FISH PASSAGE CENTER

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MEMORANDUM

TO: Jeff Fryer, CRITFC

FROM: Michele DeHart

DATE: September 27, 2018

SUBJECT: Juvenile passage timing, juvenile travel times, juvenile survival, and smolt-to-adult returns of Hanford Reach wild subyearling fall Chinook (1993-2018).

In response to your request, FPC staff updated a 2013 analysis entitled: Historical passage timing, travel times, and juvenile survival of wild Hanford Reach sub-yearling Chinook to McNary Dam (1993-2012) (FPC 2013). This update provides passage timing, travel times, and juvenile survival estimates for PIT-tagged wild subyearling fall Chinook from the Hanford reach through migration year 2018. In addition, we provide estimates of smolt-to-adult return rates (SARs) for migration years 2000-2015. Finally, in response to your request, we explored the effect of length at tagging on juvenile survival and travel time. We approached this task in a manner similar to analyses conducted for hatcheries that release PIT-tagged juvenile salmonids for the Smolt Monitoring Program (SMP) and Comparative Survival Study (CSS).

Since 1993, wild subyearling fall Chinook have been captured, PIT-tagged, and released in the Hanford Reach of the Mid-Columbia River, below Priest Rapids Dam (excluding 2002 and 2006). With the release of these PIT-tags, information on the timing and migration speed of tagged individuals becomes available, along with information on survival as these juveniles migrate downstream and estimates of smolt-to-adult return rates (SARs).

Juvenile Passage Timing and Travel Time

Estimated passage timing at McNary, John Day, and Bonneville dams for migration years 1993-2018 are summarized below (Table 1). Passage timing at McNary Dam is also illustrated in Figures 1 through 3. To better facilitate comparison, we have broken the years into three separate graphs; Figure 1 (1993-2001), Figure 2 (2003-2012), and Figure 3 (2013-2018). It is worth noting that PIT-tagging efforts were suspended in migration years 2002 and 2006.

Table 1. Estimated 10%, 50%, and 90% passage date for Hanford Reach wild subyearling fall Chinook at McNary, John Day, and Bonneville dams, 1993-2018.

Release Dates	Migration Year	Timing to McNary Dam			Timing to John Day Dam			Timing to Bonneville Dam		
		10% Date	50% Date	90% Date	10% Date	50% Date	90% Date	10% Date	50% Date	90% Date
6/7-6/15	1993	30-Jun	8-Jul	31-Jul	12-Jul	15-Aug	18-Sep	---	---	---
6/6-6/7	1994	4-Jul	9-Jul	16-Jul	19-Jul	21-Jul	29-Jul	20-Jul	23-Jul	25-Jul
6/6-6/8	1995	27-Jun	5-Jul	11-Jul	7-Jul	11-Jul	26-Jul	---	---	---
6/10-6/13	1996	16-Jun	9-Jul	19-Jul	19-Jul	22-Jul	11-Aug	---	---	---
6/9-6/13	1997	15-Jun	9-Jul	28-Jul	---	---	---	29-Jun	14-Jul	31-Jul
6/1-6/3	1998	19-Jun	2-Jul	12-Jul	25-Jun	4-Jul	23-Jul	20-Jun	9-Jul	23-Jul
6/3-6/10	1999	20-Jun	9-Jul	22-Jul	24-Jun	15-Jul	29-Jul	30-Jun	16-Jul	26-Jul
6/1-7/3	2000	30-Jun	12-Jul	3-Aug	8-Jul	31-Jul	8-Aug	20-Jul	8-Aug	12-Aug
5/29-7/1	2001	2-Jul	21-Jul	7-Aug	26-Jul	9-Aug	26-Aug	31-Jul	14-Aug	30-Aug
---	2002	---	---	---	---	---	---	---	---	---
5/27-5/30	2003	5-Jun	23-Jun	3-Jul	8-Jun	28-Jun	11-Jul	17-Jun	2-Jul	13-Jul
6/2-6/4	2004	13-Jun	24-Jun	2-Jul	21-Jun	2-Jul	9-Jul	24-Jun	2-Jul	10-Jul
5/31-7/1	2005	15-Jun	25-Jun	5-Jul	25-Jun	7-Jul	17-Jul	25-Jun	7-Jul	16-Jul
---	2006	---	---	---	---	---	---	---	---	---
6/6-6/10	2007	28-Jun	7-Jul	13-Jul	5-Jul	11-Jul	17-Jul	5-Jul	11-Jul	17-Jul
6/4-6/7	2008	5-Jul	11-Jul	20-Jul	7-Jul	14-Jul	27-Jul	10-Jul	16-Jul	25-Jul
6/2-6/8	2009	28-Jun	9-Jul	16-Jul	4-Jul	13-Jul	21-Jul	7-Jul	14-Jul	21-Jul
6/1-6/4	2010	16-Jun	7-Jul	13-Jul	23-Jun	10-Jul	16-Jul	29-Jun	12-Jul	20-Jul
6/6-6/10	2011	26-Jun	18-Jul	26-Jul	12-Jul	19-Jul	27-Jul	14-Jul	21-Jul	30-Jul
6/5-6/8	2012	6-Jul	14-Jul	25-Jul	12-Jul	19-Jul	26-Jul	12-Jul	20-Jul	25-Jul
6/4-6/7	2013	30-Jun	5-Jul	10-Jul	2-Jul	7-Jul	16-Jul	5-Jul	12-Jul	16-Jul
6/4-6/7	2014	20-Jun	4-Jul	10-Jul	26-Jun	8-Jul	13-Jul	29-Jun	10-Jul	16-Jul
6/3-6/4	2015	12-Jun	30-Jun	7-Jul	22-Jun	2-Jul	9-Jul	27-Jun	5-Jul	11-Jul
6/8-6/10	2016	16-Jun	20-Jun	2-Jul	20-Jun	26-Jun	6-Jul	22-Jun	27-Jun	6-Jul
6/7-6/10	2017	17-Jun	2-Jul	9-Jul	24-Jun	6-Jul	13-Jul	30-Jun	8-Jul	13-Jul
6/6-6/10	2018[A]	27-Jun	9-Jul	17-Jul	3-Jul	14-Jul	20-Jul	2-Jul	13-Jul	21-Jul

[A] Estimates of 2018 timing are preliminary as they are based on fish observed through September 20, 2018. Estimates may change if additional fish are detected after September 20, 2018.

