_else(Event_01 == 4, 0, Event_02))

obs_sim <- eco_sim %>%
  mutate(Event_01 = case_when(Event_01 %in% c(0,1) ~ 0,
                              Event_01 %in% c(2,3) ~
                                Event_01 * rbinom(N, 1, p[1]),
                              Event_01 == 4         ~ 4),
         Event_02 = case_when(Event_02 %in% c(0,1) ~ 0,
                              Event_02 %in% c(2,3) ~
                                Event_02 * rbinom(N, 1, p[2]),
                              Event_02 == 4         ~ 4),
         Event_03 = case_when(Event_03 %in% c(0,1) ~ 0,
                              Event_03 %in% c(2,3) ~
                                Event_03 * rbinom(N, 1, p[3]),
                              Event_03 == 4         ~ 4),
         Event_04 = case_when(Event_04 %in% c(0,1) ~ 0,
```

```
                                Event_04 %in% c(2,3) ~
                                  Event_04 * rbinom(N, 1, p[4]),
                                Event_04 == 4        ~ 4),
           Event_05 = case_when(Event_05 %in% c(0,1) ~ 0,
                                Event_05 %in% c(2,3) ~
                                  Event_05 * rbinom(N, 1, p[5]),
                                Event_05 == 4        ~ 4),
           Event_06 = case_when(Event_06 %in% c(0,1) ~ 0,
                                Event_06 %in% c(2,3) ~
                                  Event_06 * rbinom(N, 1, p[6]),
                                Event_06 == 4        ~ 4),
           Event_07 = case_when(Event_07 %in% c(0,1) ~ 0,
                                Event_07 %in% c(2,3) ~
                                  Event_07 * rbinom(N, 1, p[7]),
                                Event_07 == 4        ~ 4),
           Event_08 = case_when(Event_08 %in% c(0,1) ~ 0,
                                Event_08 %in% c(2,3) ~
                                  Event_08 * rbinom(N, 1, p[8]),
                                Event_08 == 4        ~ 4),
           Event_09 = case_when(Event_09 %in% c(0,1) ~ 0,
                                Event_09 %in% c(2,3) ~
                                  Event_09 * rbinom(N, 1, p[9]),
                                Event_09 == 4        ~ 4),
           Event_10 = case_when(Event_10 %in% c(0,1) ~ 0,
                                Event_10 %in% c(2,3) ~
                                  Event_10 * rbinom(N, 1, p[10]),
                                Event_10 == 4        ~ 4),
           Event_11 = if_else(Event_11 == 4, 4, 0))

  return(obs_sim %>%
    gather(-origin_state, -sex_state, -resid_state, -state_trait,
           key = event, value = obs_state) %>%
    group_by(event, origin_state, sex_state, resid_state) %>%
    summarise(n_return = sum(obs_state == 2),
              n_spawn  = sum(obs_state == 3),
              n_trap   = sum(obs_state == 4)) %>%
    ungroup())
}
```

APPENDIX H –

Lewis River Annual Hatchery Operations Report - 2018

WASHINGTON DEPARTMENT OF FISH AND WILDLIFE
FISH PROGRAM
HATCHERIES DIVISION

LEWIS RIVER COMPLEX OPERATIONS PROGRAM
FOR
JANUARY 1, 2018 TO DECEMBER 31, 2018

FUNDED BY
PACIFICORP ENERGY
&
COWLITZ P.U.D.

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OPERATIONS PROGRAM

LEWIS RIVER HATCHERY

FOR

JANUARY 1, 2018 TO DECEMBER 31, 2018

Washington Department of FISH and WILDLIFE

WRITTEN AND COMPILED BY:

LEWIS RIVER HATCHERY STAFF

Introduction

The Lewis River Salmon Hatchery is located approximately eight miles east of Woodland, WA. on the North Fork of the Lewis River. Originally constructed in 1909 on Johnson Creek, the hatchery was moved to its present site in 1923.

Program Goals

- 1,350,000 yearling Spring Chinook at 8 to 12 fpp released into the North Fork Lewis River.

- 1,100,000 yearling Early Coho at 16 fpp released into the North Fork Lewis River.

- 900,000 yearling Late Coho at 16 fpp released into the North Fork Lewis River.

Approximately 29,000 gallons of water per minute can be delivered to the hatchery system by eight pumps that are located at two separate intakes. Four booster pumps permit further distribution of water to other areas of the facility as needed. Three gas stabilization towers and one packed column are available to remove supersaturated gases from the water supply when necessary.

There is approximately 312,000 cubic feet of available rearing space. This space consists of 14 super raceways and 12 standard raceways. Adult holding space consists of 4 large concrete ponds with a common center channel totaling 53,000 cubic feet.

The incubation facility houses fifty stacks (16 trays/stack) of vertical incubators and four shallow troughs.

The Lewis Hatchery facility also includes three residences, hatchery/office building, freezer building, two three bay storage buildings, two small storage buildings, public restroom, two intake structures, two generator/pump control buildings, two compressor buildings a two-story adult handling facility and a domestic water pump house.

Lewis River Hatchery is staffed with a FHS 4, FHS 3, three FHS 2s and a FHT.

TRAPPING

The Merwin Fish Collection Facility (F.C.F.) and the Lewis Ladder Trap operate continuously year around. Once the fish are captured, staff identify, numerate, and sort for hatchery brood stock, watershed escapement goals, tribal harvest agreements, food banks, and nutrient enhancement.

2018 Lewis River Winter Steelhead

The last 2018 brood winter steelhead was trapped at the Lewis Ladder on January 17, 2018. The last one trapped at the Merwin F.C.F was on May 10, 2018. Broodstock was collected at the Merwin F.C.F. and shipped to Merwin Hatchery.

Total Trapped (F.C.F.)	2,845
Total Trapped (Lewis)	190
Trap Mortality	14
Recycled	0
Brood stock Shipped	134
Food Banks/Tribes	2,887

2018 Brood Lewis River Late Winter Steelhead Hatchery Origin

The last 2018 hatchery origin brood late winter steelhead trapped at the Merwin F.C.F. was on June 11, 2017. The fish returned to river were planted into the upper Lewis River at Eagle Cliff.

Total Trapped (F.C.F.)	1,223
Total Trapped (Lewis)	0
Trap Mortality	3
Planted	1,220

2019 Brood Lewis River Summer Steelhead

The first summer steelhead was trapped at Merwin F.C.F. on March 23, 2018. The first summer steelhead trapped at the Lewis Ladder was on July 10, 2018. Steelhead utilized for brood stock were collected from the Merwin F.C.F. and shipped to Merwin Hatchery from June 25, 2018 through September 12, 2018.

Total Trapped (F.C.F.)	4,037
Total Trapped (Lewis)	209
Recycled	759
Trap Mortality	41
Brood stock Shipped	366
Food Banks/Tribes	3080

2019 Brood Lewis River Winter Steelhead

The first winter steelhead was trapped at Merwin F.C.F. on November 19, 2018. Steelhead utilized for broodstock were collected from the Merwin F.C.F and shipped to Merwin Hatchery from December 5th through December 24th, 2018.

Total Trapped (F.C.F.)	323
Total Trapped (Lewis)	0
Recycled	0
Trap Mortality	0
Brood stock Shipped	97
Food Banks/Tribes	226

2017 Brood Lewis River (Type N) Coho

The last late Coho captured at Merwin F.C.F. was on January 25, 2018. The last late Coho captured at the Lewis Ladder was on January 17, 2018.

Adults Trapped (F.C.F.)	2,540
Jacks Trapped (F.C.F.)	220
Adults Trapped (Lewis)	6,595
Jacks Trapped (Lewis)	2,191
Trap Mortality (Adults)	227
Trap Mortality (Jacks)	46
Spawned (Adults)	2,835
Spawned (Jacks)	82
Food Banks/Tribes (Adults)	2,295
Food Banks/Tribes (Jacks)	2,072
Nutrient Enhancement (Adults)	3,733
Nutrient Enhancement (Jacks)	280
Brood stock Shipped (Adults)	168
Brood stock Shipped (Jacks)	5
Shipped to Swift (Adults)	2,930
Shipped to Swift (Jacks)	5

2018 Brood Lewis River Spring Chinook

The first spring Chinook trapped at the Merwin F.C.F. was February 25, 2018. The first arrival at the Lewis Ladder was May 22, 2018. Brood stock was collected at both trapping sites and shipped to Speelyai Hatchery.

Adults Trapped (F.C.F.)	2,013
Jacks Trapped (F.C.F.)	66
Adults Trapped (Lewis)	301
Jacks Trapped (Lewis)	5
Trap Mortality (Adults)	43
Trap Mortality (Jacks)	0
Nutrient Enhancement (Adults)	0
Nutrient Enhancement (Jacks)	0
Brood stock Shipped (Adults)	1,606
Brood stock Shipped (Jacks)	39
Shipped to Swift (Adults)	664
Shipped to Swift (Jacks)	32

2018 Brood Lewis River (Type S) Early Coho

The first early Coho trapped at Merwin F.C.F. was on August 21, 2018. The first early Coho trapped at the Lewis Ladder was on August 14, 2018. Brood stock for hatchery production may be collected at both trapping sites then shipped to Speelyai Hatchery. Early Coho not kept as brood stock are transported to the upper Lewis River at Eagle Cliff and released.

Adults Trapped (F.C.F.)	1,007
Jacks Trapped (F.C.F.)	1,026
Adults Trapped (Lewis)	3,352
Jacks Trapped (Lewis)	3,290
Trap Mortality (Adults)	165
Trap Mortality (Jacks)	185
Food Banks/Tribes (Adults)	1,128
Food Banks (Jacks)	4,050
Nutrient Enhanced (Adults)	0
Nutrient Enhanced (Jacks)	0
Broodstock Shipped (Adults)	1,351
Broodstock Shipped (Jacks)	85
Shipped to Swift (Adults)	1,714
Shipped to Swift (Jacks)	0

2018 Brood Lewis River (Type N) Late Coho

The first late Coho trapped at the Merwin F.C.F. and the Lewis Ladder was on October 16, 2018. All brood stock is held and spawned at the Lewis River Hatchery. The spawned carcasses were all nutrient enhanced. Late Coho not kept as brood stock were transported to the upper Lewis River at Eagle Cliff and released.

Adults Trapped (F.C.F.)	1,137
Jacks Trapped (F.C.F.)	308
Adults Trapped (Lewis)	8,329
Jacks Trapped (Lewis)	1,795
Trap Mortality (Adults)	1,739
Trap Mortality (Jacks)	36
Spawned (Adults)	1,069
Spawned (Jacks)	6
Food Banks/Tribes (Adults)	1,012
Food Banks/Tribe (Jacks)	1,006
Nutrient Enhanced (Adults)	2,472
Nutrient Enhanced (Jacks)	1,057
Broodstock Shipped (Adults)	754
Broodstock Shipped (Jacks)	23
Shipped to Swift (Adults)	4,117
Shipped to Swift (Jacks)	2

INCIDENTAL TRAPPING

2018 Brood Lewis River Wild Winter Steelhead

Brood stock was collected at the Merwin F.C.F. and then shipped to Merwin Hatchery for spawning. No fish were trapped in the Lewis Ladder. The last wild winter steelhead was trapped at the Merwin F.C.F. on June 8, 2017. Fish not used for brood stock were returned to the Lewis River.

Adults Trapped (F.C.F.)	112
Adults Trapped (Lewis)	0
Mortality	1
Returned to Stream	22
Brood stock Shipped	89

2019 Brood Lewis River Wild Summer Steelhead

The first wild summer steelhead was trapped at Merwin F.C.F. on June 18, 2018. The Lewis Ladder did not trap any wild summer steelhead. All fish were returned to the Lewis River.

Adults Trapped (F.C.F.)	19
Adults Trapped (Lewis)	0
Mortality	0
Returned to Stream	19

2019 Brood Lewis River Wild Winter Steelhead

The first 2019 brood wild winter was trapped at the Merwin F.C.F. on November 25, 2018. All fish were returned to the Lewis River.

Adults Trapped (F.C.F.)	3
Adults Trapped (Lewis)	0
Mortality	0
Returned to Stream	3

2018 Brood Lewis River Wild Spring Chinook

The first wild spring Chinook was trapped at Merwin F.C.F. on March 18, 2018. All fish trapped at the Merwin F.C.F. were shipped to Speelyai to be spawned or shipped up river to be planted back to the stream.

Adults Trapped (F.C.F.)	27
Jacks Trapped (F.C.F.)	1
Adults Trapped (Lewis)	2
Jacks Trapped (Lewis)	0
Mortality (Adults)	0
Mortality (Jacks)	0
Brood stock Shipped (Adults)	19
Brood stock Shipped (Jacks)	1
Returned to Stream (Adults)	10
Returned to Stream (Jacks)	0

2018 Brood Lewis River Sockeye (Unknown Origin)

The first Sockeye was trapped at Merwin F.C.F. on July 4, 2018. The first and only Sockeye was captured in the Lewis Ladder on August 14, 2018. All live fish were returned to the Lewis River

Adults Trapped (F.C.F.)	25
Adults Trapped (Lewis)	1
Mortality	0
Returned to Stream (Adults)	26

2018 Brood Lewis River Wild Fall Chinook

The first wild fall Chinook was trapped at Merwin F.C.F. on August 13, 2018. The first arrival at the Lewis Ladder was October 1, 2018. All fish were returned to the Lewis River.

Adults Trapped (F.C.F.)	203
Jacks Trapped (F.C.F.)	118
Adults Trapped (Lewis)	12
Jacks Trapped (Lewis)	0
Mortality	5
Mortality (Jacks)	2
Returned to Stream (Adults)	215
Returned to Stream (Jacks)	118

2018 Brood Fall Chinook (Unknown Hatchery Origin)

These fall Chinook are adipose clipped indicating that they are of hatchery origin. We identify them as unknown because the Lewis River does not have a hatchery fall Chinook program. The fish are strays from another hatchery program(s). The first fall Chinook was trapped at Merwin F.C.F. on August 21, 2018. The first arrival at the Lewis Ladder was August 28, 2018.

Adults Trapped (F.C.F.)	272
Jacks Trapped (F.C.F.)	11
Adults Trapped (Lewis)	250
Jacks Trapped (Lewis)	3
Mortality (Adult)	77
Mortality (Jack)	4
Food Banks/Tribes (Adults)	445
Food Banks/Tribes (Jacks)	10
Returned to Stream (Adults)	0
Returned to Stream (Jacks)	0

2018 Brood Lewis River Wild Early Coho

The first wild early Coho was trapped at Merwin F.C.F. was August 27, 2018. The first arrival at the Lewis Ladder was August 28, 2018. All wild early Coho were planted in to the Lewis River at Eagle Cliff above the Swift Reservoir or returned to stream above the Lewis Ladder entrance.

Adults Trapped (F.C.F.)	175
Jacks Trapped (F.C.F.)	314
Adults Trapped (Lewis)	27
Jacks Trapped (Lewis)	0
Mortality	1
Returned to Stream at Swift (Adults)	190
Returned to Stream at Swift (Jacks)	314
Returned to Stream at Lewis Ladder (Adults)	11
Returned to Stream at Lewis Ladder (Jacks)	0

2018 Lewis River Chum (Unknown Origin)

The Merwin F.C.F. captured no Chum for the year.

Adults Trapped (F.C.F.)	0
Adults Trapped (Lewis)	0
Returned to Stream	0

2018 Brood Lewis River Wild Late Coho

The first wild late Coho was trapped at Merwin F.C.F. on October 18, 2018. The first arrival at the Lewis Ladder was October 30, 2018. Some of the wild late Coho captured at Lewis were used as brood stock at Lewis River Hatchery as the integrated portion of the hatchery's late Coho program. Additional fish were shipped down from the FCF for broodstock. Live fish not used for brood stock were returned to the Lewis River above Swift reservoir.

Adults Trapped (F.C.F.)	257
Jacks Trapped (F.C.F.)	83
Adults Trapped (Lewis)	83
Jacks Trapped (Lewis)	0
Mortality (Adults)	53
Mortality (Jacks)	1
Spawned (Adults)	22
Spawned (Jacks)	0
Returned to Stream at Swift (Adults)	265
Returned to Stream at Swift (Jacks)	82
Broodstock Shipped to Lewis from FCF (Adults)	97

2018 Brood Kalama Falls Hatchery Late Coho

Due to concerns over early shortages in broodstock at the Lewis River Trap, Kalama Late Coho were shipped over to compensate. Once enough brood were attained from the Lewis River Trap, these fish were used for the USvOR program. Fish were brought over from 11-5-18 through 11-28-18.

Adults Received from Kalama	1318
Jacks Received from Kalama	5
Mortality	475
Mortality Jacks	3
Spawned Adults	807
Spawned Jacks	2

ADULT TRAPPING - LEWIS RIVER LADDER 2018

SPECIES	ESTIMATED TRAPPED/RECEIVED		RETURNED TO STREAM			RECYCLED FISH TRAPPED			RECYCLED FISH RETURNED TO STR.			SHIPPED / PLANTED			MORTALITIES			CARCASS DISTRIBUTION			LETHAL SPAWNED				LIVE SPAWNED				ESTIMATED ON-HAND				MARKS RECOVERED			ESTIMATED EGGS TAKEN
	A	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	VF	NVF	J	M	VF	NVF	J	A	J			M	F	J	
CO:NO:LEWI:17:H	108	5										230	201	4	32	27	5	466	218	50																
CO:NO:LEWI:17:W	11											6	4			1			1																	
SH:SU:MEHA:18:H																																				
SH:WI:MEHA:18:H	155																	45	110																	
SH:WL:LEWI:18:H																																				
SH:WL:LEWI:18:W																																				
CK:SP:LEHA:18:H	919	14										500	389	14	21	9		21	9																	
CK:SP:LEWI:18:W	2											1	1																							
SH:SU:MEHA:19:H	360		29	31		11	14									1		101	199																	
SH:SU:LEWI:19:W																																				
SO:NA:UNKN:18:U	1		1																																	
CT:AC:LEWI:18:W																																				
CO:SO:LEHA:18:H	3,352	3,290	1		1							1,234	923	72	94	49	114	667	527	3,217													262	163	397	
CO:SO:LEWI:18:W	27		7	4								11	5																							
CK:FA:UNKN:18:H	251	3													5	15		158	93	3													1			
CK:FA:LEWI:18:W	12		9	3																																
CO:NO:KAHA:2018:H	1,318	5													238	237	3	675	643	5	401	403	3	2									14	15	0	1,352,184
CO:NO:LEWI:18:H	9,083	1,818										2,301	1,524		787	879	34	3,252	2,007	1,817	526	542	1	6									628	303	337	721,943
CO:NO:LEWI:18:W	180											55	50		26	27		42	33		16	6														1,127,081
SH:WI:MEHA:19:H	4																	1	3																	
SH:WL:LEWI:19:W																																				
TOTALS	15,783	5,135	47	38	1	11	14	0	0	0	0	4,338	3,097	90	1,203	1,245	156	5,428	3,843	5,092	943	951	4	8	0	0	0	0	0	0	0	0	905	481	734	3,201,208

Egg Take and Incubation

2017 Brood Lewis River Late Coho (Integrated and Segregated)

Egg inventory and distribution was as follows:

Total Egg Take (green)	4,762,524
Egg Loss	189,328
Short/Over	60,289
Adjusted Egg Take	4,822,813
Total Eyed Eggs	1,584,185
Shipped	3,583,800
Fecundity	3,205

Once a strong eye developed, the eggs were shocked and picked to remove dead eggs. After the morbid eggs are removed, the eyed eggs were re-inventoried and laid down to hatch or ship. Total eggs loss (roughly 12.0%) was 189,328. All 1,049,685 of the eyed eggs for the Lewis River program were integrated and kept on station.

A total of 3,583,800, both green and eyed, segregated eggs were shipped out. Washougal Hatchery received 1,899,300 green eggs and Grays River received 1,150,000 in December of 2017. The remaining egg shipments were shipped as eyed eggs during January and February 2018. The eggs were distributed as followed: Fish First 460,000; Clark PUD 46,000; Columbia Springs 13,500; Ridgefield High School 10,000; The Steve Syverson Project 5,000.

2018 Brood Lewis River Early Coho

No fish were spawned at Lewis River Hatchery for this stock. All adult fish were shipped to Speelyai Hatchery. Eggs were incubated to the eyed stage at Speelyai Hatchery. 1,357,439 eyed eggs were transferred to the Lewis River Hatchery in November 2018.

2018 Brood Lewis River Late Coho (Integrated & Segregated)

Egg inventory and distribution was as follows:

Total Egg Take (green)	1,849,024
Egg Loss	0
Short/Over	0
Shipped	99,770
Fecundity	3,374

Over 1.8 million green eggs were taken in 2018. The first spawn of late Coho took place on November 19th and the last one on December 18th. The Washougal Hatchery received about 100k (segregated) green eggs. The remaining green eggs were laid down for incubation at Lewis River Hatchery. At the time of this report the LRH had 1.75 million green eggs on hand and of those eggs approximately 1.1 million are integrated for the Lewis River late Coho production. The remaining 622K, once eyed, will be distributed and shipped out to Fish First, Clark PUD, Ridgefield High School, Columbia Springs, and the Steve Syverson project.

