2022 Salmon Methodology Review Materials

Summary of FRAM base period Round 7.1.1 updates that potentially impact the Pacific Fishery Management Council's Chinook salmon abundance threshold for Southern Resident Killer Whales

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Introduction

The Pacific Fishery Management Council (Council) adopted a Chinook salmon abundance threshold at their November 2020 meeting, which went into effect with Amendment 21 of the Pacific Coast Salmon Fishery Management Plan. During the annual preseason fishery planning process, if projected abundances fall below the threshold, then additional management measures are triggered that are intended to potentially benefit Southern Resident Killer Whales (SRKW) while continuing to provide fishing opportunity in years of low Chinook salmon abundance. The threshold value is the arithmetic mean of the seven lowest years of October 1 abundances in the North of Falcon (NOF) area during 1993 - 2016, specifically 1994 - 1996, 1998 - 2000, and 2007. The regional abundance estimates are derived using methods outlined in the Ad-hoc SRKW Workgroup's Risk Assessment. In short, the approach uses stock/time specific distribution parameters to apportion overall ocean cohort estimates (prior to fishing mortality, maturation, and natural mortality) into regional abundance estimates. The distribution parameters for fall run stocks were derived from an ocean distribution model outlined in Shelton et al. 2019, and the overall ocean cohort estimates came primarily[1] from the October 2018 set of post-season runs of the Chinook Fishery Regulation Assessment Model (FRAM) that used Round 6.2 of the base period calibration.

Starting ocean cohort sizes by stock/age are estimated by FRAM using the "Backwards FRAM" utility, which determines FRAM stock/age specific starting cohorts given a set of inputs of terminal run sizes and fishery catch and a set of Chinook FRAM base period parameters such as base period exploitation rates, maturation rates, and natural mortality rates. The program runs the model iteratively, adjusting the starting cohorts each time until the resulting terminal run sizes match the input targets.

In March 2022 the Washington state and tribal co-managers agreed to an updated calibration of the Chinook FRAM base period data set for use in developing and assessing 2022 salmon fishery management measures for Council-area and Puget Sound fisheries. This base period update (Round 7.1.1) incorporated a variety of changes that affected core base period output such as adult equivalent values (AEQs), base period cohort sizes, base period exploitation rates, maturation rates, and fishery model-stock proportions. When post-season model runs were updated with Round 7.1.1 parameters, the resulting estimates of starting ocean cohort sizes changed.

[1] There are four stocks for which abundance information is not FRAM-based: Sacramento River fall Chinook salmon, Klamath River fall Chinook salmon, Rogue River fall Chinook salmon, and Upper Columbia River spring Chinook salmon.

In this document we focus on the following four changes, which accounted for the majority of effects on estimates of starting cohort sizes. These cohort sizes are used as inputs to estimate regional abundances with the Ad-hoc SRKW Workgroup's methods, thus, changes to starting cohorts will result in changes to the regional abundance estimates. If Round 7.1.1 cohort sizes are deemed an improvement over Round 6.2 cohort sizes, the Council may wish to adopt a new NOF threshold value that is calculated using Round 7.1.1 cohorts.

1. Updated coded-wire tag (CWT) recovery information, auxiliary recoveries, and fishery mapping.
2. Escapement expansions to account for inter-dam loss of Columbia River stocks that originate upstream of Bonneville Dam.
3. Updated stock-specific terminal run size inputs.
4. Updated estimates of catches in Canadian sport fisheries.

Description of updates

Updated coded-wire tag recovery information, auxiliary recoveries, and fishery mapping.

Prior to the Round 7.1.1 update in 2020, CWT information was last queried from the Regional Mark Information System (RMIS) for use in running the Chinook FRAM base period calibration in 2014-2015. Since then, there have been updates to expansions of escapement recoveries for tag codes used to represent Upper Columbia Summer Chinook salmon (see bottom of page 5 in the methodology review document on this topic from the November 2019 Council meeting) and Stillaguamish Chinook salmon (escapement expansions were updated to reflect trans-generational genetic mark-recapture (tGMR) escapement estimates). A secondary reason for updating the CWT information was to make sure it was in sync with information being used by the Chinook Technical Committee (CTC) of the Pacific Salmon Commission (PSC). Many of the tag codes used in the FRAM base period have overlap with the indicator stock tag codes used in the CTC's annual Exploitation Rate Analysis (ERA) and there are instances where auxiliary CWT recovery information is generated by the CTC to fill in known data gaps (e.g., Canadian stock escapements, which are not included in RMIS). This auxiliary information also had not been updated since 2014-2015. Thus as part of the Round 7.1.1 update, all base period CWT recovery information was extracted from RMIS on May 19, 2020 and all relevant CTC-derived auxiliary information was updated based on the CTC's 2020 ERA. As part of this process we also reviewed the existing CWT fishery mapping procedures and made a few notable corrections/refinements to mapping procedures:

- Elk River (Mid-Oregon Coast indicator) recoveries in Port Orford terminal troll fisheries were remapped to escapement (e.g., the terminal run) rather than to the Central Oregon Troll fishery where they had been previously mapped. The original assignment to Central Oregon Troll resulted in overestimating the contribution of the Mid-Oregon coast stock to this fishery during winter months. Port Orford troll catches are also excluded from modeling.
- Robertson Creek (West Coast Vancouver Island (WCVI) indicator) recoveries in WCVI individual stock-based management (ISBM) tidal sport fisheries were re-mapped to the WCVI sport fishery, rather than escapement (e.g., terminal run) where they had been previously mapped. This change was necessary because total catches in WCVI ISBM tidal sport fisheries are now included in the modeling.
- Numerous other minor corrections to mapping procedures as documented through the commit history for the FRAMBuilder Github Repository.

The links below provide a comparison of both the nominal and expanded CWT recovery information that went into the base period calibration between Round 6.2 and Round 7.1.1.:

- FRAM R6.2 vs R7.1.1 CWT comparison by stock
- FRAM R6.2 vs R7.1.1 CWT comparison by fishery

In general, recovery numbers by fishery/stock are very similar between Round 6.2 and Round 7.1.1. In instances where there are differences, they are explained by known changes to either the recoveries themselves or the fishery mapping procedures. For example, specific to the Elk River recovery mapping correction noted above, if you open the link for 'CWT comparison by fishery' and select the Central Oregon Troll fishery, you will see a reduction in Mid-Oregon Coast stock contribution to the fishery (163 less nominal tag recoveries).

These 163 nominal recoveries instead get mapped to escapement in Round 7.1.1 (select the 'Escapement' fishery at the bottom of the drop down list).

Escapement expansions to account for inter-dam loss of Columbia River stocks that originate upstream of Bonneville Dam.

During a review of Columbia River summer Chinook salmon representation in Round 6.2 of the Chinook FRAM base period, we identified that the FRAM calibration was not accounting for inter-dam loss (IDL) in the four model stocks that originate upstream of Bonneville Dam: Columbia R Bonneville Pool Hatchery, Columbia R Upriver Summer, Columbia R Upriver Bright, and Snake River Fall. This resulted in underestimating terminal CWT recoveries for these stocks and, in turn, potentially biasing the ocean exploitation rates high. Expansions for IDL are a way to account for fish that go unaccounted for between Bonneville Dam and a point further upstream (usually another dam, varies by stock). To account for IDL in Chinook FRAM Round 7.1.1, we calculated an auxiliary CWT recovery for each existing escapement recovery that was based on the same IDL values used by the CTC in their analyses. Further information on this is provided beginning at the bottom of page 5 in the Columbia Summer Chinook salmon methodology review document from the November 2019 Council meeting. The results of these expansions for the four relevant stocks can be seen in the above 'CWT comparison by fishery' link if you select the 'Escapement' fishery at the bottom of the list.