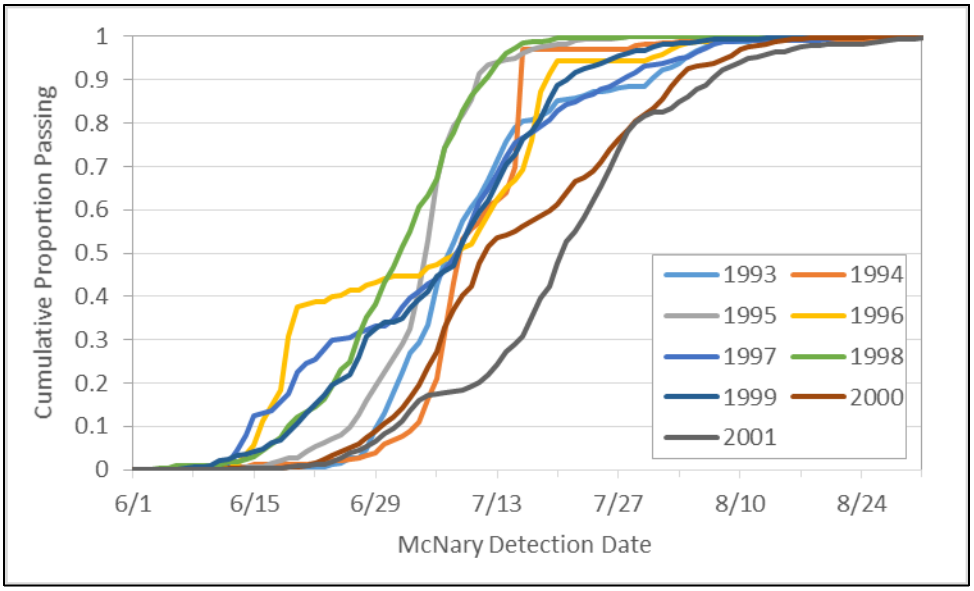

Figure 1. Passage timing to McNary Dam of PIT-tagged Hanford Reach wild subyearling fall Chinook (1993-2001).

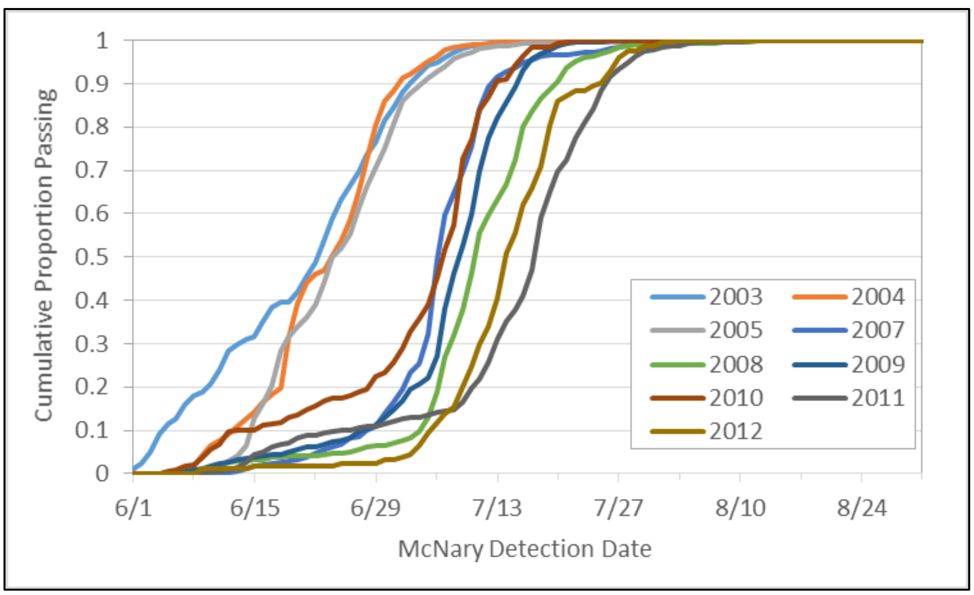

Figure 2. Passage timing to McNary Dam of PIT-tagged Hanford Reach wild subyearling fall Chinook (2003-2012). Note: There was no PIT-tagging in 2002 and 2006.