2018 Brood Kalama Falls Late Coho

Eggs were taken from the Kalama Falls Late Coho at Lewis River Hatchery from December 4th through December 11, 2018. The eggs were shipped green to Washougal River Hatchery.

Total Egg Take (green)	1,352,184
Total Shipped	1,352,184
Fecundity	3,355

REARING PROGRAM

2016 Brood Lewis River Late Coho

Lewis River Hatchery volitionally released 842,927 late Coho averaging 16.3 fpp between April 2 and 20, 2018. Approximately 75K identified with an AD+CWT, 75K was CWT only (double index group) and the rest with an AD clip only. At time of release, the fish appeared healthy and ready to emigrate.

Final Stock Inventory

Beginning Balance	974,745
Pounds Ponded	741
Rearing Mortality (4.7%)	-58,069
Adjustment	-50,693
Fish Planted	842,927
Pounds Planted	51,866
Feed Fed (lbs.)	47,114
Net Gain (lbs.)	51,125
Conversion	0.92:1
CV	7.2

2016 Brood Lewis River Early Coho

Lewis River Hatchery volitionally released 1,173,443 early Coho averaging 16.5 fpp between April 2nd and 10th, 2018. Approximately 75K identified with an AD+CWT, 75K was CWT only (double index group) and the rest with an AD clip only. At time of release, the fish appeared healthy, smolted, and ready to emigrate.

Final Stock Inventory

Beginning Balance	1,513,894
Pounds Ponded	1,038
Rearing Mortality (16.0%)	-127,115
Adjustment	-212,644
Fish Planted	1,173,443
Pounds Planted	71,119
Feed Fed (lbs.)	64,887
Net Gain (lbs.)	70,161
Conversion	0.92:1
CV	7.49

2017 Brood Lewis River Spring Chinook

On May 7th and continuing through May 9, 2018, the Lewis River Hatchery received 886,850 spring Chinook from Speelyai Hatchery. In addition, 337,950 were shipped from Speelyai to Lewis River Hatchery on December 3rd and 4th of 2018. The 2017 brood year spring Chinook were adipose clipped (AD) and snout tagged (CWT) prior to the transfer. Approximately 75K were AD+CWT, 75K CWT only (double index group), and the rest AD only. From October 17th to the 31st 2018 we volitionally released 710,708 of the fish transferred in May. The remaining fish on hand are schedule to release in February 2019.

Final Stock Inventory

Fish Received	1,224,800
Pounds Received	27,971
Rearing Mortality (.7%)	8,994
Planted	710,708
On Hand	505,098
Pounds Planted	38,206
Pounds On Hand	41,586
Feed Fed (lbs.)	57,464
Net Gain (lbs.)	72,637
Conversion	0.79:1
CV of Fish Planted	8.1

2017 Brood Lewis River Early Coho

The last take of early Coho left the incubation room and was ponded into a small raceway on February 21, 2018. The condition of the fry prior to ponding was good with fry loss (mortality between eyed and ponding) being about 1.3%. Approximately 75K was identified with an AD+CWT, 75K was CWT only (double index) and the rest AD clip only. The 2017 early Coho are scheduled for release starting April 2019.

Stock Inventory This Period

Beginning Balance	1,387,034
Pounds Ponded	1,131
Rearing Mortality (9.7%)	-55,445
Adjustment	-101,437
Fish on Hand	1,230,152
Pounds on Hand	57,753
Feed Fed (lbs.)	46,744
Net Gain (lbs.)	56,622
Conversion	0.83:1

2017 Brood Lewis River Late Coho

All 1,049,685 fry were moved from the incubation room to standard raceways outside between March 2nd, and April 17, 2018. Fry loss (mortality between eyed stage and ponding) was about 1.7%. Marking of these fish took place in June 2018. Approximately 75K was identified with an AD+CWT, 75K was CWT only (double index) and the rest AD clip only. The 2017 late Coho are scheduled for release starting April 2019.

Stock Inventory This Period

Beginning Balance	1,049,685
Pounds Ponded	801
Rearing Mortality (5.0%)	-44,388
Rearing Adjustment	-37,798
Fish on Hand	967,499
Pounds on Hand	35,363
Feed Fed (lbs.)	33,065
Net Gain (lbs.)	34,562
Conversion	0.96:1

2018 Brood Lewis River Early Coho

On December 24, 2018 the first take of early Coho, 159,837, were transferred from the incubation room to raceway two. The fry loss for the first take was high at around 3.8%, do to coagulated yolk. The remaining takes will be ponded in January and February of 2019.

Stock Inventory This Period

Beginning Balance	159,837
Pounds Ponded	104
Rearing Mortality (5.2%)	-8,449

RAINFALL REPORT

Hatchery: Lewis River **Year: 2018** **Water Source: Lewis River**

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
1	0	0.7	0.3	0.5	0	0	0	0	0	0	0.6	0	
2	0	0.2	0.1	0	0	0	0	0	0	0	0.2	0	
3	0	0.3	0	0.1	0	0	0	0	0	0	0.7	0	
4	0.2	0.1	0.2	0.1	0	0	0	0	0	0	0.1	0	
5	0.4	0	0	0.7	0	0	0	0	0	0.8	0	0	
6	0	0	0	0.3	0	0	0	0	0	0	0	0	
7	0.4	0	0	0.8	0	0	0	0	0.2	0.5	0	0.05	
8	0.5	0	0.4	0.2	0.2	0.5	0	0	0	0.4	0	0	
9	0.2	0	0	0.1	0.1	0.1	0	0	0.3	0	0	0.6	
10	0.6	0	0	0.3	0	0.5	0	0	0.1	0	0	1.1	
11	1.1	0	0	0.7	0	0	0	0.1	0.4	0	0	0.3	
12	0.1	0	0	0.5	0	0	0	0	0.2	0	0	0.6	
13	0	0.1	0.5	0.6	0	0	0	0	0.1	0	0	0	
14	0	0.2	0	0.8	0	0	0	0	0	0	0.1	0.2	
15	0.2	0.4	0.2	0.9	0	0	0	0	0.5	0	0	0.3	
16	0	0.9	0.2	0.4	0	0	0	0	0.1	0	0	0.5	
17	0.5	1.8	0.3	0.1	0	0	0	0	0	0	0	1.8	
18	0.3	0.5	0	0	0	0	0	0	0	0	0	0.3	
19	0.3	0	0	0	0	0	0	0	0	0	0	0.1	
20	0.3	0.3	0	0	0	0	0	0	0	0	0	0.1	
21	0.6	0.3	0.7	0	0	0	0	0	0.1	0	0.4	0	
22	0.3	0	0.7	0	0	0	0	0	0.1	0	0.7	1.4	
23	1.3	0.3	0.6	0	0	0	0	0	0	0.1	0.7	0.5	
24	0.7	0.5	0.3	0	0	0.1	0	0	0	0.3	0	0	
25	0.5	0.5	0.1	0	0	0.2	0	0	0	0.8	0	0.2	
26	1.1	0.1	0.4	0	0	0	0	0.5	0	0.3	0.9	0.8	
27	0.2	0.3	0.3	0.1	0	0	0	0	0	1.7	0.4	0.2	
28	0	1.1	0	0.1	0	0	0	0	0	1	0.4	1.3	
29	0.8		0	0.1	0	0	0	0	0	0.1	0.2	0.9	
30	0.1		0	0	0	0	0	0	0	0.6	0.7	0.2	
31	0		0		0		0	0		0.7		0	Year Total
TOTAL	10.70	8.60	5.30	7.40	0.30	1.40	0.00	0.60	2.10	7.30	6.10	11.45	61.3

YEARLY TEMPERATURE REPORT

HATCHERY: LEWIS RIVER YEAR: 2018 **WATER SOURCE: N.F. LEWIS RIVER**

	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC	
DAY	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
1	44	43	43	43	43	42	43	42	47	45	50	47	56	52	62	55	60	56	60	59	61	60	52	52
2	44	43	43	43	42	42	43	42	48	45	52	49	54	51	60	55	60	56	60	58	60	59	52	52
3	44	43	43	42	42	42	43	42	47	45	50	48	55	52	57	55	60	56	60	58	60	59	52	52
4	43	43	43	42	42	42	44	42	47	46	50	47	54	52	60	55	60	56	60	58	60	59	53	52
5	44	43	43	42	42	42	44	43	48	46	52	47	56	52	60	55	60	56	60	59	59	59	52	52
6	43	43	42	42	43	42	44	43	47	45	52	48	56	52	60	55	60	57	61	58	59	58	52	52
7	43	43	43	42	42	42	43	43	48	46	51	48	56	53	60	55	60	57	60	59	59	58	52	52
8	43	43	43	42	43	42	43	43	48	46	50	48	56	52	60	55	59	57	60	60	58	58	52	51
9	43	42	42	42	43	42	44	43	47	46	51	49	54	53	59	55	60	57	61	59	58	58	51	51
10	43	42	43	42	44	42	44	43	48	46	50	49	55	53	59	55	59	57	61	59	58	57	51	51
11	43	43	43	42	44	42	44	44	49	46	53	49	57	53	58	55	59	57	61	59	58	58	51	49
12	43	42	43	42	44	42	44	43	49	46	52	48	57	53	58	55	59	57	61	59	58	58	49	48
13	43	42	43	42	44	43	44	43	48	46	51	49	57	53	59	55	59	57	61	59	58	58	48	48
14	43	43	43	42	43	42	44	44	47	47	51	49	57	53	59	55	59	57	61	59	58	58	48	48
15	43	43	43	42	43	42	44	44	48	47	52	49	57	53	59	55	59	57	62	60	58	56	49	48
16	43	43	43	42	43	42	44	44	47	46	53	49	58	53	59	55	60	57	62	60	56	56	49	48
17	43	43	43	42	43	42	44	44	47	47	53	49	58	53	60	55	60	57	62	60	56	55	48	48
18	43	43	42	42	43	42	44	44	48	47	53	50	57	53	60	55	60	57	62	60	57	55	49	48
19	43	43	43	42	43	42	46	44	49	47	53	50	56	53	60	56	60	57	62	60	56	56	49	48
20	43	43	42	42	43	42	45	44	49	47	53	50	58	53	59	56	60	58	62	60	56	55	49	48
21	43	43	42	41	43	42	46	44	50	46	53	50	58	53	60	56	60	57	62	60	56	55	48	48
22	43	43	42	42	43	42	46	44	50	46	53	50	59	53	59	56	60	58	62	60	56	55	48	47
23	43	43	42	41	43	42	46	44	51	47	53	50	59	54	58	56	60	58	62	60	55	53	48	48
24	43	43	42	42	43	42	47	44	51	47	53	50	59	54	57	56	60	58	61	61	53	53	48	47
25	43	42	42	42	43	42	47	44	50	47	53	50	59	54	58	56	61	57	61	61	53	53	47	47
26	43	42	42	42	42	42	47	45	49	47	53	50	59	54	57	56	61	58	61	61	54	53	47	47
27	43	43	42	42	43	42	46	45	51	47	54	50	59	54	60	56	61	58	62	60	53	53	47	46
28	43	43	42	42	43	42	46	45	50	47	55	51	59	55	60	56	61	58	61	58	53	53	46	46
29	43	43			43	42	46	45	49	47	53	51	59	55	60	56	59	58	61	60	53	52	47	46
30	43	42			43	42	46	45	49	47	53	51	59	55	58	56	59	58	61	60	52	52	46	46
31	43	42			43	42			50	47			60	55	59	56			61	60			46	46
AVG.	43.13	42.74	42.57	42	42.94	42.03	44.7	43.63	48.58	46.35	52.17	49.17	57.19	53.16	59.16	55.42	59.83	57.13	61.1	59.48	56.7	56.07	49.23	48.77
MIN	43	42	42	41	42	42	43	42	47	45	50	47	54	51	57	55	59	56	60	58	52	52	46	46
MAX	44	43	43	43	44	43	47	45	51	47	55	51	60	55	62	56	61	58	62	61	61	60	53	52

Washington DEPARTMENT OF FISH AND WILDLIFE NPDES Chemical Operational Log. Records of Disease Control Chemicals Used

YEAR 2018

Keep records on station for at least five years

Facility: Lewis River Hatchery

NPDES Permit Number: WAG 13-1040

Brood Stock Species	Pond/ Raceway	Date of Application	Chemical Name	Dosage	Duration	Method Application	Amount used	Reason for use	Flow	Water Temp	Estimated Concentration Discharge	Method Disposal	location any disposed spent chemical dip	Name
CO:SO:LEHA:17:H	2thru7	2/27/2018	Formalin	1;6000	1 Hour	Drip	12gal	Costia	200gpm	42				JT
CO:SO:LEHA:17:H	2thru7	2/28/2018	Formalin	1;6000	1 Hour	Drip	12gal	Costia	200gpm	42				JT
CO:NO:LEWI:17:H	16-1thru3	3/12/2018	Formalin	1;6000	1 Hour	Drip	60gal	Costia	2000gpm	42				DMG
CO:NO:LEWI:17:H	16-1thru3	3/13/2018	Formalin	1;6000	1 Hour	Drip	60gal	Costia	2000gpm	42				DMG
CO:SO:LEHA:17:H	4thru6	4/7/2018	Formalin	1;6000	1 Hour	Drip	9gal	Prophylactic	300gpm	44				JT
CO:SO:LEHA:17:H	4thru6	4/7/2018	Formalin	1;6000	1 Hour	Drip	9gal	Prophylactic	300gpm	44				JT

Notes:

MAINTENANCE AND CAPITAL PROJECTS – 2018

MAINTENANCE

1. **Replaced raceway 1-12 bird netting and gate frames.**
2. **PM services and all residences HVAC systems**
3. **Lifted and pressure washed screens @ DSI pump station**
4. **Replaced egg baskets in incubation.**
5. **Pruned fruit trees.**
6. **Replaced broken and old totes.**
7. **New windshield for Gator and E-brake cable.**
8. **Added 12 volt electric pump to Day Tank @ USI.**
9. **Serviced all lawn equipment.**
10. **Pressure washed the Adult Sorting Facility.**
11. **Greased crowders and hoists @ Adult Sorting Facility.**
12. **Repaired and made new adult mort pickers.**
13. **Serviced vehicles.**
14. **Had all Hatchery septic tanks pumped (4).**
15. **Domestic Water Plant was serviced.**

CAPITAL

1. **New Heat Pump for Residence #1.**
2. **New Pick-up (Ford).**
3. **Installed new breaker on DSI Generator.**
4. **Had both generator sets serviced and load tested.**

OPERATIONS PROGRAM

MERWIN HATCHERY

FOR

JANUARY 1, 2018 TO DECEMBER 31, 2018

Washington Department of FISH and WILDLIFE

WRITTEN AND COMPILED BY:

MERWIN HATCHERY STAFF

Introduction

The Merwin Hatchery is a PacifiCorp owned and funded facility that is operated by the State of Washington's Department of Fish and Wildlife. The facility has been in operation since October of 1993.

Merwin Hatchery is located 11 miles east of Woodland off state route 503 adjacent to the PacifiCorp Merwin Dam and Lake Merwin.

Program Goals

- 50,000 Rainbow Trout at 2.5 fpp stocked into Swift Reservoir.
- 175,000 summer Steelhead at 4.8 fpp stocked into N.F. Lewis River.
- 100,000 winter Steelhead at 4.8 fpp stocked into N.F. Lewis River.
- 50,000 wild winter Steelhead at 6 fpp stocked into N.F. Lewis River.

Approximately 5,000 gallons of water per minute can be delivered to the hatchery by three-intake pumps located midway on Merwin Dam, which draft water from Lake Merwin. Two screened intakes located at depths of approximately fifteen feet and ninety feet below the surface of the reservoir enable some temperature manipulation for fish rearing.

Ozone water sterilization is part of the design criteria to meet fish health needs not only at the hatchery but also for fish stocks and the Lewis River Hatchery downstream of our effluent discharge area. Two ozone generators fed by compressed air supply ozone gas to a water/ozone contact chamber. A maximum flow of 3,800 gallons per minute can be sterilized and supplied to the hatchery building, raceways and rearing ponds. The facility has the capability to ozone treat all effluent water from the adult holding area and incubation room in the event of a viral outbreak.

There is approximately 216,470 cubic feet of rearing space. These areas consist of four one-quarter acre rearing ponds, ten 9.5 x 80 x 2.5 fingerling raceways, four 7.5 x 33 x 4 adult holding ponds, six 4.5 x 34 x 2 intermediate raceways, one 3x14x2 deep trough, four 16 c.f. fry troughs and 15 double stack Mari Source incubators.

The hatchery complex has an operations building housing the office, feed room, shop, lab, day room, locker room, shower room, mud room, crew rest room and public restrooms. Other buildings associated with this facility are; the hatchery building with attached covered adult holding ponds, water treatment facility including the ozone generator building/ contactor structure, one three bay storage building, chemical storage building and three residences.

Trapping

During this reporting period, trapping was conducted at the Merwin Dam Fish Collection Facility, Lewis River Hatchery and the lower river, depending on the species.

2019 Brood Lewis River Summer Steelhead

A total of 366 adults were received for spawning purposes. All of these fish were trapped at the Merwin Dam Fish Collection Facility. Disposition is as follows:

Adults Spawned	182
Non-Viable females	0
Mortality (6.56%)	24
Nutrient Enhancement	0

2019 Brood Lewis River Winter Steelhead

A total of 139 adults were received for spawning purposes. These fish were trapped at the Merwin Dam Fish Collection Facility. Disposition is as follows:

Adults Spawned	72
Non Viable females	0
Mortality (2.16%)	3
Nutrient Enhancement	0

2018 Brood Lewis River Wild Winter Steelhead

A total of 94 adults were received for spawning purposes. These fish were collected at various sites, to include: the Merwin Dam Fish Collection Facility, and tangle net fishing in the lower river. Disposition is as follows:

Adults Spawned	46
Non Viable Females	0
Mortality (3.19%)	3
Nutrient Enhancement	0
Culled (hatchery genetics)	0
Return to river	91

2018 Brood Lewis River Late Winter Steelhead Hatchery Origin

This stock is a result of live spawning wild winter steelhead broodstock at Merwin Hatchery. The adult wild steelhead were collected from the Merwin F.C.F., tangle netting in the lower river, and the Lewis River Ladder. These fish are reared at Merwin Hatchery and blank wire tagged as juveniles. Then, are transported upstream by PacifiCorp staff as part of a supplementation project when they return as adults. A portion of the returning adults were planted downstream for a survey of trap efficiency, these fish were then hauled upstream once recaptured.

Below is a list of fish trapped in the 2018 season. The first arrival at Merwin F.C.F. was on October 23rd, 2017. All upstream fish were planted at Eagle Cliff release site at the upper end of Swift Reservoir. Downstream plants were at Merwin boat ramp and Martins Access boat ramp (WDFW public access).

Adults Trapped (F.C.F.)	1,223
Mortality	3
Planted upstream	1,148
Planted downstream	72
Recaptured & planted upstream	72
Total planted upstream	1,220

MERWIN HATCHERY ADULT COLLECTION

SPECIES	ESTIMATED TRAPPED/RECEIVED		RETURNED TO STREAM			RECYCLED FISH TRAPPED			RECYCLED FISH RETURNED TO STR.			SHIPPED / PLANTED			MORTALITIES			CARCASS DISTRIBUTION			LETHAL SPAWNED				LIVE SPAWNED				ESTIMATED ON-HAND		MARKS RECOVERED			ESTIMATED EGGS TAKEN
	A	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	VF	NVF	J	M	VF	NVF	J	A	J	M	F	J	
SH:SU:MEHA:19:H	366	0	0	0	0	0	0	0	0	0	0	0	0	0	8	16	0	83	81	0	87	91	0	0	4	0	0	0	0	0	0	0	0	373,100
SH:WI:MEHA:19:H	139	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	30	34	0	36	36	0	0	0	0	0	0	0	0	0	0	0	158,400
SH:WL:LEHA:18:H	94	0	33	58	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	24	22	0	0	0	0	0	0	0	78,965

ADULT TRAPPING - MERWIN DAM FISH COLLECTION FACILITY 2018

SPECIES	ESTIMATED TRAPPED/RECEIVED		RETURNED TO STREAM			RECYCLED FISH TRAPPED			PLANTED UPSTREAM			SHIPPED			MORTALITIES			CARCASS DISTRIBUTION			PLANTED HORSESHOE LK			ESTIMATED ON-HAND		MARKS RECOVERED			ESTIMATED EGGS TAKEN
	A	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	A	J	M	F	J	
CK:SP:LEHA:18:H	2,013	66							203	99	24	910	787	42	7	6		1								1			
CK:SP:LEWI:18:W	27	1							6	3		14	4	1															
CK:FA:LEWI:18:W	203	118	102	96	116										3	2	2												
CK:FA:UNKN:18:H	272	11											1		34	23	4	102	112	7									
CO:SO:LEHA:18:H	1,007	1,026							368	290		115	135	14	10	12	71	43	34	942						35	27	141	
CO:SO:LEWI:18:W	175	314							93	81	314				1														
CO:NO:LEWI:17:H	17	3							1	2					9	5	3												
CO:NO:LEWI:17:W																													
CO:NO:LEWI:18:H	1,137	308							146	146	2	458	296	23	25	48	2	4	14	481						3	14	46	
CO:NO:LEWI:18:W	257	83							90	70	82	48	49				1												
SH:SU:MEHA:19:H	4,037		812	1,602		578	1,247					238	279		15	25		1,006	1,775										
SH:SU:LEWI:19:W	19		5	14																									
SH:WI:MEHA:18:H	1,086											20	21		6	7		395	637										
SH:WI:MEHA:19:H	323											46	55					85	137										
SH:WL:LEWI:18:H	1,212		45	32		45	32		681	528						3											3		
SH:WL:LEWI:19:H	8								3	5																			
SH:WL:LEWI:18:W	107		7	11								30	59																
SH:WL:LEWI:19:W	3		2	1																									
SO:NA:UNKN:18:U	25		15	10																									
CH:NA:LEWI:18:W																													
PK:EV:UNKN:18:W																													
CT:AC:LEWI:18:W	1								1																				
CT:AC:LEWI:19:W	70								67	3																			
TOTALS	11,999	1,930	988	1,766	116	623	1,279	0	1,659	1,227	422	1,879	1,686	80	110	131	83	1,636	2,709	1,430	0	0	0			39	44	187	

Egg Take and Incubation

2018 Brood Goldendale Rainbow

Merwin Hatchery received 80,000 eyed eggs from Goldendale Hatchery on November 27th, 2018.

