Technical Memorandum

To: Columbia River CWR Project Team

From: John Palmer

Date: July 23, 2020

Subject: Estimating the Number of Steelhead and Fall Chinook using CWR in the Bonneville Reservoir Reach

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This memo describes an approach to provide ball park estimates of the number of steelhead and Fall Chinook salmon within cold water refuges (CWR) in the Bonneville Reservoir Reach of the Columbia River *during the period of maximum CWR use* (mid-August to mid-September) using passage and timing information from the Columbia River DART and previous research on steelhead and Fall Chinook migration behavior in the Columbia River. Additionally, analysis of Pit-Tagged adult steelhead and Fall Chinook is assessed as a second line of evidence to evaluate the extent of CWR use in the Bonneville reach.

1. Steelhead

Figure 1 displays mean daily steelhead counts at Bonneville and The Dalles dams along with associated mean daily water temperatures for the 2007-2016 period. From mid-July (when river temperatures reach about 20C) to September 1 (when river temperatures begin to decline), a significant number of steelhead pass Bonneville Dam but do not pass The Dalles Dam as reflected by the difference between the red line (BON passage counts) and the green line (TDA passage counts), which results in the accumulation of steelhead in the Bonneville Reach. During this period, most of the steelhead are delaying upstream migration and holding in Bonneville Reach CWR before proceeding upstream when Columbia mainstem temperature are cooler in September and October.

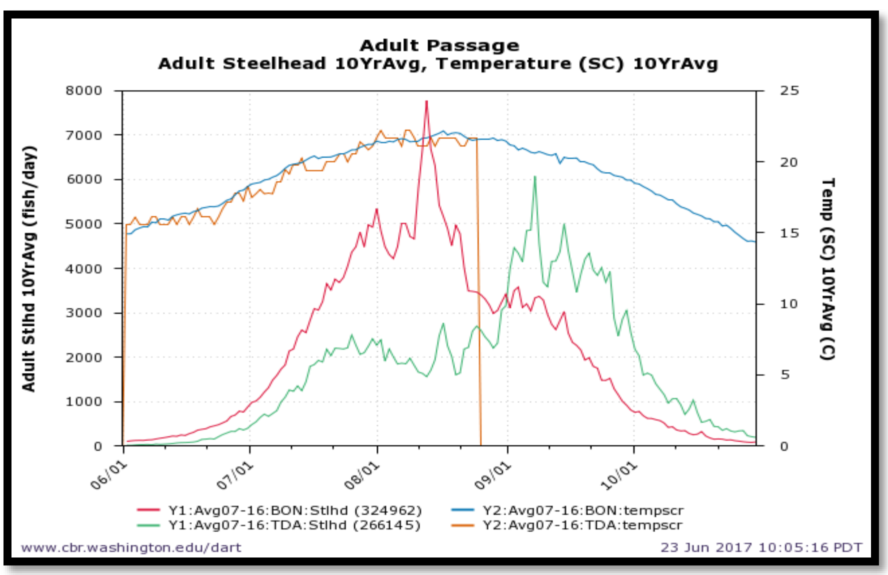

Figure 1 – Adult Steelhead Passage and Water Temperature at Bonneville Dam and The Dalles Dam (2007-2016 Average)

1.1 Number of Steelhead in Bonneville Reach CWR

Figure 2 depicts the estimated number of steelhead that are in the Bonneville Reach for each day from June through October (black line) and an estimate of the number of steelhead in CWR (blue line) for an average year (2007-2016). The daily values used to generate each of the lines in Figure 2 are displayed in Table 1.

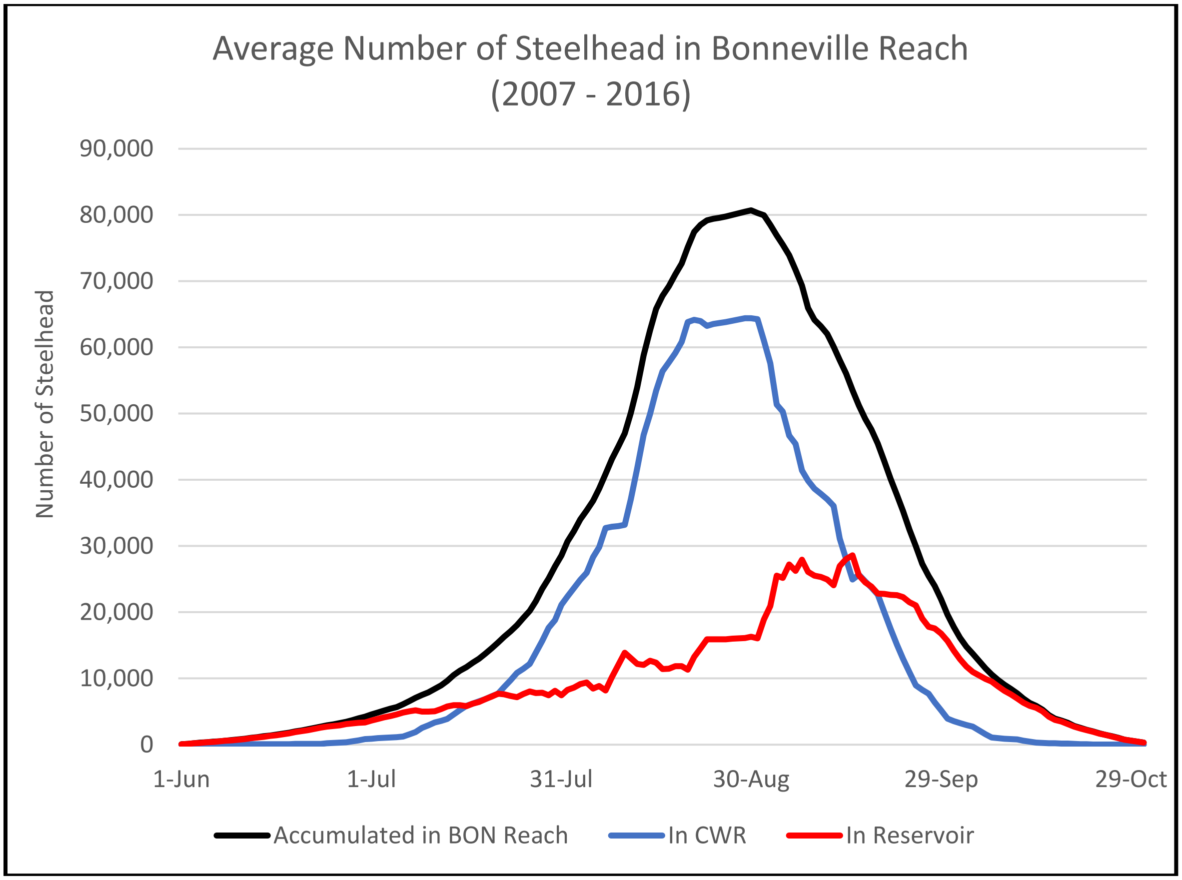

Figure 2 – Accumulation of Steelhead in the Bonneville Reach and the Number of Steelhead in CWR (2007-2016 Average)

1.1.1 Calculations and Assumptions

Table 1 shows the daily passage of steelhead at Bonneville Dam and The Dalles Dam. A portion of the steelhead that pass Bonneville Dam are not expected to pass The Dalles Dam due to entry into natal tributaries to spawn, return to hatcheries, or harvest within the Bonneville Reach. The percentage expected to not pass The Dalles Dam is estimated to be 18% based on comparing the average annual number of steelhead passing Bonneville Dam (209,078) versus The Dalles Dam (171,235) over the June 1 – October 31 period (2007-2016). Thus, for purposes of calculating the number of accumulated steelhead in the Bonneville Reach shown in Table 1 (and displayed Figure 2), 18% of the steelhead that pass Bonneville Dam are removed from the analysis. To calculate the number of steelhead in the Bonneville Reach on each day (accumulated in reach), the net number of steelhead for each day (Bonneville steelhead passage minus 18% minus The Dalles steelhead passage) is calculated and then added to the number of steelhead in the Bonneville Reach from the previous day (see Table 1).

The number of steelhead in CWR was estimated based on the percentage of the steelhead that use CWR as a function of temperature reported in Keefer et. al 2009, multiped by the accumulated steelhead in the Bonneville Reach for each day, then averaged over three days (that day, prior day, and next day). The percentage of steelhead using CWR as a function of temperature reported in Keefer et. al 2009 is summarized below.

% Steelhead use of CWR	Columbia River Temperature
85%	>22C
80%	21.5 – 21.9C
70%	21.0 – 21.4C
60%	20.5 – 20.9C
50%	20.0 – 20.4C
40%	19.5 – 19.9C
30%	19.0 – 19.4C
20%	18.0 – 18.9C
10%	17.0 – 17.9C
5%	16.0 – 16.9C
2%	14.0 – 15.9C

Table 1 – Daily Estimate of Number of Steelhead in Bonneville Reach and in CWR (2007-2016 Average)

mm/dd	BON Passage Fish/day	BON Fish/day Less 18%	Dalles Passage Fish/day	Net in BON Reach	Accumulated in BON Reach	In Reservoir	In CWR	% in CWR	BON Temp
1-Jun	97	79	19	60	60	59	1	2%	14.9
2-Jun	107	87	19	68	128	125	3	2%	14.9
3-Jun	119	97	18	79	207	203	4	2%	14.9
4-Jun	127	104	26	79	286	280	6	2%	15.2
5-Jun	129	106	32	74	359	352	7	2%	15.3
6-Jun	127	104	33	72	431	422	9	2%	15.4
7-Jun	139	114	36	77	509	498	10	2%	15.4
8-Jun	143	117	30	87	596	584	12	2%	15.8
9-Jun	161	132	46	86	682	660	22	2%	15.7
10-Jun	177	145	38	107	790	757	33	5%	16.0
11-Jun	191	157	45	112	901	856	45	5%	16.0
12-Jun	207	169	51	119	1,020	969	51	5%	15.9
13-Jun	227	186	58	128	1,148	1,091	57	5%	16.2
14-Jun	220	180	71	109	1,257	1,194	63	5%	16.3
15-Jun	252	206	78	129	1,386	1,317	69	5%	16.3
16-Jun	239	196	79	117	1,503	1,427	76	5%	16.4
17-Jun	281	230	85	145	1,648	1,565	83	5%	16.3
18-Jun	310	254	91	163	1,812	1,721	91	5%	16.5
19-Jun	360	295	108	187	1,998	1,899	99	5%	16.6
20-Jun	377	309	150	159	2,157	2,049	108	5%	16.7
21-Jun	392	322	157	165	2,322	2,205	116	5%	16.8
22-Jun	433	355	168	187	2,509	2,383	126	5%	16.9
23-Jun	457	374	159	216	2,725	2,589	136	5%	16.8
24-Jun	482	395	211	184	2,909	2,713	196	5%	16.9
25-Jun	522	428	260	169	3,078	2,818	259	10%	17.1
26-Jun	565	463	294	169	3,247	2,920	326	10%	17.3
27-Jun	668	548	331	216	3,463	3,116	347	10%	17.4
28-Jun	699	573	330	243	3,706	3,203	503	10%	17.7
29-Jun	788	646	393	253	3,960	3,290	669	20%	18.0

30-Jun	767	629	363	265	4,225	3,376	849	20%	18.0
1-Jul	878	720	400	320	4,545	3,636	909	20%	18.3
2-Jul	985	808	484	324	4,869	3,898	971	20%	18.4
3-Jul	1014	831	545	286	5,155	4,126	1029	20%	18.5
4-Jul	1099	901	644	257	5,411	4,328	1084	20%	18.6
5-Jul	1214	996	719	277	5,688	4,542	1146	20%	18.7
6-Jul	1315	1,078	670	408	6,096	4,871	1224	20%	18.8
7-Jul	1486	1,218	733	486	6,581	5,027	1554	20%	18.9
8-Jul	1592	1,305	797	508	7,089	5,190	1899	30%	19.0
9-Jul	1730	1,419	991	427	7,517	5,001	2516	30%	19.3
10-Jul	1826	1,498	1100	398	7,914	4,986	2928	40%	19.5
11-Jul	2143	1,757	1264	493	8,407	5,036	3372	40%	19.8
12-Jul	2186	1,793	1233	559	8,966	5,366	3600	40%	19.8
13-Jul	2459	2,016	1354	662	9,629	5,746	3882	40%	19.9
14-Jul	2613	2,142	1248	894	10,523	5,974	4548	40%	19.9
15-Jul	2554	2,094	1447	648	11,170	5,956	5215	50%	20.1
16-Jul	2833	2,323	1794	529	11,699	5,821	5878	50%	20.3
17-Jul	3095	2,538	1836	702	12,401	6,221	6180	50%	20.4
18-Jul	3061	2,510	1930	580	12,981	6,458	6523	50%	20.2
19-Jul	3252	2,666	1894	773	13,753	6,869	6884	50%	20.3
20-Jul	3656	2,998	2179	819	14,572	7,281	7291	50%	20.3
21-Jul	3516	2,883	2036	847	15,419	7,704	7715	50%	20.3
22-Jul	3759	3,082	2204	878	16,297	7,587	8710	50%	20.4
23-Jul	3684	3,020	2198	822	17,119	7,371	9749	60%	20.6
24-Jul	3793	3,110	2186	924	18,044	7,181	10863	60%	20.6
25-Jul	4050	3,321	2212	1,109	19,153	7,667	11486	60%	20.7
26-Jul	4366	3,580	2500	1,081	20,233	8,028	12206	60%	20.8
27-Jul	4489	3,681	2271	1,410	21,643	7,778	13865	60%	20.9
28-Jul	4818	3,951	2066	1,885	23,528	7,852	15676	70%	21.0
29-Jul	4486	3,679	2103	1,576	25,104	7,471	17633	70%	21.1
30-Jul	4982	4,085	2250	1,835	26,939	8,130	18809	70%	21.2
31-Jul	4930	4,042	2415	1,627	28,566	7,435	21131	70%	21.2
1-Aug	5345	4,383	2273	2,109	30,676	8,303	22373	80%	21.5
2-Aug	4848	3,975	2391	1,585	32,260	8,613	23647	70%	21.3
3-Aug	4488	3,680	1914	1,766	34,026	9,125	24901	70%	21.3
4-Aug	4314	3,538	2186	1,352	35,378	9,411	25967	80%	21.5
5-Aug	4221	3,461	2010	1,451	36,829	8,492	28337	70%	21.4
6-Aug	4489	3,681	1849	1,832	38,661	8,853	29809	80%	21.6
7-Aug	5002	4,101	1867	2,234	40,895	8,175	32720	80%	21.6
8-Aug	5002	4,101	1853	2,249	43,144	10,225	32919	80%	21.6
9-Aug	4719	3,870	1978	1,892	45,036	12,046	32990	70%	21.4
10-Aug	4666	3,826	1819	2,007	47,043	13,860	33183	70%	21.4
11-Aug	5802	4,757	1667	3,091	50,134	13,063	37071	70%	21.4
12-Aug	6695	5,490	1636	3,853	53,987	12,211	41776	80%	21.7
13-Aug	7781	6,380	1562	4,818	58,805	12,040	46765	80%	21.7
14-Aug	6686	5,483	1709	3,773	62,578	12,659	49919	80%	21.8
15-Aug	6318	5,180	1944	3,236	65,814	12,374	53441	80%	21.9
16-Aug	5421	4,445	2485	1,959	67,774	11,401	56373	85%	22.0
17-Aug	5167	4,237	2766	1,472	69,245	11,489	57756	85%	22.2
18-Aug	4897	4,015	2257	1,758	71,004	11,856	59148	80%	21.9
19-Aug	4514	3,701	2019	1,682	72,686	11,863	60823	85%	22.0
20-Aug	4970	4,075	1606	2,470	75,156	11,329	63827	85%	22.1
21-Aug	4781	3,920	1647	2,274	77,430	13,256	64173	85%	22.0
22-Aug	4007	3,285	2187	1,098	78,528	14,536	63991	80%	21.8
23-Aug	3493	2,865	2221	643	79,171	15,934	63237	80%	21.6
24-Aug	3483	2,856	2589	268	79,439	15,921	63518	80%	21.5
25-Aug	3467	2,843	2701	142	79,581	15,904	63676	80%	21.6
26-Aug	3407	2,793	2608	186	79,767	15,935	63832	80%	21.6
27-Aug	3313	2,717	2461	256	80,023	16,006	64017	80%	21.6
28-Aug	3179	2,607	2356	251	80,274	16,058	64217	80%	21.6