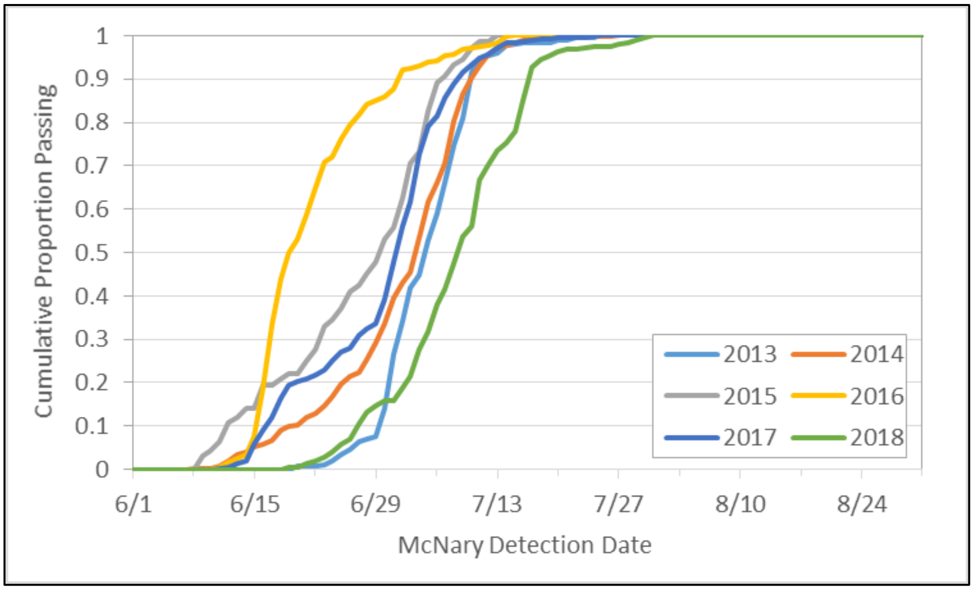

Figure 3. Passage timing to McNary Dam of PIT-tagged Hanford Reach wild subyearling fall Chinook (2013-2018). Estimates of 2018 timing are preliminary as they are based on fish observed through September 20, 2018. Estimates may change if additional fish are detected after September 20, 2018.

Minimum, median, and maximum travel times from release to McNary, release to John Day, and release to Bonneville are provided below (Table 2). Along with estimates of median travel times, Table 2 also provides estimates of the 95% confidence limits around the median travel time estimates.

Table 2. Minimum, median (95% Confidence Interval), and maximum travel time from release to McNary Dam, release to John Day, and release to Bonneville dams for Hanford Reach wild subyearling fall Chinook, 1993-2018.

Migration Year	Release to McNary Dam				Release to John Day Dam				Release to Bonneville Dam			
	Num. Det.	Min	Median (95% CI)	Max	Num. Det.	Min	Median (95% CI)	Max	Num. Det.	Min	Median (95% CI)	Max
1993	570	3.2	29.1 (28.7-30.0)	79.0	9	33.6	66.7 (34.4-77.5)	100.8	2	44.6	60.4 (N/A)	76.2
1994	325	3.1	32.5 (32.0-33.7)	109.1	3	41.9	44.5 (N/A)	53.2	3	44.0	46.3 (N/A)	48.4
1995	463	6.0	28.1 (27.7-28.5)	49.8	9	28.6	33.8 (29.6-37.8)	47.7	2	31.5	34.4 (N/A)	37.2
1996	257	1.9	31.7 (30.2-33.2)	57.2	10	31.4	38.8 (37.7-59.5)	80.1	2	33.2	33.7 (N/A)	34.2
1997	350	1.2	29.1 (28.3-30.1)	72.8	2	34.7	58.6 (N/A)	82.4	117	14.1	33.3 (31.4-34.2)	80.1
1998	751	2.3	31.6 (30.9-32.3)	56.9	177	11.2	32.4 (31.3-34.7)	65.6	42	12.7	35.4 (29.1-41.2)	69.0
1999	603	2.4	33.0 (32.0-34.1)	74.8	381	6.4	38.4 (37.3-39.4)	86.2	177	5.2	40.0 (38.3-40.9)	73.7
2000	2,652	3.7	31.1 (30.8-31.5)	80.5	456	10.1	39.8 (38.2-41.3)	73.3	45	20.6	43.6 (39.0-46.6)	63.8
2001	1,637	1.6	33.0 (31.9-33.8)	146.2	843	9.7	50.1 (49.4-50.8)	97.9	111	25.4	56.5 (52.4-59.7)	135.3
2002	---	---	---	---	---	---	---	---	---	---	---	---
2003	525	2.1	26.3 (25.6-27.1)	58.9	104	4.4	29.8 (28.4-33.6)	60.5	96	9.4	33.4 (32.6-35.2)	58.6
2004	586	4.0	23.2 (22.4-23.8)	57.7	123	8.4	28.5 (27.1-30.2)	61.6	56	11.4	28.7 (26.6-31.0)	46.4
2005	2,361	2.1	14.5 (14.0-14.9)	154.7	758	6.3	27.8 (27.0-28.4)	54.4	173	10.4	25.8 (23.5-28.2)	50.1
2006	---	---	---	---	---	---	---	---	---	---	---	---
2007	2,054	2.3	28.7 (28.5-28.9)	63.3	1,146	8.3	32.7 (32.5-33.2)	63.7	458	9.2	33.8 (33.4-34.5)	64.0
2008	862	1.9	35.8 (35.1-36.0)	75.8	544	13.7	39.5 (38.6-40.4)	85.7	274	12.0	39.1 (38.2-40.0)	76.6
2009	916	1.8	35.0 (34.6-35.3)	55.4	401	7.5	39.1 (38.5-39.7)	63.4	213	13.0	39.2 (38.3-39.6)	56.6
2010	307	3.1	34.5 (33.7-35.2)	50.9	147	8.6	37.5 (36.5-37.7)	54.7	113	6.9	38.4 (36.1-41.2)	62.7
2011	599	3.3	39.9 (39.3-40.6)	65.9	446	6.7	41.6 (41.3-42.4)	74.5	228	12.7	43.4 (42.8-44.4)	85.1
2012	179	2.1	38.9 (37.8-39.4)	57.0	239	23.7	42.6 (41.8-43.2)	73.5	94	25.7	44.0 (42.6-45.2)	58.9
2013	236	14.2	30.3 (29.2-31.3)	49.6	151	13.7	31.8 (31.0-33.2)	50.8	115	21.3	35.5 (34.4-36.6)	58.0
2014	880	3.5	28.5 (28.2-29.3)	50.0	455	8.2	32.7 (32.3-33.0)	51.9	341	6.1	34.3 (33.6-35.2)	59.6
2015	77	4.9	26.4 (21.8-28.6)	39.9	77	13.9	27.8 (26.5-29.9)	42.3	24	7.2	31.2 (29.7-32.6)	41.9
2016	330	3.4	10.7 (9.9-11.7)	35.8	166	6.7	17.3 (15.7-18.6)	113.0	99	10.4	18.3 (16.6-20.1)	32.2
2017	537	4.1	23.6 (22.9-23.9)	46.5	317	9.6	26.9 (26.1-27.6)	52.8	355	8.5	28.9 (28.2-29.4)	41.3
2018[A]	289	12.2	31.2 (30.2-31.9)	53.7	224	17.2	35.9 (34.8-36.7)	56.8	128	16.0	35.1 (33.5-35.9)	49.6