2019 Brood Lewis River Summer Steelhead

The first eggs were taken on November 19, 2018. Disposition of this stock to date is as follows:

Total Egg Take	462,164
Egg Loss (21.5%)	99,299
Eggs Destroyed	74,032
Shipped	0
Fecundity	5,079

2019 Brood Lewis River Winter Steelhead

The first eggs were taken on December 26th, 2018. All of these eggs are incubating and none of the egg takes have been shocked or picked. Disposition of this stock to date is as follows:

Estimated Total Egg Take	158,400
Egg Loss	0
Eggs Destroyed	0
Estimated Fecundity	4,400

2018 Brood Lewis River Winter Steelhead

The first eggs were taken on December 27th, 2017 and finalized by January 10th, 2018. Disposition of this stock to date is as follows:

Total Egg Take	129,955
Egg Loss	3,792
Eggs Destroyed	4,955
Fecundity	4,055

2018 Brood Lewis River Winter Steelhead

The first eggs were taken on December 27th, 2017 and finalized by January 10th, 2018. Disposition of this stock to date is as follows:

Total Egg Take	129,955
Egg Loss	3,792
Eggs Destroyed	4,955
Fecundity	4,055

2018 Brood Lewis River Wild Winter Steelhead

These fish were spawned from March 26th - May 25th, 2018. Disposition is as follows:

Total Egg Take	76,724
Egg Loss (11.29%)	8,663
Eggs Destroyed	0
Fecundity	3,487

REARING PROGRAM

2017 Brood Lewis River Summer Steelhead

The rearing of this brood went very well year and all program goals were achieved. During this rearing cycle these fish were diagnosed with ichthyopthirius. They were therapeutically treated accordingly with normal mortality rates. 30,880 fingerlings were planted in Battle Ground Lake on October 11th 2017. Hatchery staff began releasing the fish on station in April 2018. All of these fish were trucked and planted at river mile 5 on the North Fork of the Lewis River.

Final Stock Inventory

Fry Ponded	299,008
Pounds Ponded	120
Fingerlings Planted	30,880
Fingerling Pounds Planted (52 fpp)	594
Smolts Planted	182,178
Pounds @ Smolt Release (6.1 fpp)	29,865
Rearing Mortality (7.02%)	20,997
Destroyed	0
Shortage	0
Feed Fed (lbs)	39,997
Net Gain (lbs)	30,339
Conversion	1.32:1
Average CV @ Release	7.93

2017 Brood Lewis River Summer Steelhead @ Echo Net Pens

65,155 adipose only clipped summer steelhead were shipped from Merwin Hatchery to Echo Net Pen site on March 7th, 2018. These fish were released on April 15th, 2018.

Stock Inventory This Period

Juveniles Received	65,155
Pounds Received (8.0 fpp)	8,144
Smolts Planted	65,155
Pounds @ Release (6.0 fpp)	10,859
Rearing Mortality (0.0%)	0
Feed Fed (lbs.)	2,200
Net Gain (lbs.)	2,715
Conversion	0.81:1
Average CV @ Release	7.5

2017 Brood Lewis River Winter Steelhead

The rearing of this brood went very well this year and all programs goals were achieved. During this rearing cycle these fish were diagnosed with ichthyopthirius and bacterial cold water disease. They were therapeutically treated accordingly with average mortality rates. 92,710 juveniles were shipped to Beaver Creek Hatchery on October 19th, 2017. Hatchery staff began releasing the remaining fish on hand in April 2018. All fish on site were trucked and planted at river mile 5 on the North Fork of the Lewis River.

Final Stock Inventory

Fry Ponded	220,822
Pounds Ponded	88
Juveniles Shipped	92,710
Juvenile Pounds Shipped (35 fpp)	2,649
Smolts Planted	104,746
Smolt Pounds @ release (5.8 fpp)	18,060
Rearing Mortality (9.52 %)	21,020
Destroyed	0
Shortage	0
Feed Fed (lbs)	19,542
Net Gain (lbs)	20,709
Conversion	0.94:1
Average CV @ Release	7.3

2017 Brood Lewis River Wild Winter Steelhead

The overall rearing of this brood went well and all program goals were achieved. During this rearing cycle these fish were diagnosed with ichthyopthirius. They were therapeutically treated accordingly with average loss. Hatchery staff released these fish in May 2018. All of these fish that were volitional release were planted at the Merwin Boat Launch on the North Fork of the Lewis River. The remaining forced out fish were planted at Martin Access river mile 5 on the North Fork of the Lewis River.

Final Stock Inventory

Fry Ponded	73,753
Pounds Ponded	30
Smolts Planted	52,119
Pounds @ Release (9.3 fpp)	5,604
Rearing Mortality (25.08 %)	18,496
Planted as unfed fry	0
Transferred	0
Shortage	0
Feed Fed (lbs)	6,493
Net Gain (lbs)	5,574
Conversion	1.16:1
Average CV @ Release	9.9

2018 Brood Lewis River Summer Steelhead

The overall rearing of this brood has gone really well and program goals will be achieved. 8,484 juveniles were shipped to Beaver Creek Hatchery. During this rearing cycle, these fish were diagnosed with ichthyopthirius. They were therapeutically treated accordingly with average loss. Hatchery staff will start the release of the remaining fish on hand in April 2019.

Stock Inventory this period

Fry Ponded	274,117
Pounds Ponded	110
Juveniles on hand	239,890
Pounds on hand (8.0 fpp)	29,986
Rearing Mortality (6.8%)	18,566
Destroyed	0
Eggs Transferred	0
Juveniles Transferred	8,484
Pounds Transferred	514
Fish Planted	0
Feed Fed (lbs)	25,648
Net Gain (lbs)	29,876
Conversion	0.86:1

2018 Brood Lewis River Winter Steelhead

The overall rearing of this brood has gone really well and program goals will be achieved. During this rearing cycle, these fish were diagnosed with ichthyopthirius. They were therapeutically treated accordingly with average loss. Hatchery staff will start the release of the fish on hand in April 2019.

Stock Inventory this period

Fry Ponded	120,086
Pounds Ponded	48
Juveniles on hand	109,329
Pounds on hand (8.5 fpp)	12,862
Rearing Mortality (.09%)	11,060
Destroyed	0
Eggs Transferred	0
Juveniles Transferred	0
Pounds Transferred	0
Feed Fed (lbs)	10,787
Net Gain (lbs)	12,814
Conversion	0.84:1

2018 Brood Lewis River Wild Winter Steelhead

The overall rearing of this brood has gone well but due to insufficient broodstock collection and higher mortality rates program goals will not be met. During this rearing cycle these fish were diagnosed with ichthyopthirius. They were therapeutically treated accordingly with higher than average loss. Hatchery staff will start the release of the fish on hand in May 2019.

Stock Inventory this period

Fry Ponded	66,671
Pounds Ponded	27
Rearing Mortality (28.3%)	18,867
Unfed Fry Plant	0
Fish Transferred	0
Juveniles on Hand	44,930
Pounds on Hand (20 fpp)	2,247
Feed Fed (lbs)	1,956
Net Gain (lbs)	2,220
Conversion	.88:1

2019 Brood Lewis River Summer Steelhead

Spawning operations were completed in three egg-takes and went well this period. All takes are still in the incubators with the last take yet to hatch. Both female fecundities (5,074) and eyed egg loss (21.5%) were higher than average this year. 74,032 surplus eyed eggs were culled. Currently there are a combination of 288,395 alevin and eggs on hand.

2019 Brood Lewis River Winter Steelhead

Spawning operations were completed in two egg-takes and went excellent this period. Currently there are 158,400 eggs on hand; these eggs have not been picked yet.

2018 Brood Goldendale Rainbow

We received 80,000 eyed eggs from Goldendale Hatchery in November. These fish will be ponded to IR#6.

Stock Inventory this period

Fry Ponded	0
Pounds Ponded	0
Rearing Mortality	0
Shortage	0
Fry on Hand	Approx. 80K

2017 Brood Goldendale Rainbow

The rearing of this stock has gone really well. During this rearing cycle these fish were diagnosed with ichthyopthirius. They were therapeutically treated accordingly with average loss. A total of 41,985 fish were transferred to Speelyai Hatchery on December 4th, 2018. Approximately 2,500 of the remaining fish on hand will be panted to Swift Power Canal in April 2019. The remaining fish will used for the Merwin Park Fishing Derby in June 2019 and the Merwin Special Kids Derby (MSKD) in July 2019. Also, 2000 fish will be held over for the 2020 MSKD.

Stock Inventory this period

Fry Ponded	70,831
Pounds Ponded	24
Fish Planted	0
Rearing Mortality (21.6%)	15,276
Destroyed	0
Transferred	41,985
Pounds Transferred (11.0 fpp)	3,817
Pounds on Hand (6.0 fpp)	1,250
Shortage	0
Feed Fed (lbs)	4,030
Net Gain (lbs)	5,043
Conversion	.80:1
Fish on Hand (Derby fish 2018/2019)	4,997
Fish on Hand for Swift Power Canal Plant	2,505

2018 Merwin Special Kids Derby and Forest Service Derby

For the purpose of this report, we have listed all these fish under one section. Ten of the 2015 Brood Goldendale Rainbow were planted into Merwin Reservoir for the Forest Service Derby in June 2018. The remaining 2015 brood were caught at the MSKD derby in July 2018 or planted into Merwin Reservoir following the derby. The disposition of the 2015 brood is as follows: 1,270 planted into Merwin Reservoir and 378 caught at the derby.

The disposition of the 2016 brood is as follows: 3,303 planted in Swift Power Canal in April 2018, 1,980 planted in Merwin Reservoir for Forest Service Derby in June 2018, 2,228 planted in Merwin Reservoir following the MSKD derby in July 2018, and 152 caught at the derby (July 2018). Approximately 2,000 were kept for the 2019 MSKD derby and 2,500 for Swift Power Canal plant in April 2019.

Stock Inventory This Period 2015 Brood: Derby Goldendale Rainbow

Beginning Balance	1,800
Rearing Mortality (6.18%)	142
Fish Caught 2018 Derby	378
After MSKD Merwin Plant	1,270
Forest Service Derby Plant	10
Shortage	0
On Hand (Derby fish 2019)	0

Stock Inventory This Period 2016 Brood: Derby & Planting Goldendale Rainbow

Beginning Balance	9,748
Rearing Mortality (2.69%)	145
Fish Planted to Swift Power Canal	3,303
Fish Caught 2018 Derby	152
After MSKD Merwin Plant	2,228
Forest Service Derby Plant	1,980
Shortage	0
On Hand (Derby fish 2019)	1,940

RAINFALL REPORT

Rainfall is recorded from 8:00 a.m. to 8:00 a.m. day prior

HATCHERY: MERWIN HATCHERY **YR:** 2018 **WATER SOURCE:** MERWIN

YEAR TOTAL: 65.68 INCHES

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
1	0	1.1	0.15	0.55	0	0	0	0	0	0.1	0.8	0.05	
2	0	0.25	0.1	0.1	0	0	0	0	0	0	0.15	0	
3	0	0.25	0	0.1	0	0	0	0	0	0	1.05	0	
4	0.1	0.15	0	0.2	0	0	0	0	0	0	0.05	0	
5	0.45	0.02	0	0.9	0	0	0	0	0	1.4	0.4	0	
6	0	0	0	0.55	0	0	0	0	0	0	0.01	0	
7	0.25	0	0	0.75	0	0	0	0	0	0.4	0	0	
8	0.5	0	0.5	0.2	0.2	0.55	0	0	0.2	0.6	0	0	
9	0.1	0	0	0.1	0	0.1	0.01	0	0	0.05	0	0.65	
10	0.8	0	0	0.35	0	0.55	0	0	0.3	0	0	0.6	
11	1.25	0	0	0.6	0	0	0	0.2	0.15	0	0	1.15	
12	0.1	0	0	0.5	0	0	0	0	0.25	0	0	0.25	
13	0	0.4	0.65	0.75	0	0.01	0	0	0.2	0	0.05	0	
14	0	0.3	0.01	0.8	0	0	0	0	0.01	0	0.1	0.25	
15	0.15	0.4	0.01	0.6	0	0	0	0	0	0	0	0.25	
16	0.01	1.2	0.15	0.3	0	0.1	0	0	0.5	0	0.01	0.5	
17	0.5	0.9	0.4	0.1	0	0	0	0	0.3	0	0	2.05	
18	0.3	0.4	0	0	0	0	0	0	0	0	0	0.35	
19	0.25	0.2	0	0	0	0	0	0	0	0	0	0.05	
20	0.25	0.2	0	0	0	0	0	0	0	0	0	0.15	
21	0.5	0.5	0.75	0	0	0	0	0	0	0	0.4	0.05	
22	0.1	0.01	0.8	0	0	0	0	0	0.1	0	0.75	1.2	
23	1.4	0.95	0.9	0	0	0	0	0	0.05	0.15	0.5	0.4	
24	0.6	0.3	0.25	0	0	0.01	0	0	0	0.1	0.01	0.1	
25	0.7	0.55	0	0	0	0.2	0	0	0	0.95	0.01	0	
26	1.6	0.05	0.6	0	0	0	0	0.8	0	0.3	1	0.9	
27	0.1	0.3	0.3	0.2	0	0.01	0	0	0	1.9	0.25	0.1	
28	0	1.15	0	0.1	0	0	0	0	0	0.7	0.35	1.6	
29	1		0	0.1	0	0	0	0	0	0.25	0.1	1.6	
30	0.01		0	0.01	0	0	0	0	0.05	0.7		0.15	TOTAL
31	0.01		0		0		0	0		0.8		0	RAINFALL
Total	11.0	9.58	5.57	7.86	0.2	1.53	0.01	1	2.11	8.4	5.99	12.4	65.68

* SNOW

YEARLY TEMPERATURE REPORT

HATCHERY **MERWIN HATCHERY** **YEAR:** **2018** **WATER SOURCE:** **N.F. LEWIS RIVER**

MERWIN RESERVOIR

	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC	
DAY	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
1	44	43	43	43	42	42	43	43	48	46	51	50	55	54	59	57	61	59	63	62	61	60	53	52
2	44	43	43	42	42	42	43	42	48	46	51	50	56	54	59	57	62	59	63	62	60	60	53	52
3	44	43	43	43	42	42	44	43	48	46	51	50	55	54	59	57	62	59	63	62	60	60	53	52
4	43	43	43	42	42	42	45	43	47	46	53	50	56	54	59	57	61	58	63	62	60	59	53	52
5	43	43	43	42	42	42	46	45	48	46	51	50	56	54	59	57	60	59	63	62	59	59	52	51
6	43	43	42	42	43	42	46	43	48	47	51	51	56	54	59	57	60	59	63	62	60	59	52	51
7	43	43	44	42	43	42	45	43	48	47	53	51	55	54	60	57	62	59	63	62	59	59	51	51
8	43	43	44	42	43	42	44	43	48	47	51	51	56	54	59	57	60	59	63	62	59	58	51	51
9	43	42	42	42	43	42	45	44	48	47	52	51	57	54	59	58	60	59	62	62	59	58	51	51
10	43	42	43	42	43	42	46	44	48	47	52	51	56	55	59	57	61	60	63	62	59	58	51	50
11	43	42	43	42	43	42	46	44	48	47	51	51	56	55	61	57	61	60	63	62	59	58	50	48
12	43	42	43	42	44	43	45	44	51	48	52	51	57	55	59	57	61	60	62	62	58	57	49	48
13	43	43	43	42	44	43	45	44	49	48	53	51	57	55	60	57	62	60	62	62	58	57	50	48
14	44	43	42	42	43	42	45	44	49	48	53	51	58	55	59	58	62	60	63	62	57	57	50	48
15	43	43	42	42	43	42	45	44	49	48	53	51	57	55	59	58	62	61	63	62	57	57	50	49
16	43	43	42	42	43	42	45	44	50	48	54	51	57	56	60	57	61	60	63	62	57	56	49	49
17	43	43	42	42	43	42	45	45	50	48	53	51	57	55	60	57	62	61	63	62	57	56	49	48
18	43	42	42	42	43	42	45	44	49	48	53	52	58	55	60	57	63	61	63	62	57	56	48	48
19	43	42	42	42	43	42	45	44	49	48	54	52	58	55	60	58	62	61	62	62	56	56	49	48
20	43	42	42	42	43	42	45	44	50	48	53	52	57	55	61	58	62	60	62	62	56	55	48	48
21	43	42	42	42	43	42	45	45	50	48	55	52	58	55	61	58	62	61	62	61	56	55	48	48
22	43	42	42	42	43	42	45	44	50	48	54	52	59	56	60	59	62	61	62	61	55	54	48	47
23	43	43	42	42	43	42	46	45	51	48	54	53	57	56	60	58	63	62	62	61	54	54	48	48
24	43	42	42	42	43	42	47	46	52	48	56	53	58	65	60	58	62	61	62	61	54	53	48	47
25	43	42	42	42	43	42	47	46	51	49	56	53	58	56	60	58	63	61	61	61	54	53	47	47
26	43	42	42	42	43	42	47	46	52	49	55	53	58	56	60	59	62	61	61	61	54	54	47	46
27	43	42	42	42	43	42	47	46	51	49	55	53	59	56	59	59	63	62	61	61	5	53	47	46
28	43	43	42	42	43	42	47	46	52	49	56	53	58	56	60	59	63	61	61	61	53	52	46	46
29	43	42			43	42	47	46	51	49	55	53	58	56	60	59	63	62	61	61	53	52	46	46
30	43	42			43	42	47	46	51	49	55	54	59	57	62	59	63	62	61	60			46	46
31	43	42			43	42			51	50			59	57	61	59			61	60			46	46
AVG	43.12903	42.48387	42.46429	42.07143	42.90323	42.06452	45.43333	44.33333	49.51613	47.74194	53.2	51.56667	57.12903	55.41935	59.77419	57.74194	61.76667	60.26667	62.25806	61.58065	55.37931	56.37931	49.32258	48.6451613
MIN	43	42	42	42	42	42	43	42	47	46	51	50	55	54	59	57	60	58	61	60	5	52	46	46
MAX	44	43	44	43	44	43	47	46	52	50	56	54	59	65	62	59	63	62	63	62	61	60	53	52

DISEASES AND TREATMENTS

DATE:	1/1/18 - 12/31/18	HATCHERY:	MERWIN HATCHERY

DATE	BROOD YEAR/ SPECIES	POND NUMBERS	TREATMENT CHEMICAL	DISEASE
January-July	2018 Summer, Winter & Wild Winter Steelhead	(Eggs) Incubators	Formalin	Fungus
June - November	2019 Summer Steelhead Brood	SP 1 & 2	Formalin	Fungus
September- October	2016 Goldendale Rainbow	RW's 9 &10	Formalin	Ichthyopthirius
September- October	2017 Goldendale Rainbow	RW's 1, 2, 5, & 6	Formalin	Ichthyopthirius
September- October	2018 Winter Steelhead	RW 4 & RP-13	Formalin	Ichthyopthirius
September- October	2018 Summer Steelhead	RW 3 & RP 11, 12, & 14	Formalin	Ichthyopthirius
September- October	2018 Wild Winter Steelhead	RW's 7 & 8	Formalin	Ichthyopthirius
December	2018 Goldendale Rainbow	(Eggs) Incubators	Formalin	Fungus
November - December	2019 Summer & Winter Steelhead	(Eggs) Incubators	Formalin	Fungus
December	2019 Winter Steelhead Brood	AP-2	Formalin	Fungus

MAINTENANCE AND CAPITAL PROJECTS

Maintenance

1. Cleaned all dielectric tubes and inspected all fuses and rings on Ozone Generator #2
2. Replaced all elements and filters on Kaser compressor supply lines and Pure Gas air dryers
3. Replaced air compressor copper supply line with stainless steel
4. Yearly calibration for ambient ozone sensors and generators
5. Replaced inverter cooling pump in Ozone Generator #2
6. Facility tress pruned
7. Installed new ignition coils on John Deere Z-Trak Mower
8. Routine maintenance for Ford Cargo planting Truck
9. Replaced front and rear brakes for Ford-F250
10. Replaced air compressor for Ozone Plant fire suppression system
11. Replaced driver's side window on Ford Cargo planting truck
12. Installed life ring cabinets on rearing ponds
13. Routine service for Hatchery building walk in freezer compressor & heat pump
14. Repair and service for one residence heat pump & all residence's heat pumps
15. New gravel, drain line and drain rock for 3-Bay storage area
16. Tank removed from GMC planting truck and installed on new International planting truck
17. Replaced hatchery raceway sprinkler system
18. Replaced worn out tires and broken wheel on John Deere Gator
19. Replaced worn out bearings for cooling water pump #4 at Ozone Plant
20. Repaired broken shift linkage for Ford Cargo planting truck
21. Repaired broken walkway arm for International planting truck
22. Replaced damaged mower deck wheel on John Deere Z-Trak
23. New blocks and slides for rearing pond gates purchased

Capital

1. New International planting truck purchased
2. Facility asphalt cracks filled and sealed
3. Rearing Ponds 11-13 cracks were resealed

OPERATIONS PROGRAM

SPEELYAI HATCHERY

FOR

JANUARY 1, 2018 TO DECEMBER 31, 2018

Washington Department of FISH and WILDLIFE

WRITTEN AND COMPILED BY:

SPEELYAI HATCHERY STAFF

Introduction

The Speelyai Hatchery is a PacifiCorp owned and funded facility that is operated by the Washington Department of Fish and Wildlife. It has been in operation since 1958.