Updated stock-specific terminal returns.

Snake River fall Chinook salmon Snake River fall Chinook salmon are a subcomponent of the Columbia River Upriver Bright (URB) stock aggregate. In Chinook FRAM, there are separate URB and Snake River fall model stocks, as the ocean distribution and harvest patterns are notably different between the two. In previous versions of Chinook FRAM base period calibrations and post-season modeling exercises, estimates of Snake River fall Chinook salmon returns to the mouth of the Columbia River were unavailable and derived simply as an assumed proportion of the total URB stock aggregate returns to the mouth of the Columbia River. This assumed proportion was 1% for return years 1988 to 1999, 3% for 2000 to 2009 and 5% for 2010 onward. As the abundance of Snake River fall Chinook salmon began to increase in the early 2000s, it became evident that this approach was underestimating the abundance of the stock.

To address this, in 2019 we developed a terminal run reconstruction for Snake River fall wild and hatchery Chinook salmon that provided estimates of returns to the Columbia River mouth by age and mark-status (as required for input into FRAM), which were used in place of the above mentioned proportions. This was shared with the U.S. v Oregon Technical Advisory Committee (TAC) in November 2019.

Canadian Chinook salmon stocks We updated terminal return estimates for Canadian Chinook salmon stocks, most notably for Fraser Early and Lower Georgia Strait. These changes are largely a result of an update to the PSC Chinook Model base period, which occurred in 2020. One component of this model update was a finer level of stratification for some model stocks, including many of the Southern British Columbia stocks, which is documented here.

In the previous version of the PSC Chinook model, Fraser early Chinook salmon were represented by a single stock aggregate which was split into four separate components in the updated model: Fraser spring 1.2, Fraser spring 1.3, Fraser summer 0.3, and Fraser summer 1.3. With this restructuring there were some stocks that were added to the model as well as some that were removed. This resulted in an overall net increase to the terminal runs size inputs and resulting ocean cohorts for the FRAM Fraser Early stock (Figure A.30).

For the Lower Georgia Strait stock, the differences in ocean cohorts varied throughout the time series of post-season runs (Figure A.31). Cohort sizes were generally higher in calibration Round 6.2 versus calibration Round 7.1.1 prior to 2000, but lower than Round 7.1.1 after 2000. Similar to the Fraser Early stock, changes were caused by updates to stock definitions used by the PSC.

Puget Sound Chinook salmon stocks In most cases, terminal run size inputs for Puget Sound Chinook salmon stocks from 1992 through 2016 were unchanged or nearly identical between Round 6.2 and Round 7.1.1. There were, however, some instances where regional co-manager staff provided revised inputs that were incorporated into Round 7.1.1. Most notably, there were updates to the estimated age composition for the Mid Puget Sound fall fingerling stock from 2006 onward and for the Strait of Juan de Fuca (JDF) Tributaries stock for the entire time series.

Updated estimates of catches in Canadian sport fisheries.

In 2012, the Department of Fisheries and Ocean Canada (DFO) initiated an online sport catch reporting system (iRec) that produces year-round catch estimates for all salmon species in all marine areas. Prior to this, catch of Chinook salmon in BC sport fisheries was estimated via creel surveys that varied in spatio-temporal coverage, but generally occurred between May and September. Total catch estimates were not produced in time/area strata where creel surveys did not occur, even though voluntary CWT sampling did occur in these areas and CWT recoveries were reported in RMIS. The magnitude of missing catch varied considerably by area, but was substantial in some fisheries. For example, during the October to April time period, the Northern Georgia Strait sport FRAM fishery had an average (2012 - 2016) catch input in calibration Round 6.2 of 58 Chinook salmon, but an average (2012 - 2016) catch input in calibration Round 7.1.1 of 2,743 Chinook salmon.

As a result, previous iterations of FRAM base period calibrations and postseason modeling exercises have under-represented catch in some winter BC sport fisheries. Beginning in 2019, DFO shared Chinook salmon sport catch estimates derived through iRec back to fishing year 2012 for time/area strata that previously lacked estimates. FRAM fishery inputs from 2012 onward were updated accordingly. To account for missing catches prior to 2012, we collaborated with DFO staff to develop "unofficial" catch estimates to be used in FRAM for 1992-2011, based on the new iREC estimates.

Effect of Round 7.1.1 changes on starting cohort sizes

For each stock we compared starting cohort sizes that were estimated using Round 6.2 with those that were estimated using Round 7.1.1 (Table 1, Appendix A). For consistency with the modeling approach and units used by the Ad-hoc SRKW Workgroup, we aggregated across the marked and unmarked components of each stock, as well as across ages 3 through 5 (age 2 was excluded). For most stocks, the starting cohort sizes in Round 7.1.1 were very similar to Round 6.2 across the entire time series. There were some stocks where starting cohorts were consistently higher across years (Stillaguamish, JDF Tributaries, Snake River fall, WCVI, and Fraser Early) and others where they were consistently lower (Tulalip, Columbia Upriver Bright, Willamette spring, Fraser Late, Mid-Oregon Coast). Additionally, there were some stocks where starting cohort sizes differed, but with no consistent direction (Columbia Summer, North Oregon Coast, Lower Georgia Strait).

Effect of Round 7.1.1 changes on North of Falcon October 1 abundances and the threshold value

We next computed the annual October 1 pre-fishing abundance estimates for the NOF region using starting cohorts derived from Round 6.2 and using starting cohorts derived from Round 7.1.1, while holding distribution parameters and other inputs constant. In all but two years (1997 & 2010), using Round 7.1.1 starting cohorts resulted in a small increase to the estimated NOF abundance (Table 2). The existing threshold value is 966,000, which was derived by taking the arithmetic mean of the seven lowest abundances between 1993 and 2016 (1994 - 1996, 1998 - 2000, and 2007) based on the Round 6.2 starting cohort sizes. If we were to re-calculate the threshold using the same seven years and abundances derived from Round 7.1.1 starting cohorts with the original distribution parameters, the threshold value would increase by 3.6% to 1,001,000.

Table 1: Comparison between Round 6.2 and Round 7.1.1 mean 1992-2016 starting cohort size for each FRAM stock, aggregated across ages (age 3 through 5) and mark-status (adipose-clipped and unclipped).

		1992 - 2016 Average Starting Cohort		
StockID	**StockName**	**Round 6.2**	**Round 7.1.1**	**Difference**
1	Nooksack Samish Fall	84,889	86,479	1,590
2	Nooksack Spring	12,560	13,265	705
4	Skagit Summer-Fall Fingerling	37,199	38,592	1,393
5	Skagit Summer-Fall Yearling	1,843	1,900	57
6	Skagit Spring Yearling	13,952	14,500	548
7	Snohomish Fall Fingerling	23,395	23,871	476
8	Snohomish Fall Yearling	10,935	11,548	613
9	Stillaguamish Fall Fingerling	4,315	4,753	438
10	Tulalip Fall Fingerling	50,150	35,045	-15,105
11	Mid Puget Sound Fall Fingerling	131,690	132,321	631
12	UW Accelerated	18,926	18,449	-477
13	South Puget Sound Fall Fingerling	140,858	142,177	1,319
14	South Puget Sound Fall Yearling	13,104	13,178	74
15	White River Spring Fingerling	6,841	7,278	437
16	Hood Canal Fall Fingerling	102,265	102,213	-52
17	Hood Canal Fall Yearling	1,259	1,473	214
18	JDF Tributaries	6,274	9,415	3,141
19	Col R OR Hatchery Tules	50,406	51,302	896
20	Col R WA Hatchery Tules	182,268	188,704	6,436
21	Lower Columbia River Wild	147,044	153,223	6,179
22	Col R Bonneville Pool Hatchery	162,107	165,530	3,423
23	Col R Upriver Summer	163,569	191,838	28,269
24	Col R Upriver Bright	1,070,987	970,434	-100,553
25	Cowlitz River Spring	23,561	24,021	460
26	Willamette River Spring	115,532	105,457	-10,075
27	Snake River Fall	38,848	105,110	66,262
28	Oregon North Coast Fall	304,640	326,984	22,344
29	WCVI Fall	578,675	703,772	125,097
30	Fraser River Late	486,200	417,190	-69,010
31	Fraser River Early	445,427	737,669	292,242
32	Lower Georgia Strait	103,891	106,673	2,782
33	White River Spring Yearling	1,387	1,354	-33
34	Lower Columbia Naturals	18,549	18,697	148
36	WA North Coast Fall	192,514	192,863	349
37	Willapa Bay Fall	136,718	145,124	8,406
38	Hoko River	3,397	3,397	0
39	Mid Oregon Coast Fall	229,726	204,613	-25,113