[A] 2018 travel time estimates are preliminary as they are based on fish observed through September 20, 2018. Estimates may change if additional fish are detected after September 20, 2018.

Juvenile Survival

Methods

Our 2013 analysis of Hanford Reach wild subyearling fall Chinook provided estimates of juvenile survival from release to McNary Dam (Rel-MCN) (FPC 2013). However, in response to your most recent request, we also attempted to estimate survival from release to John Day (Rel-JDA) and release to Bonneville (Rel-BON). It is worth noting that estimating survival to Bonneville Dam requires detections below Bonneville Dam, which can sometimes be difficult for summer migrants as the NOAA estuary trawl does not always operate later in the summer.

To estimate survival from Rel-JDA, we developed a 4-digit capture history, which included the following: 1) release, 2) detection at MCN, 3) detection at JDA, and 4) detection at either BON or the estuary trawl. To estimate survival from Rel-BON, we developed a 5-digit capture history for each PIT-tagged fish. This 5-digit capture history included the following: 1) release, 2) detection at MCN, 3) detection at JDA, 4) detection at BON, and 5) detection at the estuary trawl. Using these capture histories, single mark-release mark-recapture survival estimates were generated using Cormack-Jolly-Seber (CJS) methodology, as described by Burnham et al. (1987) with program MARK (software available free from Colorado State University). (White and Burnham 1999). This generated estimates of survival for each of the individual reaches: 1) Rel-MCN, 2) MCN-JDA, and 3) JDA-BON. These individual reach survivals were combined to estimate survival for combined reaches (Rel-JDA and Rel-BON). Variance estimates for the product of individual reach survivals were generated using the delta method (Burnham et al. 1987). Using this methodology, estimates of individual reach survival (e.g., Rel-MCN, MCN-JDA, or JDA-BON) can exceed 100%. However, individual reach estimates are often negatively correlated with adjacent reaches. Therefore, when estimating combined reach survivals (e.g., Rel-JDA and Rel-BON), we allow individual reach survival estimates to exceed 100%. A combined reach survival was considered unreliable when its point estimate exceeded 100% or its coefficient of variation exceeded 25%.

Results

We were able to estimate survival from release to McNary (Rel-MCN) for nearly every year that PIT-tagging has occurred (Table 3). The only exceptions to this were migration years 1993, 1996, and 2015. In addition, we were only able to estimate survival from release to John Day (Rel-JDA) for 14 of the possible 24 years (Table 3). Finally, we were only able to estimate survival from release to Bonneville (Rel-BON) for five of the possible 24 years. Much of our inability to estimate survival to Bonneville was due to a lack of detections below Bonneville. In fact, 13 of the 24 possible years of PIT-tagging efforts had no detections at the estuary trawl. These 13 years included 1993-2001, 2011, 2015, 2017, and 2018.

Table 3. Survival of Hanford Reach wild subyearling fall Chinook from release to McNary Dam, release to John Day Dam, and release to Bonneville Dam, 1993-2018. Numbers in parentheses are the estimated 95% confidence intervals.

Release Dates	Migration Year	PIT-Tags Released	Release to McNary Dam	Release to John Day Dam	Release to Bonneville Dam
6/7-6/15	1993	3,040	---	---	---
6/6-6/7	1994	2,983	0.13 (0.10-0.16)	---	---
6/6-6/8	1995	2,991	0.46 (0.14-0.82)	---	---
6/10-6/13	1996	2,957	---	---	---
6/9-6/13	1997	2,980	0.49 (0.34-0.64)	---	---
6/1-6/3	1998	2,955	0.62 (0.52-0.71)	0.25 (-0.00-0.51)	---
6/3-6/10	1999	5,042	0.40 (0.35-0.45)	0.33 (0.23-0.43)	---
6/1-7/3	2000	10,967	0.42 (0.39-0.45)	---	---
5/29-7/1	2001	9,973	0.37 (0.34-0.39)	0.20 (0.16-0.25)	---
---	2002	0	---	---	---
5/27-5/30	2003	2,975	0.31 (0.27-0.35)	0.18 (0.11-0.26)	---
6/2-6/4	2004	2,989	0.33 (0.29-0.38)	---	---
5/31-7/1	2005	22,634	0.29 (0.26-0.31)	0.17 (0.02-0.33)	---
---	2006	0	---	---	---
6/6-6/10	2007	21,007	0.38 (0.35-0.41)	0.29 (0.23-0.35)	0.23 (0.03-0.44)
6/4-6/7	2008	16,651	0.33 (0.29-0.39)	0.19 (0.13-0.26)	---
6/2-6/8	2009	13,728	0.33 (0.28-0.38)	0.20 (0.13-0.27)	0.12 (-0.00-0.24)
6/1-6/4	2010	4,850	0.28 (0.23-0.34)	---	---
6/6-6/10	2011	10,337	0.38 (0.32-0.45)	0.23 (0.15-0.32)	---
6/5-6/8	2012	4,891	0.27 (0.21-0.34)	---	---
6/4-6/7	2013	4,184	0.33 (0.26-0.42)	0.27 (0.10-0.43)	0.18 (-0.08-0.44)
6/4-6/7	2014	9,940	0.34 (0.31-0.38)	0.28 (0.21-0.35)	---
6/3-6/4	2015	4,965	---	---	---
6/8-6/10	2016	9,926	0.56 (0.30-0.79)	0.11 (-0.01-0.22)	0.06 (-0.06-0.18)
6/7-6/10	2017	9,989	0.30 (0.25-0.34)	0.19 (0.13-0.24)	---
6/6-6/10	2018[A]	9,987	0.24 (0.18-0.32)	0.12 (0.05-0.18)	---