29-Aug	2988	2,450	2209	241	80,515	16,118	64398	80%	21.7
30-Aug	3053	2,504	2317	187	80,702	16,298	64404	80%	21.5
31-Aug	3243	2,659	3065	-406	80,296	16,045	64251	80%	21.6
1-Sep	3419	2,804	3157	-353	79,943	18,896	61047	80%	21.5
2-Sep	3109	2,549	3995	-1,445	78,498	20,920	57578	70%	21.2
3-Sep	3500	2,870	4466	-1,597	76,901	25,542	51359	70%	21.1
4-Sep	3581	2,936	4341	-1,405	75,496	25,208	50288	60%	20.8
5-Sep	3122	2,560	4150	-1,589	73,907	27,226	46680	70%	21.0
6-Sep	3203	2,626	4851	-2,225	71,682	26,238	45444	60%	20.8
7-Sep	3045	2,497	4864	-2,368	69,314	27,920	41394	60%	20.7
8-Sep	3337	2,737	6076	-3,340	65,974	26,082	39892	60%	20.6
9-Sep	3371	2,764	4565	-1,801	64,173	25,507	38666	60%	20.7
10-Sep	3288	2,696	3685	-989	63,184	25,307	37877	60%	20.6
11-Sep	2968	2,434	3588	-1,155	62,030	24,963	37067	60%	20.5
12-Sep	2744	2,250	4159	-1,910	60,120	24,069	36051	60%	20.5
13-Sep	2623	2,151	4166	-2,015	58,105	26,988	31117	60%	20.6
14-Sep	2825	2,317	4380	-2,063	56,042	28,028	28013	40%	19.9
15-Sep	3030	2,485	5005	-2,520	53,521	28,593	24928	50%	20.3
16-Sep	2544	2,086	4394	-2,308	51,214	25,558	25656	50%	20.2
17-Sep	2336	1,916	3931	-2,015	49,199	24,531	24668	50%	20.2
18-Sep	2266	1,858	3465	-1,606	47,593	23,878	23715	50%	20.3
19-Sep	2165	1,775	3871	-2,096	45,497	22,836	22661	50%	20.0
20-Sep	1938	1,589	4210	-2,621	42,876	22,792	20084	50%	20.0
21-Sep	1990	1,632	4344	-2,712	40,164	22,639	17524	40%	19.9
22-Sep	1795	1,472	3963	-2,491	37,673	22,592	15080	40%	19.8
23-Sep	1754	1,438	3844	-2,406	35,267	22,295	12972	40%	19.5
24-Sep	1482	1,216	4018	-2,803	32,464	21,517	10947	30%	19.3
25-Sep	1479	1,213	3691	-2,478	29,986	21,010	8976	30%	19.2
26-Sep	1526	1,252	3926	-2,674	27,312	19,033	8279	30%	19.2
27-Sep	1291	1,059	2880	-1,821	25,491	17,815	7676	30%	19.0
28-Sep	1154	946	2482	-1,536	23,955	17,549	6406	30%	19.0
29-Sep	1009	827	2856	-2,029	21,926	16,760	5166	20%	18.9
30-Sep	920	755	3051	-2,296	19,630	15,677	3953	20%	18.7
1-Oct	813	667	2563	-1,896	17,734	14,164	3569	20%	18.7
2-Oct	759	622	2183	-1,561	16,173	12,927	3246	20%	18.5
3-Oct	781	641	2035	-1,394	14,779	11,799	2980	20%	18.4
4-Oct	685	562	1598	-1,036	13,743	11,001	2742	20%	18.3
5-Oct	625	513	1645	-1,132	12,611	10,470	2141	20%	18.1
6-Oct	622	510	1598	-1,088	11,523	9,945	1578	10%	17.9
7-Oct	596	488	1403	-914	10,609	9,545	1064	10%	17.7
8-Oct	574	471	1280	-809	9,800	8,817	983	10%	17.7
9-Oct	520	426	1159	-733	9,067	8,156	910	10%	17.5
10-Oct	421	345	969	-624	8,443	7,602	841	10%	17.3
11-Oct	435	357	1066	-709	7,734	6,963	771	10%	17.3
12-Oct	363	298	1069	-771	6,963	6,368	595	10%	17.1
13-Oct	341	279	929	-650	6,313	5,878	435	5%	16.8
14-Oct	348	285	715	-429	5,884	5,593	291	5%	16.7
15-Oct	285	233	832	-599	5,285	5,025	261	5%	16.6
16-Oct	256	210	1034	-824	4,461	4,233	228	5%	16.4
17-Oct	268	220	753	-533	3,928	3,728	201	5%	16.3
18-Oct	326	267	536	-269	3,660	3,479	181	5%	16.2
19-Oct	227	186	557	-371	3,289	3,126	163	5%	16.0
20-Oct	184	151	599	-449	2,840	2,721	119	5%	16.0
21-Oct	154	126	443	-317	2,523	2,444	79	2%	15.8
22-Oct	161	132	434	-302	2,221	2,176	45	2%	15.8
23-Oct	156	128	355	-227	1,994	1,955	40	2%	15.5
24-Oct	136	112	393	-281	1,713	1,678	35	2%	15.5
25-Oct	142	116	340	-224	1,489	1,459	30	2%	15.3
26-Oct	121	99	320	-221	1,268	1,243	25	2%	15.1
27-Oct	111	91	342	-251	1,017	997	20	2%	14.8

28-Oct	98	80	348	-268	749	733	16	2%	14.6
29-Oct	88	72	233	-161	588	576	12	2%	14.4
30-Oct	84	69	213	-144	444	435	9	2%	14.4
31-Oct	94	77	197	-120	324	318	6	2%	14.4

Source: Columbia River DART

1.1.2 Results

As shown Table 1 (and displayed in Figure 2), steelhead accumulate in the Bonneville Reach until August 30th when the maximum number of steelhead using CWR is estimated to be approximately 65,000, for an average year. On August 31st and thereafter, more steelhead are passing The Dalles Dam versus Bonneville Dam and the number of steelhead accumulated in the Bonneville Reach and in CWR begins to decrease.

The peak CWR use period is from mid-August through early-September. From August 15 – September 5, the average number of steelhead in CWR exceeds 50,000 fish each day. During this period of peak CWR use, 80-85% of the steelhead in the Bonneville reach are estimated to be in CWR and 15-20% in the reservoir.

1.1.3 Field Verification

To test the above assumptions on the percentage of accumulated steelhead in the Bonneville reach that are in the reservoir versus in CWR, the location of 219 radio-tagged steelhead from the University of Idaho 2000 and 2002 research studies were analyzed. As shown in Figure 3, the number of steelhead in the Bonneville reach peaked in late August and early September and the vast percentage of steelhead were in CWR (approximately 90%) versus in the reservoir during this period.

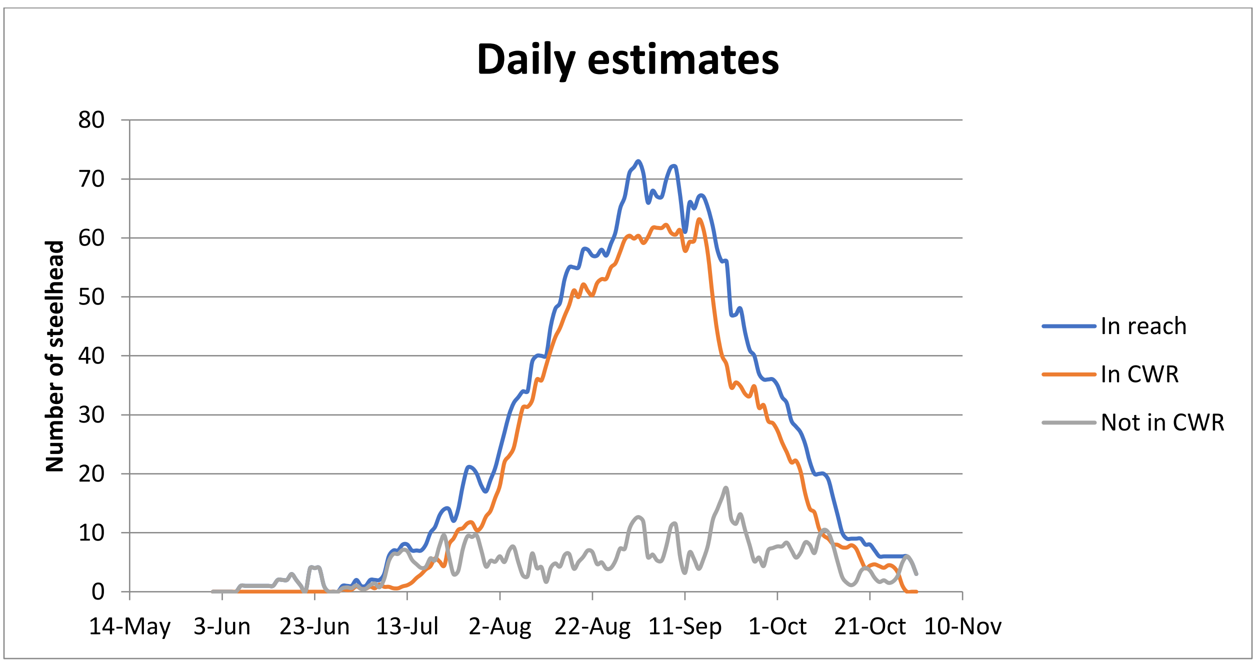

Figure 3 – Distribution of 219 Radio-Tagged Steelhead in Bonneville Reach from University of Idaho 2000 and 2002 Research Studies (Keefer 8/31/17 email)

1.2 Simplified Multi-Year Estimate of Number of Steelhead in Bonneville Reach CWR

The above approach estimates the number of steelhead in the Bonneville Reach CWR on a daily basis using daily fish passage numbers at Bonneville Dam and The Dalles Dam. An alternative simplified approach estimates the number steelhead in CWR using total steelhead passage counts at Bonneville Dam and The Dalles Dam for the critical July 15 – August 31 period, when average temperatures exceed 20C and steelhead are accumulating in the Bonneville Reach.

As shown in Table 2, during the July 15 through August 31 period, 209,078 steelhead passed Bonneville Dam on average in 2007-2016, but only 101,670 passed The Dalles Dam. As discussed above, 18% of the steelhead passing Bonneville Dam are estimated to enter tributaries, hatcheries, or are harvested in the Bonneville Reach. Thus, 171,235 (82% of the average count at Bonneville Dam) are expected to ultimately pass The Dalles Dam and would be expected to pass The Dalles Dam during the July 15-August 31 period if were not for temporary use of CWR. 171,235 (expected to pass) minus 101,670 (actually passed) approximates the number of steelhead (69,565) in the Bonneville Reach during the July 15 – August 31 period which are either temporarily in CWR or migrating in the reservoir. The number in the reservoir under this approach is estimated to be 15%, leaving 59,130 in CWR. The 15% was based on the analysis and field verification presented above for the approximate percentage of steelhead in the reservoir versus within CWR during the period of peak CWR use.

The average estimate of 59,130 steelhead in the Bonneville Reach CWR using this simplified approach is consistent with the daily analysis described above in Figure 2 and Table 1. The 59,130 number of steelhead in CWR represents the period of maximum CWR use, which is late-August – early September.

Table 2 – Estimated Number of Steelhead in CWR (2007-2016 Average)

Passed BON	Exp to Pass DAL	Passed DAL	In BON Reach	In CWR
7/15 -8/31	7/15 -8/31	7/15 -8/31	7/15 -8/31	7/15 -8/31
209,078	171,235	101,670	69,565	59,130

Source: Columbia River DART

Table 3 applies the same methodology as described above to estimate the number of steelhead in CWR for each individual year from 1999 to 2016. As shown, the number of steelhead in CWR varies in response to run size and river environment, ranging from 23,107 during a low-abundance year with below-average water temperatures (2012) to 155,492 during a high-abundance warm year (2009) with an average of 65,639 over the 1999-2016 period. In 2009 (Figure 4), temperatures reached 20°C in mid-July and climbed steeply to 23°C by early August resulting in low passage at The Dalles Dam relative to passage at Bonneville Dam and high CWR use during the July 15-August 31 period. Conversely, in 2012 (Figure 5), river temperature did not reach 20°C until the 2nd week of August and exceeded 20°C for just a few weeks, resulting in high passage at The Dalles Dam relative to passage at Bonneville Dam and low CWR use during the July 15-August 31 period.

Table 3 – Estimated Number of Steelhead in CWR Each Year (1999-2016)

Year	Ave Temp July 15 -Aug 31	Passed BON July 15 -Aug 31	Passed Dalles July 15 -Aug 31	Measured % That Passed Dalles June 1-Oct 31	Expected to Passed Dalles July 15 -Aug 31	In BON Reach July 15 -Aug 31	In CWR July 15 -Aug 31
2016	21.4	83,919	24,212	80%	66,868	42,656	36,258
2015	21.8	165,138	69,059	84%	137,893	68,834	58,509
2014	21.5	175,686	70,488	80%	140,923	70,435	59,869
2013	21.5	166,926	68,949	83%	138,059	69,110	58,743
2012	20.1	142,032	95,612	86%	122,797	27,185	**23,107**
2011	19.5	252,331	176,573	82%	207,452	30,879	26,248
2010	21.0	231,804	121,974	82%	189,445	67,471	57,350
2009	21.6	451,509	205,163	86%	388,094	182,931	**155,492**
2008	20.0	225,506	117,044	79%	177,048	60,004	51,004
2007	21.1	229,124	83,820	76%	173,420	89,600	76,160
2006	21.1	187,415	53,379	72%	134,561	81,182	69,005
2005	21.4	175,028	55,866	77%	135,090	79,224	67,340
2004	22.0	155,516	42,744	78%	120,905	78,161	66,437
2003	21.7	209,328	58,083	77%	160,904	102,821	87,398
2002	20.4	257,857	131,121	82%	210,238	79,117	67,250
2001	20.7	397,879	169,554	80%	319,544	149,990	127,491
2000	20.6	164,593	75,954	75%	124,114	48,160	40,936
1999	20.0	136,136	76,782	77%	104,458	27,676	23,524
Average	20.9	219,048	98,363		175,585	77,222	65,639

Source: Columbia River DART

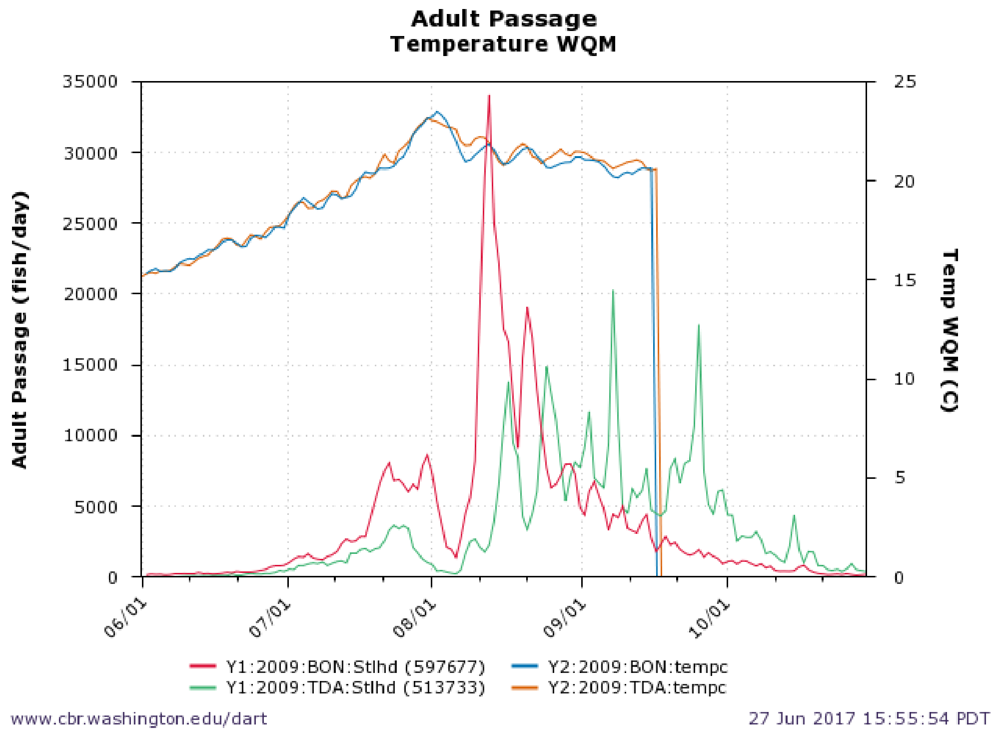

Figure 4 – Adult Steelhead Passage and Water Temperature at Bonneville Dam and The Dalles Dam During a Year with High Steelhead Returns and Above Average Temperatures (2009)

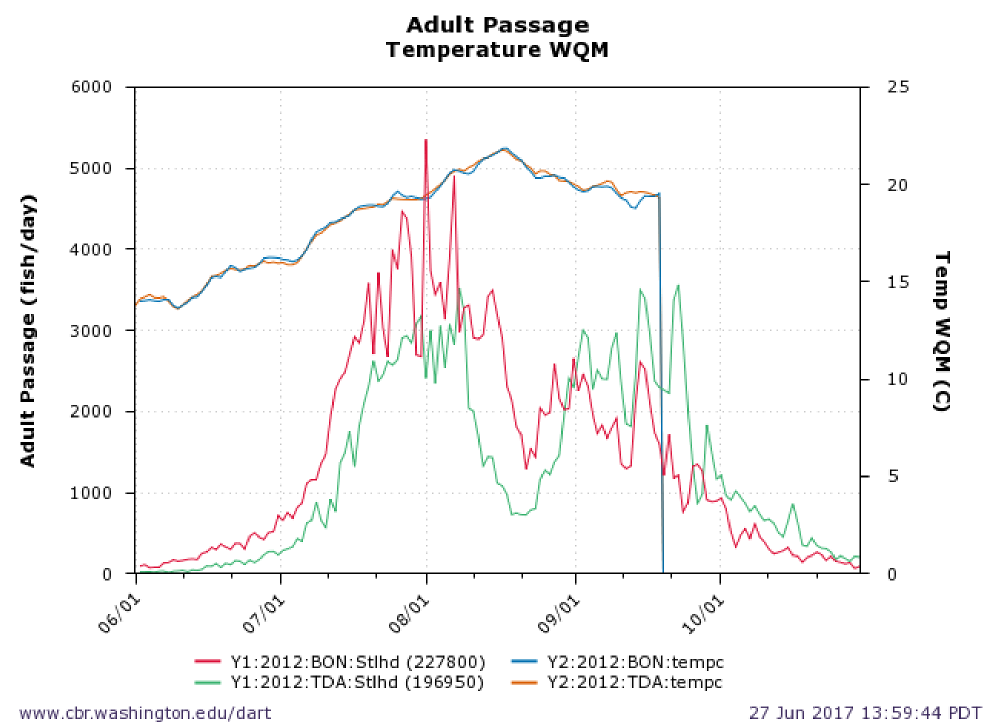

Figure 5 – Adult Steelhead Passage and Water Temperature at Bonneville Dam and The Dalles Dam During a Year with Low Steelhead Returns and Below Average Temperatures (2012)

Using data in Table 3, the following multiple linear regression (R^2=0.95) was developed to predict the number of steelhead in CWR during the period of maximum CWR use based on the average temperature and the cumulative Bonneville Dam steelhead passage for the July 15-August 31 period.

# of Steelhead in CWR = 23722.35 (Ave $T_{\text{July 15-Aug 31}}$) + 0.328729 (# $\text{Steelhead}_{\text{July 15-August 31}}$) – 503,150

1.3 Number of Steelhead in Each CWR Area

EPA has identified 23 CWR areas and associated CWR volumes between the Columbia River mouth and the Snake River confluence, eight of which are in the Bonneville Reach and are shown in Table 4. A total of 1,784,298 m^3 of CWR (greater than 2C cooler than the Columbia River) is estimated to occur in this reach. The majority (62%) occurs in Drano Lake (Little White Salmon River), followed by the Klickitat River (12%), Herman Creek (10%), and the White Salmon River (9%). Table 4 includes the estimated number of steelhead in each of the eight CWR areas for an average year, a high abundance year, and a low abundance year assuming steelhead are distributed proportionately to CWR volume. For example, an average of 40,507 steelhead are estimated to temporarily use Drano Lake as CWR each day during the period of maximum CWR use (mid-August through early September) during an average year, ranging from 14,260 during a low year and 95,957 during high year.

Table 4 – Estimated Number of Steelhead in Each Bonneville Pool CWR (>2C Δ CWR)

Tributary Name	Tributary Temp	Plume CWR Volume (> 2°C Δ)	Stream CWR Volume (> 2°C Δ)	Total CWR Volume (> 2°C Δ)	% of CWR in BON Reach	# Steelhead in Each CWR (1999-2016 Ave)	# Steelhead in Each CWR High Year (2009)	# Steelhead in Each CWR Low Year (2012)
	°C	m3	m3	m3				
Eagle Creek	15.1	2,100	888	2,988	0.2%	109	259	39
Rock Creek	17.4	530	1,178	1,708	0.1%	63	148	22
Herman Creek	12.0	168,000	1,698	169,698	9.5%	6,216	14,726	2,188
Wind River	14.5	60,800	44,420	105,220	5.9%	3,854	9,131	1,357
Little White Salmon River	13.3	1,097,000	11,661	1,108,661	61.9%	40,613	96,208	14,297
White Salmon River	15.7	72,000	81,529	153,529	8.6%	5,624	13,323	1,980
Hood River	15.5	28,000	0	28,000	1.6%	1,026	2,430	361
Klickitat River	16.4	73,000	149,029	222,029	12.4%	8,133	19,267	2,863
Total		1,501,430	290,403	1,791,833	100%	65,639	155,492	23,107

Studies indicate that steelhead seek cold water (8-18°C) when temporarily staying in CWR, thus a better indicator of CWR volume may be the volume less than 18C (Keefer and Caudill 2017). Table 5 displays the same information as Table 4, except only for CWR less than 18°C, which is estimated to be 954,176 m^3 for the Bonneville Reach. The distribution of CWR volume and steelhead is roughly the same under this scenario, with most CWR volume/steelhead in Drano Lake/Little White Salmon (57%), followed by the Klickitat River (16%), Herman Creek (10%), and the White Salmon River (10%).