Table 2: Comparison between Round 6.2 and Round 7.1.1 of annual October 1 pre-fishing abundances in the North of Falcon region. Shaded rows indicate years used in calculating the threshold value.

RunYear	Round 6.2	Round 7.1.1	Difference
1992	1,037,717	1,045,154	7,437
1993	1,079,609	1,113,993	34,384
1994	813,496	864,802	51,306
1995	1,023,196	1,061,620	38,424
1996	1,035,298	1,072,843	37,545
1997	1,144,311	1,133,318	-10,993
1998	861,060	879,596	18,536
1999	1,046,803	1,069,361	22,558
2000	1,036,777	1,097,210	60,433
2001	1,921,284	1,981,902	60,618
2002	2,135,524	2,179,640	44,116
2003	1,961,412	2,041,672	80,260
2004	1,969,918	2,037,024	67,106
2005	1,479,101	1,497,312	18,211
2006	1,279,111	1,300,767	21,656
2007	946,534	964,276	17,742
2008	1,253,810	1,327,574	73,764
2009	1,062,844	1,096,557	33,713
2010	1,941,252	1,916,653	-24,599
2011	1,523,081	1,552,971	29,890
2012	1,553,165	1,590,635	37,470
2013	2,440,406	2,482,455	42,049
2014	1,976,400	2,046,114	69,714
2015	2,292,869	2,413,744	120,875
2016	1,437,249	1,481,619	44,370

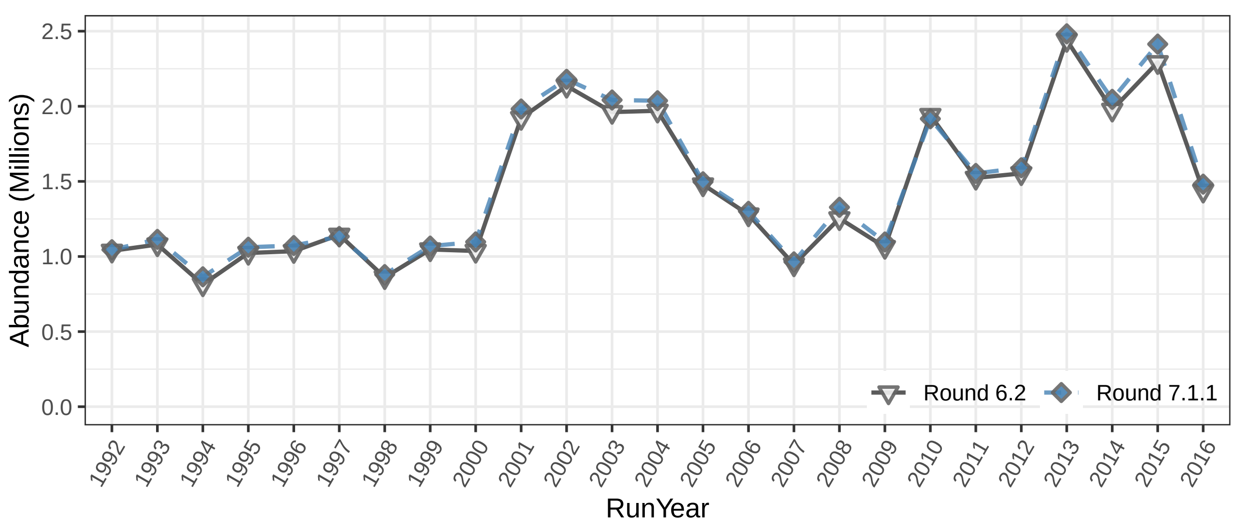


Figure 1: Estimates of October 1 pre-fishing Chinook salmon abundance in the North of Falcon region between 1992 and 2016, derived using FRAM Round 6.2 and Round 7.1.1 starting cohorts.

Appendix A

The figures below compare October 1 starting cohort sizes for each FRAM stock between 2018 post-season runs that used base period calibration Round 6.2 and 2021 post-season runs that used base period calibration Round 7.1.1. The values presented for each stock are aggregated across ages (3 through 5) and mark-status (marked and unmarked). Round 6.2 starting cohorts are represented by a blue line and blue points. Round 7.1.1 starting cohorts are represented by a black line and yellow points. Overlapping points that are similar or equal result in a green color.