Speelyai Hatchery is located 21 miles east of Woodland, just off Highway 503. The hatchery is adjacent to Speelyai Creek on the north shore of Lake Merwin.

Program Goals

- 1,100,000 Spring Chinook transferred to Lewis River Hatchery in May.
- 300,000 Spring Chinook transferred to Lewis River Hatchery in December.
- 45,000 Rainbow planted in Swift Reservoir at 2.5fpp.
- 2,500 Rainbow planted in Swift power canal at 2.5fpp.
- 45,000 Kokanee released into Merwin Reservoir at 8.0fpp.
- 48,000 Kokanee released into Merwin Reservoir at 6.9fpp.
- 1,325,000 Type S coho eyed eggs transferred to Lewis river hatchery.

Approximately 9,200 gallons of water per minute can be delivered to the hatchery system by gravity flow from Speelyai Creek.

There are approximately 166,450 cubic feet of available rearing space. This space consists of four 17'x3'x3' intermediate troughs, twenty-four 10'x 80'x4' raceways, four 115'x10'x5' raceways, and one large asphalt pond that serves as an adult holding/spawning pond for both Spring Chinook and Type S Coho stocks.

Incubation consists of fifty stacks of FAL vertical incubators, two deep troughs, and a shallow trough.

The Speelyai hatchery site also includes two residences, a hatchery building, a two bay storage building, a shop/garage, a domestic pump house, a small storage building, and two chemical storage buildings.

The Speelyai hatchery staff is also responsible for ten 20'x20'x20' net pens located at Speelyai Bay in Merwin Reservoir.

Adult Holding

2018 Lewis River Spring Chinook, Hatchery Origin

The first fish was received on February 26, 2018. Brood stock was collected from both the Merwin Dam Fish Collection Facility and Lewis river hatchery. Disposition is as follows:

Adults Received	1,598
Jacks Received	36
Mortality (16.0%)	256
Adults Spawned	1328
Non-Viable	1
Nutrient Enhancement	0
Landfill	1,634

Both ELISA and PCR (Polymerase Chain Reaction) testing that checks DNA extracts for bacterium in salmonid eggs were performed. A sufficient number of females were tested to ensure that only gametes from females that tested in the "Below Low" range will be used in the February release groups. All mortality was disposed of at the Cowlitz County Landfill.

2018 Lewis River Spring Chinook, Wild Origin

The first fish was received on March 19, 2018. Brood stock was collected from both the Merwin Dam Fish Collection Facility and Lewis river hatchery. Disposition is as follows:

Adults Received	19
Jacks Received	1
Mortality (0.0%)	0
Adults Spawned	0
Non-Viable	0
Landfill	0
Nutrient Enhancement	0

A decision was made to discontinue the mixed origin program. On July 5, 2018, all 19 adults and one jack were hauled to the upper Lewis river above Swift reservoir.

2018 Lake Merwin Kokanee

Adult collection started September 14, 2018. Fish were collected from the hatchery effluent Kokanee trap and held in raceway 12. All carcasses were disposed of at the Cowlitz County landfill. Disposition is as follows:

Adults Trapped	288
Mortality (0.0%)	0
Returned to Stream	0
Adults Spawned	288
Non-Viable	0

2018 Lewis River Type S Coho

The first fish were received on September 11, 2018. Brood stock was collected at the Merwin Dam Fish Collection Facility and Lewis River trap. Disposition is as follows:

Adults Received	1,328
Jacks Received	77
Mortality (4.1%)	54
Adults Spawned	1,169
Non-Viable	5
Nutrient Enhancement	0
Landfill	1,405

All carcasses were disposed of at the Cowlitz County Landfill.

SPEELYAI HATCHERY ADULT COLLECTION

SPECIES	ESTIMATED TRAPPED / RECEIVED		RETURNED TO STREAM			SHIPPED / PLANTED			MORTALITIES			CARCASS DISTRIBUTION			LETHAL SPAWNED				LIVE SPAWNED			ESTIMATED ON-HAND		MARKS RECOVERED			ESTIMATED EGGS TAKEN
	A	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	NVF	J	M	F	J	A	J	M	F	J	
CK:SP:LEHA:18:H	1,598	36							92	164	22	3	10		526	802	1	14	262					152	201	9	2,498,000
CK:SP:LEWI:18:W	19	1				15	4	1																N/A	N/A	N/A	0
CO:SO:LEHA:18:H	1,328	77							14	40	6	24	76	46	572	597	5	25						161	214	7	1,500,000
KO:NA:MERL:18:M	288	0													144	144								N/A	N/A	N/A	140,000

Egg Take and Incubation

2018 Lewis River Spring Chinook, Hatchery Origin

Egg Inventory and distribution is as follows:

Total Egg Take	2,527,850
Egg Loss (5.2%)	131,850
Destroyed	0
Shipped	0
Ponded	2,396,000
Fecundity	3,152

2018 Lewis River Type S Coho, Hatchery Origin

Egg Inventory and distribution is as follows:

Total Egg Take	1,556,439
Egg Loss (12.8%)	199,000
Shipped	1,357,439
Fecundity	2,607

2018 Lake Merwin Kokanee, Mixed Origin

Egg Inventory and distribution is as follows:

Total Egg Take	140,000
Adjustment	-16,600
Egg Loss (10.9%)	13,400
Fecundity	857

At the time of this report, the 2018 Kokanee are still in incubation and will be ponded in January 2019.

Rearing Program

2016 Lake Merwin Kokanee

On March 20, 2018, the remaining total of 44,255 Kokanee were released from Speelyai hatchery at an average size of 5.63 F/LB.
Disposition is as follows:

Stock Inventory

Beginning Balance	94,300
Rearing Mortality (9.7%)	9,125
Fish Shipped	0
Pounds Shipped	0
Fish Planted	85,175
Pounds Planted	11,269
Beginning Pounds	23
Feed Fed (lbs.)	8,857
Net gain (lbs.)	11,246
Conversion	0.79:1
Population Adjustment	0

2016 Goldendale Rainbow

The power canal received 2,670 fish at 2.67 F/LB on May 24th and Swift reservoir received 41,920 at 2.52 F/LB on May 29th.
Disposition is as follows:

Stock Inventory

Beginning Balance	58,000
Rearing Mortality (4.1%)	1,910
Beginning Pounds	580
Pounds Planted	17,635
Feed Fed (lbs.)	13,137
Net Gain (lbs.)	17,055
Conversion	0.77:1
Population Adjustment	-11,500

2017 Lewis River Spring Chinook, Hatchery Origin

Coded-wire tagging and mass marking were completed on April 17, 2018. In May, 886,850 hatchery origin spring Chinook were shipped to Lewis river hatchery at an average size 139 F/LB. In December, the remaining 337,950 were shipped to Lewis river hatchery. Disposition is as follows:

Stock Inventory

Beginning Balance	1,287,600
Rearing Mortality (4.0%)	50,407
Fish Shipped	1,224,800
Pounds Shipped	27,984
Fish Planted	0
Pounds Planted	0
Beginning Pounds	1,171
Feed Fed (lbs.)	21,449
Net gain (lbs.)	26,813
Conversion	0.80:1
Population Adjustment	-12,393

2017 Lewis River Spring Chinook, Mixed Origin

From September 25th through September 27th, 91,420 mixed origin spring Chinook were LV clipped. On November 1st, 15th, and the 27th, a total 91,340 were hauled to the PacifiCorp stress-relief raceways in Woodland to be planted.
Disposition is as follows:

Stock Inventory

Beginning Balance	93,000
Rearing Mortality (3.3%)	3,155
Fish Shipped	0
Pounds Shipped	0
Fish Planted	91,340
Pounds Planted	6,888
Beginning Pounds	85
Feed Fed (lbs.)	4,979
Net gain (lbs.)	6,803
Conversion	0.73:1
Population Adjustment	1,635

2017 Lake Merwin Kokanee

On June 1st, 73,230 kokanee at 134 F/LB were released from Speelyai hatchery. Another 46,495 were released on October 15th at an average size 9.23 F/LB. At the time of this report, there are 51,200 fish on hand at an average size of 9.78 F/LB scheduled to be released from raceways into Speelyai bay in March 2019.
Disposition is as follows:

Stock Inventory

Beginning Balance	209,000
Rearing Mortality (14.3%)	28,610
Fish Planted	119,725
Pounds Planted	5,586
Beginning Pounds	46
Feed Fed (lbs.)	9,106
Net gain (lbs.)	10,776
Conversion	0.85:1
Population Adjustment	-9,465

2017 Goldendale Rainbow

On December 4, 2018, 41,950 fish were received from Merwin Hatchery at an average 11 F/LB. At the time of this report there are 41,800 fish at an average size 10.30 F/LB. These fish are currently being reared in Pond 13 and are on schedule to be planted into Swift reservoir and the power canal in May 2019.

2018 Lewis River Spring Chinook, Hatchery Origin

At the time of this report, 2,050,300 Chinook have been ponded and are at an average size of 840 F/LB. There are an additional 300,000 in incubation that will be ponded in early January and are included in the disposition below. Mass marking and coded-wire tagging will begin in March 2019.
Disposition is as follows:

Stock Inventory

Beginning Balance	2,396,000
Ponding Mortality (2.0%)	48,350
Pounds Ponded	2,178
Pounds on Hand	2,441
Feed Fed (lbs.)	379
Net gain (lbs.)	263
Conversion	1.44:1

2018 Lake Merwin Kokanee

At the time of this report there are 110,000 fish in incubation to be ponded in early January 2019.

YEARLY TEMPERATURE REPORT

HATCHERY: Speelyai **YEAR:** 2018 **WATER SOURCE:** Speelyai Creek

DAY	JAN MAX	JAN MIN	JAN RAIN	FEB MAX	FEB MIN	FEB RAIN	MAR MAX	MAR MIN	MAR RAIN	APR MAX	APR MIN	APR RAIN
1	48.2	45.9		48.7	47.8	1.00	46.9	46.4	1.35	49.1	48.2	0.04
2	48.2	45.7		48.6	48.4	0.56	48.4	46.4	0.24	49.1	48.2	0.5
3	46.9	45.7		48.9	48.4	0.27	48.0	45.7	0.03	48.9	47.8	0.02
4	47.7	46.2		49.6	48.7	0.28	48.2	45.7		48.7	48.2	0.1
5	47.8	46.6	0.39	50.0	49.3	0.15	48.2	45.7	0.19	48.9	48.6	0.17
6	48.4	47.7	0.80	50.0	48.7	0.15	48.9	45.5		49.5	48.9	1.05
7	48.7	47.7		49.8	48.7		48.9	45.3		50.4	49.3	1
8	48.6	46.9	0.29	49.8	48.7		49.3	46.8	0.04	50.4	49.6	1.1
9	48.2	46.8	0.60	49.5	47.8		48.6	47.8	0.83	49.6	49.3	0.44
10	48.7	47.7	0.15	49.1	47.7		49.8	46.0		50.5	48.6	0.08
11	48.2	47.7	1.03	48.4	46.9		50.0	46.0		50.2	49.6	0.7
12	48.7	47.7	1.10	48.6	46.2		51.1	47.3		49.8	49.1	0.89
13	49.1	47.7	0.23	46.9	45.3		51.6	48.0		49.1	48.6	1.34
14	49.1	48.4	0.55	46.9	45.3	0.27	49.8	48.4	0.34	48.9	48.6	1.89
15	49.1	48.0		47.3	45.5	0.79	50.5	46.6	0.02	49.3	48.7	1.15
16	49.3	48.0	0.59	48.2	45.5	0.44	50.5	46.2	0.07	49.6	48.7	0.91
17	49.5	48.0	0.05	48.2	46.8	1.67	50.0	47.1	0.28	48.9	48.6	0.49
18	49.6	48.4	1.09	48.6	47.1	1.36	48.9	47.3	0.18	49.1	48.4	0.13
19	49.1	48.0	0.53	46.8	46.8	0.30	49.8	46.4		49.8	48.4	
20	48.4	47.8	0.89	46.9	45.9		51.1	46.6		50.5	48.6	
21	48.4	47.8	0.62	46.9	45.0	0.18	51.1	46.2	0.88	50.9	48.6	0.1
22	48.7	48.2	0.60	47.1	44.8	0.08	50.0	46.5		50.7	49.1	
23	48.9	47.8	0.27	46.4	44.8		48.9	46.9	1	50.8	48.9	
24	48.4	47.5	1.15	46.6	43.3		48.9	46.2	0.55	57.4	49.3	
25	48.6	47.5	0.93	46.4	43.1	1.00	47.7	46.2	0.45	52.6	49.9	
26	47.5	46.8	1.20	46.6	45.9	0.63	50.4	46.2	0.18	53.0	50.0	
27	48.7	46.9	1.15	46.6	44.5	0.12	49.8	46.8	0.73	53.2	50.4	
28	48.6	46.9	0.37	46.8	46.2	0.53	48.4	47.8	0.4	52.5	50.3	0.08
29	49.3	48.2	0.03				48.9	47.8		52.5	50.2	0.08
30	48.9	48.2	1.25				49.1	47.8		51.3	50.2	0.08
31	48.7	48.0	0.04				48.9	48.4				
Avg / Tot	48.6	47.4	15.90	48.0	46.5	9.78	49.4	46.7	7.76	50.5	49.0	12.34
Acc. Rain	15.90			25.68			33.44			45.78		

DAY	MAY MAX	MAY MIN	MAY RAIN	JUN MAX	JUN MIN	JUN RAIN	JUL MAX	JUL MIN	JUL RAIN	AUG MAX	AUG MIN	AUG RAIN
1	51.1	50.0		52.3	51.8	0.11	54.5	52.9		57.4	55.4	
2	51.1	50.0		52.5	51.6		54.5	53.4	0.04	57.2	55.4	
3	52.2	49.8		53.8	51.6		54.5	52.9		55.8	55.0	
4	52.5	49.8		53.9	52.6		54.5	52.5		55.2	54.0	
5	52.7	51.3		52.9	52.2		54.7	54.0		55.9	54.1	
6	52.7	51.4	0.08	54.1	51.3		55.6	53.6		56.5	54.9	
7	53.1	51.8		53.2	52.9		55.6	53.8		56.8	55.4	
8	53.1	51.8		53.1	52.5		55.6	54.0		57.2	55.2	
9	53.2	51.8	0.38	52.9	52.3	0.36	55.8	54.0		57.2	55.8	
10	52.9	51.8	0.04	52.9	52.3	0.25	55.0	54.1		57.2	55.8	
11	52.3	51.4	0.1	52.3	51.8	0.67	54.9	54.0		57.2	55.9	0.1
12	52.7	50.9		53.6	51.4		55.8	53.6		56.3	55.0	0.1
13	52.2	51.1		53.6	51.6	0.02	56.5	54.7		56.3	55.0	
14	54.0	52.2		53.2	52.5	0.01	56.5	55.2		56.3	54.9	
15	56.0	52.7		52.7	52.0		55.6	54.9		56.3	54.9	
16	54.0	52.7		52.9	51.8		55.8	55.0		56.7	54.7	
17	54.0	51.8		53.6	51.8	0.3	57.0	55.0		55.6	54.9	
18	54.0	52.1		54.3	52.7	0.03	56.8	55.2		56.7	54.9	
19	52.3	51.6		54.6	53.0		56.1	55.2		56.1	54.7	
20	53.1	51.6		54.9	53.1		55.4	54.5		56.3	55.0	
21	53.4	52.0		55.9	54.0		55.6	53.8		56.3	55.0	
22	53.9	52.0		55.2	53.4		55.6	54.0		56.3	55.0	
23	54.3	52.5		55.1	53.4		56.3	54.1		56.3	55.0	
24	54.5	53.1		54.5	53.6		56.7	54.1		55.6	55.0	
25	54.5	53.1		55.4	53.6	0.05	56.8	55.0		55.4	53.8	
26	53.8	52.0		55.0	53.6		56.8	55.0		54.5	53.2	
27	52.3	51.6		55.0	52.9		57.0	55.0		54.5	54.0	0.8
28	53.6	51.6		54.7	53.1		56.8	55.0		55.2	53.2	
29	53.8	52.3		54.0	53.2		56.8	54.9		55.9	52.0	
30	53.2	51.8		54.5	52.9					56.7	53.8	
31	52.7	51.1								55.9	54.5	
Avg / Tot	53.2	51.6	0.60	53.9	52.6	1.80	55.8	54.3	0.04	56.2	54.7	1.00
Acc. Rain	46.38			48.18			48.22			49.22		

DAY	SEP MAX	SEP MIN	SEP RAIN	OCT MAX	OCT MIN	OCT RAIN	NOV MAX	NOV MIN	NOV RAIN	DEC MAX	DEC MIN	DEC RAIN
1	55.9	53.4		53.1	51.4	0.05	52.2	51.3	1	50.4	48.7	1
2	55.2	51.8		54.1	52.3	0.05	52.9	52.2	0.9	49.8	48.6	
3	55.9	51.8		54.1	49.3		53.1	52.0	0.3	49.6	46.4	
4	55.9	52		52.7	48.7		53.1	52.0	0.92	47.1	46.3	
5	55.8	51.4		52.5	48.9		52.9	51.6	0.2	47.1	45.9	
6	56.5	52.2		52.5	48.9	1.04	52.3	51.1	0.65	46.2	45.1	
7	56.5	52.3		53.2	48.9		52.2	50.4	0.07	44.9	43.7	
8	55.9	52.2	0.13	52.9	51.8	0.33	51.1	47.7		45.3	43.7	0.14
9	55.9	52.2		53.2	51.5	0.56	48.6	47.3		46.6	45.3	0.03
10	55.6	52.2	0.25	54.0	50.9		50.2	47.3		46.6	46.0	0.85
11	55.0	53.1	0.28	53.1	50.2		48.9	47.5		47.8	46.4	0.78
12	54.0	52.9	0.71	52.5	49.5		49.6	47.8		48.1	46.7	1.78
13	54.3	52.7	0.15	52.3	48.9		49.3	48.4		48.4	46.9	0.39
14	54.1	52.5	0.11	51.8	48.7		50.5	48.0		48.6	46.6	0.01
15	54.9	52.0		51.8	49.3		50.7	48.7	0.14	48.7	46.6	0.32
16	54.0	52.0	0.64	52.7	49.3		50.0	48.4	0.02	48.2	47.3	0.27
17	54.0	51.8	0.41	53.2	49.3		51.8	48.6		48.7	48.0	0.55
18	54.1	50.7		53.1	49.5		51.8	48.6		49.3	48.0	2.54
19	54.1	50.2		52.0	48.7		49.6	48.6		49.8	48.7	0.22
20	54.1	51.3		51.8	48.7		49.6	48.6		50.0	48.7	0.03
21	54.5	51.1		51.1	48.7		50.0	48.7		50.0	46.8	
22	54.1	50.9	0.17	51.6	48.7		50.7	50.0		47.7	45.9	0.06
23	54.1	51.6	0.17	51.3	48.6		51.3	50.5	2.08	47.1	46.0	1.55
24	53.6	50.5		51.8	48.9	0.14	50.9	49.6	0.15	47.7	46.0	0.31
25	53.8	50.4		52.7	50.5	0.19	51.3	47.7		48.4	45.5	
26	54.1	50.4		52.2	51.4	1.15	50.0	47.7		46.4	46.0	0.1
27	54.5	50.7		52.7	51.6	0.35	50.9	49.6	1.1	46.8	46.2	0.6
28	54.7	51.3		53.4	51.4	3.12	50.9	49.6	0.28	47.7	47.1	0.1
29	55.2	51.8		52.9	51.6	0.75	50.9	48.7		47.8	46.9	1.03
30	53.2	51.4		52.9	51.3	0.25	50.0	48.6		48.7	47.3	1.1
31				52.5	51.3	0.55				48.2	47.1	
Avg / Tot	54.8	51.7	3.02	52.6	50.0	8.53	50.9	49.2	7.81	48.0	46.6	13.76
Acc. Rain	52.24			60.77			68.58			82.34		

DISEASES AND TREATMENTS

DATE:	1/1/18 - 12/31/18	HATCHERY:	SPEELYAI HATCHERY

DATE	BROOD YEAR/ SPECIES	POND NUMBERS	TREATMENT CHEMICAL	DISEASE
2/3 - 4/19	2017 Lewis River Spring Chinook	Raceways	Formalin Drip	Costia
3/4	2017 Kokanee	Raceways	Formalin Drip	Costia
3/15 - 9/3	2018 Lewis River Spring Chinook Brood	Raceways 25-28	Formalin Drip	Fungus
9/28 - 10/26	2018 Lewis River Type S Coho Brood	Adult Pond	Hydrogen Peroxide	Fungus
9/14 - 9/24	2018 Kokanee Brood	Raceway 12	Formalin Drip	Fungus
10/14 - 11/17	2018 Type S Coho	Incubation	Formalin Drip	Fungus
8/30 - 11/22	2018 Spring Chinook	Incubation	Formalin Drip	Fungus
9/28 - 12/3	2018 Kokanee	Incubation	Formalin Drip	Fungus

MAINTENANCE AND CAPITAL PROJECTS

Maintenance