Table 5 – Estimated Number of Steelhead in Each Bonneville Pool CWR (<18C Δ CWR)

Tributary Name	Tributary Temp	Plume CWR Volume (< 18°C)	Stream CWR Volume (< 18°C)	Total CWR Volume (< 18°C)	% of CWR in BON Reach	# Steelhead in Each CWR (1999-2016 Ave)	# Steelhead in Each CWR High Year (2009)	# Steelhead in Each CWR Low Year (2012)
	°C	m3	m3	m3				
Eagle Creek	15.1	610	888	1,498	0.2%	102	242	36
Rock Creek	17.4	26	1,178	1,204	0.1%	82	195	29
Herman Creek	12.0	93,958	1,698	95,656	9.9%	6,529	15,466	2,298
Wind River	14.5	20,390	44,420	64,810	6.7%	4,423	10,479	1,557
Little White Salmon River	13.3	531,524	11,661	543,185	56.5%	37,074	87,824	13,051
White Salmon River	15.7	14,000	81,529	95,529	9.9%	6,520	15,445	2,295
Hood River	15.5	7,500	0	7,500	0.8%	512	1,213	180
Klickitat River	16.4	3,300	149,029	152,329	15.8%	10,397	24,629	3,660
Total		671,308	290,403	961,711	100%	65,639	155,492	23,107

1.3.1 Comparison to Field Studies

In 2000, of 243 radio-tagged steelhead documented in Bonneville Reach CWR, 144 (59%) were detected in the Little White Salmon River/Drano Lake, 33 (14%) were detected in Herman Creek/Cove, 30 (12%) were detected in the White Salmon River, 20 (8%) were detected in the Wind River, 15 (6%) were detected in the Klickitat River, 1 was detected in Eagle Creek, and none were detected in the Hood River (Keefer and Caudill 2017). These data affirm most steelhead CWR use is in the Little White Salmon River/Drano Lake and the estimated proportion of CWR use aligns with the proportion of CWR volume available in each of the eight refuges; except the field data indicates a slightly higher amount of CWR use of Herman Creek and the White Salmon River and a lesser amount of CWR use of the Klickitat River than what is predicted based on CWR volume as shown in Tables 4 and 5. One reason for lesser CWR use of the Klickitat River than predicted based on CWR volume is that the Klickitat River delta is shallow at the confluence with the Columbia River and that may impede access up the Klickitat River.

The University of Idaho radio-tagged data for 2000 and 2001 was analyzed on two specific days to see what CWR sites were used on those specific days. Table 6 shows the distribution of steelhead in the Bonneville Reservoir reach for August 7 and August 31. August 7 was chosen to reflect the early phase on accumulation of steelhead in the Bonneville reservoir reach. August 31 was chosen to reflect the time of peak accumulation of steelhead in the Bonneville reservoir reach and maximum amount of CWR use (see Figures 2 and 3). These data confirm the Little White Salmon/Drano Lake and Herman Creek/Cove as the highest used CWR sites. These data also suggest Herman Creek/Cove is used in higher proportion earlier in the season and steelhead tend to accumulate in Little White Salmon/Drano Lake as the season progresses.

Table 6 – Distribution of Radio-Tagged Steelhead in the Bonneville Reach on Two Specific Days (Combined 2000/2001 Data Set) (Keefer 9/11/2017 email)

	August 7	August 31
Below Bonneville Dam	1 (2.9%)	0 (0%)
Bonneville Reservoir	3 (8.8%)	9 (12.5%)
Herman Creek	8 (23.5%)	6 (8.3%)
Wind River	1 (2.9%)	1 (1.4%)
Little White Salmon/Drano Lake	12 (35.3%)	40 (55.6%)
White Salmon	3 (8.8%)	4 (5.6%)
Klickitat River	4 (11.8%)	4 (5.6%)
Unknown CWR	0 (0%)	4 (5.6%)
The Dalles Dam Tailrace/Fishway	2 (5.9%)	4 (5.6%)
Total	34 Steelhead	72 Steelhead

1.4 Steelhead Density in CWR

The fish density within CWR in the Bonneville Reach can be calculated by dividing the number of steelhead estimated to be in CWR by the volume of CWR. Table 7 presents the fish density for the different scenarios presented in Tables 4 and 5. For example, considering just CWR less than 18°C, for an average year, the fish density in each of the CWR areas in the Bonneville Reach is estimated to be 171 steelhead per 2,500 m^3 (size of an Olympic swimming pool), ranging from 404 per Olympic pool in a high year and 60 per Olympic pool in a low year.

Table 7 – Estimated Steelhead Density in CWR

	CWR Volume (> 2°C Δ)			CWR Volume (< 18°C)		
	Average	High	Low	Average	High	Low
	1999-2016	2009	2012	1999 -2016	2009	2012
# fish/m3	0.0366	0.0868	0.0129	0.0683	0.1617	0.0240
# fish/2500 m3	92	217	32	171	404	60

1.5 Historical Analysis of Bonneville Reservoir Reach Steelhead CWR Use

The comparison of steelhead passage at the Bonneville Dam versus The Dalles Dam is available since 1957, when The Dalles Dam was built. As shown in Figure 1 and in this memo, passage data from the last decade shows there is a significant delay in passage over the The Dalles Dam and accumulation of steelhead in the Bonneville Reservoir Reach during the period of summer maximum temperatures. Interestingly, as shown in Figure 6, there is not a significant delay over the The Dalles Dam in the decade after the The Dalles Dam was built (1957-1966). Limited temperature data collected in this decade depicted in Figure 6 also shows summer peak temperatures were lower compared current day temperatures. These data suggest steelhead use of CWR sites in the Bonneville Reach was less historical°ly than what we observe today and that steelhead are using CWR more today in response to increased summer temperatures of the Columbia River.

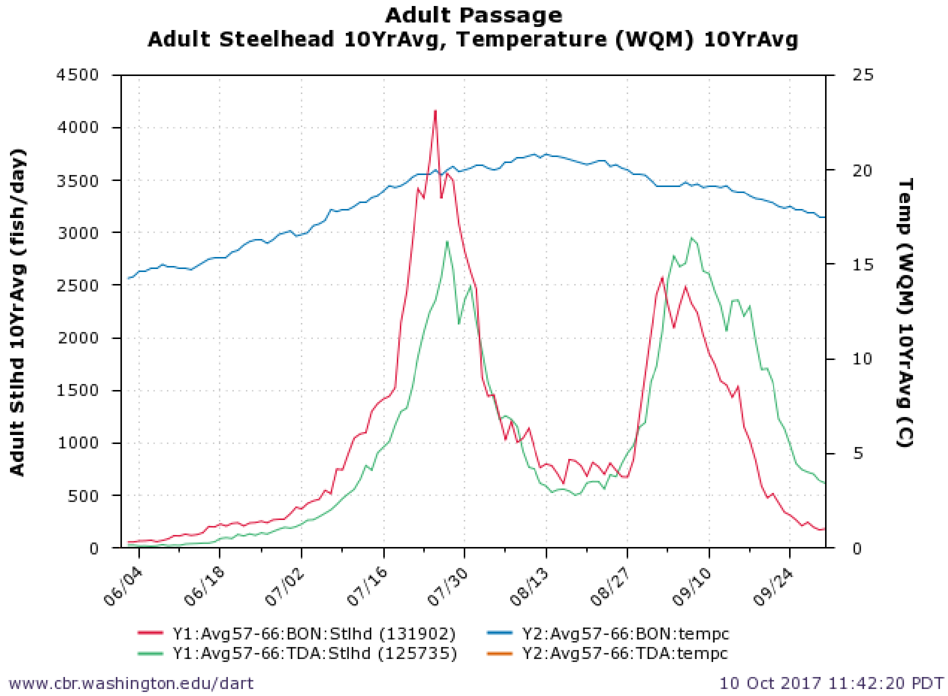

Figure 6 – Adult Steelhead Passage and Water Temperature at Bonneville Dam and The Dalles Dam (1957-1966 Average)

1.6 Analysis of Pit-Tagged Summer Steelhead

Analysis of PIT-tagged adult summer steelhead passing Bonneville Dam and The Dalles Dam conducted by Brian Maschhoff was provided to EPA (Attachment 1) and is summarized below. Data from PIT-tag detectors in the fish ladders at each dam can be used to determine if an individual fish that passed Bonneville Dam also passes The Dalles Dam and to track the time it takes an individual fish to travel from Bonneville Dam to the Dalles Dam. Figure 7 displays the number of PIT-tagged adult steelhead that passed Bonneville Dam by date on the x-axis (daily count on top of figure) and the number that passed The Dalles Dam on the y-axis (daily count on right side of figure) in 2013. Each individual blue or red dot in Figure 7 reflects an individual steelhead and the date of which it passed Bonneville Dam (x-axis) and the date for of which it passed The Dalles Dam (y-axis). Individual steelhead that took less than four days to travel between the two dams are color coded blue and those that took more than four days are color coded red in Figure 7. Those steelhead coded red (and taking more than four days to travel between the dams) in Figure 7 are likely to have used CWR because the median time to travel between the two dams is three days absent CWR use (Keefer et. al 2009). Also shown on Figure 7 is the temperature at Bonneville Dam by date.

Figure 7 shows most adult steelhead that passed Bonneville Dam in August when temperatures exceeded 21°C likely used CWR (color coded red) and then passed the Dalles Dam in September when temperatures cooled. Figure 7 also shows that most steelhead passing Bonneville Dam in July when temperature climbed from 18 to 21°C did not use CWR and passed The Dalles Dam in less than four days.

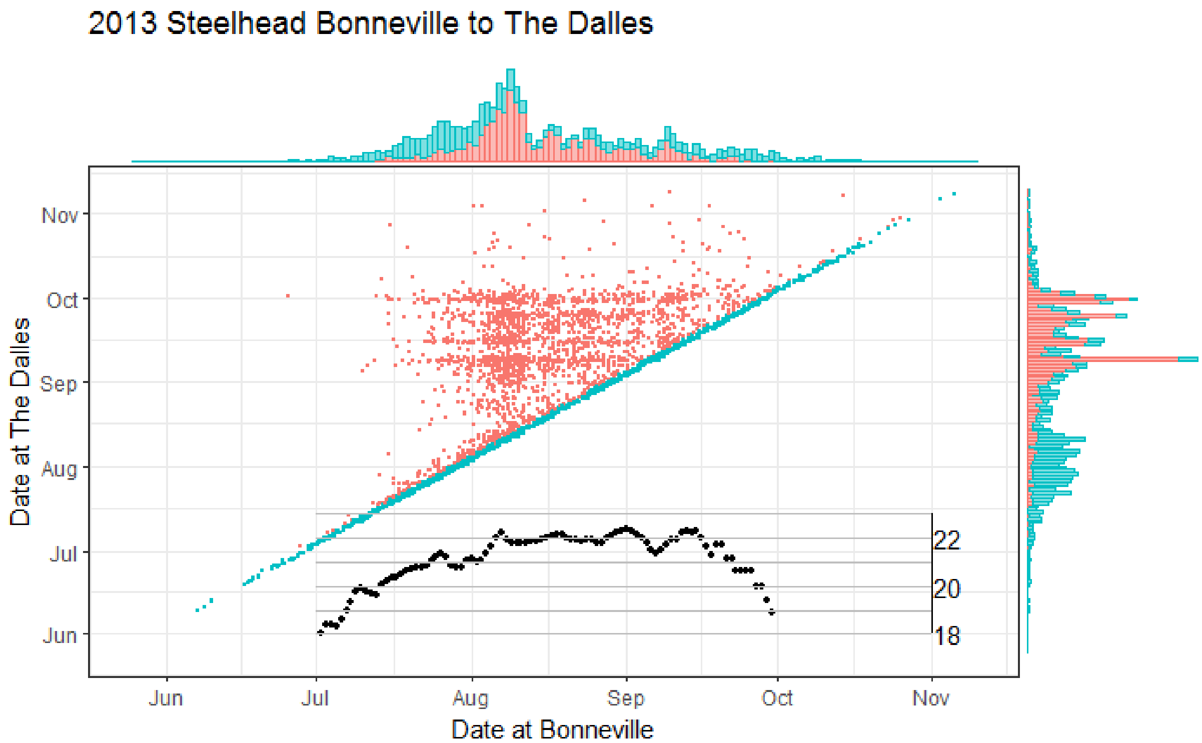

Figure 7 – PIT-Tagged Adult Steelhead Passage at Bonneville Dam and The Dalles Dam in 2013 (Attachment 1)

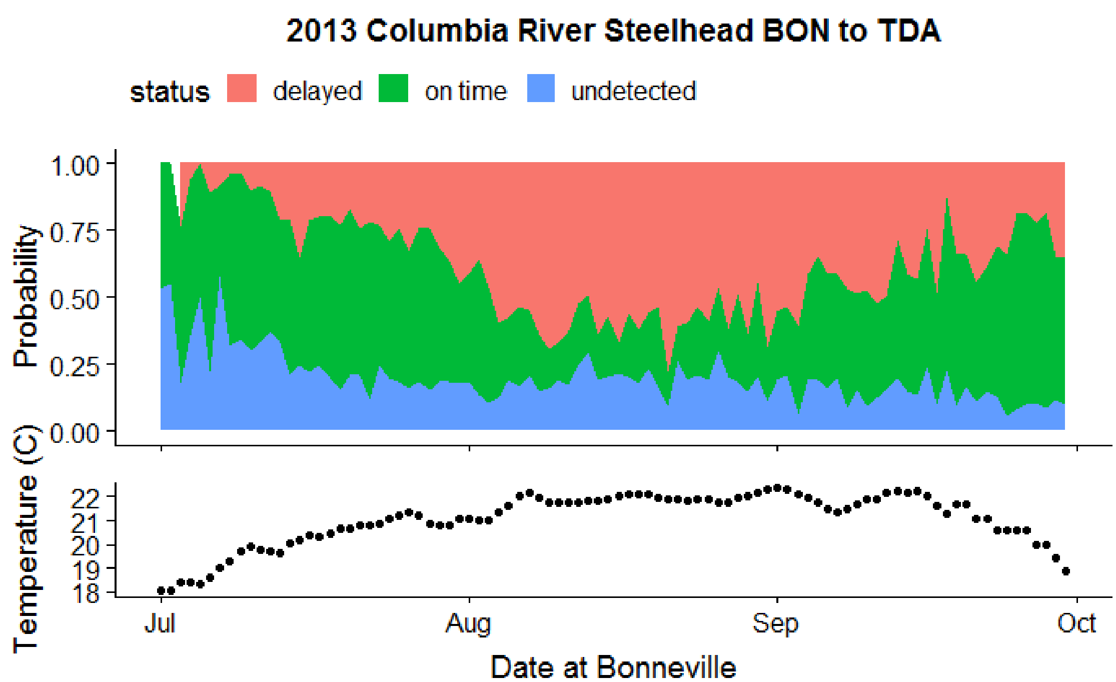

Figure 8 – Status of PIT-Tagged Adult Steelhead Between Bonneville Dam and The Dalles Dam in 2013 (Attachment 1)

Figure 8 shows the probability that migrating summer steelhead are delayed (greater than four-day travel time between dams and presumably using CWR), on-time (less than four days travel time), and undetected (passed Bonneville Dam, but did not pass The Dalles Dam) by date of Bonneville passage. Figure 8 depicts the pattern of extensive delayed, presumed CWR use, for those steelhead passing Bonneville Dam in August.

The PIT-Tag assessment results shown in Figures 7 and 8 corroborate the estimates of steelhead CWR use presented in Figure 2 and Table 1 above. 16% of the steelhead passing Bonneville Dam did not pass The Dalles Dam in August in Figure 8, which is consistent with the 18% that were estimated not to pass The Dalles Dam in the analysis displayed in Figure 2 and Table 1. 70% of the steelhead passing Bonneville Dam in August that ultimately passed The Dalles Dam were delayed (used CWR) when temperatures were in the 21-22°C range, which is consistent with Keefer et. al 2009 data showing 70-85% use CWR when temperatures are in the 21-22°C.

Brian Maschhoff ‘s PIT-Tag analysis looked to see if there were differences in the extent of steelhead delay between the Bonneville Dam and The Dalles Dam between hatchery and wild fish, fish that were transported as juveniles versus those that weren’t, and between basins of origin (Attachment 1). Generally, there was little differences in the extent of delay for these different groups when temperatures exceeded 21°C in 2013 (August – Mid September). Wild steelhead, which migrate in greater numbers in July, had slightly fewer delayed fish in July compared to hatchery fish, but both had similar delay in August. There was no noticeable difference in delay for steelhead transported as juveniles compared to those that were not. Steelhead from the Upper Columbia basin had a little less delay in August compared to steelhead from the Snake River, Clearwater, and Mid-Columbia basins (Attachment 1).

2. Fall Chinook Salmon

Figure 9 shows the average daily passage of Fall Chinook at Bonneville Dam and The Dalles Dam for the 2008-2017 period. Unlike summer steelhead as discussed above, there is not a pronounced delay in Fall Chinook passage between Bonneville Dam and The Dalles Dam. Rather, there is a small delay in August and early September and very little delay in late September and October. The small delay in August and early September is likely associated with CWR use, but the duration of Fall Chinook CWR use is less than steelhead CWR use (Goniea et al. 2006 and Keefer et al. 2009)

The delay of Fall Chinook passage between Bonneville Dam and The Dalles Dam is best illustrated in a year such as in 2017 that had relatively warm temperatures in August and early September as shown in Figure 10. In 2017, temperatures were about 22°C in August and early September and there were two spikes of Fall Chinook passing Bonneville Dam but no corresponding spikes in passage at The Dalles Dam. Presumably, many of the Fall Chinook passing Bonneville Dam in August and early September of 2017 passed The Dalles Dam later in September and likely used CWR in the Bonneville reach to temporarily escape the warm mainstem river temperatures.