Stock

Figure A.1. Nooksack Samish Fall

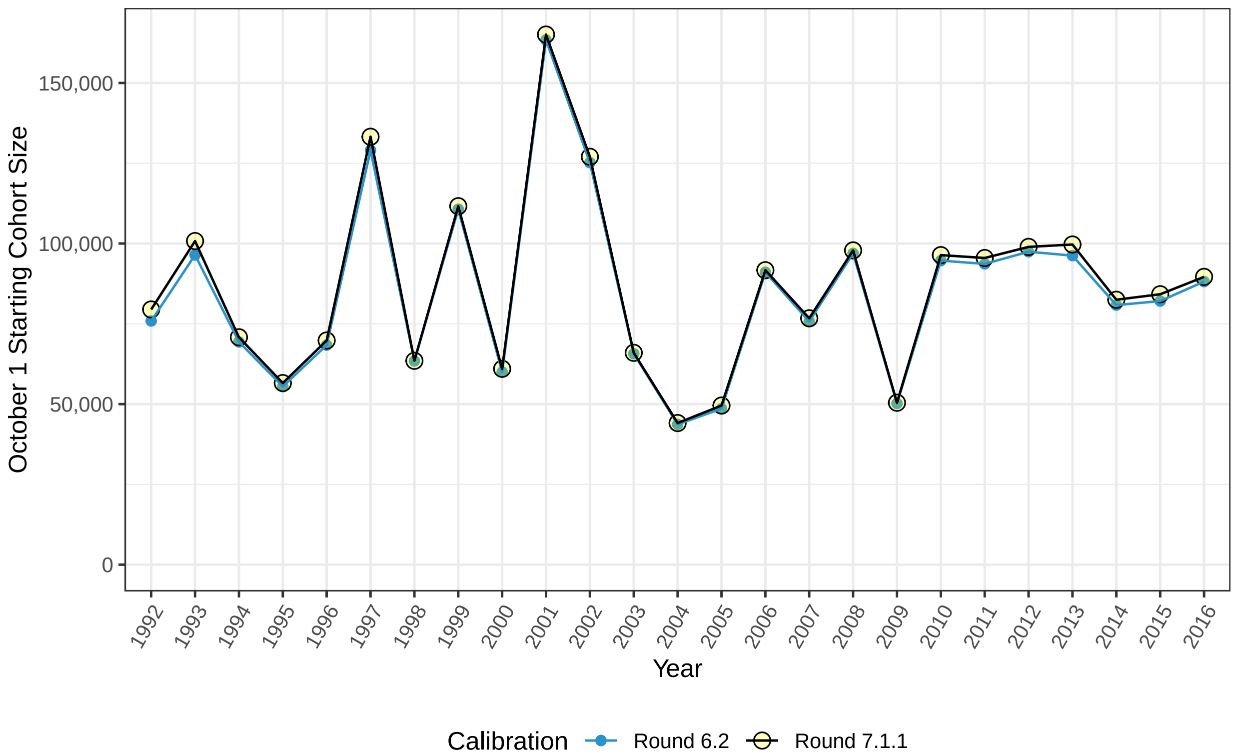


Figure A.2. Nooksack Spring

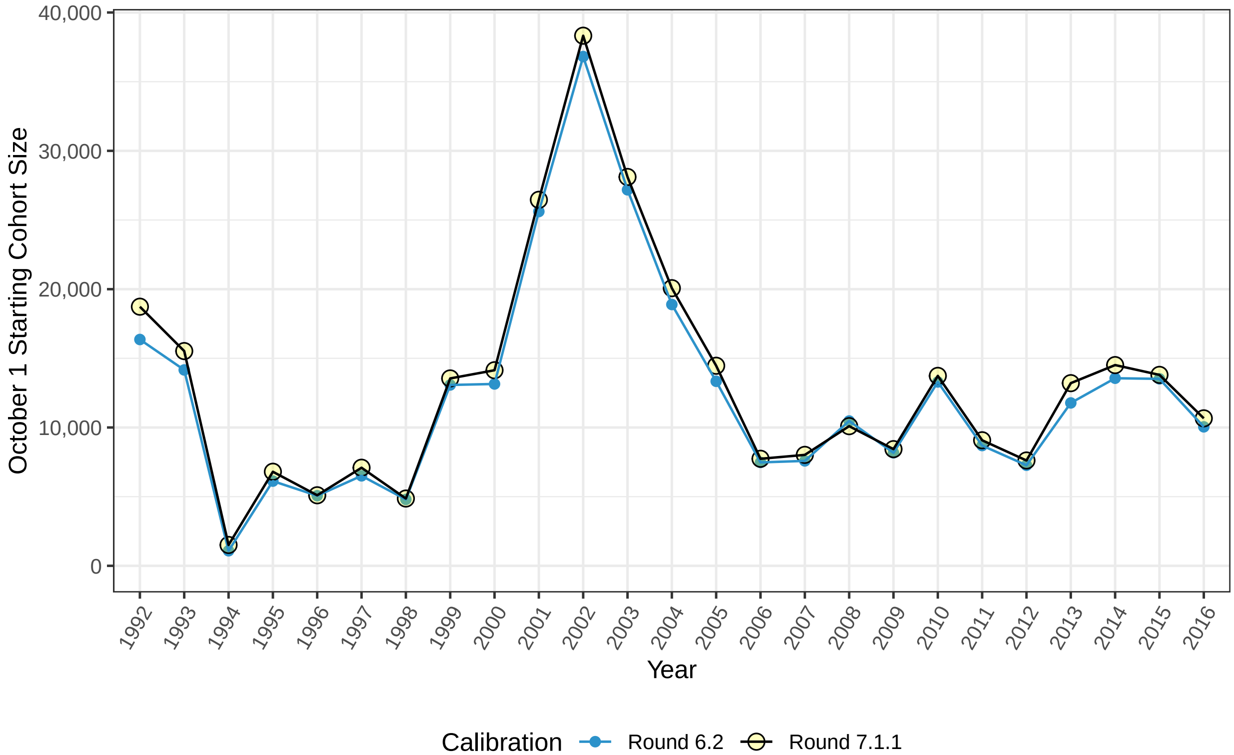


Figure A.3. Skagit Summer-Fall Fingerling

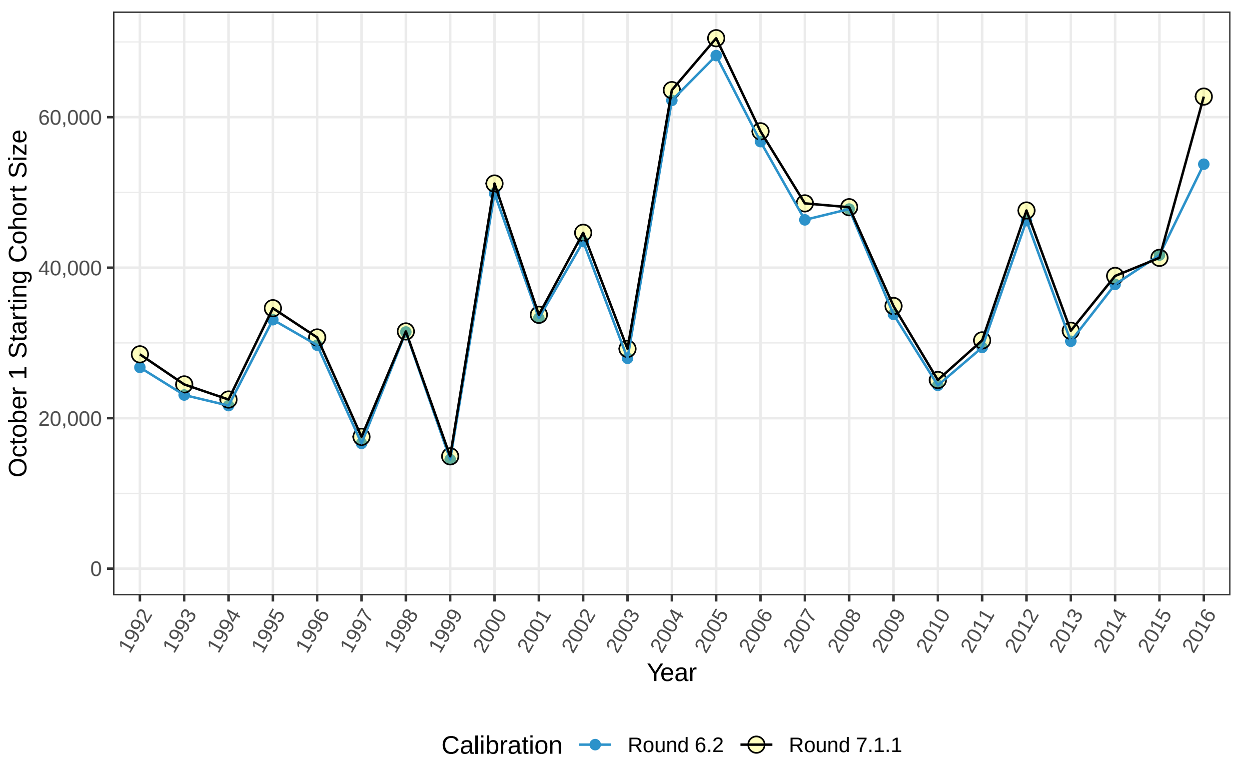