[A] 2018 survival estimates are preliminary as they are based on fish observed through August 16, 2018. Estimates may change if additional fish are detected after August 16, 2018.

Effects of Length at Tagging on Survival

Methods

Given that the most consistent and reliable estimates of survival were for the release to McNary reach, we chose to focus on this reach when investigating the effects of length at tagging on survival. For this analysis, we included all juveniles that had a length at tagging between 50 and 150 mm. Lengths of less than 50 mm and greater than 150 mm were considered erroneous. To estimate survival from Rel-MCN for this analysis, we developed a 3-digit capture history, which included the following: 1) release, 2) detection at MCN, 3) detection at either JDA, BON, or the estuary trawl. Length at tagging and date of release (Jday) were used as individual covariates, and survival estimates were generated using single mark-release mark-recapture CJS methodology in Program MARK (White and Burnham 1999).

Results

Survival from release to McNary, as a function of length at tagging, was estimable for all years between 1993 and 2018. These estimates varied considerably, but in general, survival increased with length at tagging in most years (Figures 4, 5, and 6). This length to survival relationship was well supported in all years with exception of the years 1995-1997 (Figure 6), and 2015 (Figure 4), where the relationship was still apparent but with enough uncertainty to preclude a statistically meaningful differentiation between the range of sizes and survival within each cohort. Similarly, due to the relatively small percentage of fish greater than 80mm at tagging in all years, survival estimates for larger fish were subject to higher levels of uncertainty.

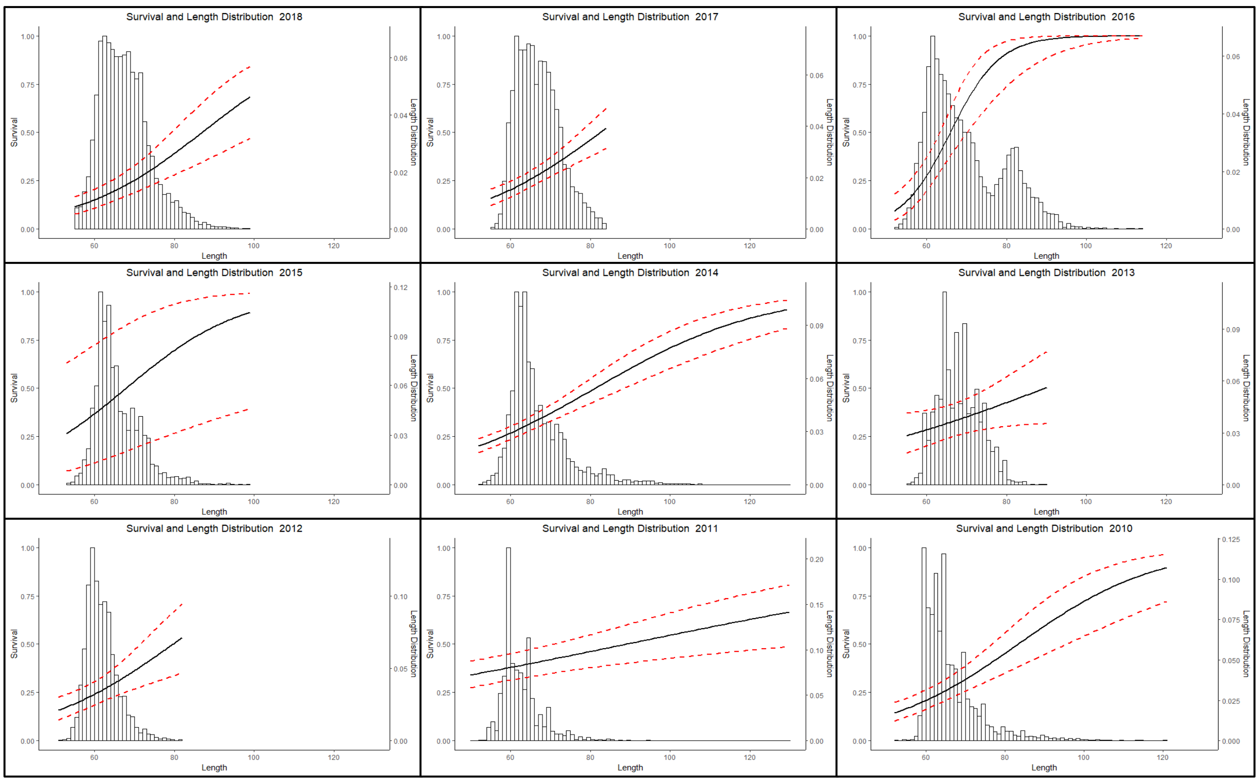

Figure 4: Release to McNary survival (black solid line) and 95% confidence interval (red dotted lines), as a function of length at tagging and length frequency histogram (secondary y-axis) for migration years 2010-2018.