1. Replace UV bulbs on domestic water system.
2. Annual preventative maintenance to fork-lift.
3. Annual preventative maintenance to generator.
4. Annual preventative maintenance to three-phase compressor.
5. Annual preventative maintenance to residential HVAC.
6. Continual patching of potholes in entry road.
7. Annual preventative maintenance to tractor.
8. Annual maintenance completed on traveling screens at intake structure.

Capital

1. Pond 13 re-lined with new asphalt.
2. New F-250 pickup truck

Complex Staff Jan. 2018-Dec. 2018

Complex Manager-	**Aaron Roberts**
FHS4-	**Michael Chamberlain**
FHS4-	**Kevin Young**
FHS3-	**Scott Peterson**
FHS3	**Luke Miller**
FHS3	**Jesse Cody**
FHS2-	**Jay VonBargen**
FHS2-	**Jim Trammell**
FHS2-	**Dwayne Fossen**
FHS2-	**Bryan Coyle**
FHS2-	**Grant Sill**
FHS2-	**Tiffany Farrar**
FHS2-	**Doni Grove**
FHS2-	**Chris Roe**
MHCC Student-Work Study	**Buddy Phibbs**
MHCC Student-Work Study	**Max Wagner**

2018 LEWIS RIVER COMPLEX

DISTRIBUTION	CK:SP:LEHA:H:18			CK:FA:UNKN:W:18			CK:FA:UNKN:H:18			CK:FA:UNKN:H:17			CO:SO:LEHA:H:18			CO:SO:LEWI:W:18			CO:NO:KAHA:H:18			CO:NO:LEWI:H:18		
	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J
AMERICAN CANADIAN							18	26	2				88	35	126				238	237	3	610	763	17
CAP							12	10	1				0	1	1,150									
Landfill	649	992	36	3	2	2	21	12	2			1	626	744	136	1						263	230	20
NW Harvest							228	161	9				616	511	2,882				437	406	2	709	301	1,006
Forest Service																								
Nutrient Enhancement																						1,698	774	1,057
Salvation Army																								
Shoshone Bannock																								
Schools																								
Cowlitz Tribe	1						15	19							13							1	1	
Chinook Tribe																								
Faith Harvest																								
Yakima Tribe																								
N. County FB																								
NW Indian V.A.																								
Wanapum Tribe																								
TOTAL	650	992	36	3	2	2	294	228	14			1	1,330	1,291	4,307	1			675	643	5	3,281	2,069	2,100

DISTRIBUTION	CO:NO:LEWI:W:18			CO:NO:LEWI:H:17			CO:NO:LEWI:W:17			SH:SU:MEHA:H:19			SH:WI:MEHA:H:19			SH:WI:MEHA:H:18			SH:WL:LEWI:18:H			SH:WL:LEWI:18:W			KO:NA:MERL:M:18			Total
	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	
AMERICAN CANADIAN	15	26								1	3																	2,208
CAP										176	341																	1,691
Landfill	13	1	1	43	33	9		1		192	211		21	37		61	64			3		2	2		144	144		4,722
NW Harvest	14	6								112	203		11	18		153	214											7,999
Forest Service																												
Nutrient Enhancement				432	190	44																						4,195
Salvation Army																												
Shoshone Bannock																												
Schools																												
Cowlitz Tribe										729	1,265		75	122		264	500											3,005
Chinook Tribe										69	120					23	33											245
Faith Harvest																												
Yakima Tribe										21	44																	65
N. County FB																												
NW Indian V.A.																												
Wanapum Tribe																												
TOTAL	42	33	1	475	223	53		1		1,300	2,187		107	177		501	811			3		2	2		144	144		24,130

Executive Summary

All adult returns on the NF Lewis River for all species were good with a significant improvement in Spring Chinook. All broodstock numbers were met with the ability to send Early Coho, Late Coho, Late Winter Steelhead and Spring Chinook upstream for reintroduction. Broodstock holding and mortality was normal for all stocks the biggest improvement again were Spring Chinook being held at Speelyai Hatchery and staff had provided shade covers on the ponds along with prescribed formalin treatments and salt to ensure the best possible conditions for these fish. As a result of broodstock being met and mortality not increasing we were able to meet all egg take program goals.

As all stocks are important on this watershed but again emphasis was on Spring Chinook. Starting with the 2017 brood we now have five release strategies. The release strategies are to plant one group in October, three groups in February and one group in June. The total segregated production is now 1.35 million versus 1.25 million. Due to the agreement with PacifiCorp that the 100K NOR Spring Chinook planted upstream will now be incorporated into the lower river segregated hatchery production with split of 50K in October and 50K in June to establish a zero age release strategy. The June release is a minimum 50K program release goal but may have the ability to provide more pending on available broodstock. The 2017BY we were not able to plant a June release group but with the 2018BY we will be planting in June 2019 as our first zero age plant. All release strategies have allocated coded wire tags for the ability to track each strategy. This study will continue for a minimum of three years with the potential of continuing longer until results can be shown.

All facilities kept up with routine maintenance and had some minor projects done this year. There were only a few capital projects done in 2018. Thanks to our outstanding WDFW staff and the local staff from PacifiCorp, all three stations are looking and operating well.

As we move forward into re-licensing, we will be presented with many new challenges, both with upstream re-introduction, facilities modifications and continuing changes to our program goals to better provide higher quality smolts and better adult returns. Staff here on the Lewis River system are some of the best in the industry, and committed to facing these challenges with both professionalism and dedication. Their efforts are much appreciated.

Mitigation Summary

Stock	Mitigation Target	Actual Production
Spring Chinook	**1,250,000@ 8-12 FFP**	710,708 @ 12 FPP
Early Coho	**1,100,000@ 16 FFP**	1,173,443 @ 16.3 FPP
Late Coho	**900,000@ 16 FFP**	842,928 @ 16.2 FPP
Summer Steelhead	**175,000@ 4.8 FFP**	182,178 @ 6.1 FPP
Winter Steelhead	**100,000@ 4.8 FFP**	104,746 @ 5.7 FPP
Wild Winter Steelhead	**50,000@ 6-8 FFP**	52,119 @ 8.6 FPP
Kokanee	**12,500 Pounds**	11,269 Pounds
Rainbow	**50,000@ 2.5 FFP**	47,893 @ 2.5
***Wild Spring Chinook**	**100,000 @ 45-55 FFP**	91,340 @ 13.3 FPP

*** Planted in lower river at the stress relief ponds in November 2018.**

ATTACHMENT 1 –
Total Dissolved gas and Water Temperature assessment: Lewis River Hatchery, North fork Lewis River

ATTACHMENT 1

Total Dissolved Gas and Water Temperature Assessment

Lewis River Hatchery, North Fork Lewis River.

PACIFICORP
A BERKSHIRE HATHAWAY ENERGY COMPANY

Erik Lesko
Senior Environmental Analyst

Table of Contents

Attachments

Figures

Tables

I. Introduction

Elevated TDG levels at Lewis River Hatchery have been a concern since at least 1988. In a memo from Mr. Robin Nicolay (hatchery manager at the time) to Mr. Wayne Daley of Fish Pro dated June 29, 1988, chronically high total dissolved gas (TDG) levels and extreme temperature ranges were identified as potential contributors to disease outbreaks at the hatchery. More recently, concerns have been raised regarding the effect of elevated TDG levels on the fitness and survival (SAR's) of smolts released from the facility.

This assessment focuses on six questions related to how infrastructure or operations at the hatchery may influence natural TDG and temperature levels (i.e., in-river conditions).

1) Are TDG and temperature levels measured in the ponds (using upwelling) different than ambient in-river conditions?
2) Does the upstream intake air burst system or pumps elevate TDG above ambient in-river conditions?
3) Describe the TDG and temperature profile within a loaded rearing pond?
4) What affect do the aeration towers have on TDG?
5) What affect does the reuse wall have on TDG?
6) Are there TDG and temperature differences between pond banks?

II. Site Description

The Lewis River Hatchery is located on the north bank of the North Fork Lewis at river mile 15.8 in southwest Washington State (Figure 1). Source water for the hatchery is provided by two pumping stations (the "upstream" and "downstream" intakes) that pump water directly from the river. Source water is not filtered or treated prior to entering rearing ponds. The upstream intake directs water through an underground pipeline to rearing banks 13 and 14 as well as the sorting facility (Figure 1). Water enters Bank 13 through submerged header pipes using an upwelling configuration installed in 2011. Water entering Bank 14 can be first pass, reuse from Bank 13, or a combination of both (Figure 2). First pass water in Bank 14 uses the same upwelling configuration present for Bank 13. Reuse water from Bank 13 enters Bank 14 by flowing over a concrete wall (Figure 2). Because the wall exposes reuse water to atmosphere and removes hydrostatic pressure it allows dissolved gas pressure present in the reuse water to equilibrate to ambient atmosphere (i.e., 100 percent saturation).

During periods of spill at Merwin Dam (RM 19.8), source water can be routed through degassing towers prior to entering the rearing banks to reduce potentially elevated dissolved gas pressure.

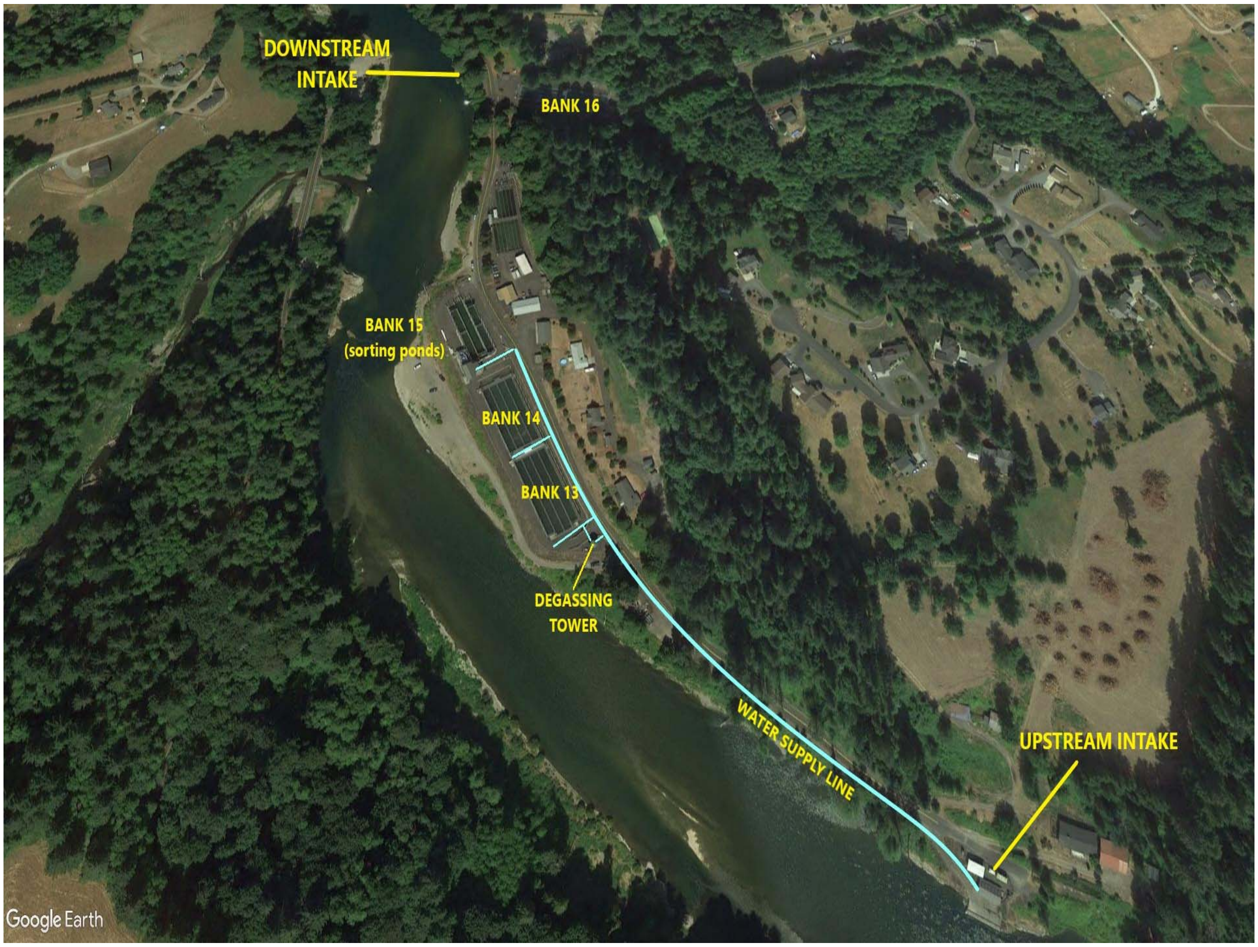


Figure 1. Aerial view of Lewis River Hatchery showing the location of rearing banks and water supply infrastructure

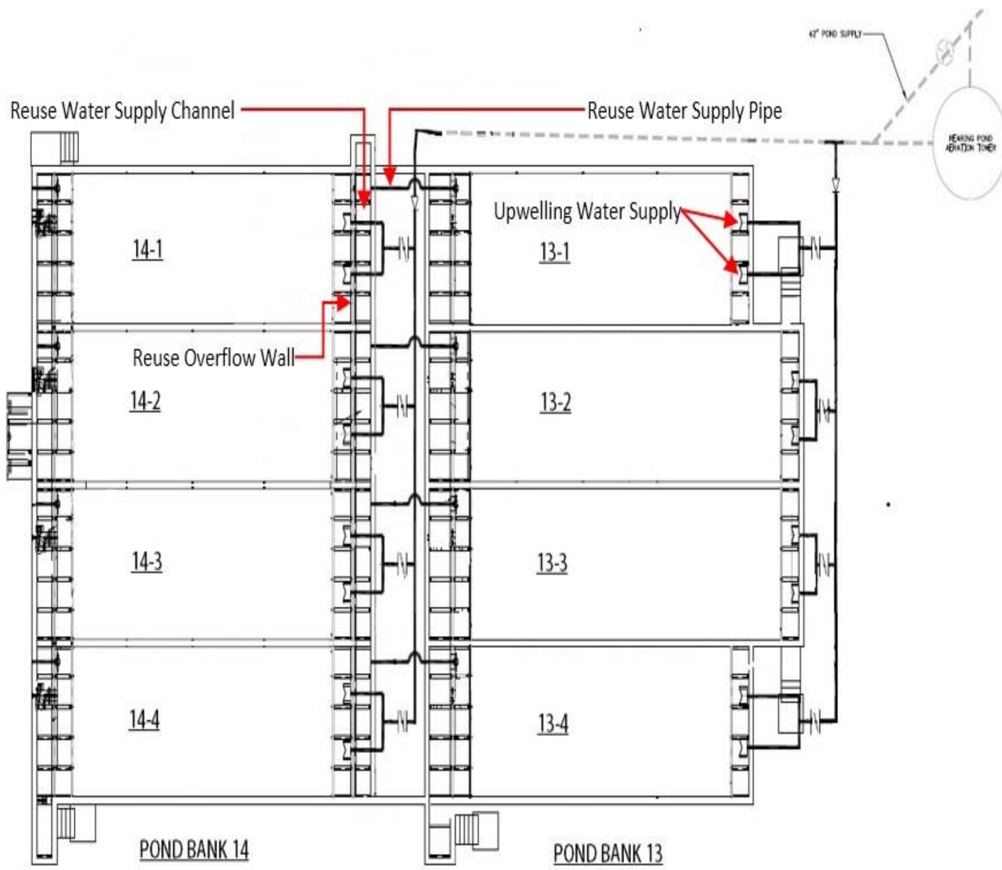


Figure 2. Piping diagram for rearing banks 13 and 14 indicating the location of the reuse water supply channel and wall.

Figure 3. Inflow configuration for Bank 14 showing the upwelling and reuse design

III. Methods

Hydrolab MS5 datasondes were deployed on August 2 until September 15, 2017. All sondes were set to continuously record temperature, TDG, depth, and battery voltage at 30-minute intervals. An external barometric pressure logger (Extech® SD700) was also placed near the upstream intake to log ambient atmospheric pressure during the assessment for calculation of percent gas saturation in the water. Deployment locations, duration and their intended purpose for each datasonde is provided in Table 1. Figure 3 illustrates these locations relative to the hatchery site.

Datasondes were suspended to a depth of 10 feet or within six inches of the bottom of each location (whichever is deepest). In rearing ponds, datasondes were suspended above the floor 6 to 8 inches to prevent erroneous readings from decaying fish waste and food.

Table 1. Site designation, location and purpose of each datasonde placement

SITE	LOCATION	PURPOSE
A (8/2 – 8/25)	Upstream of hatchery intake in the North Fork Lewis River	To measure ambient in-river TDG and water temperature without influence from the hatchery (primary control)
B (8/2 – 9/15)	Inside the screened pump intake well (upstream intake)	To measure TDG and water temperature at the pump source and near the air burst system (secondary control)
C (8/2 – 9/15)	Upstream end of Pond 13-1	To measure TDG and water temperature exiting the upwelling system
D (9/5 – 9/15)	In the water reuse channel from Pond Bank 13 to 14	To act as a control for Site E, and to provide a longitudinal TDG profile within Pond 13-1.
E (8/17 – 9/15)	Immediately downstream of the reuse inflow wall into Pond 14-1	To measure TDG after flowing over the reuse wall to determine if aeration (or degassing) benefits are observed
F (8/17 – 9/5)	Upstream end of Pond 16-3	To compare Bank 16 TDG and temperature with other rearing banks and determine if significant differences exists among individual banks or pumping stations.

***( ) denotes deployment duration**

Figure 4. Illustrated deployment location of each MS5 datasonde

IV. Results

Results here summarize various comparisons among available sites (A – F) to identify specific areas that may affect ambient TDG or temperature profiles. These comparisons are also selected to provide sufficient information to answer key questions stated in the introduction of the report. For time series comparison between sites, a summary of all measurements for all locations are represented in Attachment A1 (TDG) and A2 (water temperature).