Figure A.4. Skagit Summer-Fall Yearling

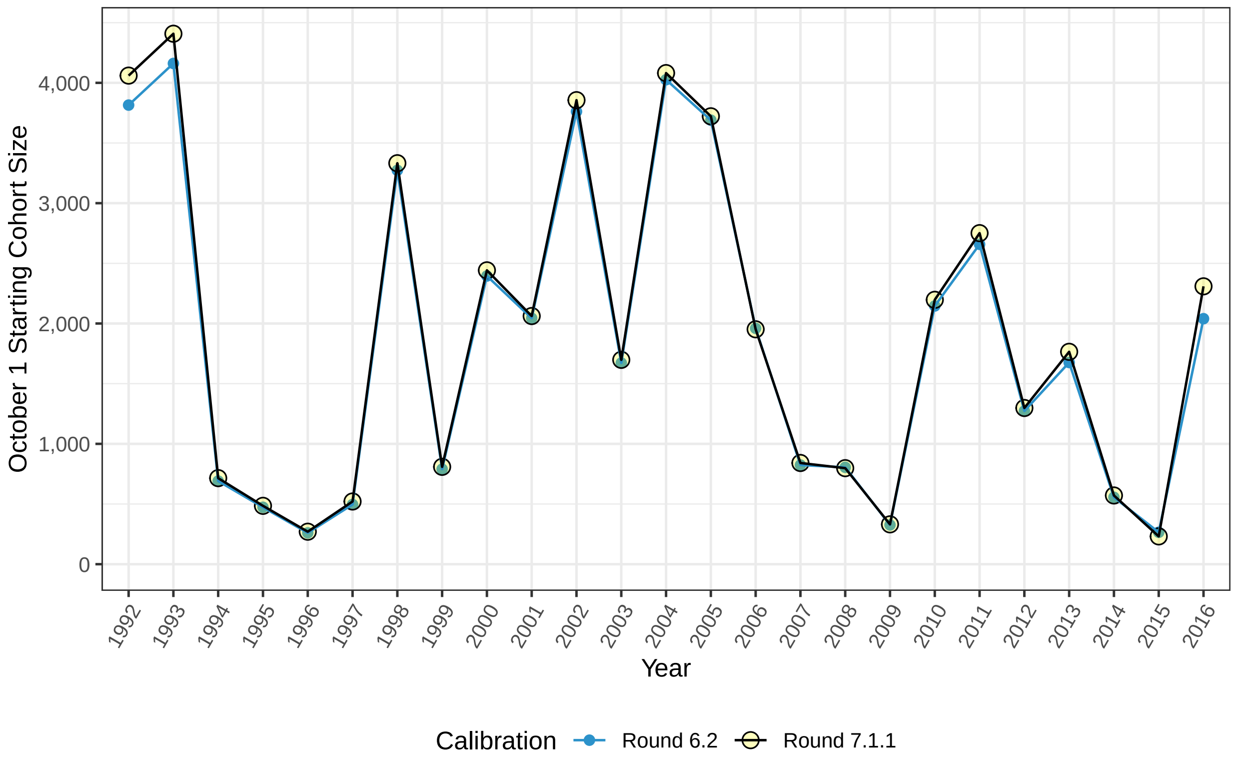


Figure A.5. Skagit Spring Yearling

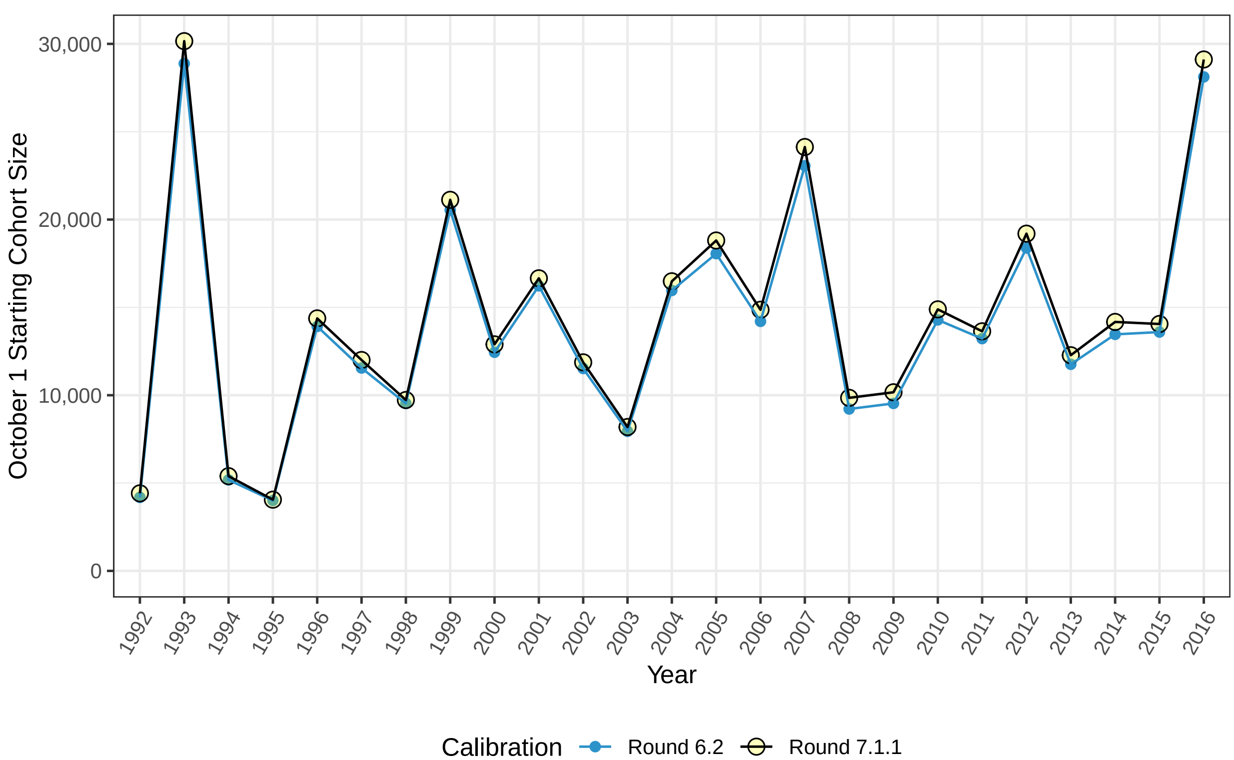


Figure A.6. Snohomish Fall Fingerling