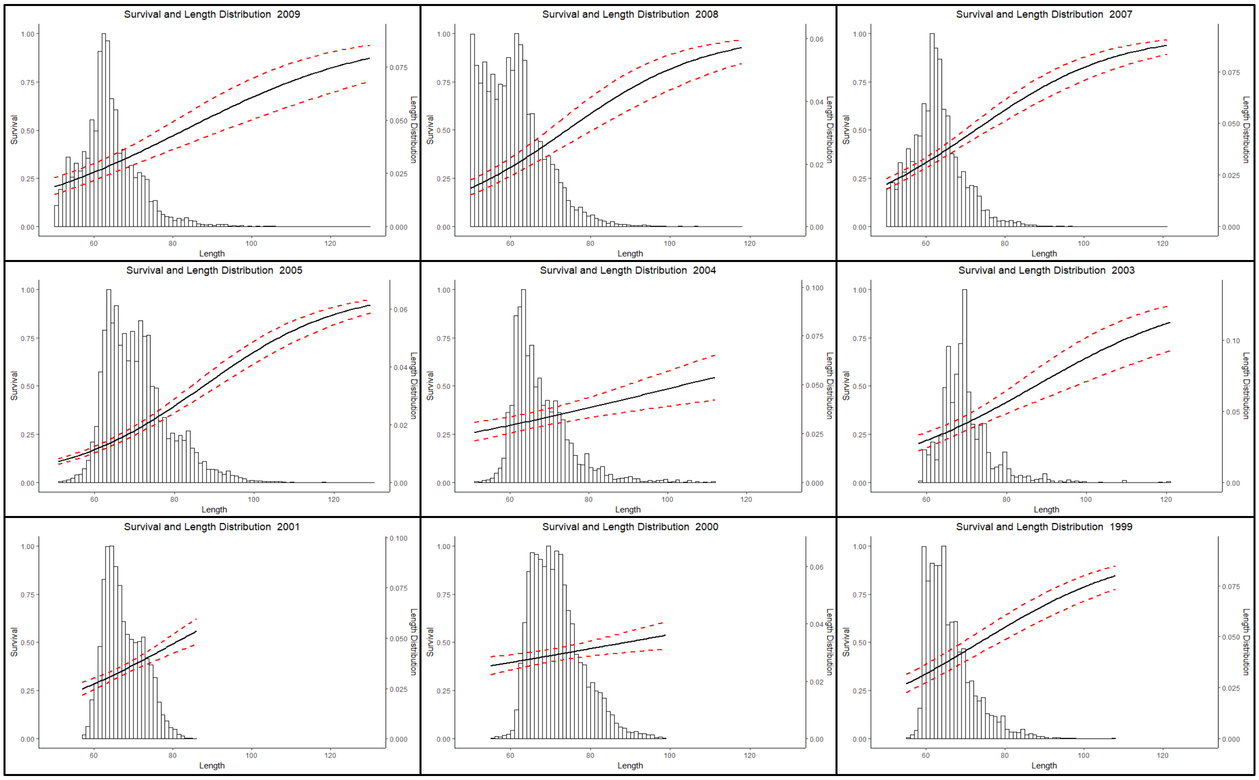

Figure 5: Release to McNary survival (black solid line) and 95% confidence interval (red dotted lines), as a function of length at tagging and length frequency histogram (secondary y-axis) for migration years 1999-2009.

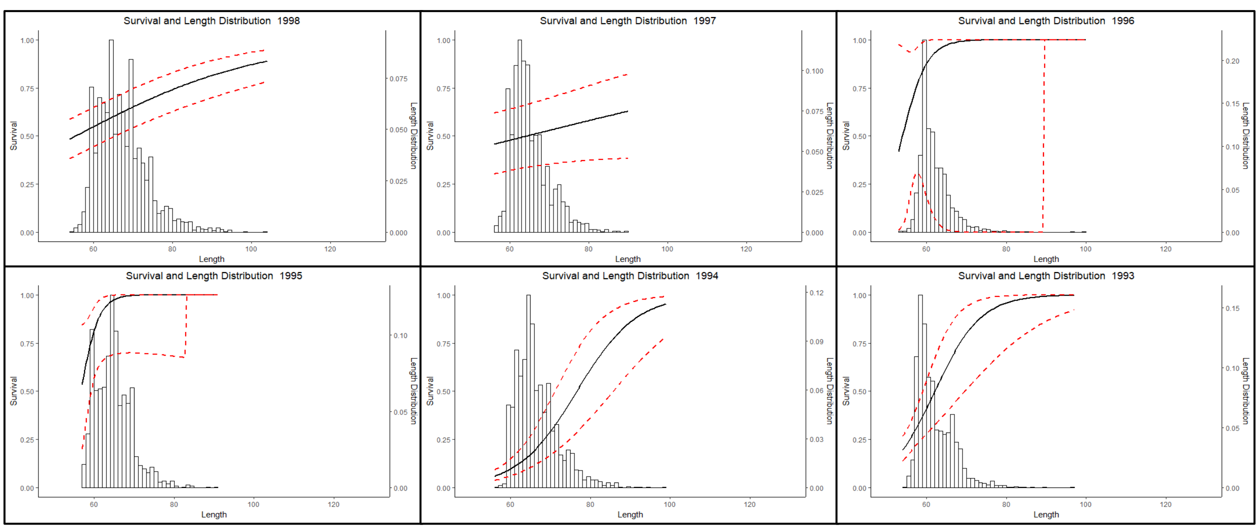

Figure 6: Release to McNary survival (black solid line) and 95% confidence interval (red dotted lines), as a function of length at tagging and length frequency histogram (secondary y-axis) for migration years 1993-1998.