1) Comparison between Pond 13-1 (Site C) and ambient river conditions (Site B)

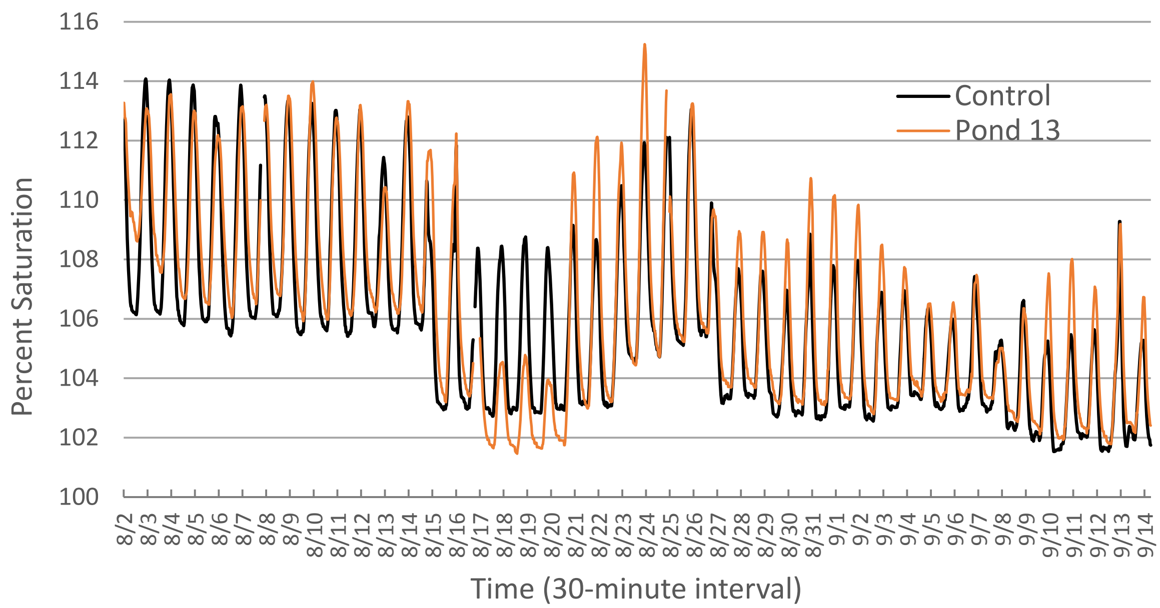


Figure 5. Time series comparison of percent saturation between the intake control (Site B) and Pond 13-1 (Site C).

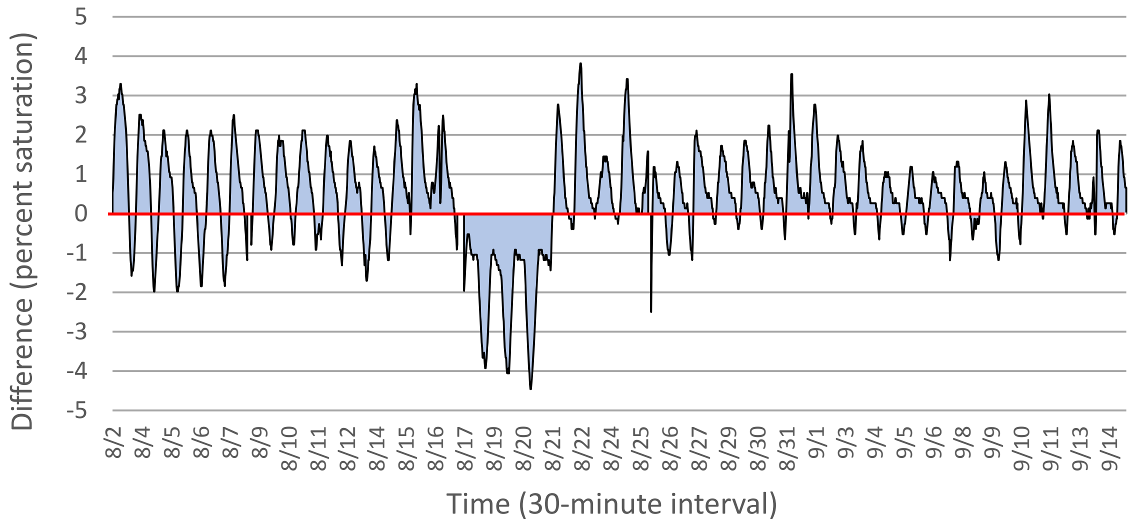


Figure 6. Difference in percent saturation measured between the intake control (Site B) and Pond 13-1 (Site C).

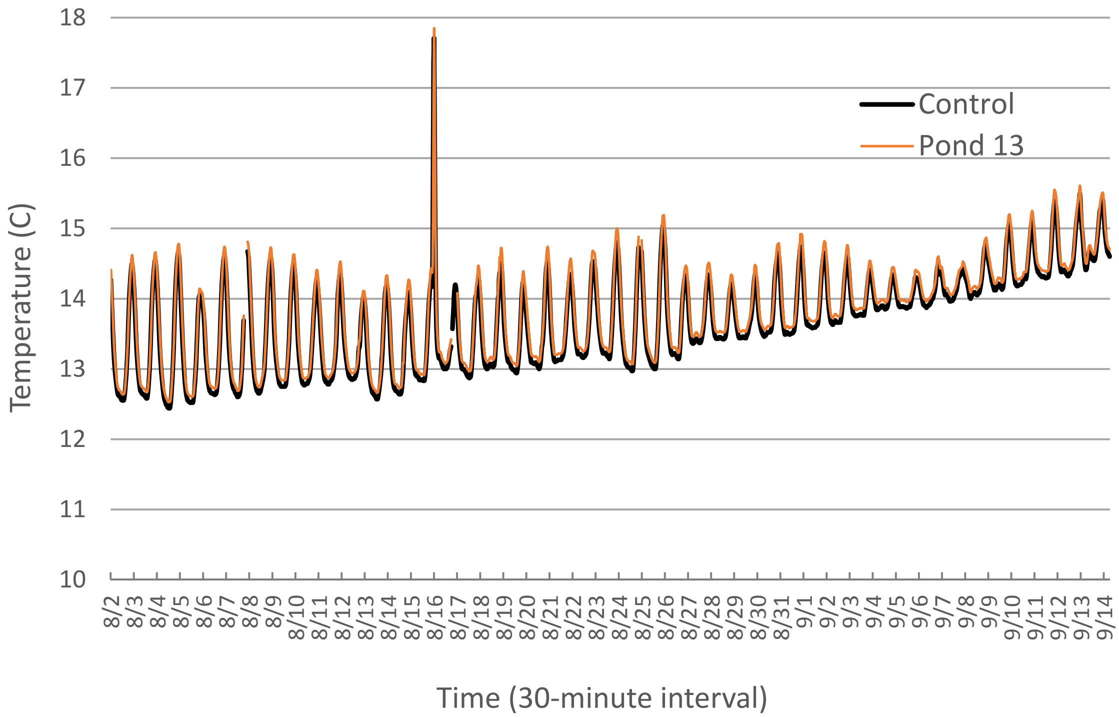


Figure 7. Time series comparison of water temperature between the intake control (Site B) and Pond 13-1 (Site C).

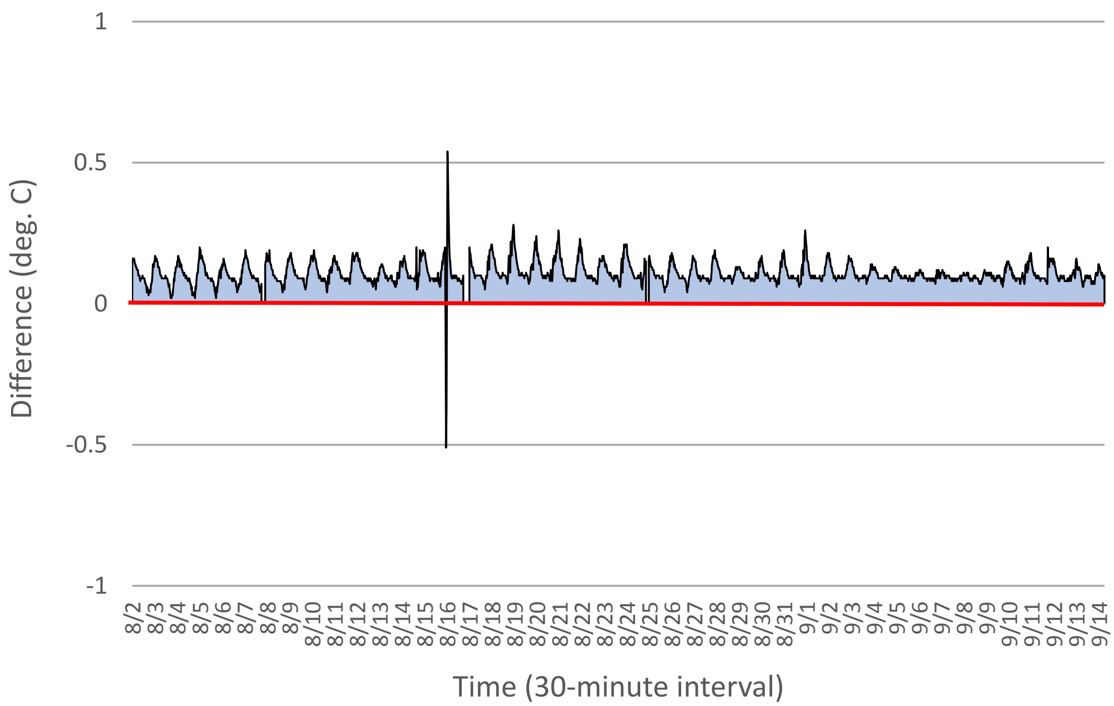


Figure 8. Difference in water temperature measured between the intake control (Site B) and Pond 13-1 (Site C).

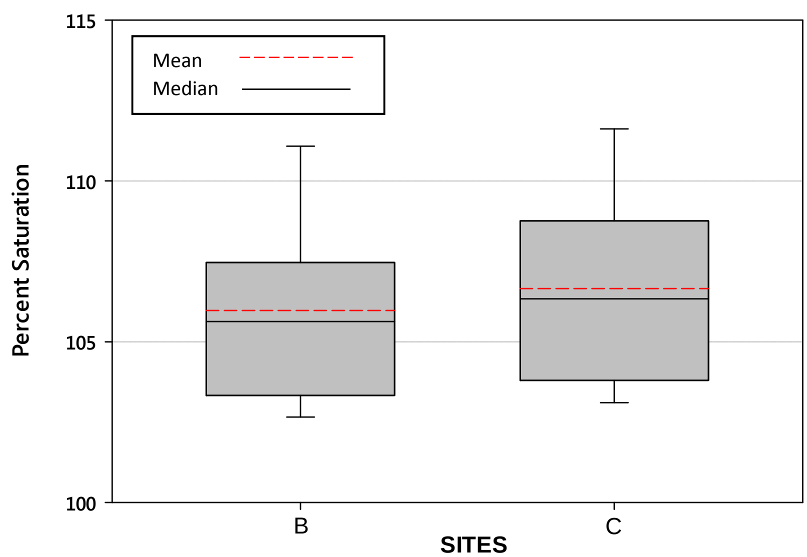


Figure 9. Box plot comparing percent saturation between sites B and C

Table 2. Summary statistics for TDG and Temperature between the intake control (Site B) and Pond 13-1 (Site C)

Metric	TDG Saturation		Temperature (C)	
	Site B	***Site C***	***Site B***	***Site C***
Mean	105.97	106.65	13.74	13.85
Standard Error	0.07	0.07	0.02	0.02
Median	105.63	106.34	13.79	13.91
Standard Deviation	3.07	3.14	0.69	0.70
Sample Variance	9.41	9.86	0.47	0.49
Range	12.55	13.46	5.27	5.32
Minimum	101.53	101.79	12.44	12.53
Maximum	114.08	115.24	17.71	17.85
Count	1825	1825	1825	1825
Significant Difference*	*Yes*		*Yes*	

* the differences in the median values among the sites are greater than would be expected by chance alone; a statistically significant difference exists (P = <0.001)

2) Comparison of TDG saturation between in-river control (Site A) and upstream intake control (Site B)

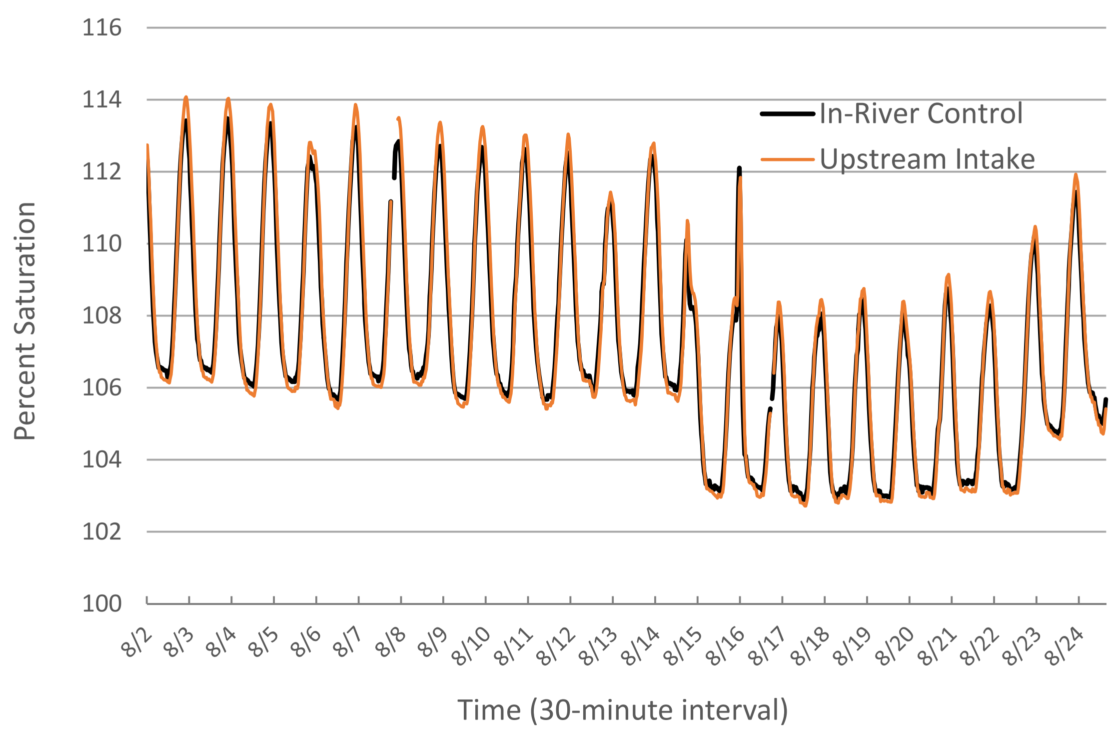


Figure 10. Time series comparison of percent saturation between the in-river control and upstream intake well (control sites)

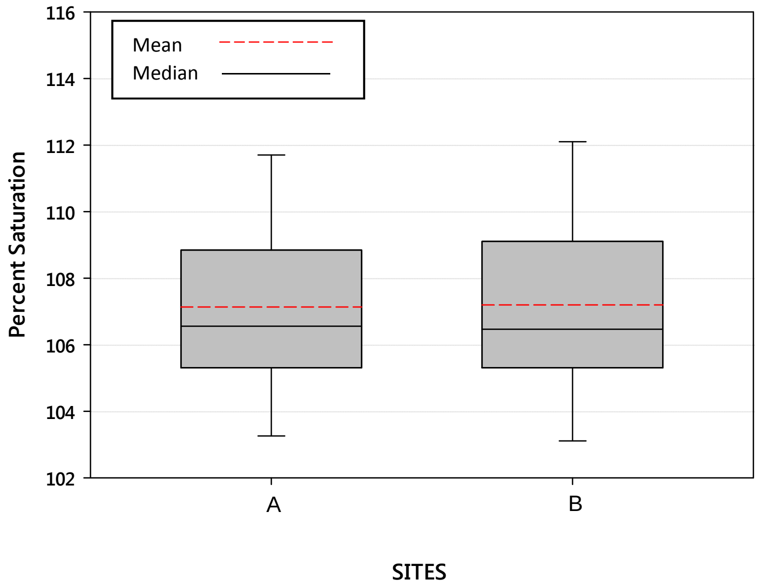


Figure 11. Box plot comparing percent saturation at sites A and B.

Table 3. Summary statistics between the in-river control (Site A) and upstream intake well (Site B)

Metric	TDG Saturation	
	Site A	***Site B***
Mean	107.14	107.20
Standard Error	0.09	0.09
Median	106.56	106.46
Standard Deviation	2.83	3.04
Sample Variance	8.02	9.25
Range	10.59	11.36
Minimum	102.89	102.72
Maximum	113.48	114.08
Count	1077	1077
Significant Difference*	*No*	

* the differences in the median values among the sites are NOT greater than would be expected by chance alone (P= 0.526)

3) Comparison of TDG and water temperature between the upstream (Site C) and downstream (Site D) areas within Pond 13-1.