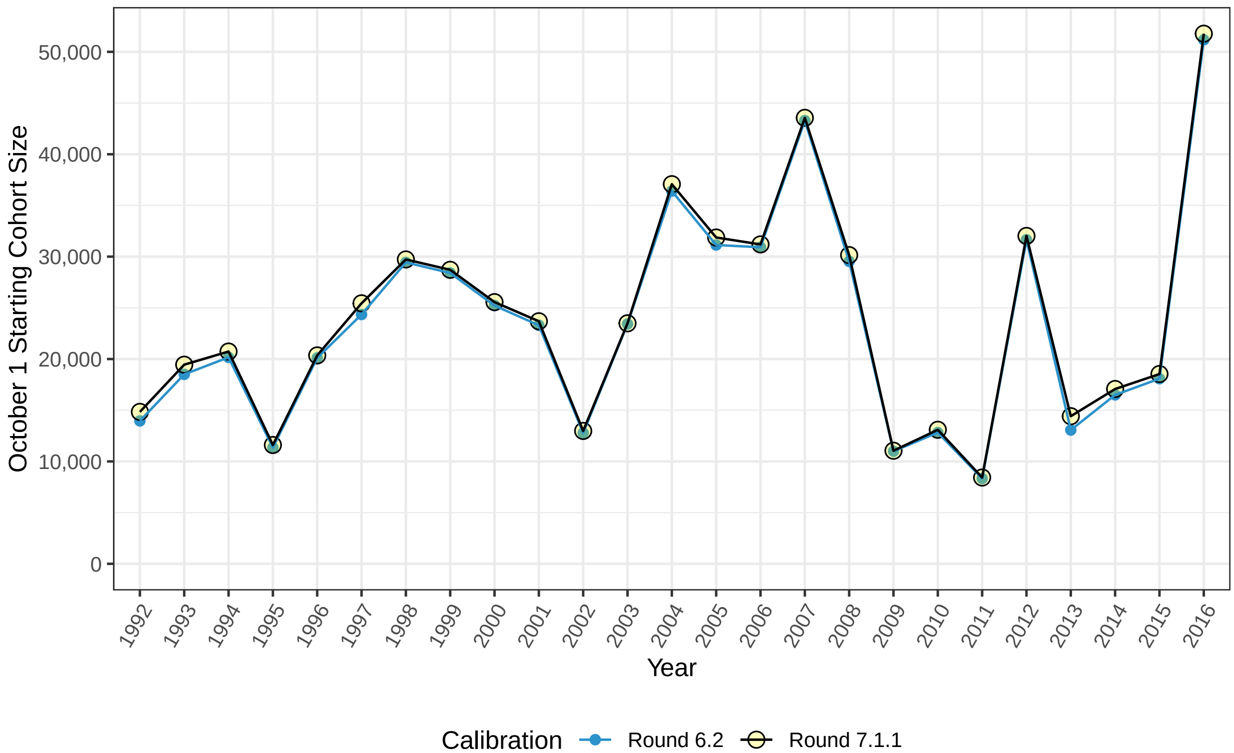


Figure A.7. Snohomish Fall Yearling

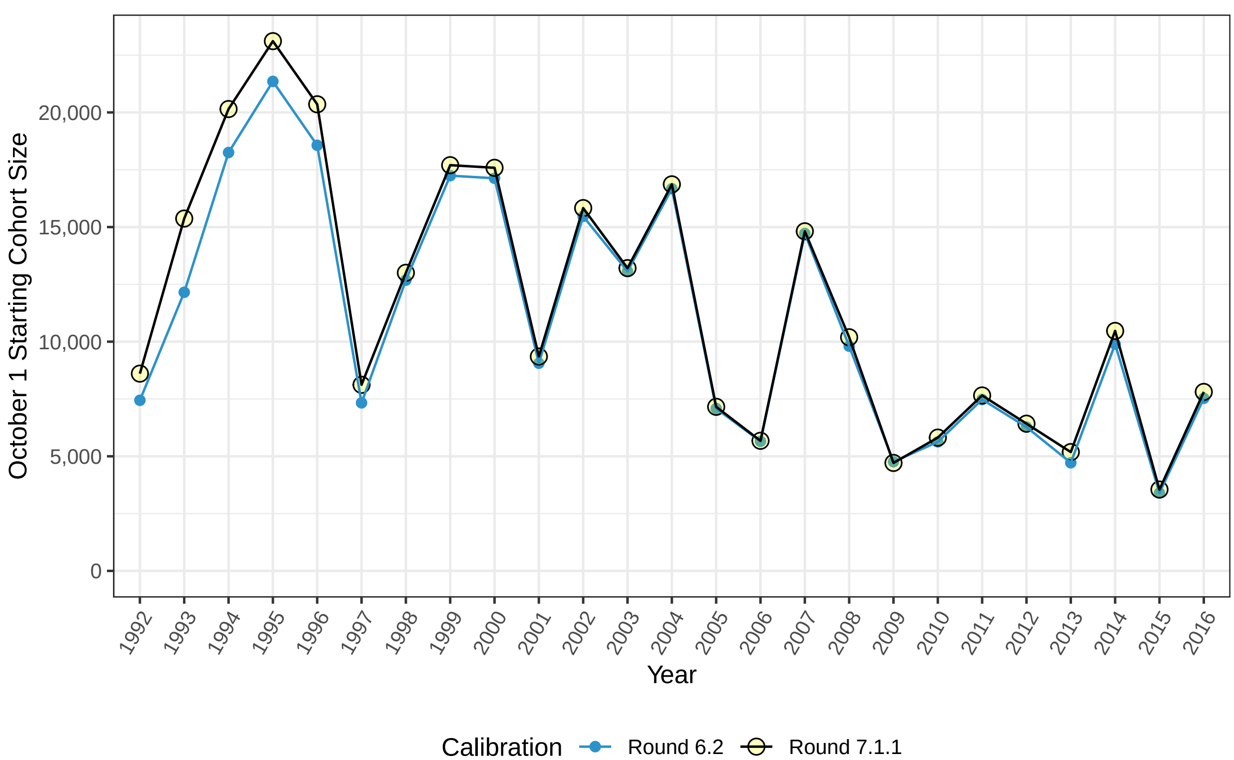


Figure A.8. Stillaguamish Fall Fingerling

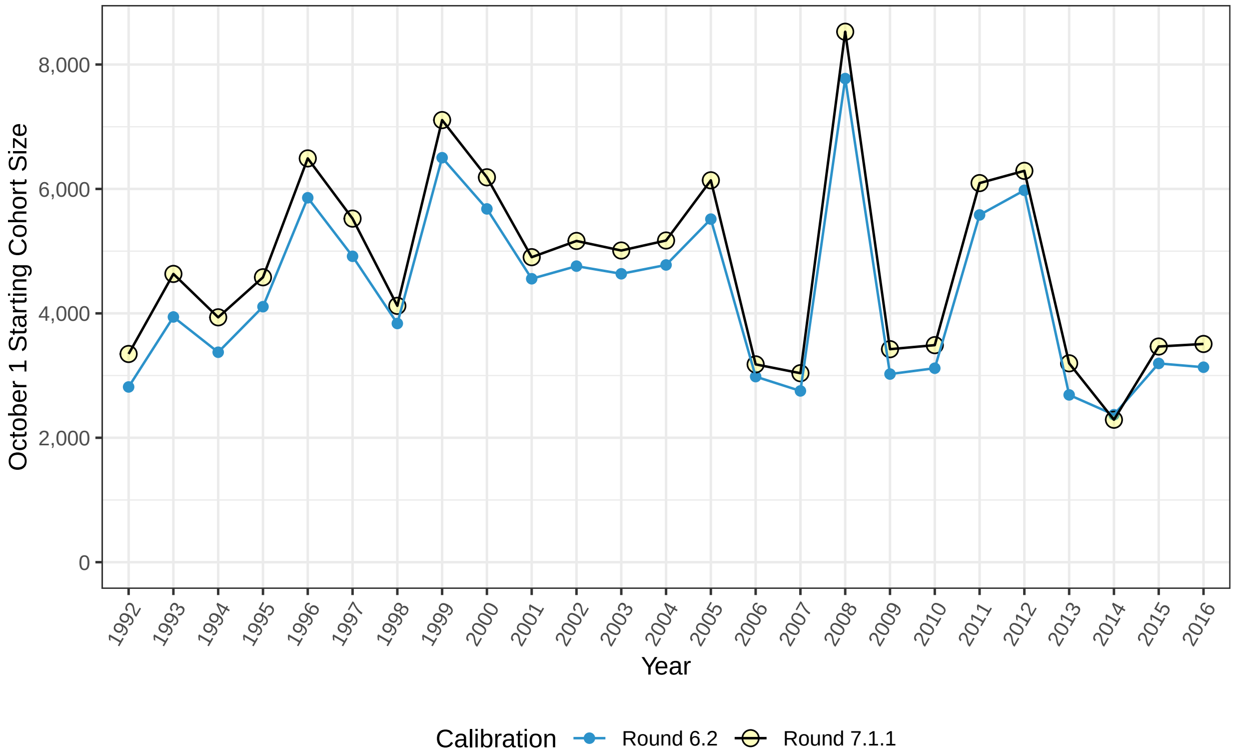