Effects of Length at Tagging on Travel Time

Methods

Generalized linear mixed models were used to assess how fish travel time (TT) between release and detection at McNary Dam was affected by length at tagging. Migration year was fit as a random explanatory effect, while length, average daily flow at McNary Dam at the time of passage (MCN), average daily flow at Priest Rapids Dam on the date of tagging (PRD), and Julian date of tagging/release (Jday) were fit as fixed effects. Models were fit using the lmer() function in the *lme4* package (Bates et al 2015), with fish travel time as the response and each regression containing different combinations of explanatory variables. Given their high degree of correlation, the MCN and PRD variables were not included in any of the same models tested. Model comparison and selection was done using the best fitting model based on Akaikes Information Criterion (Akaike 1973).

Results

The modeling results indicated length at tagging, flow and seasonality were all significant predictors of travel time between release and detection at McNary Dam for Hanford Reach wild subyearling fall Chinook (Table 4). Length at tagging was the strongest predictor of juvenile travel time, as was flow at McNary and the seasonal component of date of tagging (Jday). In general, fish tend to move faster downstream the bigger they are at tagging, with higher flows, and later in the season (Table 5).

Table 4: Candidate model sets for Hanford Reach wild subyearling fall Chinook that were released and subsequently detected at McNary Dam, 1993-2018. The top model, based on AIC score, is highlighted in grey.

Model	AIC
TT ~ TagDOY +(1|Y)	132549.2
TT ~ length +(1|Y)	128246.4
TT ~ MCN +(1|Y)	125757.1
TT ~ PRD +(1|Y)	132787.2
TT ~ length+MCN +(1|Y)	122345.8
TT ~ length+ PRD +(1|Y)	128257.7
TT ~ length+MCN+Jday+(1|Y)	122253.9
TT ~ length+PRD+Jday+(1|Y)	128266.3

Table 5: Fixed effects coefficient estimates for best fitting model in the candidate set

Fixed effects:	Estimate	Std. Error	p-value
(Intercept)	103.8518	2.612789	<0.001
length	-0.43971	0.007751	<0.001
MCN	-0.13021	0.001539	<0.001
Jday	-0.10289	0.01021	<0.001

However, these relationships vary considerably between years, with travel time being primarily related to flows in some years, and length at tagging in others. To illustrate how the primary explanatory variable can vary by year, we fit simple linear regressions to travel time data in each year for flow at McNary, as well as by length. In some years, the singular variable, length, explained a large proportion of the variability in travel times, while flow explained very little (Figure 7). In contrast, in other years, such as 2017, almost all of the variability in travel time could be explained by flows, while very little was explained by length at tagging (Figure 8).

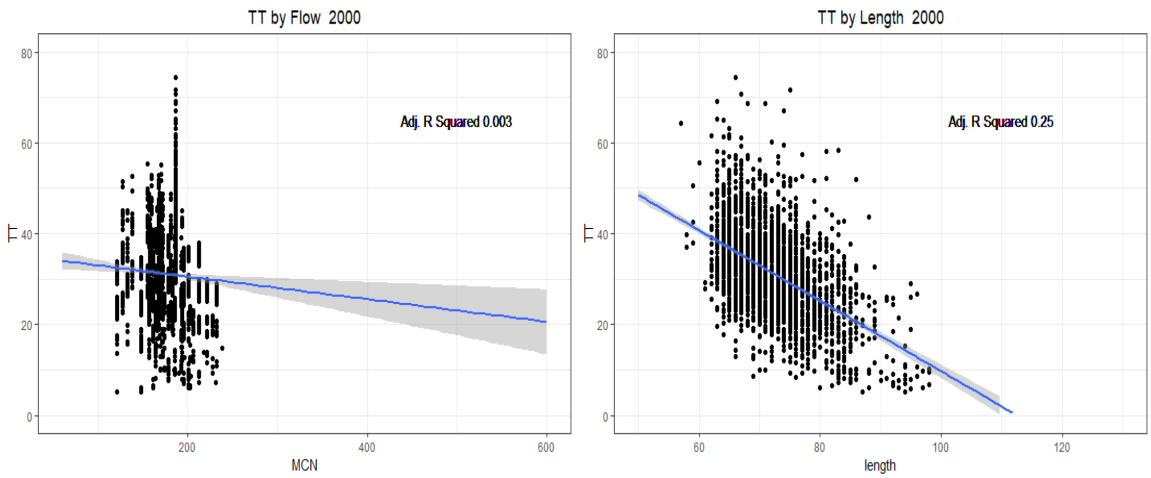

Figure 7: Travel time (days) vs mean daily flow at McNary Dam (Kcfs) (left), and length at tagging (mm) (right) with linear model fit and 95% confidence intervals, migration year 2000.