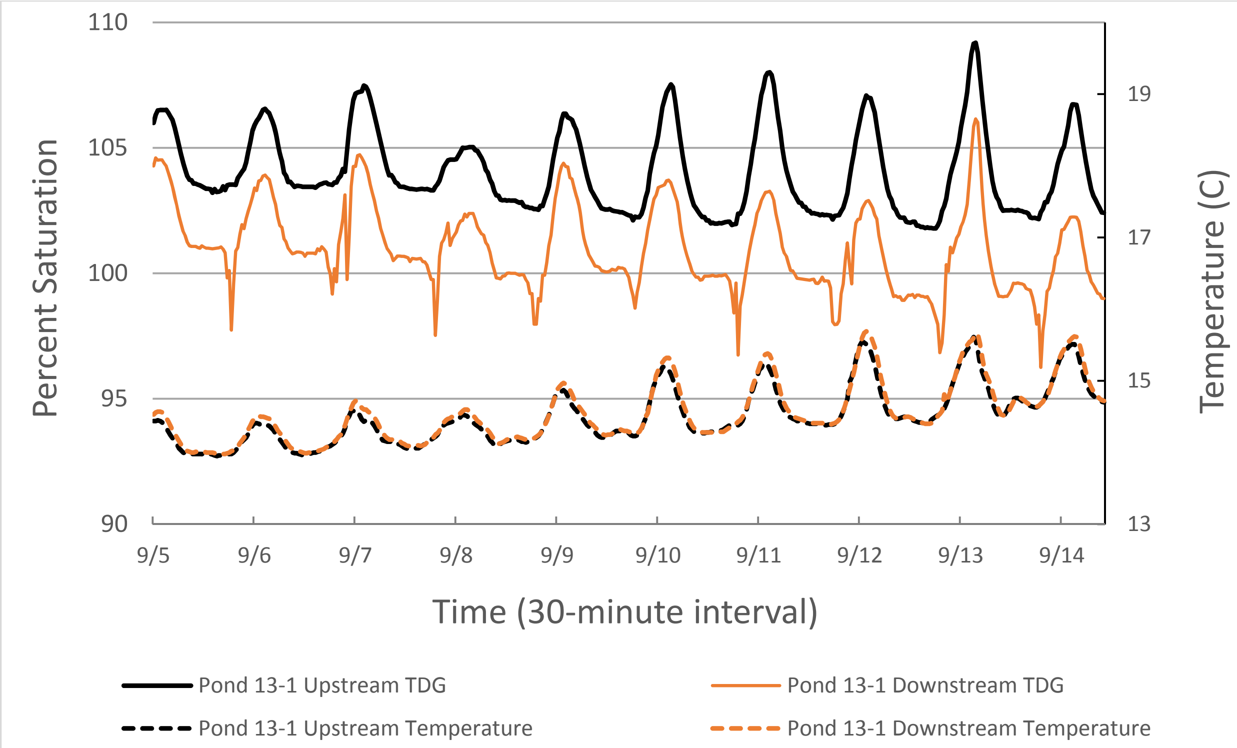


Figure 12. Time series comparison of percent saturation between the upstream (Site C) and downstream (Site D) ends in rearing pond 13-1

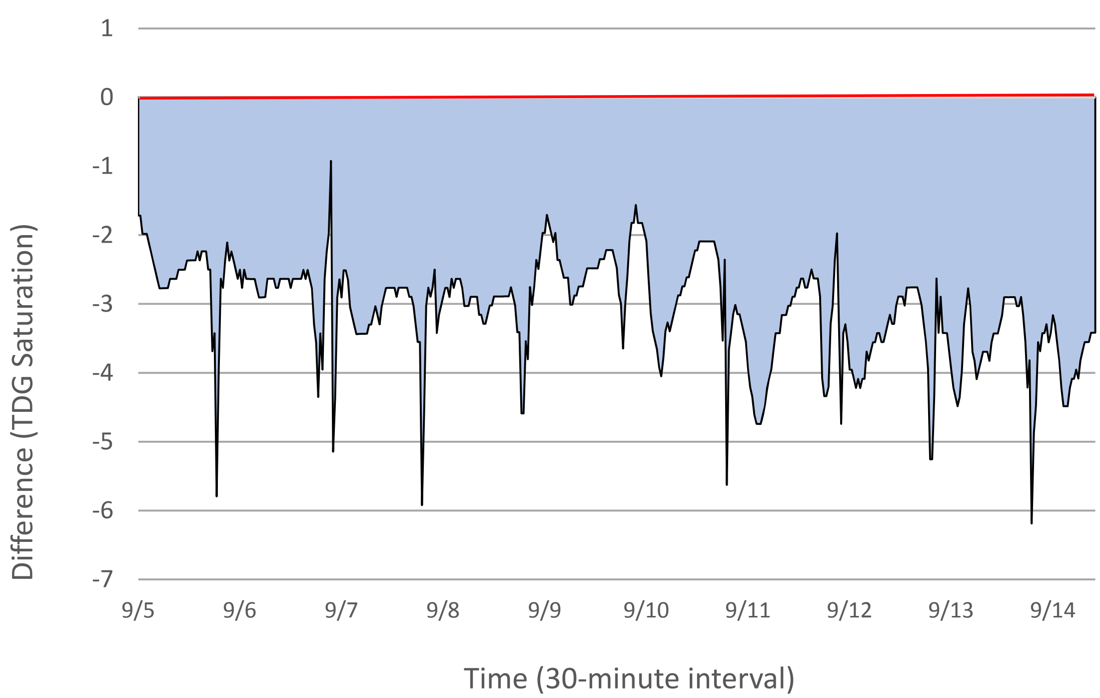


Figure 13. Differences in percent saturation between Site C and Site D in Pond 13-1

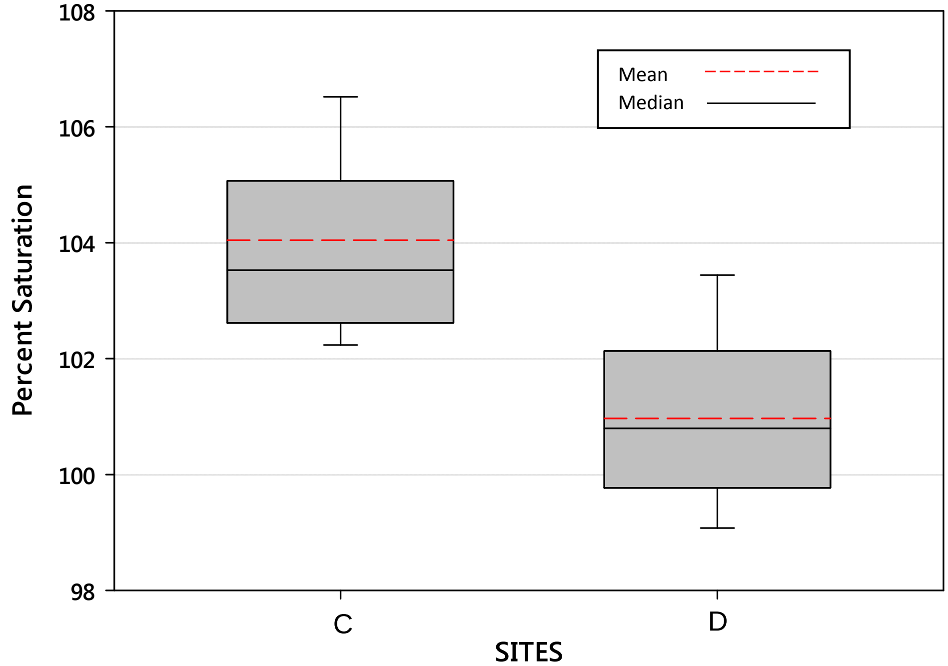


Figure 14. Box plot comparing percent saturation between sites C and D

Table 4. Summary statistics between the upstream (Site C) and downstream (Site D) locations within Pond 13-1

Metric	TDG Saturation		Temperature (C)	
	Site C	***Site D***	***Site C***	***Site D***
Mean	104.04	100.97	14.49	14.55
Standard Error	0.08	0.08	0.02	0.02
Median	103.53	100.79	14.41	14.47
Standard Deviation	1.66	1.69	0.39	0.42
Sample Variance	2.75	2.84	0.16	0.18
Range	7.40	9.91	1.66	1.71
Minimum	101.79	96.25	13.95	13.98
Maximum	109.19	106.15	15.61	15.69
Count	453	453	453	453
Significant Difference*	*Yes*		*Yes (p= <0.038)*	

* the differences in the median values among the sites are greater than would be expected by chance alone; a statistically significant difference exists (P = <0.001)

4) Comparison between in-river control (Site A), upstream intake control (Site B) and Pond 13-1 (Site C) during operation of the degassing (aeration) tower

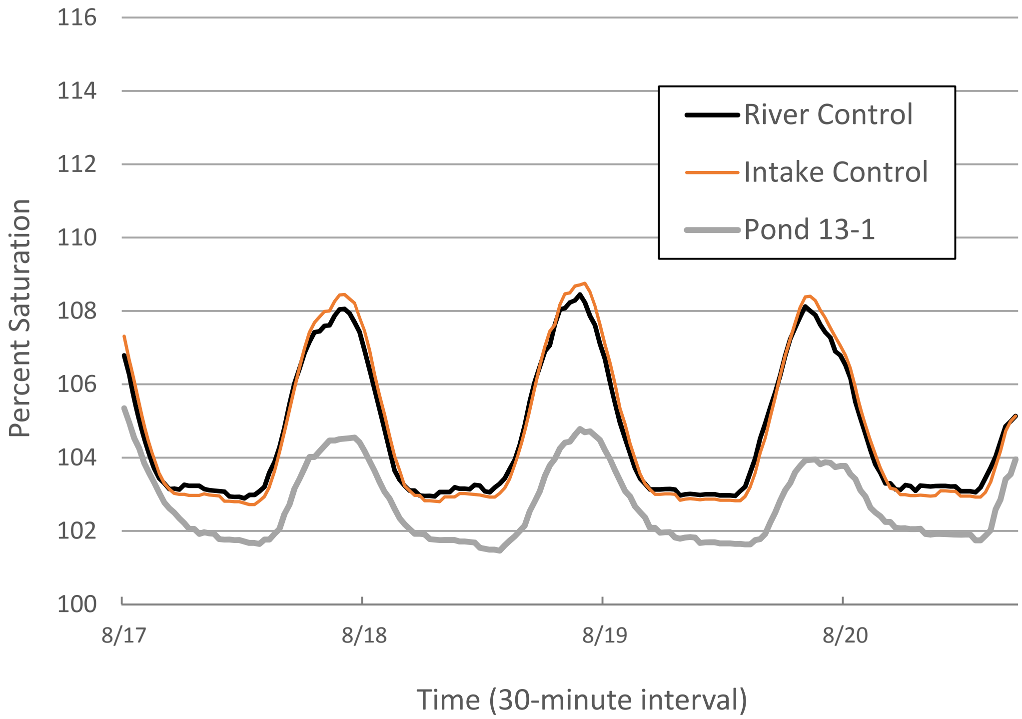


Figure 15. Time series comparison of percent saturation the in-river control (Site A), upstream intake (Site B) and pond 13-1 (Site C, downstream of degassing tower) while operating degassing tower.

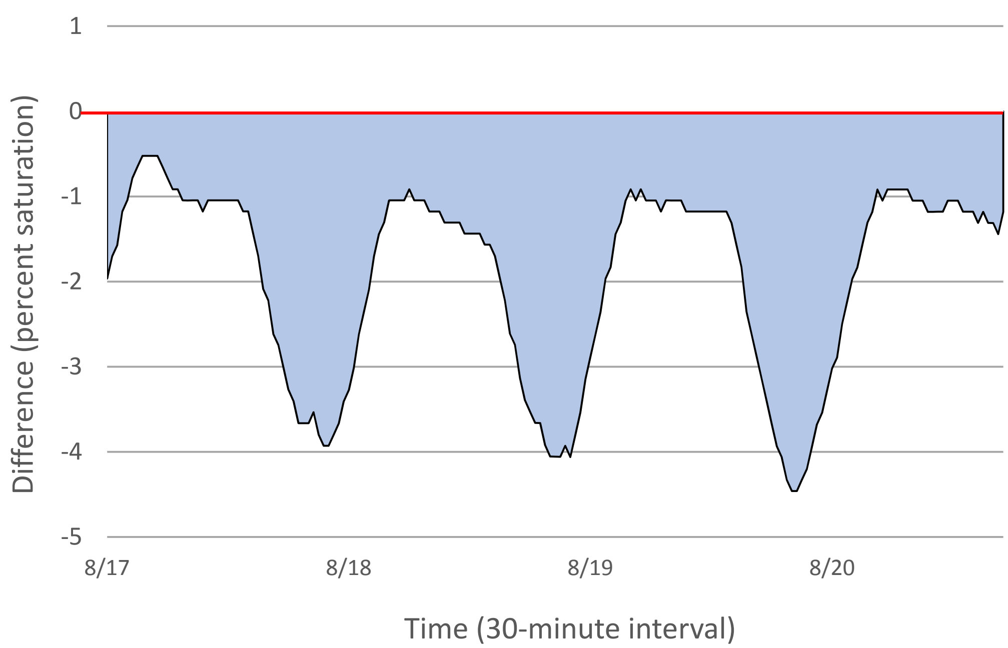


Figure 16. Difference in percent saturation between upstream intake (Site B) and pond 13-1 (Site C, downstream of degassing tower) while operating degassing tower

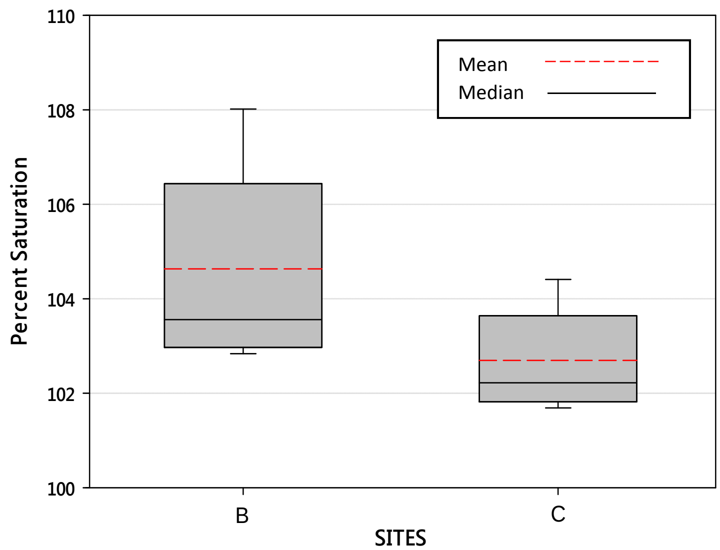


Figure 17. Box plot comparing percent saturation between sites B and C

Table 5. Summary statistics for Site B and Site C while operating the degassing tower.

Metric	TDG Saturation	
	Site B	*Site C*
Mean	104.64	102.69
Standard Error	0.15	0.08
Median	103.56	102.23
Standard Deviation	2.02	1.03
Sample Variance	4.07	1.06
Range	6.03	3.88
Minimum	102.72	101.46
Maximum	108.75	105.35
Count	179	179
Significant Difference*	*Yes*	

* the differences in the median values among the sites are greater than would be expected by chance alone; a statistically significant difference exists (P = <0.001)

5) Comparison between the downstream side of Pond 13-1 (Site D) and downstream of the water reuse wall of Pond 14-1 (Site E)

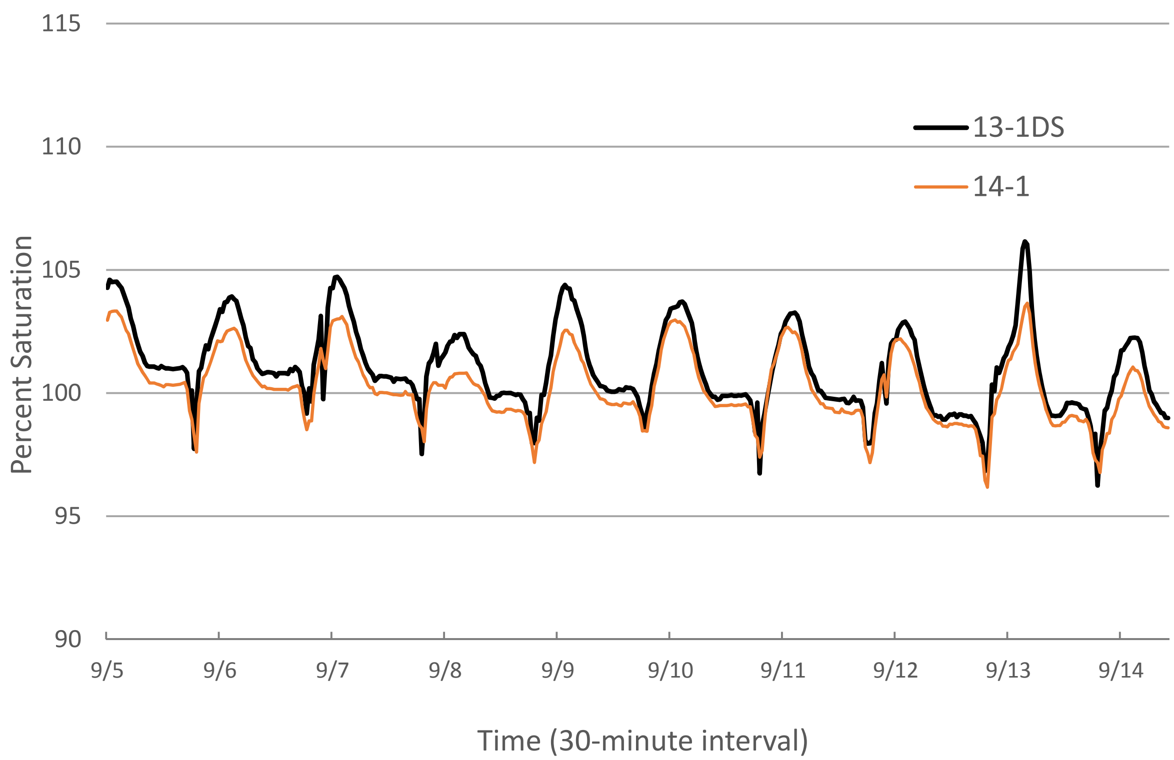


Figure 18. Time series comparison between percent gas saturation the downstream end of Pond 13-1 and upstream end of Pond 14-1

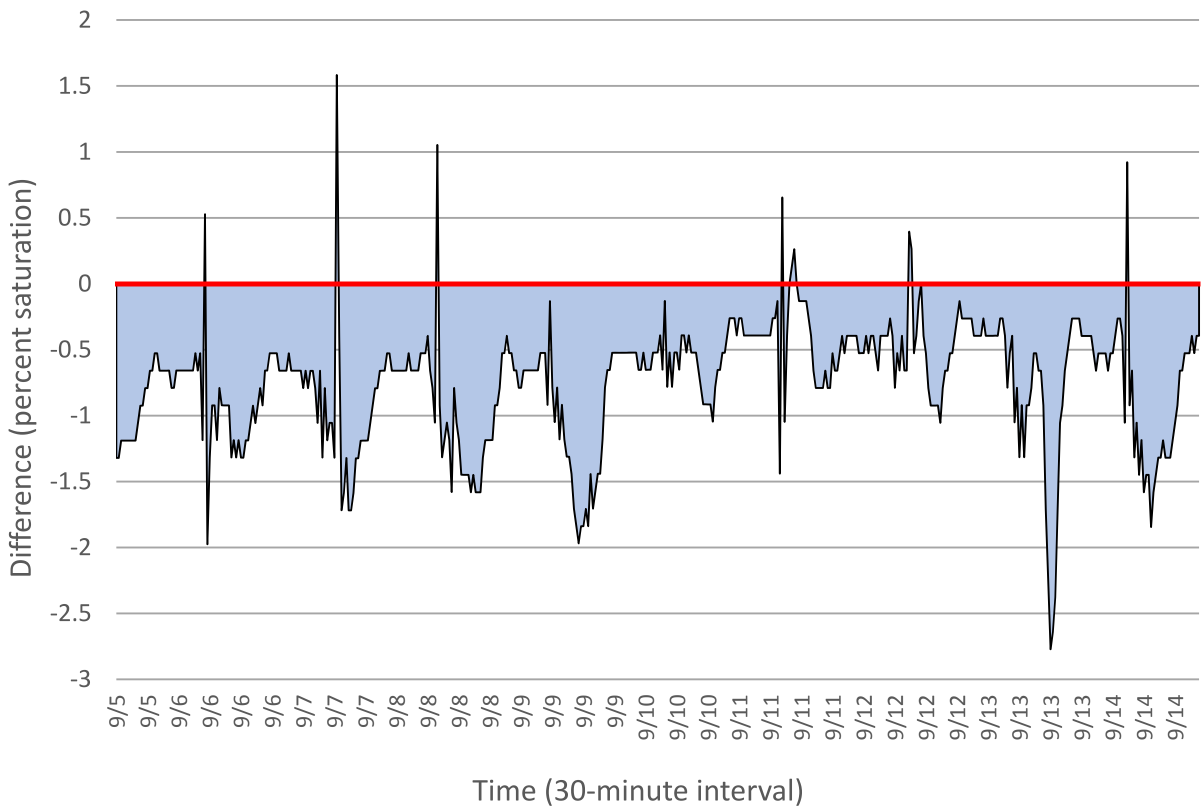


Figure 19. Difference in percent gas saturation between downstream end of Pond 13-1(D) and upstream end of Pond 14-1(E)

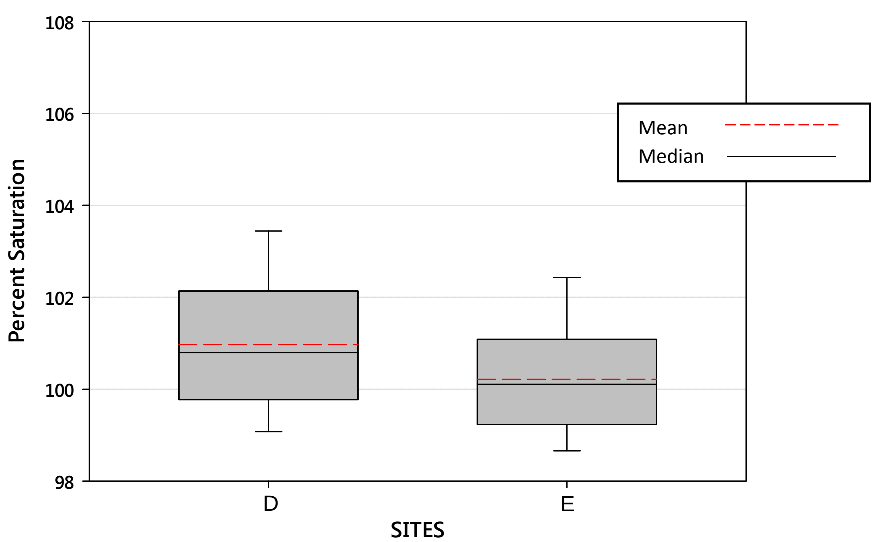


Figure 20. Box plot comparing percent saturation between sites D and E

Table 6. Summary statistics for the downstream end of Pond 13-1 (Site D) and upstream end of Pond 14-1 (Site E, post reuse wall measurement)

Metric	TDG Saturation	
	Site D	*Site E*
Mean	100.97	100.22
Standard Error	0.08	0.07
Median	100.79	100.10
Standard Deviation	1.69	1.43
Sample Variance	2.84	2.04
Range	9.91	7.47
Minimum	96.25	96.18
Maximum	106.15	103.64
Count	453	453
Significant Difference*	*Yes*	

* the differences in the median values among the sites are greater than would be expected by chance alone; a statistically significant difference exists (P = <0.001)

6) Comparison between upstream locations of Ponds 13-1 (Site C), 14-1 (Site E) and 16-3 (Site F)

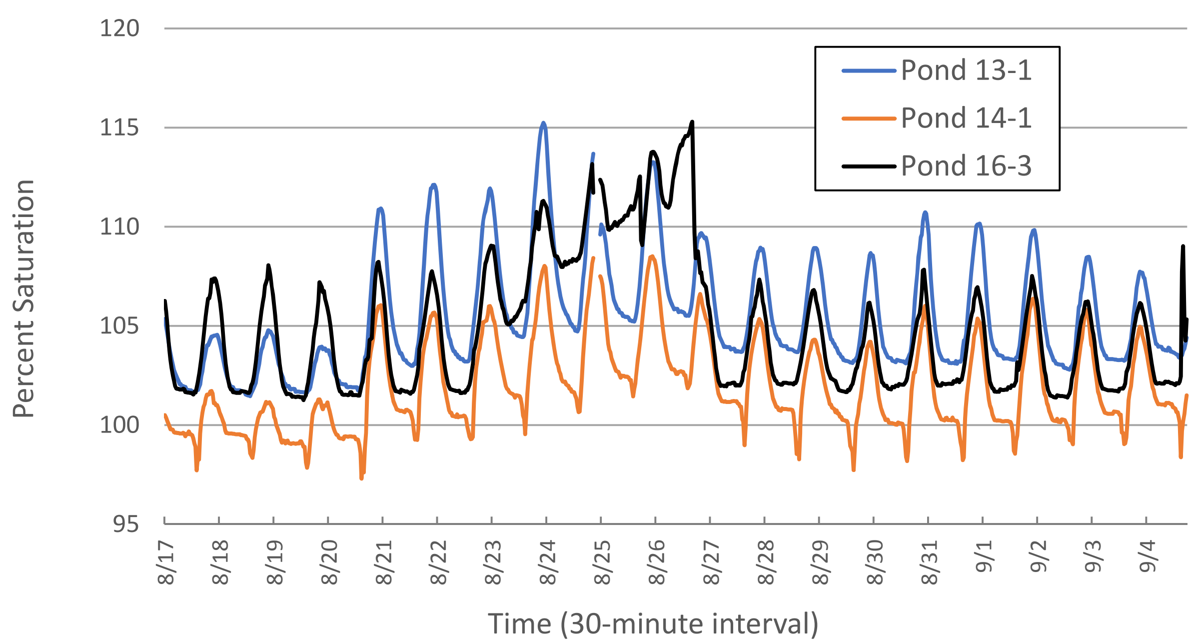


Figure 21. Time series comparison of percent gas saturation measured between ponds 13-1, 14-1 and 16-3

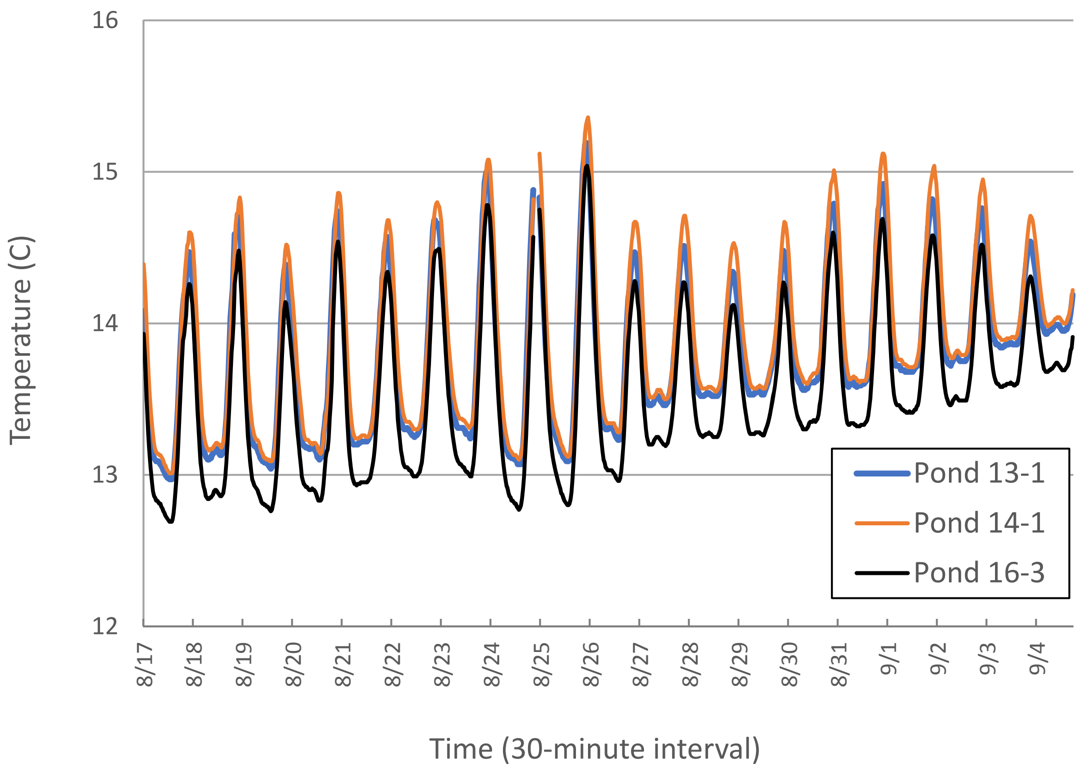


Figure 22. Time series comparison of water temperatures between ponds 13-1, 14-1 and 16-3

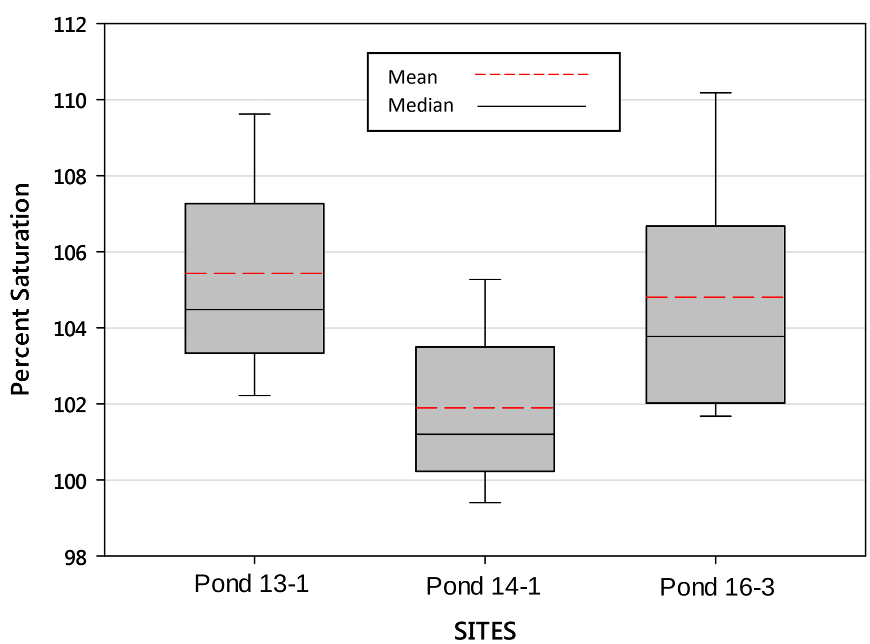


Figure 23. Box plot comparing percent saturation between sites C, E and F

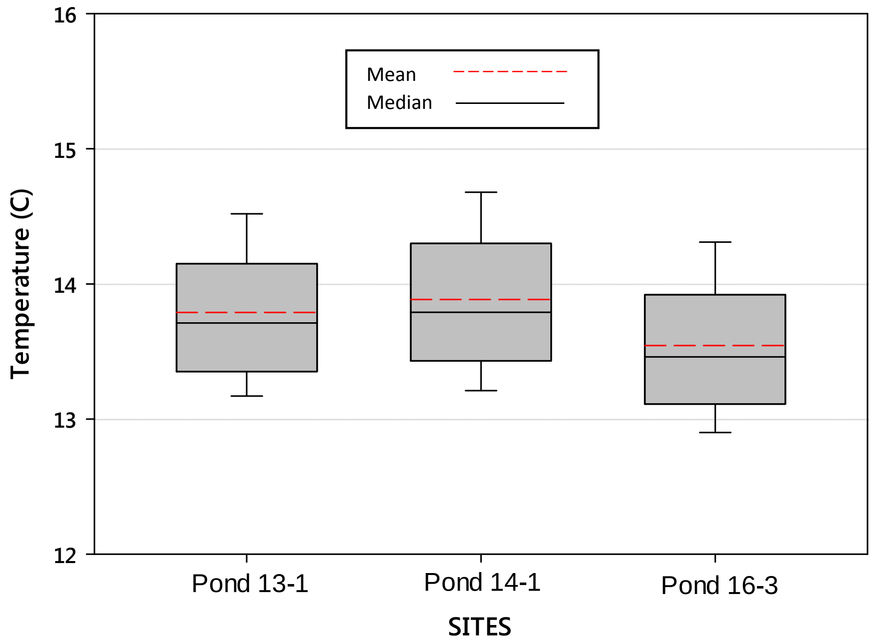


Figure 24. Box plot comparing water temperature between sites C, E and F

Table 7. Summary statistics for percent gas saturation and temperature for ponds 13-1 (Site C), 14-1 (Site E) and 16-3 (Site F)

Metric	Total Saturation			Temperature (deg. C)		
	Site C	***Site E***	***Site F***	***Site C***	***Site E***	***Site F***
Mean	105.43	101.89	104.81	13.79	13.89	13.54
Standard Error	0.10	0.08	0.11	0.02	0.02	0.02
Median	104.48	101.20	103.77	13.71	13.79	13.46
Standard Deviation	2.88	2.28	3.33	0.51	0.55	0.52
Sample Variance	8.28	5.19	11.11	0.26	0.30	0.27
Range	13.78	11.21	14.04	2.22	2.35	2.35
Minimum	101.46	97.30	101.26	12.97	13.01	12.69
Maximum	115.24	108.51	115.30	15.19	15.36	15.04
Count	895	895	895	895	895	895
Significant Difference*		*Yes*			*Yes*	

* the differences in the median values among the sites are greater than would be expected by chance alone; a statistically significant difference exists (P = <0.001)

V. Discussion

The stated purpose of this assessment is to identify and describe TDG and temperature profiles or characteristics at the hatchery that may be contributing to poor fish health, especially during times of stress (e.g., smolting, feeding, handling, warming water temperatures etc.). Any decisions to initiate structural or operational modifications will be developed through the Aquatic Technical Subgroup (ATS) in consultation with the Aquatic Coordination Committee (ACC). The goal of any modification should be to improve the overall health and fitness of juvenile fish rearing at the hatchery, with the intent of improving survival (and consequently adult return rates) after release from the hatchery.

Ambient conditions

Site A (in river control) and Site B (upstream intake well) provide measurements of percent gas saturation and temperature as they normally occur in the river prior to entering the hatchery intake pumps. When comparing both sites there is no statistical difference between the two (Table 3) with strong correlation (r^2 =0.99). Therefore, the in river probe was removed on August 25, 2018 to avoid theft and for use in other areas (e.g., site F). After August 25, Site B was used as the control site.

Ambient or natural in-river conditions were on average over saturated (~107%) during the study period. Whether this oversaturation is caused by oxygen, nitrogen or both is not known. Diel fluctuations were observed in both temperature and TDG which may have been exaggerated by relatively low flows (~1,200 cfs) and solar warming during the summer study period. That is, the average saturation and diel fluctuations observed during the study period may not be present during periods of higher flows and less solar warming. Nonetheless, it is a concern to observe ambient conditions that are consistently over saturated. Further study is needed to better understand the cause for over saturation in the river - at least during the summer months.

Are TDG and temperature levels measured in the ponds (using upwelling) different than ambient river conditions?

In 2011, an upwelling inflow design was put into service on pond banks 13 and 14. This design is different than inflow designs in use prior to 2011. Prior to 2011, inflow water poured into the pond via an above water header pipe. Prior to this study, there was concern that submerged upwelling designs may contribute to TDG levels as inflow water entering the pond would not be open to atmosphere and enter the ponds under hydrostatic pressure with no means to relieve the partial pressures of dissolved gases. In an open system, oversaturated water entering the ponds are exposed to atmosphere and would tend to equilibrate (although briefly) with atmospheric pressure.

Site C represents TDG and water temperature at the discharge upwelling pipe into Pond 13-1. Site B represents ambient water conditions prior to being pumped into the ponds. While statistically there is a difference in both TDG and temperature, the differences are relatively small. For TDG, the mean difference between the two sites was 0.68% with similar maximum and minimum values. Looking at only the average increase (i.e., taking only the measurements that show an increase), the data show a 1.06 percent increase from ambient levels. While there is some increase in TDG with the upwelling system, it is not likely to be a biological concern affecting fish health as natural diurnal fluctuations exceed effects of the upwelling system on TDG and that increase spike (of 2 or 3 percent) are of very short duration. However, as ambient conditions approach 110 percent saturation, this incremental increase may be a factor affecting fish health. With respect to temperature, the effects are (understandably) even less pronounced.

Recommendation: Discuss with fish health staff whether the incremental increase caused by the upwelling system presents a fish health concern. No changes to the current design are recommended.