Figure A.9. Tulalip Fall Fingerling

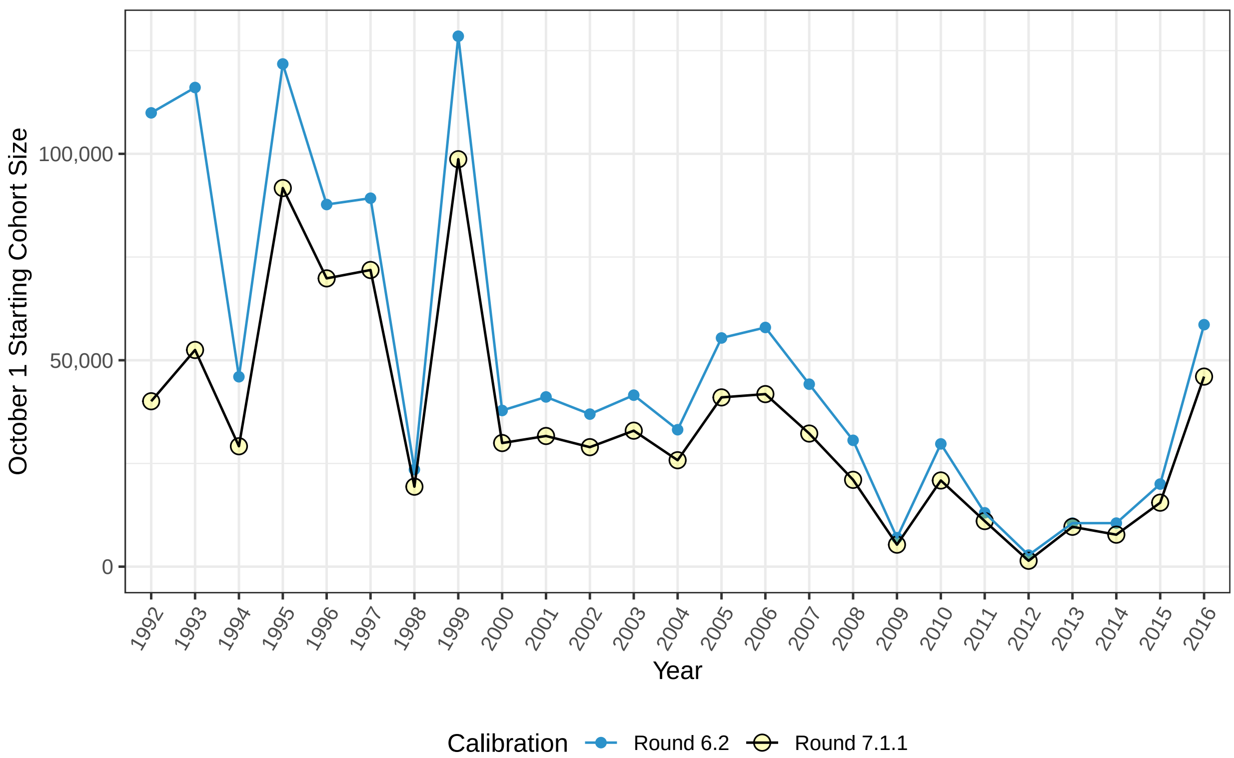


Figure A.10. Mid Puget Sound Fall Fingerling

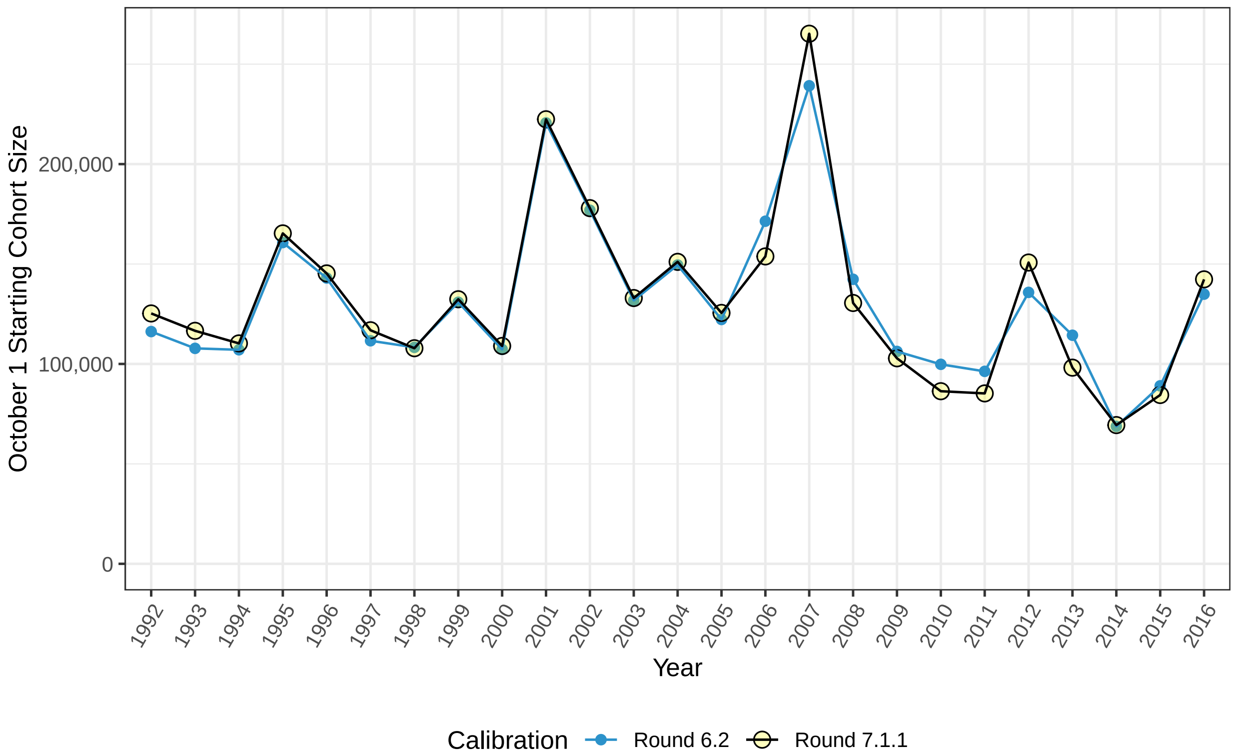


Figure A.11. UW Accelerated

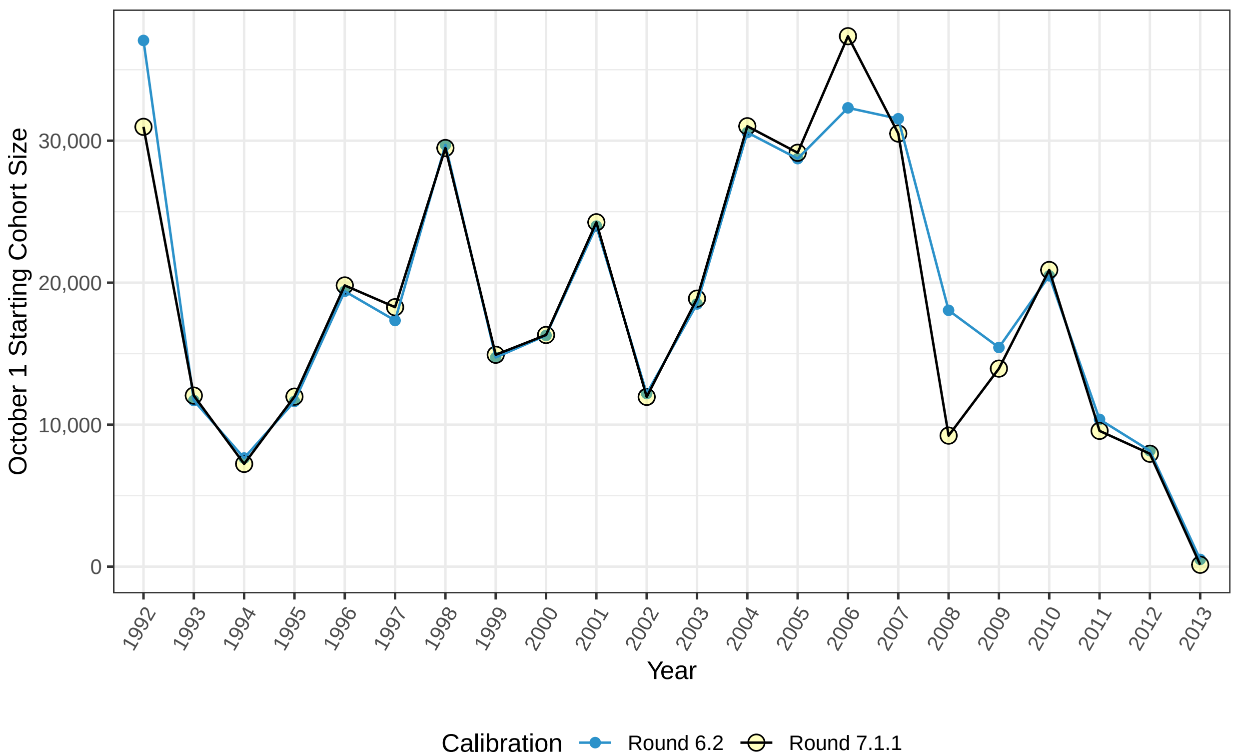