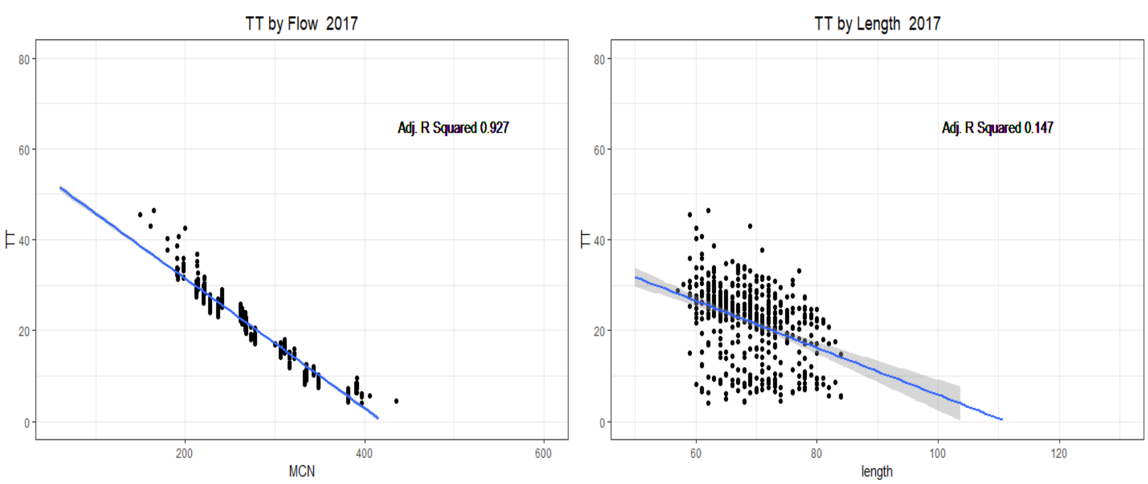

Figure 8: Travel time (days) vs mean daily flow at McNary Dam (Kcfs) (left), and length at tagging (mm) (right) with linear model fit and 95% confidence intervals, migration year 2017.

Smolt-to-Adult Returns

The Comparative Survival Study (CSS) began including estimates of smolt-to-adult returns (SARs) for Hanford Reach wild subyearling fall Chinook in their 2014 Annual Report. Due to lack of PIT-tag detection in the adult fish ladders at BON, SARs for this group are limited to migration years 2000 and later. The CSS has provided updates to these SAR estimates in each year's Annual Report. Table 6 provides estimates of SARs from McNary to Bonneville (MCN-to-BOA) and Release to Bonneville (Rel-to-BOA) for migration years 2000-2015. These SAR estimates were taken from Appendix B of the Draft 2018 CSS Annual Report (McCann et al. 2018).

Table 6. Overall MCN-to-BOA and Rel-to-BOA SARs for Hanford Reach wild subyearling fall Chinook, 2000-2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving MCN [A]	MCN-to-BOA without Jacks			MCN-to-BOA with Jacks			Smolts released	REL-to-BOA without Jacks		
		%SAR	Non-parametric CI		%SAR	Non-parametric CI			%SAR	Non-parametric CI	
		Estimate	90% LL	90% UL	Estimate	90% LL	90% UL		Estimate	90% LL	90% UL
2000	4,521	2.68	2.27	3.11	2.88	2.45	3.32	10,967	1.10	0.93	1.28
2001	3,642	0.68	0.47	0.91	0.71	0.50	0.94	9,973	0.25	0.17	0.33
2002	--	--	--	--	--	--	--	--	--	--	--
2003	820	0.43	0.11	0.82	0.43	0.11	0.82	2,975	0.13	0.03	0.27
2004	1,000	0.20	0.00	0.44	0.20	0.00	0.44	2,989	0.07	0.00	0.17
2005	6,602	0.26	0.15	0.37	0.29	0.18	0.40	22,634	0.08	0.04	0.11
2006	--	--	--	--	--	--	--	--	--	--	--
2007	7,790	0.35	0.24	0.46	0.45	0.33	0.58	21,007	0.13	0.09	0.17
2008	5,543	2.00	1.62	2.39	2.27	1.88	2.71	16,651	0.67	0.56	0.77
2009	4,614	0.72	0.51	0.96	0.89	0.65	1.17	13,728	0.24	0.17	0.31
2010	1,418	2.61	1.88	3.40	2.96	2.15	3.88	4,850	0.76	0.56	0.97
2011	4,050	3.21	2.65	3.84	3.46	2.88	4.12	10,337	1.26	1.08	1.43
2012	1,335	1.80	1.17	2.47	1.87	1.22	2.57	4,885	0.49	0.33	0.66
2013	1,454	2.41	1.68	3.27	2.75	1.95	3.67	4,184	0.84	0.60	1.10
2014[B]	3,423	0.67	0.44	0.93	0.85	0.60	1.15	9,940	0.23	0.15	0.32
2015[C,D]	--	--	--	--	--	--	--	4,965	0.02	0.00	0.06
geometric mean		0.95			1.06				0.26		

[A] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[B] Incomplete, 3-salt returns through December 31, 2017.
[C] Incomplete, 2-salt returns through December 31, 2017.
[D] MCN-to-BOA SAR not calculated, release to MCN survival unreliable.

Literature Cited:

Akaike H. 1973. Information theory as an extension of the maximum likelihood principle. Pages 267-281 in BN Petrov, Csaki F, editors. Second International Symposium on Information Theory. Akade´miai Kiado´, Budapest, Hungary

Bates, D., M. Maechler, B. Bolker, and S. Walker. 2015. Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, 67(1):1-48. doi:10.18637/jss.v067.i01.

Burnham, K. P., D.R. Anderson, G.C. White, C. Brownie, and K.H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release–recapture. American Fisheries Society Monograph, 5(5).

Fish Passage Center. 2013. Update: Passage timing, travel times, and juvenile survival of wild Hanford Reach subyearling Chinook to McNary Dam (1993-2012). http://www.fpc.org/documents/memos/06-13.pdf

McCann, J, B. Chockley, E. Cooper, Bobby Hsu, S. Haeseker, R. Lessard, C. Petrosky, T. Copeland, E. Tinus, A. Storch, and D. Rawding. 2018. Comparative Survival Study of PIT-tagged Spring/Summer/Fall Chinook, Summer Steelhead, and Sockeye DRAFT 2018 Annual Report. BPA Contract #19960200. September 2018. http://www.fpc.org/documents/CSS/DRAFT2018CSSReport.pdf

White, G.C. and K.P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46: S120-S139.