Figure 11 shows the average passage rate (travel speed) of Fall Chinook between Bonneville Dam and The John Day Dam is reduced by about half when temperatures rise above 21°C (Goniea et al., 2006). It should be noted that this study includes delays that may occur while passing the Dalles Dam, which likely effects the average passage rate shown in this figure. Keefer et al. (2004) documented a Fall Chinook average passage rate of about 65 km/day (40 miles/day) through the Bonneville Reservoir, which was heavily weighted with Fall Chinook migrating when temperatures were below 21°C. Thus, Fall Chinook not using CWR can travel through 45-mile Bonneville Reservoir reach in a little more than a day. Keefer et al. (2009) noted that the typical resident time in CWR for Fall Chinook was 3-5 days for Fall Chinook using CWR (up to 40% based on Goniea et al., 2006), which likely explains the decrease in the average passage rate when temperature exceed 21°C.

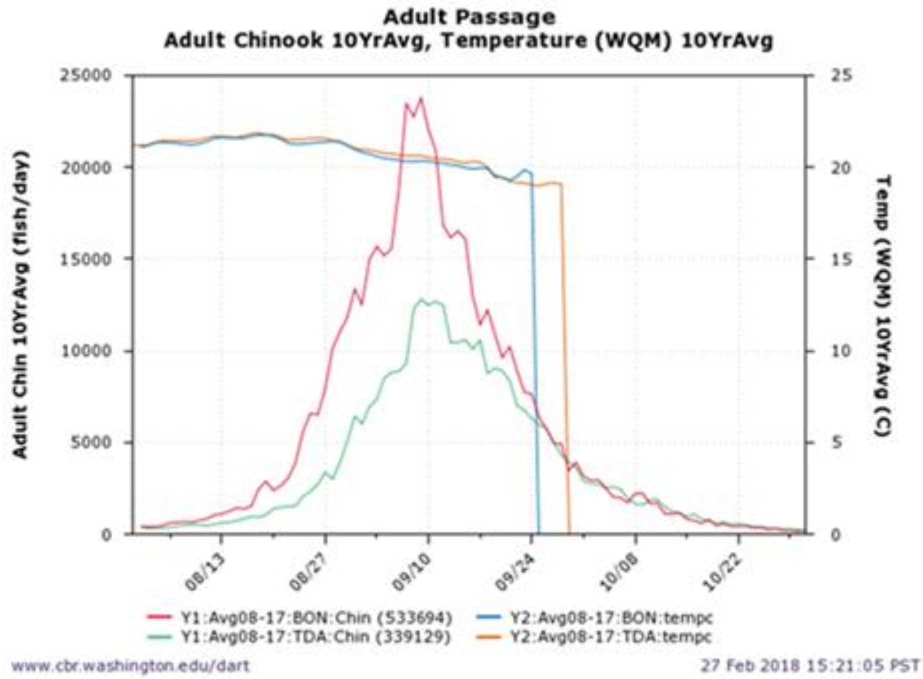

Figure 9 – Adult Fall Chinook Passage and Water Temperature at Bonneville Dam and The Dalles Dam (2008-2017 Average)

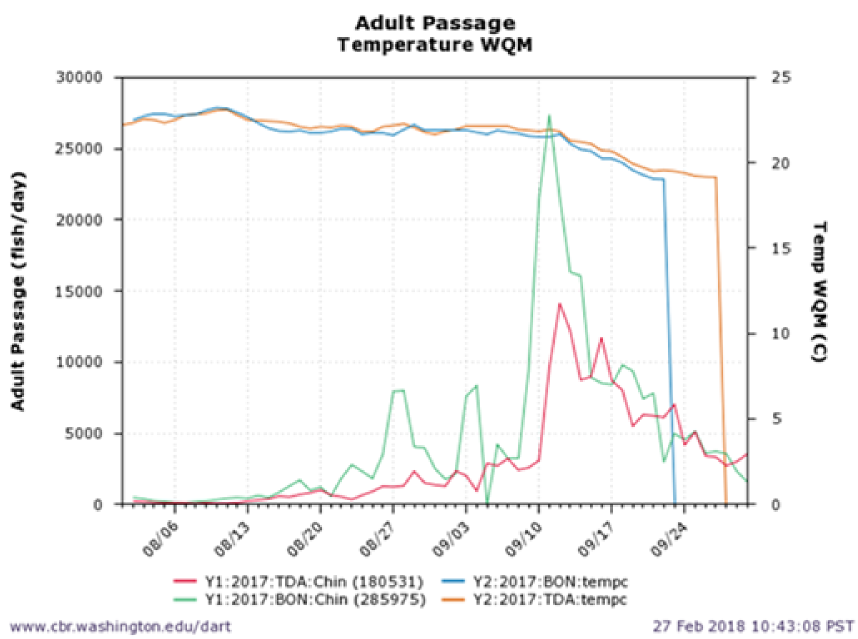

Figure 10 – Adult Fall Chinook Passage and Water Temperature at Bonneville Dam and The Dalles Dam (2017)

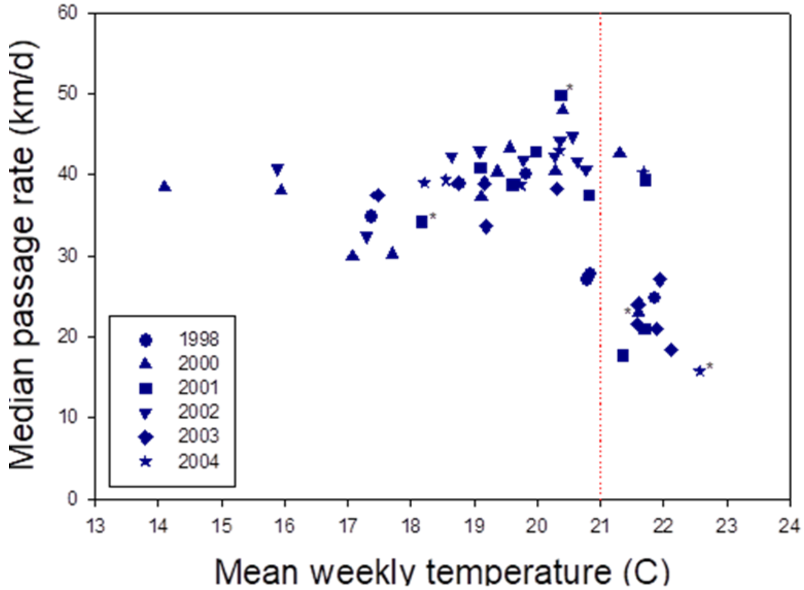

Figure 11 – Adult Fall Chinook Passage Rate between Bonneville Dam and The John Day Dam (Goniea et al., 2004)

2.1 Number of Fall Chinook Salmon in Bonneville Reach CWR

Figure 12 depicts the estimated number of Fall Chinook that are in the Bonneville Reach for each day from August through October (black line) and an estimate of the number of Fall Chinook in CWR for each day (blue line) for an average year (2008-2017). The daily values used to generate each of the lines in Figure 10 are displayed in Table 8.

2.1.1 Calculations and Assumptions

Table 8 shows the daily passage of Fall Chinook at Bonneville Dam and The Dalles Dam. A portion of the Fall Chinook that pass Bonneville Dam are not expected to pass The Dalles Dam due to entry into natal tributaries to spawn, return to hatcheries, or harvest within the Bonneville Reach. The percentage expected to not pass The Dalles Dam is estimated to be 36% based on comparing the average annual number of Fall Chinook passing Bonneville Dam (533,695) versus The Dalles Dam (339,129) over the August 1 – October 31 period (2008-2017). Thus, for purposes of calculating the accumulation of Fall Chinook in the Bonneville Reach in Table 8 (and displayed in Figure 12), 36% of the Fall Chinook that pass Bonneville Dam are removed from the analysis. To calculate the number of Fall Chinook in the Bonneville Reach on each day, the net number of Fall Chinook for each day (Bonneville Fall Chinook passage minus 36% minus The Dalles Fall Chinook passage) is calculated and then added to the number of Fall Chinook in the Bonneville Reach from the previous day (see Table 8).

Many of the "accumulated" Fall Chinook in the Bonneville Reservoir shown in Figure 12 are due to the increasing number of Fall Chinook migrating through the reach and not using CWR. To estimate the number of accumulated Fall Chinook in the Bonneville Reach that are in CWR versus in the Bonneville Reservoir, it is estimated that the percent in CWR is a function of the temperature as reported in Goniea et al. (2006), which summarized below.

% Fall Chinook in CWR	Columbia River Temperature
40%	>22C
30%	21.5 – 21.9C
20%	21.0 – 21.4C
10%	20.0 – 20.9C
5%	19.0 – 19.9C
2%	<19C

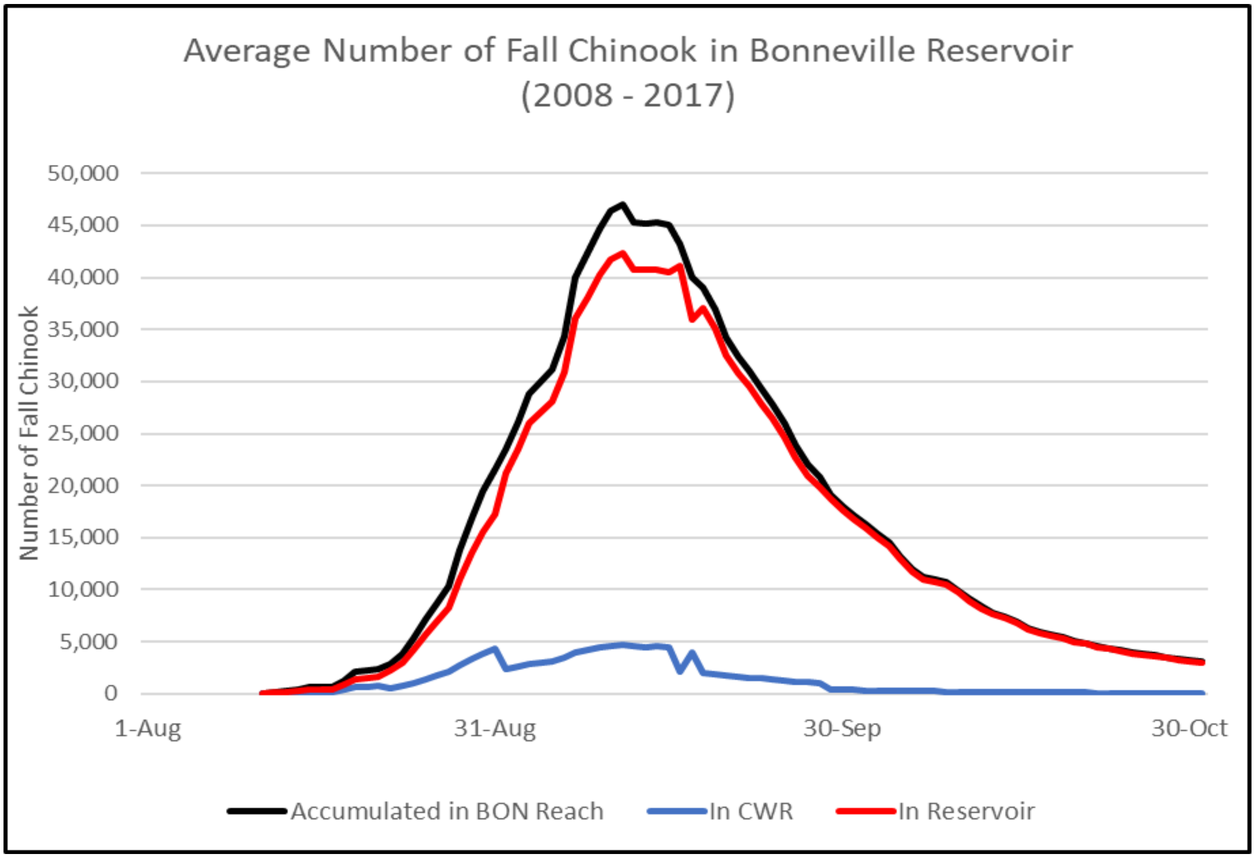

Figure 12 – Accumulation of Fall Chinook in the Bonneville Reach and the Number of Fall Chinook in CWR (2008-2017 Average)

Table 8 – Daily Estimate of Number of Fall Chinook in Bonneville Reach and in CWR (2008-2017 Average)

mm/dd	BON Passage Fish/day	BON Fish/Day Less 36%	Dalles Passage Fish/day	Net In BON Reach	Accumulated in BON Reach	In Res	In CWR	% in CWR	Temp @ BON
1-Aug	494	316	481	0					21.1
2-Aug	450	288	410	0					21.1
3-Aug	434	278	332	0					21.2
4-Aug	436	279	372	0					21.3
5-Aug	493	315	341	0					21.4
6-Aug	640	409	392	0					21.3
7-Aug	658	421	452	0					21.3
8-Aug	698	447	513	0					21.2
9-Aug	664	425	523	0					21.2
10-Aug	780	499	532	0					21.3
11-Aug	854	546	492	55	55	44	11	20%	21.4
12-Aug	1057	676	569	107	162	113	49	30%	21.6
13-Aug	1134	726	625	100	262	184	79	30%	21.6
14-Aug	1264	809	676	133	396	277	119	30%	21.6
15-Aug	1451	929	733	195	591	414	177	30%	21.6
16-Aug	1393	892	856	35	627	439	188	30%	21.6
17-Aug	1540	986	980	5	632	443	190	30%	21.7
18-Aug	2479	1586	940	646	1278	895	384	30%	21.7
19-Aug	2896	1853	1065	789	2067	1447	620	30%	21.7
20-Aug	2410	1543	1420	123	2190	1533	657	30%	21.7
21-Aug	2654	1699	1472	227	2417	1692	725	30%	21.5
22-Aug	3076	1969	1528	441	2858	2286	572	20%	21.3
23-Aug	3912	2504	1559	945	3802	3042	760	20%	21.2
24-Aug	5596	3581	2083	1498	5301	4240	1060	20%	21.3
25-Aug	6593	4220	2350	1870	7170	5736	1434	20%	21.3
26-Aug	6524	4176	2705	1471	8641	6913	1728	20%	21.4
27-Aug	7904	5059	3388	1670	10311	8249	2062	20%	21.4
28-Aug	10126	6481	3020	3461	13772	11018	2754	20%	21.4
29-Aug	11028	7058	3911	3147	16919	13535	3384	20%	21.4
30-Aug	11810	7558	5046	2512	19430	15544	3886	20%	21.2
31-Aug	13358	8549	6433	2116	21546	17237	4309	20%	21.0
1-Sep	12527	8017	6035	1982	23528	21175	2353	10%	20.8
2-Sep	14979	9587	6959	2628	26156	23540	2616	10%	20.7
3-Sep	15672	10030	7350	2680	28836	25952	2884	10%	20.6
4-Sep	15193	9723	8513	1211	30046	27042	3005	10%	20.5
5-Sep	15552	9953	8835	1118	31164	28048	3116	10%	20.4
6-Sep	18858	12069	8881	3188	34352	30917	3435	10%	20.4
7-Sep	23452	15009	9321	5688	40040	36036	4004	10%	20.3
8-Sep	22750	14560	12279	2281	42321	38089	4232	10%	20.3
9-Sep	23766	15210	12801	2409	44730	40257	4473	10%	20.3
10-Sep	22049	14112	12483	1629	46359	41723	4636	10%	20.3
11-Sep	20872	13358	12696	662	47020	42318	4702	10%	20.2
12-Sep	16848	10782	12480	-1697	45323	40791	4532	10%	20.2
13-Sep	16163	10344	10451	-106	45217	40695	4522	10%	20.1
14-Sep	16524	10576	10463	112	45329	40796	4533	10%	20.1
15-Sep	16094	10300	10585	-285	45045	40540	4504	10%	20.0
16-Sep	12983	8309	10103	-1794	43251	41088	2163	5%	19.9
17-Sep	11424	7311	10569	-3258	39993	35994	3999	10%	20.0
18-Sep	12233	7829	8771	-941	39052	37099	1953	5%	19.9
19-Sep	10898	6975	9060	-2085	36967	35119	1848	5%	19.5
20-Sep	9627	6161	8917	-2756	34212	32501	1711	5%	19.4

21-Sep	10238	6552	8384	-1832	32379	30760	1619	5%	19.3
22-Sep	8928	5714	7030	-1317	31063	29510	1553	5%	19.5
23-Sep	7743	4956	6764	-1808	29254	27792	1463	5%	19.9
24-Sep	7652	4897	6300	-1403	27852	26459	1393	5%	19.7
25-Sep	6372	4078	5992	-1914	25938	24641	1297	5%	
26-Sep	5740	3674	5770	-2096	23841	22649	1192	5%	
27-Sep	4962	3176	4977	-1801	22040	20938	1102	5%	
28-Sep	4947	3166	4335	-1169	20871	19828	1044	5%	
29-Sep	3483	2229	3978	-1749	19123	18740	382	2%	
30-Sep	3926	2513	3637	-1124	17999	17639	360	2%	
1-Oct	3168	2027	2909	-881	17118	16776	342	2%	
2-Oct	2957	1892	2778	-886	16232	15907	325	2%	
3-Oct	2978	1906	2743	-837	15395	15087	308	2%	
4-Oct	2544	1628	2530	-901	14493	14204	290	2%	
5-Oct	2056	1316	2597	-1281	13212	12948	264	2%	
6-Oct	2008	1285	2482	-1197	12015	11775	240	2%	
7-Oct	1738	1112	1950	-837	11178	10954	224	2%	
8-Oct	2224	1423	1664	-240	10938	10719	219	2%	
9-Oct	2242	1435	1630	-195	10743	10528	215	2%	
10-Oct	1688	1080	1888	-808	9935	9736	199	2%	
11-Oct	1719	1100	1911	-810	9124	8942	182	2%	
12-Oct	1158	741	1494	-753	8372	8204	167	2%	
13-Oct	1158	741	1286	-545	7827	7671	157	2%	
14-Oct	1183	757	1143	-386	7441	7292	149	2%	
15-Oct	832	533	993	-461	6981	6841	140	2%	
16-Oct	760	486	1112	-625	6355	6228	127	2%	
17-Oct	620	397	836	-439	5916	5798	118	2%	
18-Oct	811	519	729	-209	5707	5593	114	2%	
19-Oct	482	308	618	-310	5397	5289	108	2%	
20-Oct	578	370	675	-305	5092	4990	102	2%	
21-Oct	455	291	509	-218	4874	4777	97	2%	
22-Oct	448	286	587	-301	4574	4482	91	2%	
23-Oct	472	302	511	-209	4365	4277	87	2%	
24-Oct	365	233	430	-197	4168	4085	83	2%	
25-Oct	381	244	430	-186	3982	3902	80	2%	
26-Oct	274	175	368	-193	3789	3713	76	2%	
27-Oct	329	211	324	-113	3676	3603	74	2%	
28-Oct	219	140	298	-158	3519	3448	70	2%	
29-Oct	211	135	306	-171	3347	3280	67	2%	
30-Oct	177	113	263	-149	3198	3134	64	2%	
31-Oct	203	130	222	-92	3106	3044	62	2%	

Source: Columbia River DART

Notes: 1) Not feasible to calculate accumulated Fall Chinook from Aug. 1 to Aug. 10 with the method and assumptions; 2) Bonneville Forebay temperatures not available after September 24.