Does the upstream intake air burst system or pumps elevate TDG above ambient river conditions?

The median differences observed between the in-river control site ‘A’ and the upstream intake site ‘B’ are not great enough to exclude the possibility that the difference is due to random sampling variability, therefore, the air burst system is not a contributing or significant factor relative to gas saturation.

Recommendation: None

Describe the TDG and temperature profile within a loaded rearing pond?

There is a significant difference in TDG measurements from at the upstream and downstream end of Pond 13-1. There is a notable dip in TDG observed at the downstream end every morning beginning around 0800 hours and lasting for approximately two hours. This ‘dip’ almost always creates a short-term under saturated condition whereas the upstream end appears to remain oversaturated (Figure 12). The cause for this dip is unknown, but may be related to morning feeding schedules that cause increased respiration (stress) by fish or possibly the timing of primary production through photosynthesis. During the afternoon, both temperature and TDG become elevated typically peaking in the late afternoon. The influence of temperature on TDG is well established and the relationship of increasing water temperatures causing higher saturation levels is well established and observed both in Pond 13 (Figure 12) and at the in-river control sites.

Recommendation: Determine the cause for under saturated dips observed in the early morning. Are these dips the result of feeding schedules, loss of photosynthetic activity or both? Explore delaying feeding until late morning to mitigate saturation dips at the downstream ends of the rearing ponds. Explore different feeding methods such as demand feeders or underwater timed feeders that reduce stressful and chaotic feeding activity observed from the current feeding regime.

What affect do the aeration towers have on TDG?

Using the degassing tower at Pond 13 produces a mean reduction in gas saturation of about 2 percent (Table 5). This reduction becomes even more pronounced during periods when in-river TDG levels are highest in the late afternoon (mean reduction of about 4 percent). Therefore, use of the degassing towers are effective in reducing over saturated waters entering the rearing ponds. Whether it is practical to use the towers on a continual basis would need to be balanced with head loss and consequently less water inflow rates while the towers are in use. However, it is important that these towers be used consistently whenever periods of spill are initiated from Merwin Dam. Another option may be to use the towers on a seasonal basis when in-river gas saturation levels are highest during the summer months if rearing pond saturation levels are a concern affecting fish health or fitness.

Recommendation: Continue to use degassing towers continuously during spill events at Merwin Dam. Explore the practicality of using the towers during the summer months when in-river TDG levels are highest – especially during periods of high water temperatures and solar radiation (e.g., afternoon).

What affect does the Pond 14 reuse have on TDG?

The reuse wall causes water exiting from Pond 13 to collect within a reuse water supply channel (Figure 2) before flowing over the reuse wall into Pond 14 (Figure 3). Reuse water flowing over the wall increases the surface area of water exposed to atmosphere. This configuration allows dissolved gases in the reuse water to come out of solution and acts to bring dissolved gas pressure to ambient levels (i.e., barometric pressure). Figure 19 shows that water flowing over the wall and into Pond 14 is consistently less saturated than water exiting Pond 13. The mean difference, however, is less than 1 percent. As observed with the degassing towers, the significance of this reduction is greater with higher levels of initial gas saturation present in the effluent water from Pond 13. That is, higher saturation levels exposed to atmosphere from flowing over the wall will naturally desaturate at a faster rate than water that is only slightly over saturated.

Figure 18 provides a time series comparison between these two sites. It is notable that the 'dip' observed at the downstream end of Pond 13 in the early morning hours persists into Pond 14 despite water flowing over the reuse wall. That is, under saturated water flowing over the wall should increase in saturation. Figure 19 shows only very short term spikes in saturation during these periods however. Perhaps of more significance are the saturation levels present at the downstream end of Pond 14 in the early morning as the inflow water is already at a saturation deficit compared to first pass water which is typically oversaturated (e.g., Pond 13 Site C). This should be evaluated as under saturation can result in low dissolved oxygen levels in the rearing pond.

Recommendation: All reuse water should continue to flow over the reuse wall. The benefits with respect to TDG are likely insignificant given the diel fluctuations observed. There may be opportunities to increase the surface area of the water exposed to atmosphere while flowing over the wall including a screened section that would increase the effectiveness and improve the water quality entering Pond 14.

An evaluation of the downstream end of Pond 14 should be done in 2019 to evaluate the significance of early morning TDG 'dips' especially when using reuse water that already is under saturated upon entering Pond 14. This evaluation should focus on dissolved oxygen levels present at the downstream ends of ponds using reuse water as their source.

Are there TDG and temperature differences between pond banks?

Figure 21 shows the time series TDG observation between first pass source water ponds 13, 16 and reuse source water pond 14. Pond 16 derives source water from the downstream intake pumps and Pond 13 from the upstream intake. Ponds 13 and 16 show similar TDG profiles and diurnal fluctuations. Ponds 13 and 16 exceeded the 110 percent standard during a portion of this two week assessment; however, these exceedences occurred when the river water also exceeded 110 percent of saturation (week of August 17). Pond 14 TDG levels are consistently less than either pond 13 or 16. This difference is attributed to reuse source water. Temperature differences were much less pronounced between the three ponds, although Pond 16 is always incrementally cooler than ponds 13 or 14.

Recommendation: None

VI. Conclusions

Generally, total dissolved gas levels at the hatchery remain below the state standard of 110 percent. When exceedances of this standard did occur, they were more closely related to ambient in river conditions rather than any design elements at the hatchery (Attachment A1). Elevated levels in the river are not as concerning as levels in the hatchery. Raceways are relatively shallow compared to in river conditions and fish are not able to sound or leave to escape the effects of over saturation.

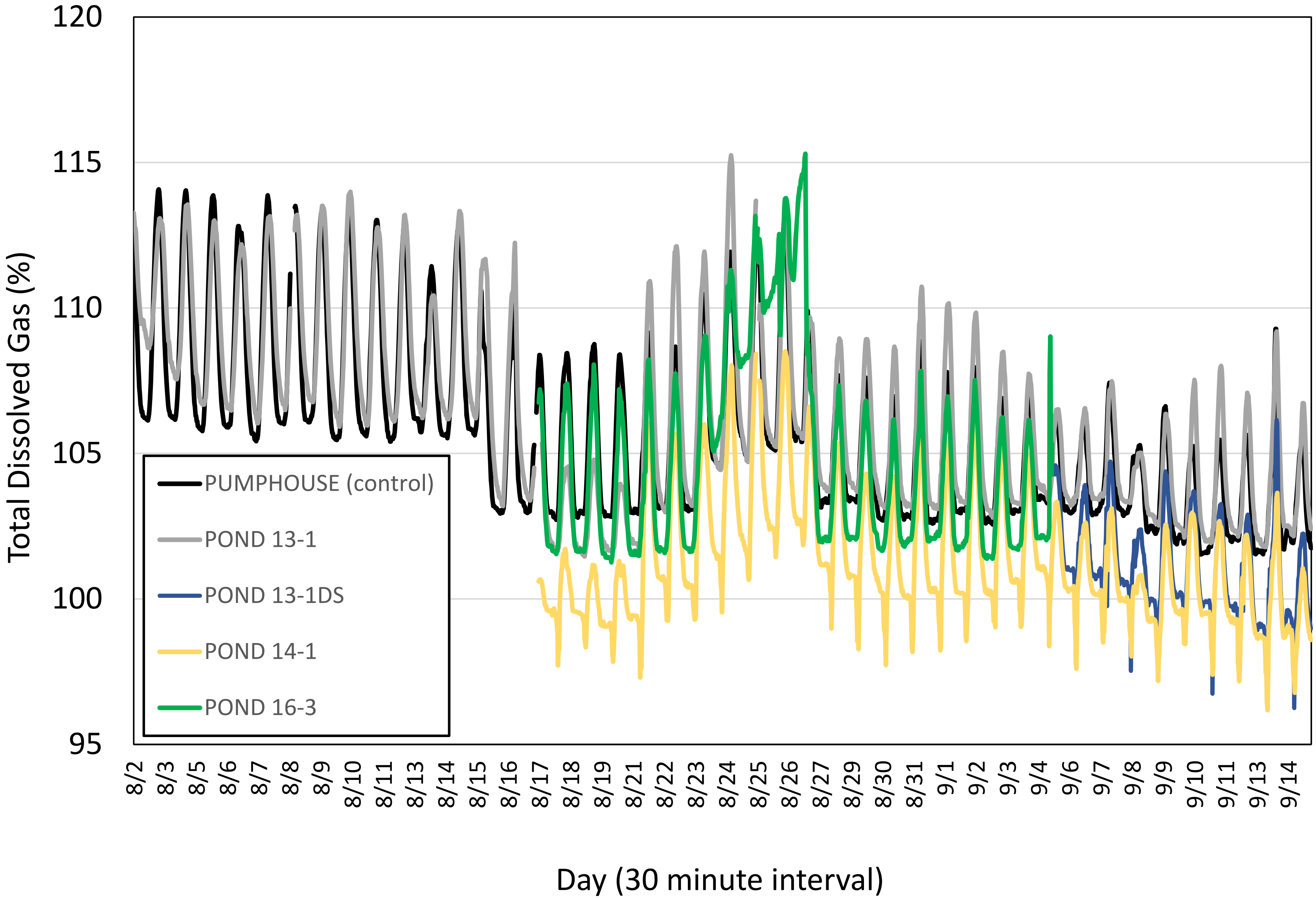
The use of degassing towers is shown to be an effective measure to reduce over saturation. Not just during spill events, but during the summer months when the potential of TDG to exceed healthy levels is greatest. The use of the degassing towers should be discussed further with fish health staff at WDFW to determine whether the towers should be selectively used.

An unexpected observation was made during this assessment regarding significant dips in TDG during the early morning hours. This dip is unique to loaded raceways and not observed in the river. This observation is most likely related to feeding or fish densities in the rearing raceways. More work should be done to determine the cause of these dips and whether they are causing any negative effects. A measure to improve aeration of water flowing over the reuse wall would have benefits to reuse water (e.g., a screened portion on top of reuse wall to increase the surface area of reused water). Dissolved oxygen levels should be monitored in raceways relying on reuse water to ensure that oxygen levels remain at healthy levels throughout the length of the rearing raceway.

Feeding schedules and methods should be evaluated to determine if modifications should be initiated as a means to reduce potential stress from erratic and chaotic behavior exhibited with current methods. Feeding methods or timing may be contributing to saturation dips observed.

Temperature profiles for all raceways were very similar to in-river conditions. No significant warming was noted (from a biological perspective) in any of the raceways.

ATTACHMENT A1: Summary of total dissolved gas measurement of all sites



ATTACHMENT A2: Summary of water temperature measurement of all sites