2.1.2 *Results*

As shown in Figure 12 (and Table 8), the number of Fall Chinook using CWR in the Bonneville Reservoir reach is estimated to be approximately 5,000 during the last week of August and the first two weeks of September for an average year (2008-2017). Unlike steelhead, the majority of Fall Chinook that are in the Bonneville Reservoir are estimated to be migrating in the reservoir. After mid-September, the number Fall Chinook passing Bonneville Dam begins to decrease, the accumulated number of Fall

Chinook in the reach begins to decrease, and temperatures are 20°C and declining resulting in fewer Fall Chinook in CWR after mid-September in an average year.

On warmer years, when temperatures remain above 21°C into early September, which is the peak of the Fall Chinook run passing Bonneville Dam, it would be expected that a higher number of Fall Chinook would be in CWR within the Bonneville Reach. Also, this analysis excluded 36% of the Fall Chinook passing Bonneville Dam as explained above. Many of those Fall Chinook are likely harvested by fishing in CWR. Thus, this analysis may underestimate the number of Fall Chinook in Bonneville Reach CWR.

2.1.3 Field Verification

To test the above assumptions on the percentage of Fall Chinook in the Bonneville reach that are in the reservoir versus in CWR, the location of 49 radio-tagged Fall Chinook from the University of Idaho 2000 and 2002 research studies were analyzed. As shown in Figure 13, the percentage of Fall Chinook in the CWR was highest in in mid-August (about 44% averaged over the August 12-27th period), then dropped to 25% then 10% in late August and early September. After the first week of September nearly all the Fall Chinook were migrating in the reservoir and were not in CWR.

The results shown in Figure 13 generally comport to the percentages and pattern of Fall Chinook in CWR depicted in Figure 12 above, although the 44% of the Fall Chinook using CWR in August is slightly higher than the assumptions used in Table 8 and Figure 12. Also, Fall Chinook use of CWR in Figure 13 drops off more rapid than in Figure 12, which is likely because early September temperatures in 2000 and 2002 were below average. The results in Figure 13 should, however, be viewed with caution due to the low number of Fall Chinook on each day.

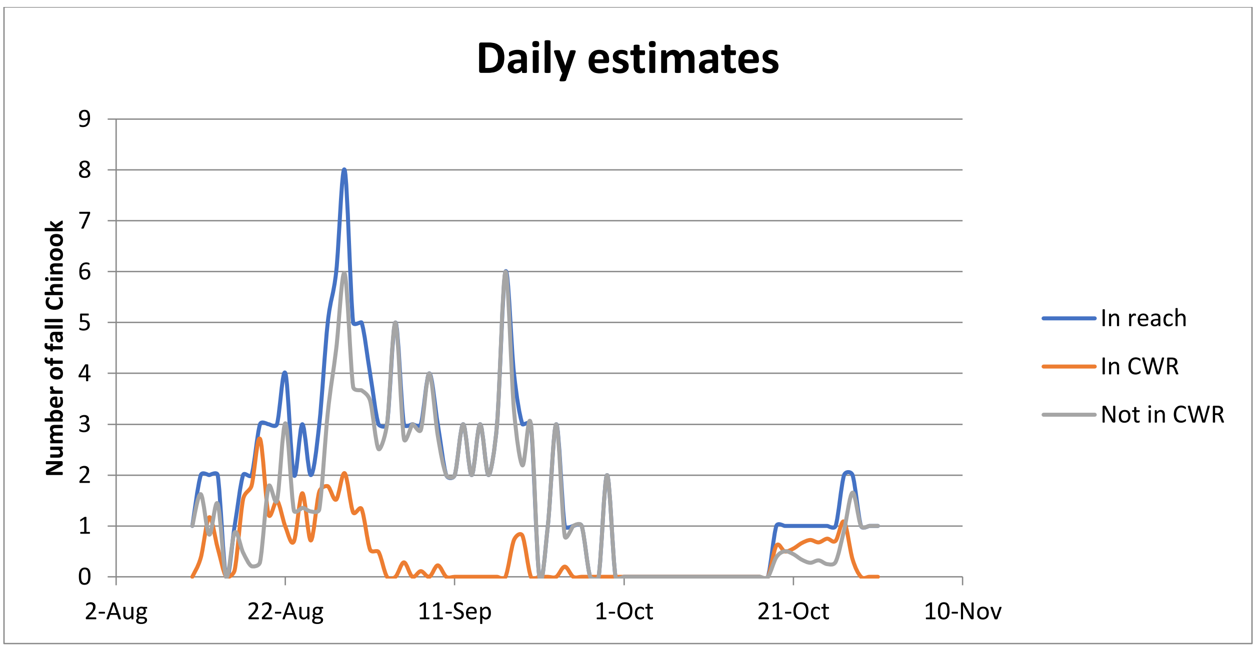

Figure 13 – Distribution of 49 Radio-Tagged Fall Chinook in Bonneville Reach from University of Idaho 2000 and 2002 Research Studies (Keefer 6/22/17 email)

2.2 Number of Fall Chinook Salmon in Bonneville Reach CWR in 2013

Using the same methodology as described in Section 2.1 above, the number of Fall Chinook Salmon in CWR is estimated for 2013 and is shown in Figure 12 and Table 9. 2013 was selected because it represents a relatively warm Columbia River temperature year for August and September and represents a relatively large Fall Chinook run. And therefore, represents conditions that would be expected to result in the highest number of Fall Chinook using CWR.

As shown in Figure 14 and Table 9, 20,000 to 40,000 Fall Chinook are estimated to have been in Bonneville Reach CWR in 2013 in the latter part of August through mid-September. This is four to eight times the estimated number of Fall Chinook (5,000) in CWR in an average year (2006-2017) as shown in Section 2.1. Late August and early September temperatures were consistently around 22°C in 2013, and as documented by Goniea et al. (2006), are temperatures at which a significant number of Fall Chinook seek CWR. In 2013, 953,222 Adult Fall Chinook passed Bonneville Dam, which is about twice the 10 year (2007-2016) annual average of 504,148 (Fish Passage Center Annual Reports).

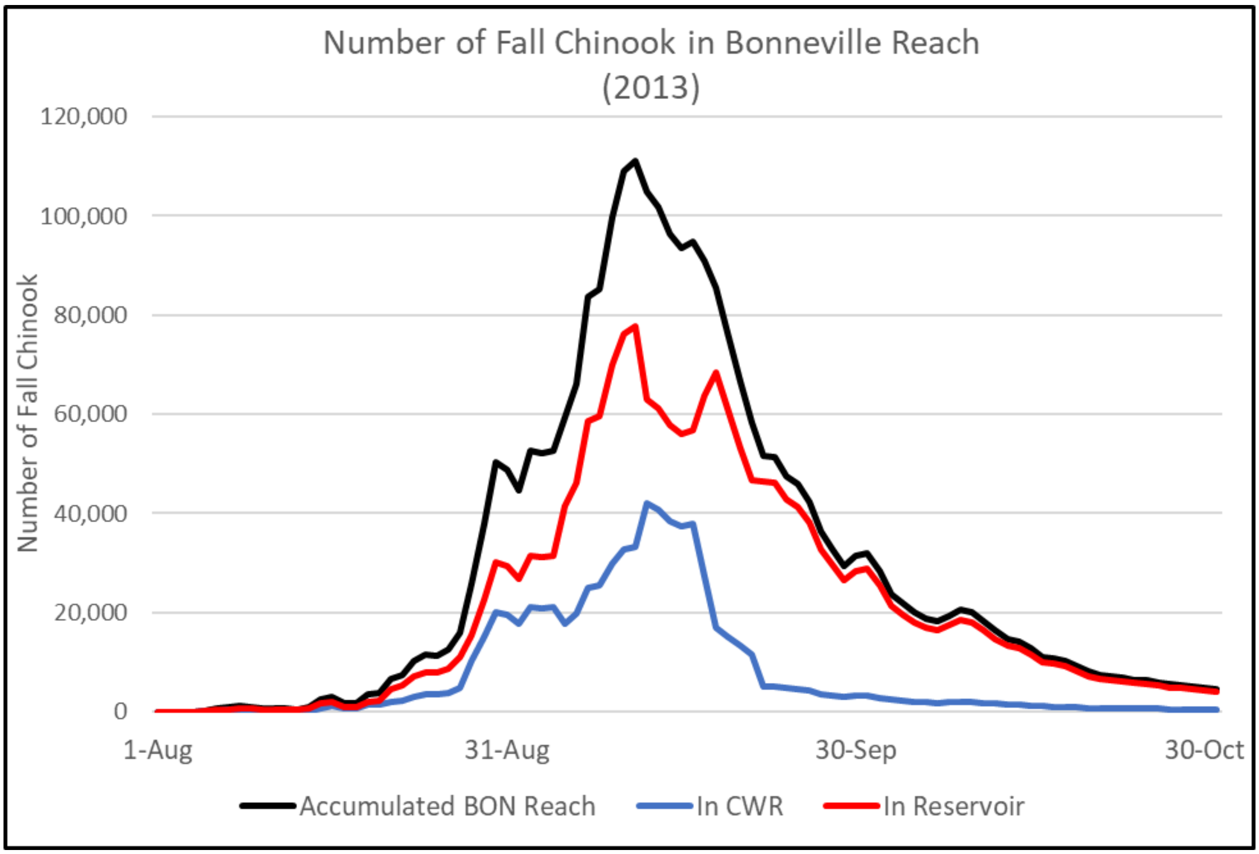

Figure 14 – Accumulation of Fall Chinook in the Bonneville Reach and the Number of Fall Chinook in CWR (2013)

Table 9 – Daily Estimate of Number of Fall Chinook in Bonneville Reach and in CWR (2013)

mm/dd	BON Passage Fish/day	BON Fish/Day Less 36%	Dalles Passage Fish/day	Net In BON Reach	Accumulated in BON Reach	In Res	In CWR	% in CWR	Temp @ BON
1-Aug	456	292	486	-194					21.1
2-Aug	556	356	317	39					21.0
3-Aug	461	295	463	-168					21.0
4-Aug	648	415	402	13	13	10	3	20%	21.3
5-Aug	1062	680	447	233	245	172	74	30%	21.6
6-Aug	1623	1039	532	507	752	451	301	40%	22.0
7-Aug	1441	922	742	180	932	559	373	40%	22.2
8-Aug	1774	1135	938	197	1130	791	339	30%	21.9
9-Aug	1310	838	908	-70	1060	742	318	30%	21.8
10-Aug	1345	861	1249	-388	672	470	202	30%	21.8
11-Aug	1464	937	823	114	786	550	236	30%	21.7
12-Aug	1102	705	848	-143	643	450	193	30%	21.8
13-Aug	1250	800	961	-161	482	338	145	30%	21.8
14-Aug	2222	1422	891	531	1013	709	304	30%	21.8
15-Aug	4009	2566	1048	1518	2531	1772	759	30%	21.9
16-Aug	2816	1802	1204	598	3129	1878	1252	40%	22.0
17-Aug	1326	849	2196	-1347	1782	1069	713	40%	22.1
18-Aug	2130	1363	1353	10	1792	1075	717	40%	22.1
19-Aug	4060	2598	906	1692	3484	2091	1394	40%	22.1
20-Aug	3255	2083	1742	341	3826	2295	1530	40%	22.0
21-Aug	7650	4896	2028	2868	6694	4686	2008	30%	21.9
22-Aug	6857	4388	3552	836	7530	5271	2259	30%	21.9
23-Aug	9622	6158	3426	2732	10262	7184	3079	30%	21.9
24-Aug	9038	5784	4609	1175	11438	8006	3431	30%	21.9
25-Aug	8431	5396	5451	-55	11382	7968	3415	30%	21.9
26-Aug	8023	5135	3966	1169	12551	8786	3765	30%	21.8
27-Aug	13312	8520	5136	3384	15935	11154	4780	30%	21.7
28-Aug	21720	13901	4159	9742	25677	15406	10271	40%	22.0
29-Aug	29308	18757	6449	12308	37985	22791	15194	40%	22.1
30-Aug	33819	21644	9366	12278	50263	30158	20105	40%	22.2
31-Aug	25199	16127	17511	-1384	48879	29328	19552	40%	22.3
1-Sep	14086	9015	13289	-4274	44605	26763	17842	40%	22.4
2-Sep	26807	17156	9223	7933	52539	31523	21016	40%	22.3
3-Sep	12593	8060	8383	-323	52215	31329	20886	40%	22.1
4-Sep	13045	8349	8031	318	52533	31520	21013	40%	22.0
5-Sep	20216	12938	6074	6864	59397	41578	17819	30%	21.8
6-Sep	25956	16612	9954	6658	66055	46239	19817	30%	21.5
7-Sep	48710	31174	13612	17562	83618	58532	25085	30%	21.3
8-Sep	42445	27165	25628	1537	85154	59608	25546	30%	21.5
9-Sep	63870	40877	26225	14652	99806	69864	29942	30%	21.7
10-Sep	56044	35868	26710	9158	108964	76275	32689	30%	21.9
11-Sep	42506	27204	25140	2064	111028	77720	33308	30%	21.9
12-Sep	27964	17897	24071	-6174	104854	62912	41942	40%	22.2
13-Sep	24175	15472	18441	-2969	101885	61131	40754	40%	22.3
14-Sep	22755	14563	20037	-5474	96411	57847	38565	40%	22.2
15-Sep	28761	18407	21239	-2832	93579	56148	37432	40%	22.3
16-Sep	21370	13677	12402	1275	94854	56912	37942	40%	22.0
17-Sep	18896	12093	15951	-3858	90997	63698	27299	30%	21.7
18-Sep	23268	14892	20357	-5465	85531	68425	17106	20%	21.3
19-Sep	21118	13516	22700	-9184	76347	61077	15269	20%	
20-Sep	18390	11770	21544	-9774	66572	53258	13314	20%	
21-Sep	13789	8825	16993	-8168	58404	46723	11681	20%	

22-Sep	9725	6224	13030	-6806	51598	46438	5160	10%	
23-Sep	14803	9474	9735	-261	51337	46203	5134	10%	
24-Sep	11596	7421	11150	-3729	47609	42848	4761	10%	
25-Sep	13906	8900	10534	-1634	45974	41377	4597	10%	
26-Sep	10857	6948	10501	-3553	42422	38180	4242	10%	
27-Sep	6901	4417	10474	-6057	36365	32728	3636	10%	
28-Sep	7041	4506	8055	-3549	32816	29534	3282	10%	
29-Sep	5286	3383	6760	-3377	29439	26495	2944	10%	
30-Sep	11556	7396	5269	2127	31566	28409	3157	10%	

Source: Columbia River DART

Notes: 1) Started calculation of accumulated Fall Chinook on Aug. 4 to avoid a negative initial count; 2) Bonneville Forebay temperatures not available after September 18; 3) the % in CWR after September 18 is based on estimated temperatures through September.

Due to the high number of Fall Chinook passing both Bonneville Dam and The Dalles Dam relative to the accumulative number of Fall Chinook in the Bonneville Reservoir during the peak CWR use period, an adjusted method was applied to provide a more conservative estimate of the number of Fall Chinook in CWR in 2013, which is shown in Figure 15. In this alternative method, the number of Fall Chinook passing each dam was subtracted from the daily accumulated number of Fall Chinook in the Bonneville Reach. Then this adjusted accumulated number of Fall Chinook for each day was multiple by the percent predicted to be in CWR as a function of the temperature. Using this adjusted method, approximately 20,000-25,000 Fall Chinook were estimated to be in CWR in 2013 during the peak CWR use period in mid-September.

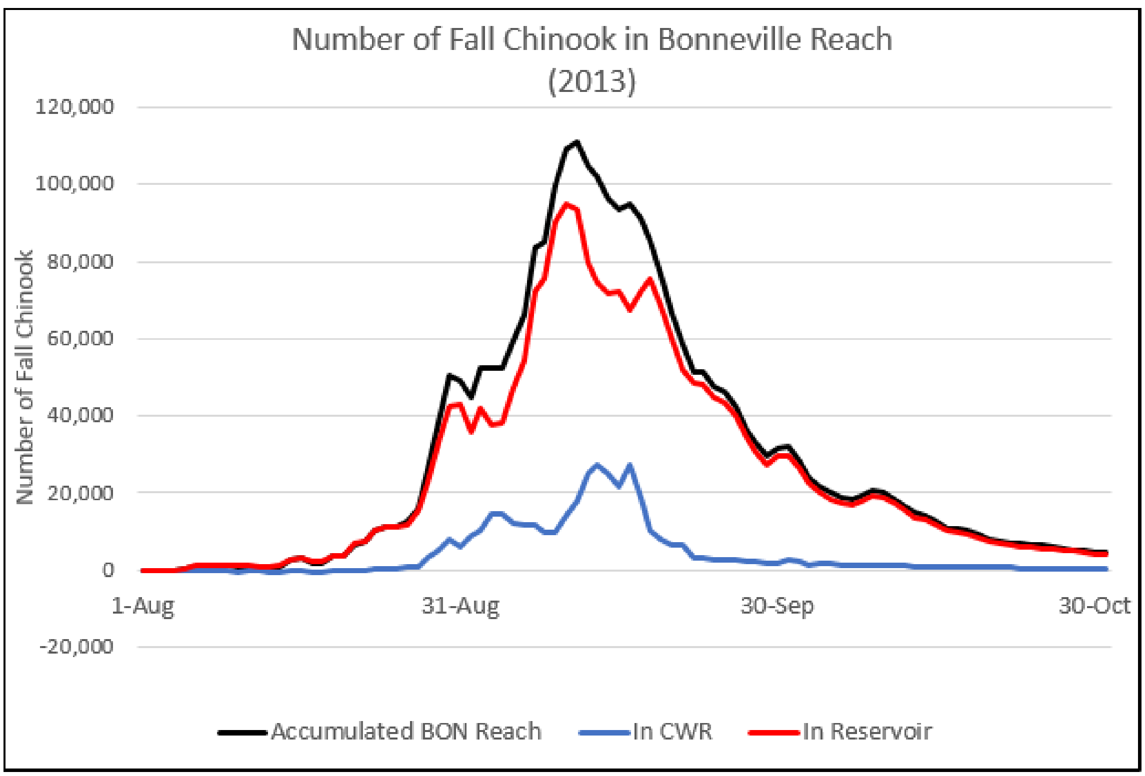

Figure 15 – Accumulation of Fall Chinook in the Bonneville Reach and the Number of Fall Chinook in CWR (2013) with Adjusted Method for a more Conservative Estimate

2.3 Most Used Bonneville Reach CWR by Fall Chinook

As reported in Goniea et al. 2006, Fall Chinook appear to use the larger CWR tributaries in the Bonneville Reach, including the Little White Salmon (Drano Lake), White Salmon, Klickitat rivers. Herman Creek/Cove is also likely used by Fall Chinook salmon.

2.4 Analysis of Pit-Tagged Fall Chinook

Analysis of PIT-tagged adult Fall Chinook (mostly Snake River Fall Chinook) passing Bonneville Dam and The Dalles Dam conducted by Brian Maschhoff was provided to EPA (Attachment 1) and is summarized below. Data from PIT-tag detectors in the fish ladders at each dam can be used to determine if an individual fish that passed Bonneville Dam also passes The Dalles Dam and to track the time it takes an individual fish to travel from Bonneville Dam to the Dalles Dam. Figure 16 displays the number of PIT-tagged adult fall Chinook that passed Bonneville Dam by date on the x-axis (daily count on top of figure) and the number that passed The Dalles Dam on the y-axis (daily count on right side of figure) in 2013. Each individual blue or red dot in Figure 16 reflects an individual Chinook and the date of which it passed Bonneville Dam (x-axis) and the date for of which it passed The Dalles Dam (y-axis). Individual Chinook that took less than four days to travel between the two dams are color coded blue and those that took more than four days are color coded red in Figure 16. Those Chinook coded red (and taking more than four days to travel between the dams) in Figure 16 are likely to have used CWR because the median time to travel between the two dams is about two days absent CWR use (Keefer et al. 2004). Also shown on Figure 16 is the temperature at Bonneville Dam by date.

Figure 16 shows that during the peak of the Fall Chinook run in mid-August through mid-September at Bonneville Dam a modest number of Fall Chinook were delayed (coded red - more than four days travel between dams) and likely used CWR.

Figure 17 shows the probability that migrating Snake River Fall Chinook are delayed (greater than four-day travel time between dams and presumably using CWR), on-time (less than four days travel time), and undetected (passed Bonneville Dam, but did not pass The Dalles Dam) by date of Bonneville passage.

During August, when temperatures were consistently around 22°C, 14% percent of Fall Chinook that ultimately passed The Dalles Dam were delayed. 14% is less than the 40% CWR use for Fall Chinook at 22°C temperatures reported in Goniea et. al (2006). Part of this discrepancy maybe because some fall Chinook could use CWR for 1-2 days and still travel between Bonneville Dam and The Dalles Dam under four days and therefore not be classified as delayed under this analysis. Further, many of the 11% of undetected fish were likely to have been harvested in CWR. It is also possible that the Goniea et. al (2006) study reflected Fall Chinook that were more inclined to stray and use CWR because when that study was done there was a higher proportion of fall Chinook juveniles that were transported (barged) downstream as juveniles.

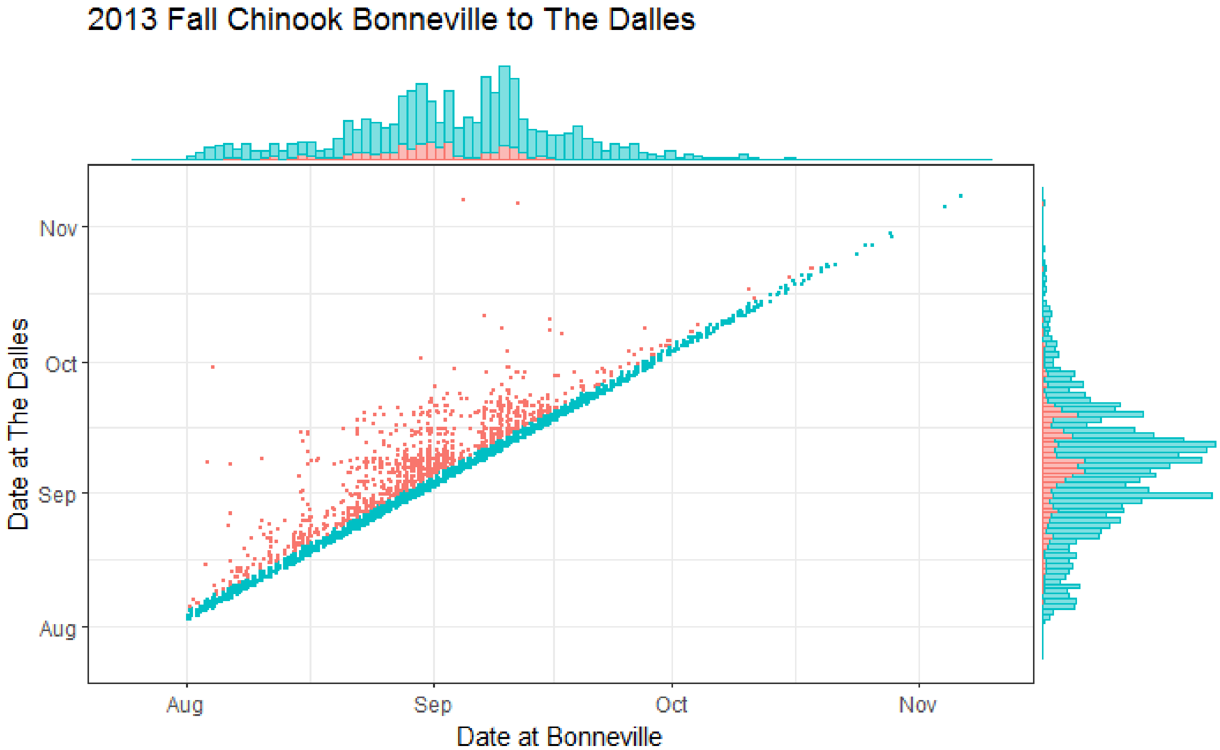

Figure 16 – PIT-Tagged Adult Fall Chinook Passage at Bonneville Dam and The Dalles Dam in 2013 (Attachment 1)

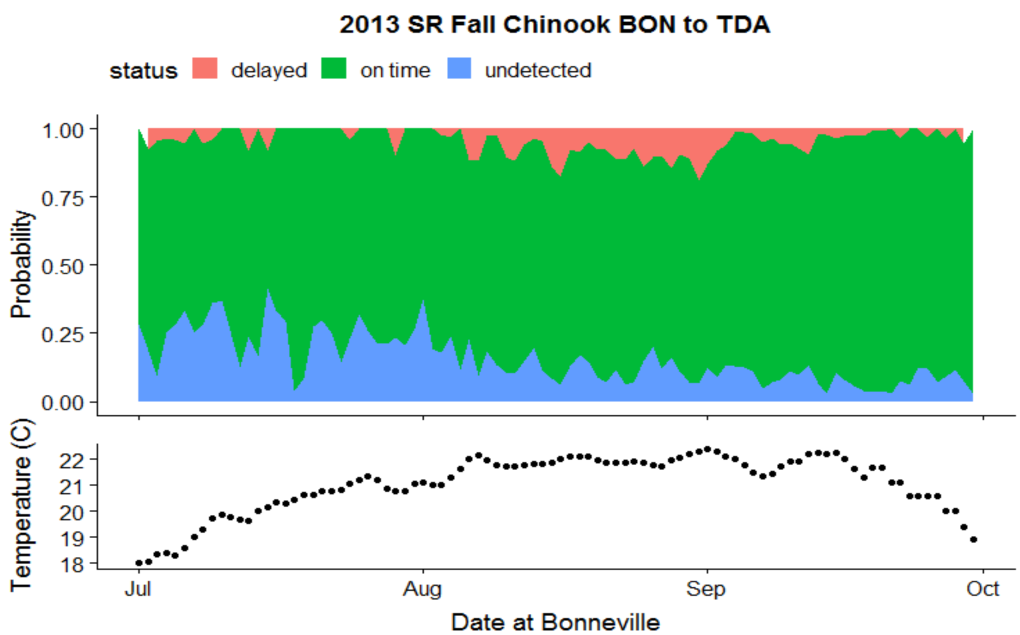

Figure 17 – Status of PIT-Tagged Adult Fall Chinook Between Bonneville Dam and The Dalles Dam in 2013 (Maschhoff)

3. Summary

Peak use of Bonneville Reservoir CWR by steelhead occurs mid-August through early September and peak use by Fall Chinook occurs in late August through mid-September. During an average year (river temperatures and run size), approximately 65,000 steelhead and 5,000 Fall Chinook are estimated to be in Bonneville Reservoir CWR. During years with warm August-September Columbia River temperatures and high run size, as many as 155,000 steelhead and 40,000 Fall Chinook are predicated to be in Bonneville Reservoir CWR during the period of peak CWR use, although these peak numbers for steelhead and Fall Chinook may not occur in the same years.

The estimates above are ballpark estimates using indirect methods to estimate the number of steelhead and Fall Chinook salmon that use CWR in the Bonneville Reach. Thus, there is uncertainty to these estimates that are not quantified in this memo. The analysis above indicates that there is considerable year-to-year variability in CWR use based on run size and Columbia River mainstem summer temperatures, which appears to be more variable than the uncertainty around the CWR use estimates for a particular year. In general, there is more uncertainty regarding the number of Fall Chinook in Bonneville Reach CWR presented above than the number of steelhead in CWR because Fall Chinook use CWR for a shorter duration making the estimates using the indirect methods more uncertain.

References

Goniea, T. M., M. L. Keefer, T. C. Bjornn, C. A. Peery, D. H. Bennett, and L. C. Stuehrenberg. 2006. Behavioral thermoregulation and slowed migration by adult fall Chinook salmon in response to high Columbia River water temperatures. Transactions of the American Fisheries Society 135:408-419.

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Keefer, M. L., C. A. Peery, T. C. Bjornn, M. A. Jepson, and L. C. Stuehrenberg. 2004. Hydrosystem, dam, and reservoir passage rates of adult chinook salmon and steelhead in the Columbia and Snake rivers. Transactions of the American Fisheries Society 133:1413-1439.

Keefer, M. L., C. A. Peery, and B. High. 2009. Behavioral thermoregulation and associated mortality trade-offs in migrating adult steelhead (*Oncorhynchus mykiss*): variability among sympatric populations. Canadian Journal of Fisheries and Aquatic Sciences 66:1734-1747.

Keefer, M.L., and Caudill, C. 2017. Assembly and Analysis of Radiotelemetry and Temperature Logger Data From Adult Chinook Salmon and Steelhead Migrating Through the Columbia River Basin. Technical Report 2017-1.

Keefer, M.L. Email to John Palmer, EPA. 8/31/17.

Keefer, M.L. Email to John Palmer, EPA. 9/11/17

Attachment 1

The following report was developed by Brian Maschhoff and was downloaded from https://github.com/salmonetics/Columbia_CWR

Summary

This report is submitted as supplemental data and analysis for the EPA document Columbia River Cold Water Refuges Plan 2019. The main document provided estimates of Cole Water Refuge (CWR) use by Chinook salmon and steelhead using a model which incorporates fish count differential (differences in daily counts at Bonneville and The Dalles dams adult fish ladders) and limited radio-tagging experiments in 2000 and 2002. This report describes similar estimates using PIT-tag detection data, providing additional evidence as to the nature and extent of the inter-dam migrational delay for these species for years 2013-2019 (PIT-tag interrogation began at The Dalles in 2013).

1. The measured incidence of migrational delay (or protracted inter-dam transit time) of adult steelhead, and to a much lesser extent Fall Chinook salmon, between Bonneville and The Dalles dams using PIT-tag detections is consistent with previous studies using radio-tagged fish indicating the use of cold water refuges (CWR), although the locations and paths of PIT-tagged fish in between detection sites cannot be determined.
2. Onset of delay is described as the point in the migration season where the probability of a fish having an unusually long BON-TDD transit time increases, and this coincides with dam scroll case temperatures above 20-21C. The lessening of this probability coincides with water temperatures decreasing below that threshold.
3. The time series of PIT-tag detections of steelhead at The Dalles Dam often indicate one or more narrow peaks in arrivals, and these fish have Bonneville departures distributed across the span of the delay period (#2, above).
4. In year 2013, for example, large numbers of steelhead, having departed Bonneville Dam over a span of two months, nonetheless ascended The Dalles Dam adult ladders on a single day (almost 10,000 on 9/8/2013).

Methods

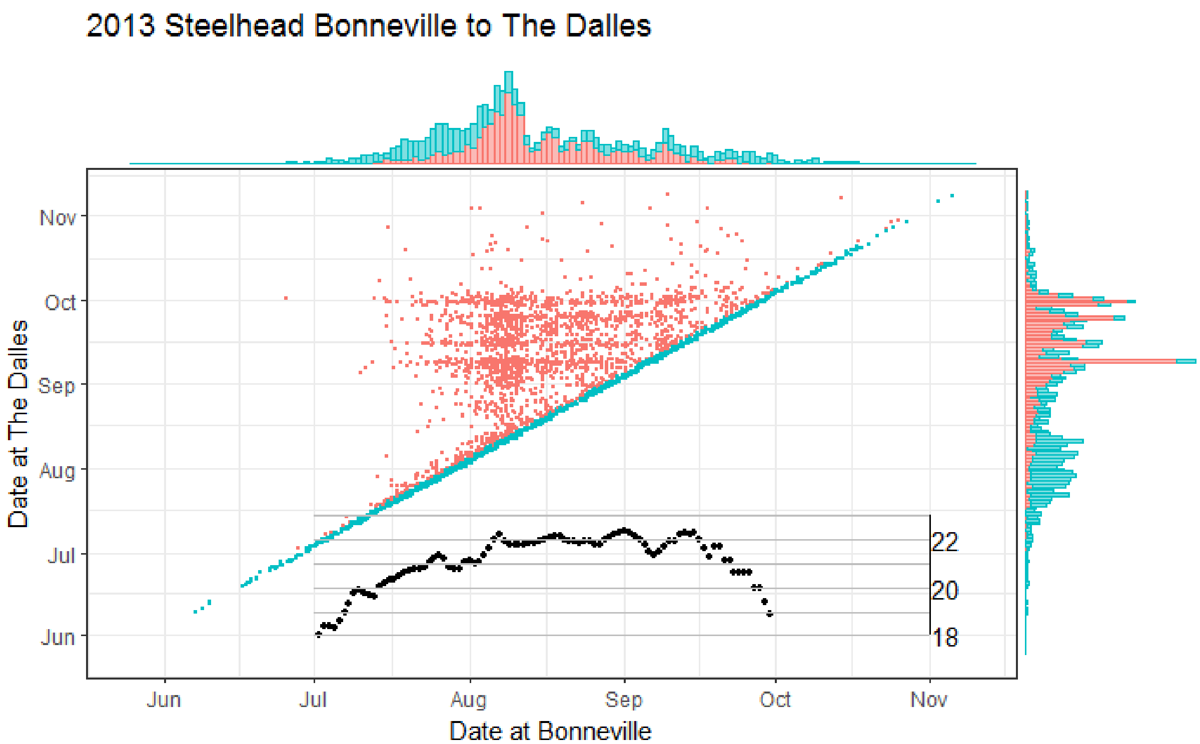
PIT-tag detections for Chinook and Steelhead were obtained from the PTAGIS database (https://ptagis.org/). A query of type "Interrogation Summary" was created, which retrieves the first and last detections (timestamp) at each interrogation site. Other attributes output in the search results included unique tag (one for each fish), run (e.g. Summer, Fall…), rear-type (Natural Origin or Wild, Hatchery), release site (PTAGIS code, basin, subbasin) and species. This study was focused on adults migrating upstream between Bonneville and The Dalles dams on the Columbia River. The following interrogation sites were of most interest:

PTAGIS code	Site Name
BO1	Bonneville Bradford Island Ladder
BO4	Bonneville WA Ladder Slots
TD1	The Dalles East Fish Ladder
TD2	The Dalles West Fish Ladder

The two BON (Bonneville Dam) sites are starting points for the path between dams, whereas the TDA (The Dalles) sites are the destination points. Sites at upstream dams were included in the query to provide evidence that a fish detected at BON but not TDA nevertheless passed The Dalles Dam undetected, although the true fate of undetected fish above Bonneville remains uncertain for fish not subsequently detected upstream. Daily measurements for Columbia River mainstem adult ladder fish counts, water flow, and temperature were obtained from University of Washington DART site (http://www.uw.dart.edu) which compiles data from the US Army Corps of Engineers and WA state public utility districts. Raw data was processed using the R programming language within the RStudio integrated development language, and this environment was also used to produce the graphics in this report.

Results

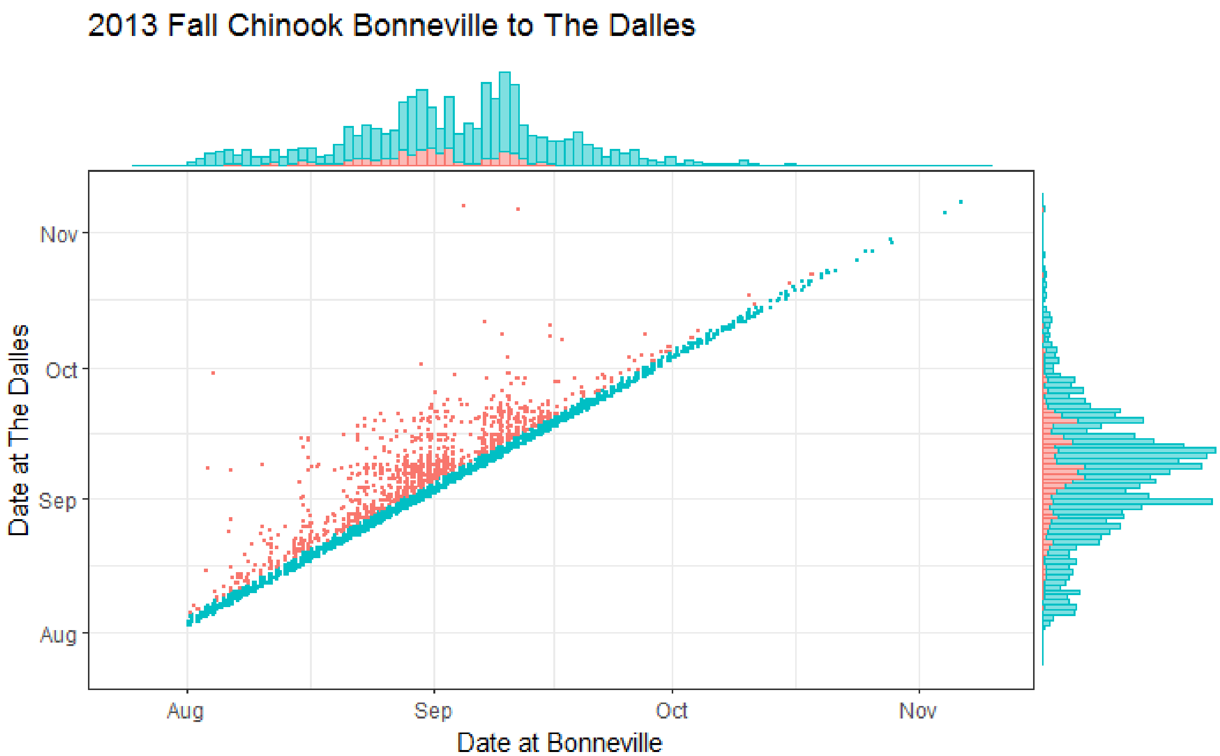
Scatterplot+Histograms+Temperature of PIT-tag Detection Pairs



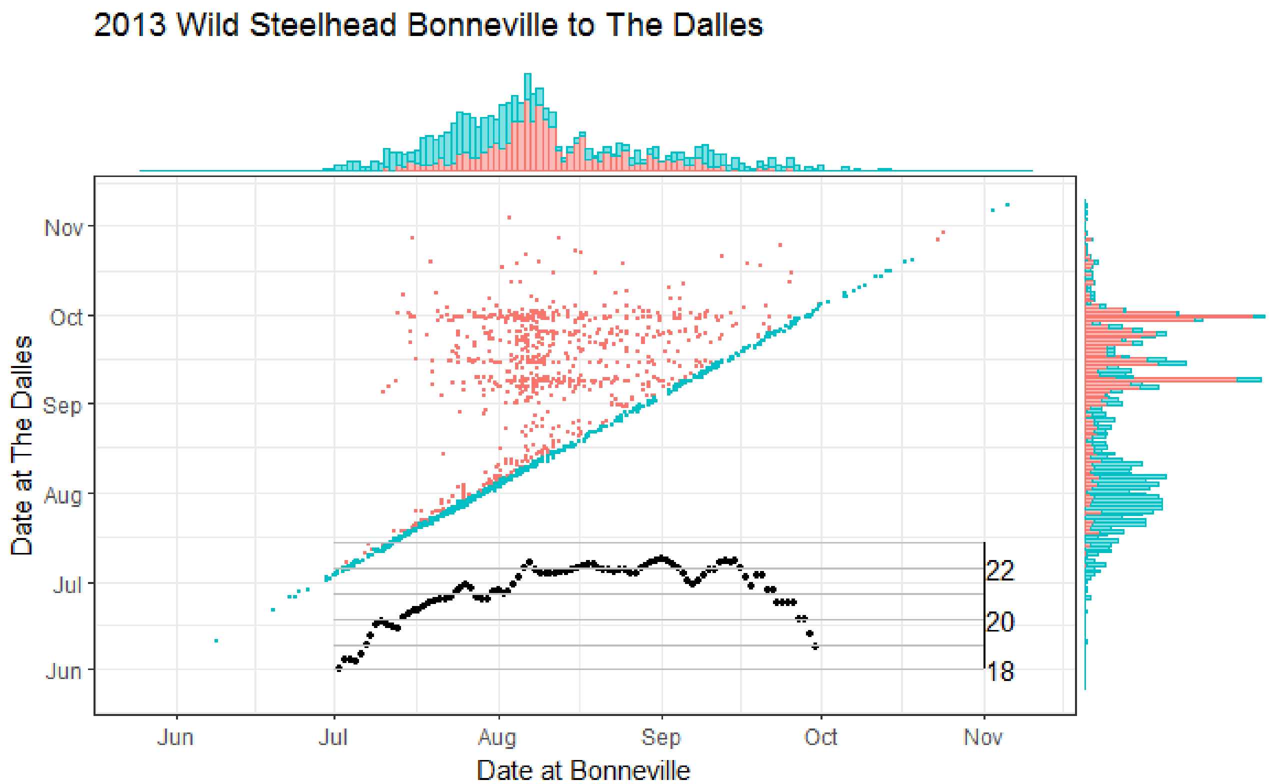
There are four components to the above chart:

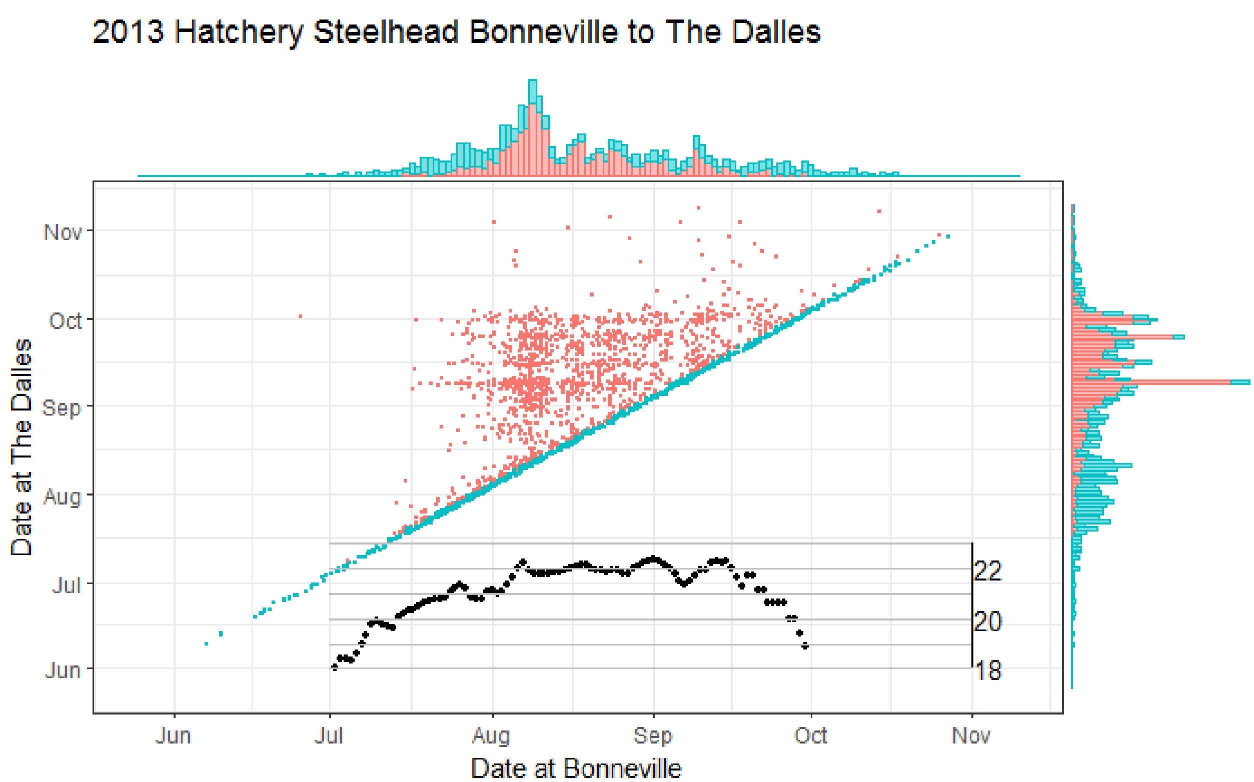
1. Scatterplot of detection datetime at Bonneville (the last adult detection at one of the BON adult sites) vs. the first detection datetime at The Dalles. The color encoding is red= “delayed” and blue=”not delayed”. This is a binary classification in which a threshold travel time between dams is chosen so as to This is arbitrary, but as you can observe in the above, is a reasonable choice. In any case, for the clearly delayed steelhead, there are rather interesting patterns in both the vertical and horizontal directions. This scatterplot doesn’t give a provide a clear assessment of the relative number of fish delayed, though, since a lot of blue dots might be overlapping near the apparent diagonal.

2. At the top is a histogram of the detections, aggregated by date at (leaving) BON, with the same color encoding. This is of course the arrival rate, and the relative height of red to blue at a given day corresponds to the fraction which will take longer than tmax (or 4 days) to get to TDA
3. On the left is the corresponding histogram for arrivals at The Dalles, rather different, and highly structured profile from the top. Clearly, many of the fish which depart Bonneville from July into August don't arrive until September-October, but more interestingly, they arrive in bunches (OK, schools), with each group including fish with a large spread of travel times.
4. Inset at the bottom is the forebay daily mean temperature at Bonneville (degrees C). This provides one measure of the reservoir temperature around the time that the fish finally arrive at TDA (as shown below). One could also use temperatures at TDA tailrace (or some average), but there is minimal difference between these. Also apparent is the temperatures at which the probability of delay becomes large.



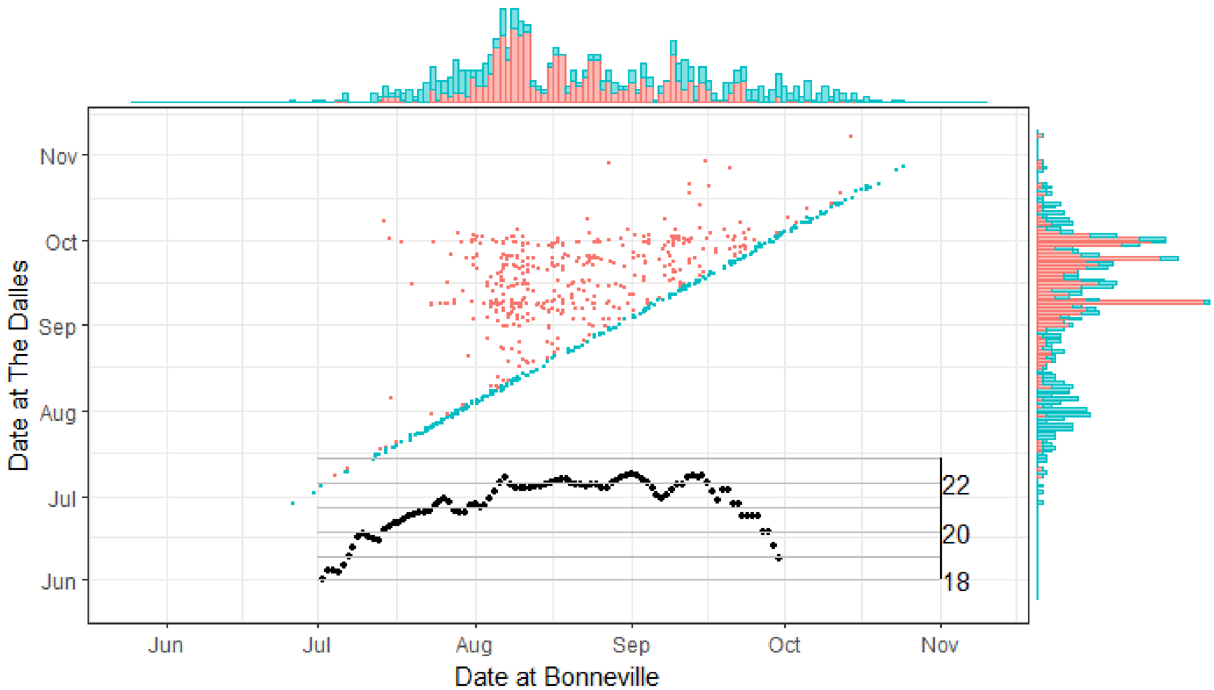
Effect of Rear Type



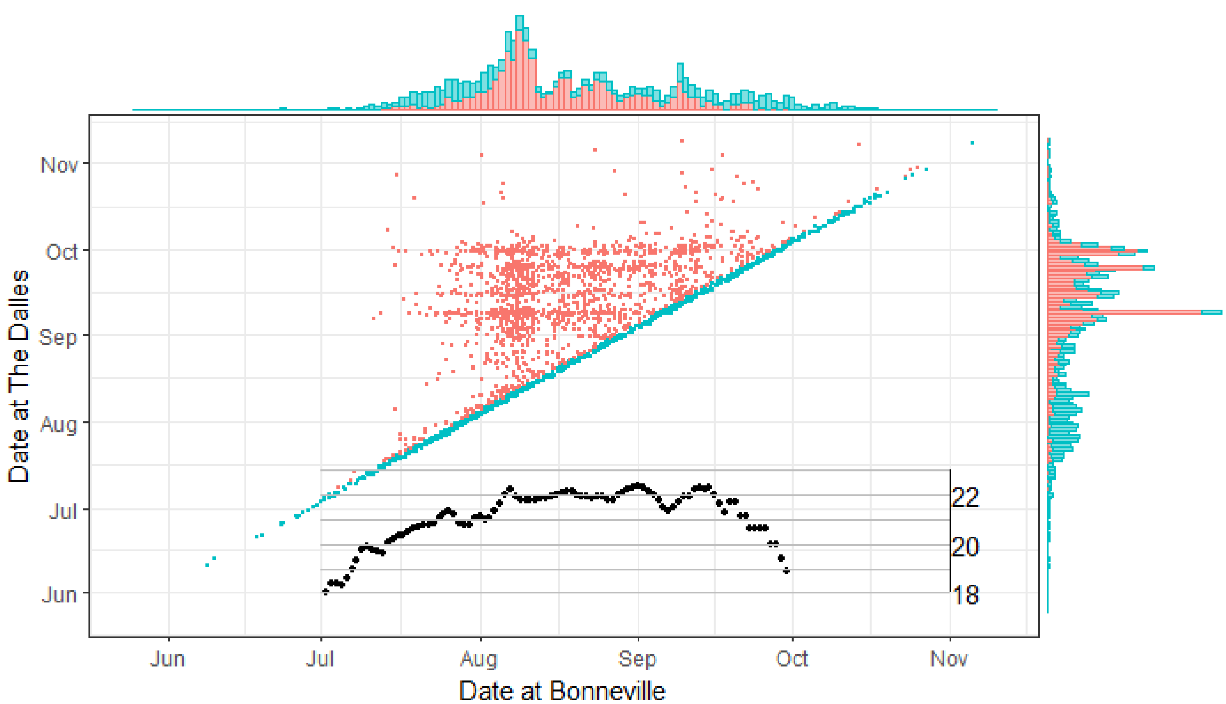


Effect of Transport (T=transported as juvenile; F=false, not transported)

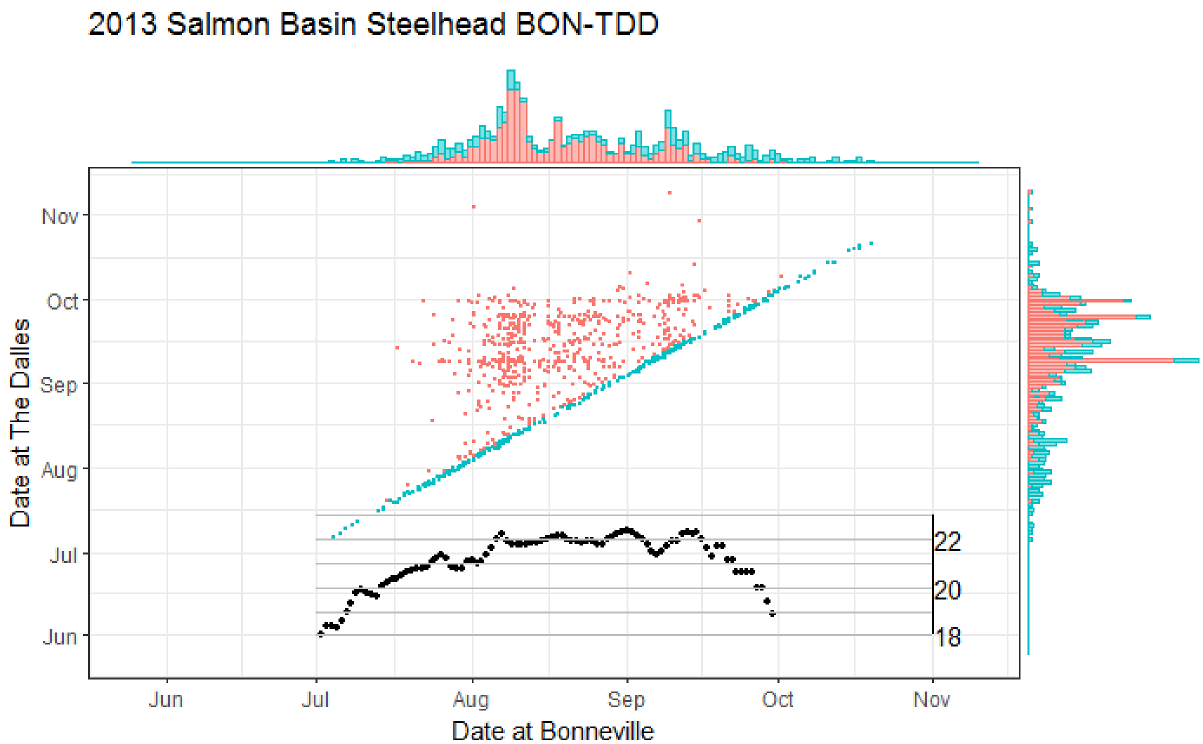
2013 SR Steelhead BON-TDD, Transport=T (n=694, 58% delayed)

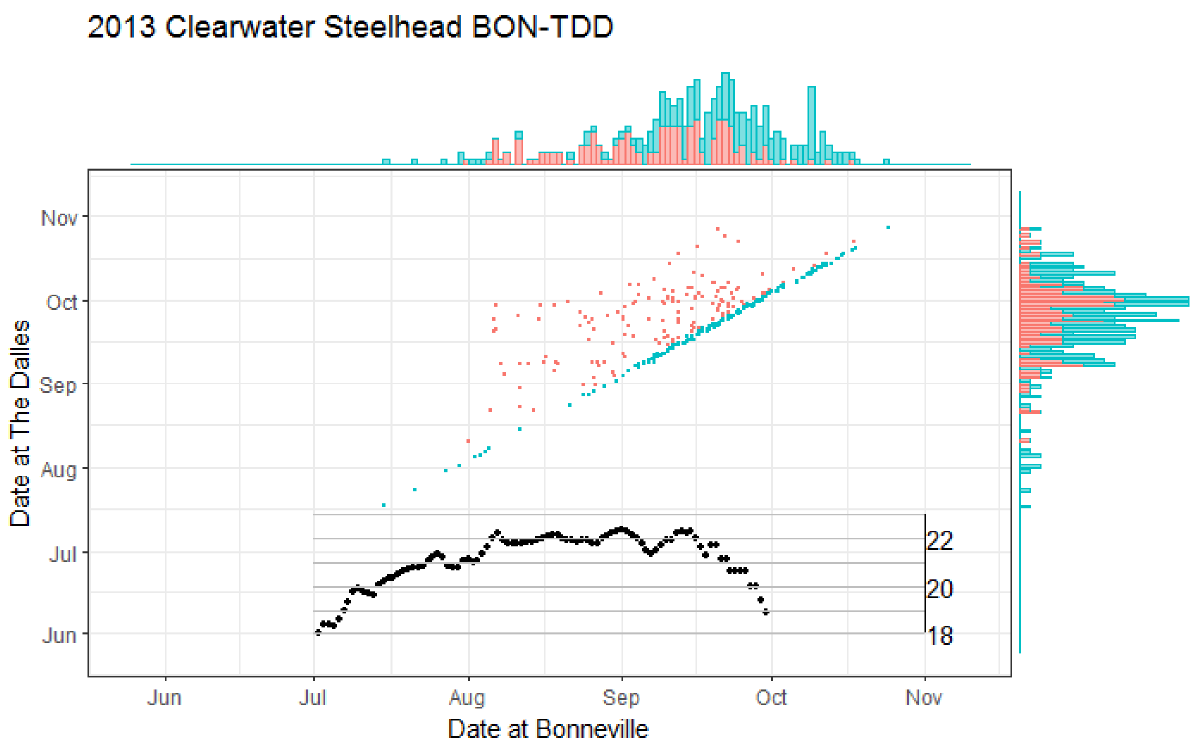


2013 SR Steelhead BON-TDD, Transport=F (n=2954, 57.5% delay

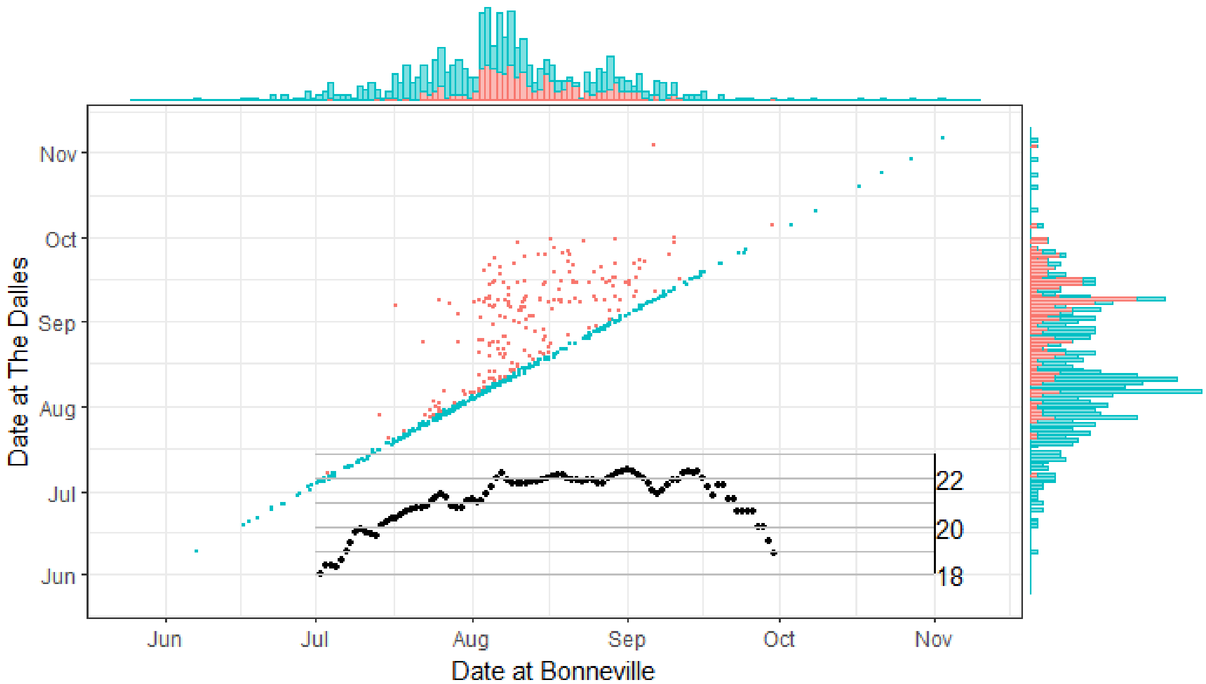


Effect of Release Basin

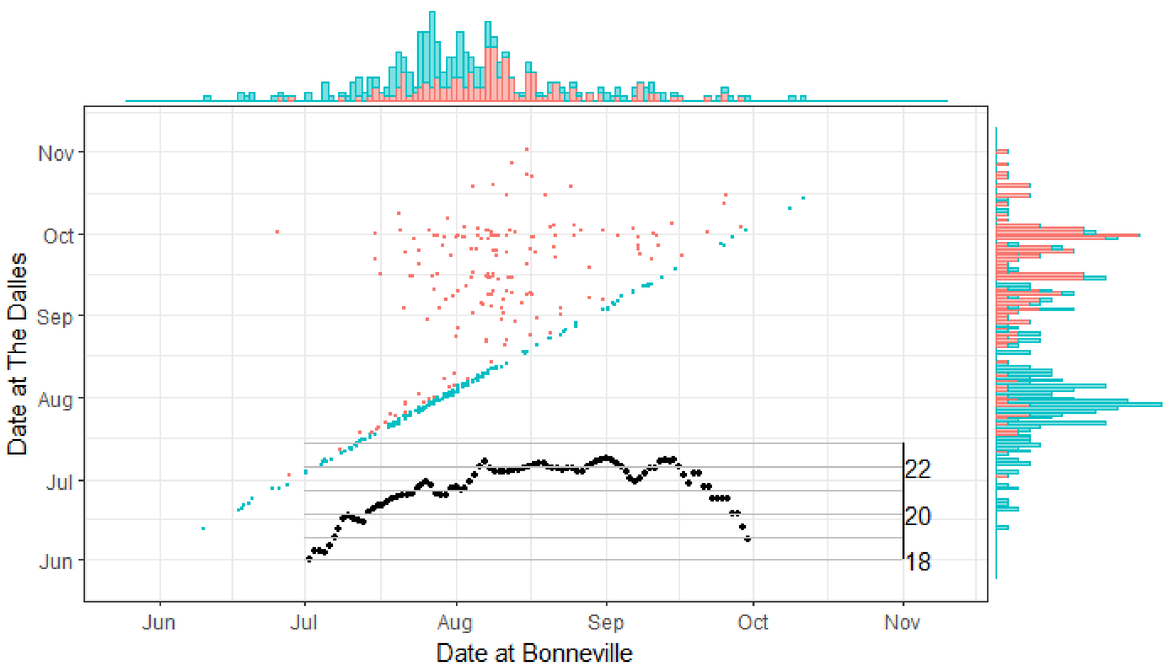




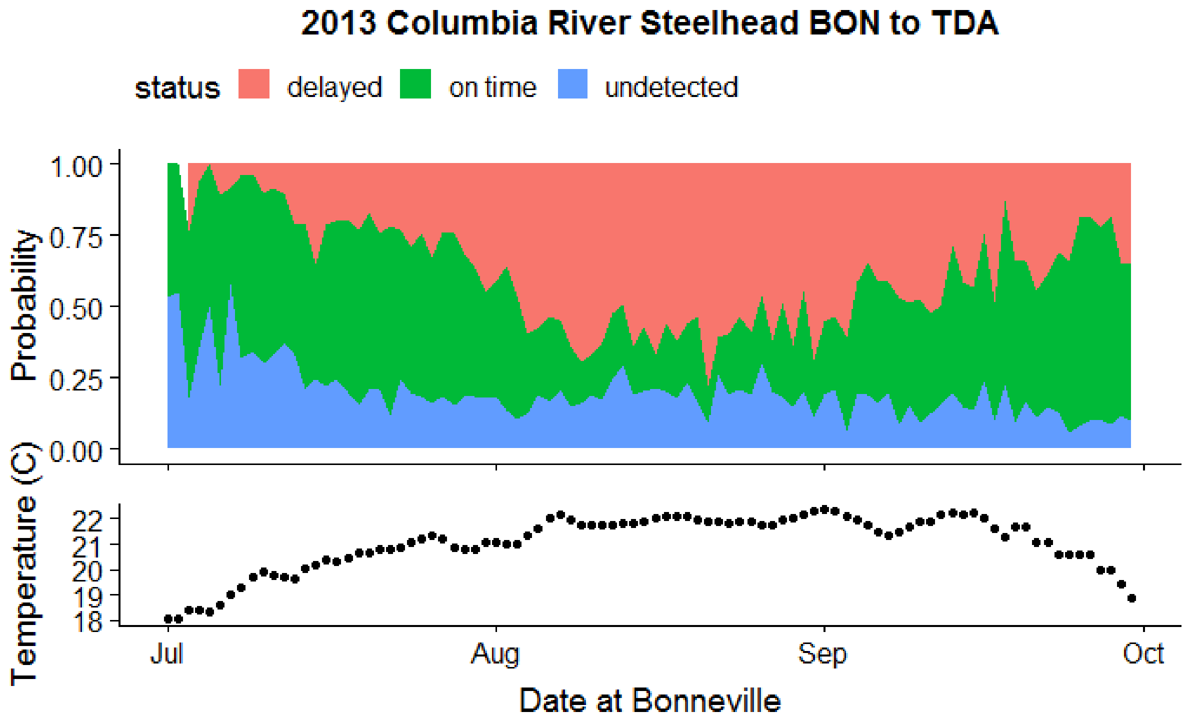
2013 Upper Columbia Steelhead BON-TDD

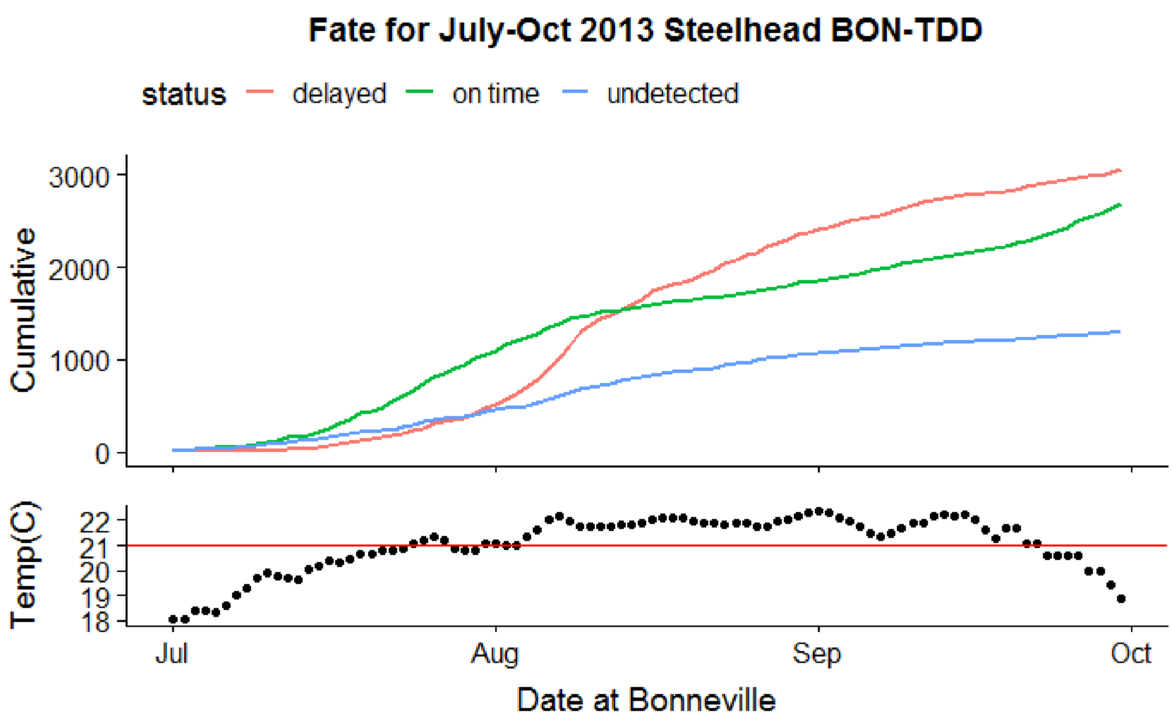


2013 Middle Columbia/Yakima Steelhead BON-TDD



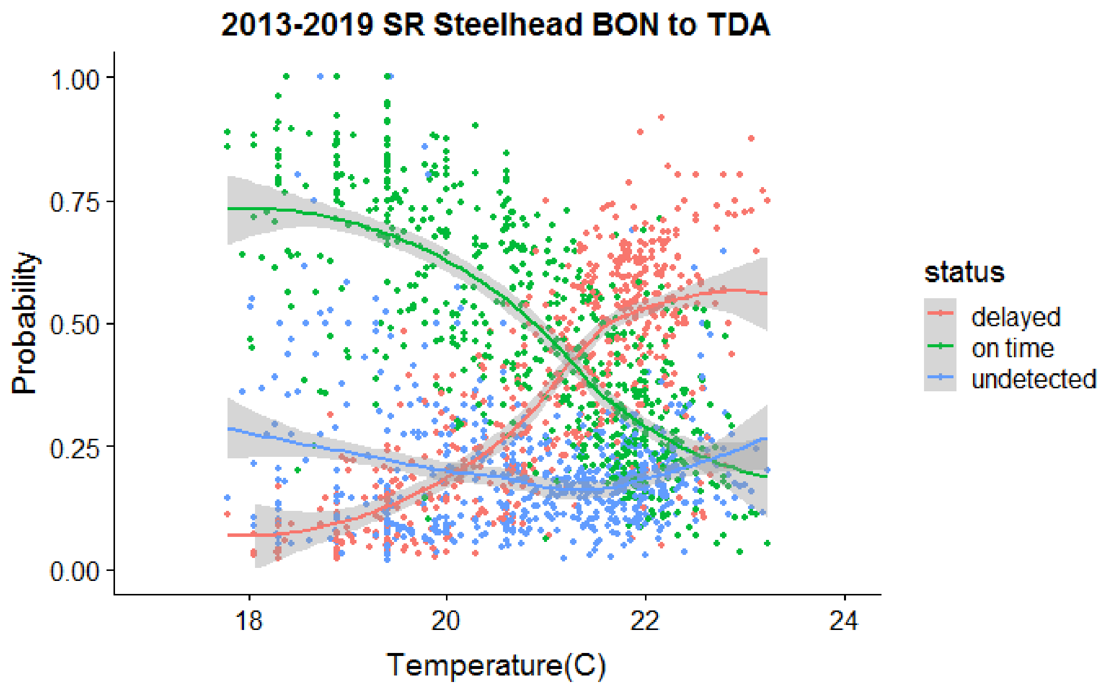
Probability of Delay or Loss



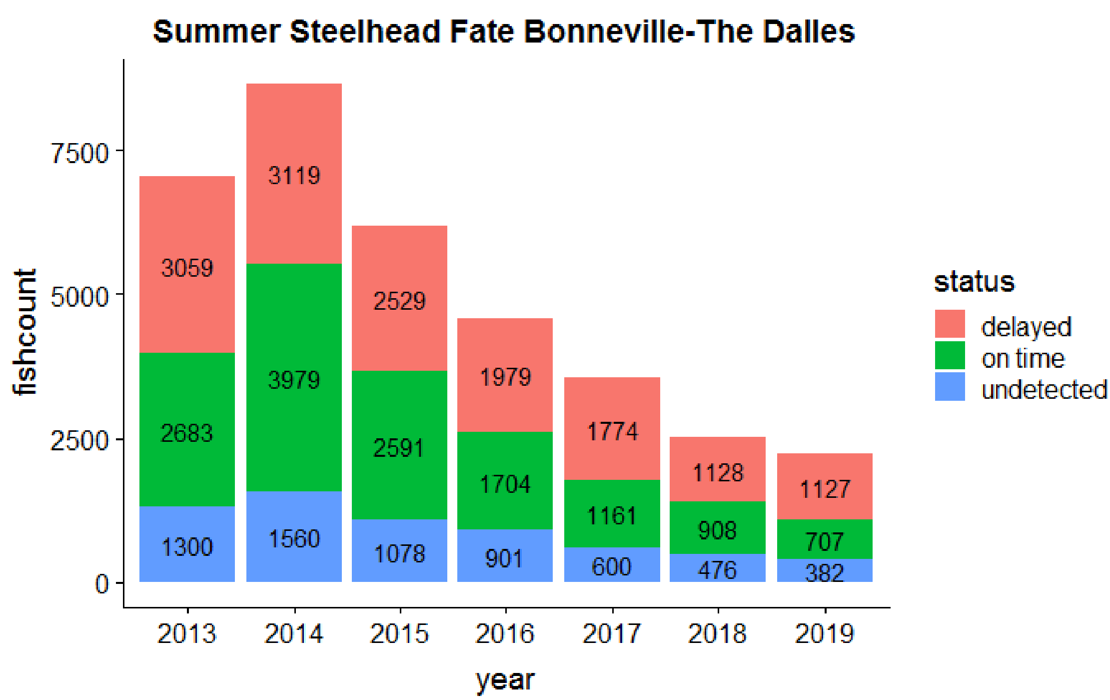


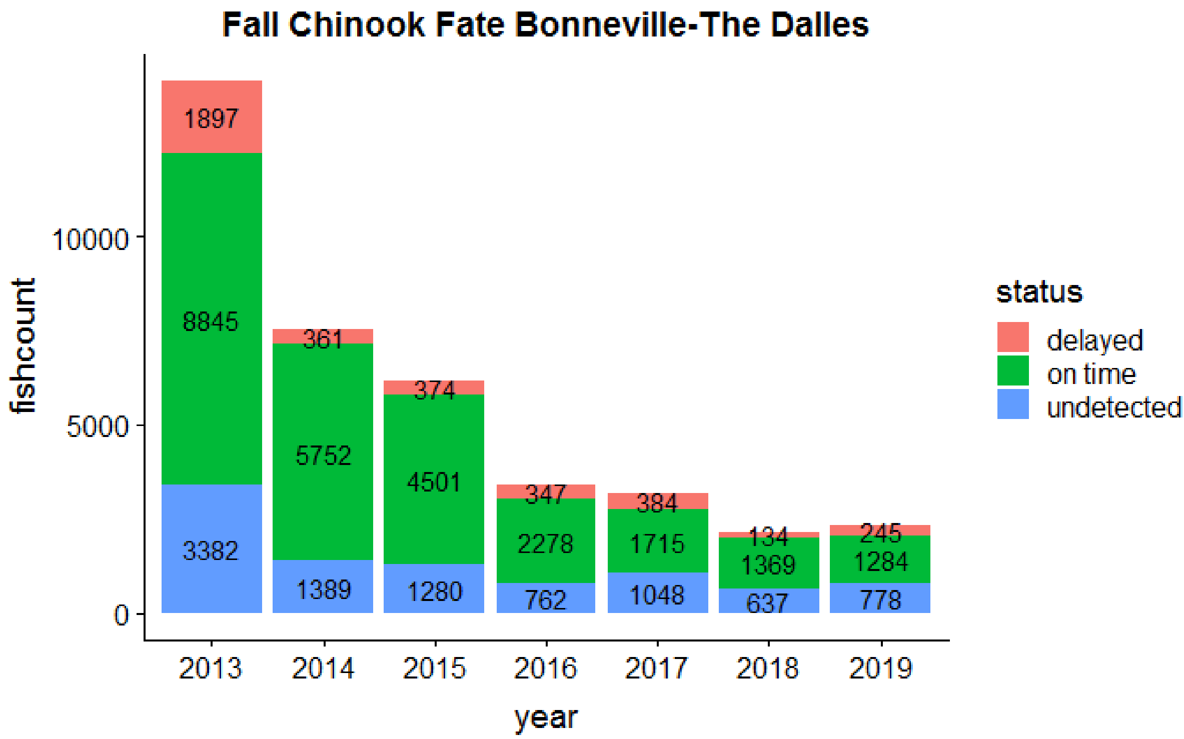
Composite Results 2013-2019

Probability of Delay/Loss vs. River Temperature



Aggregate Delay and Loss





Comparison with Adult Fish Ladder Visual Count at The Dalles Dam