Figure A.12. South Puget Sound Fall Fingerling

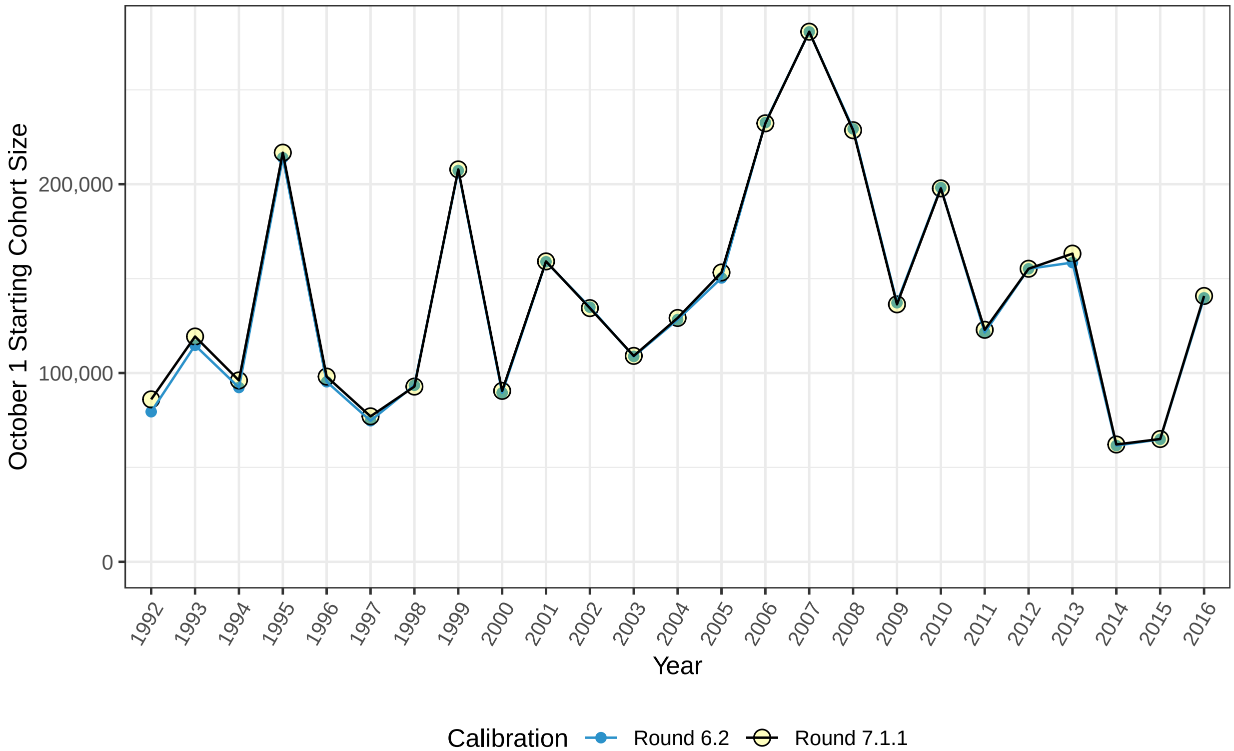


Figure A.13. South Puget Sound Fall Yearling

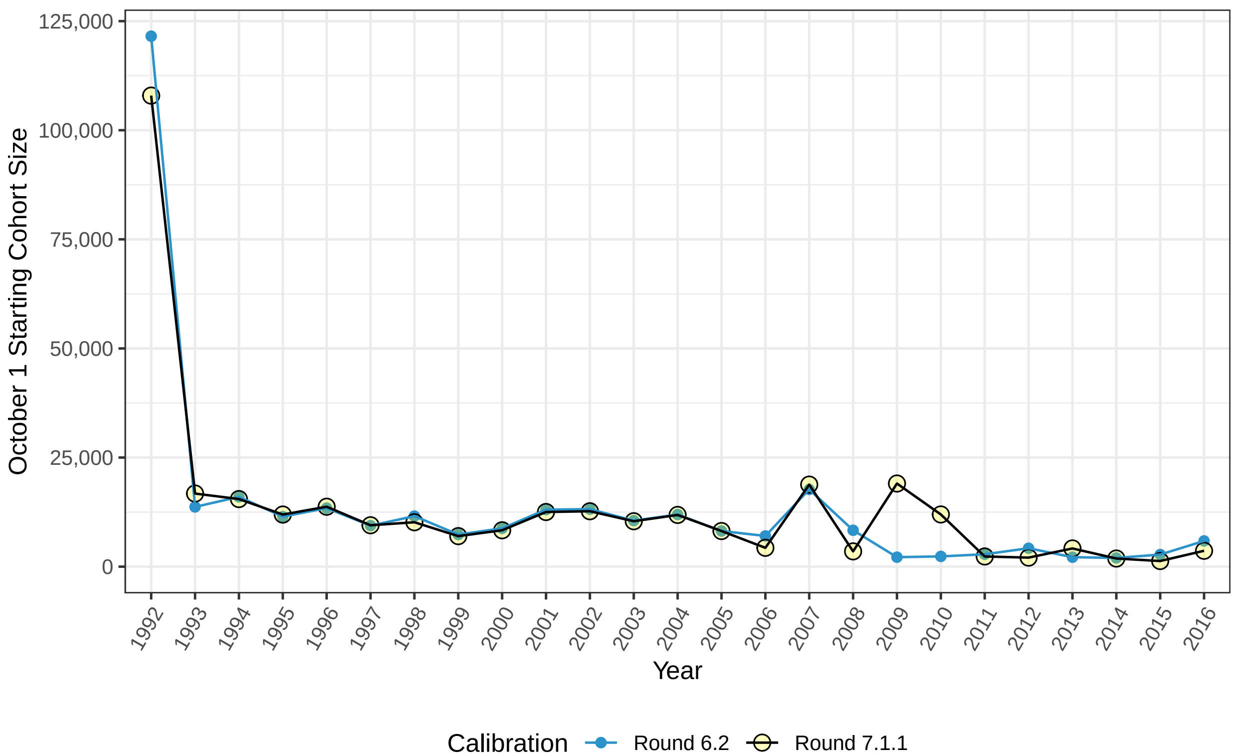


Figure A.14. White River Spring Fingerling

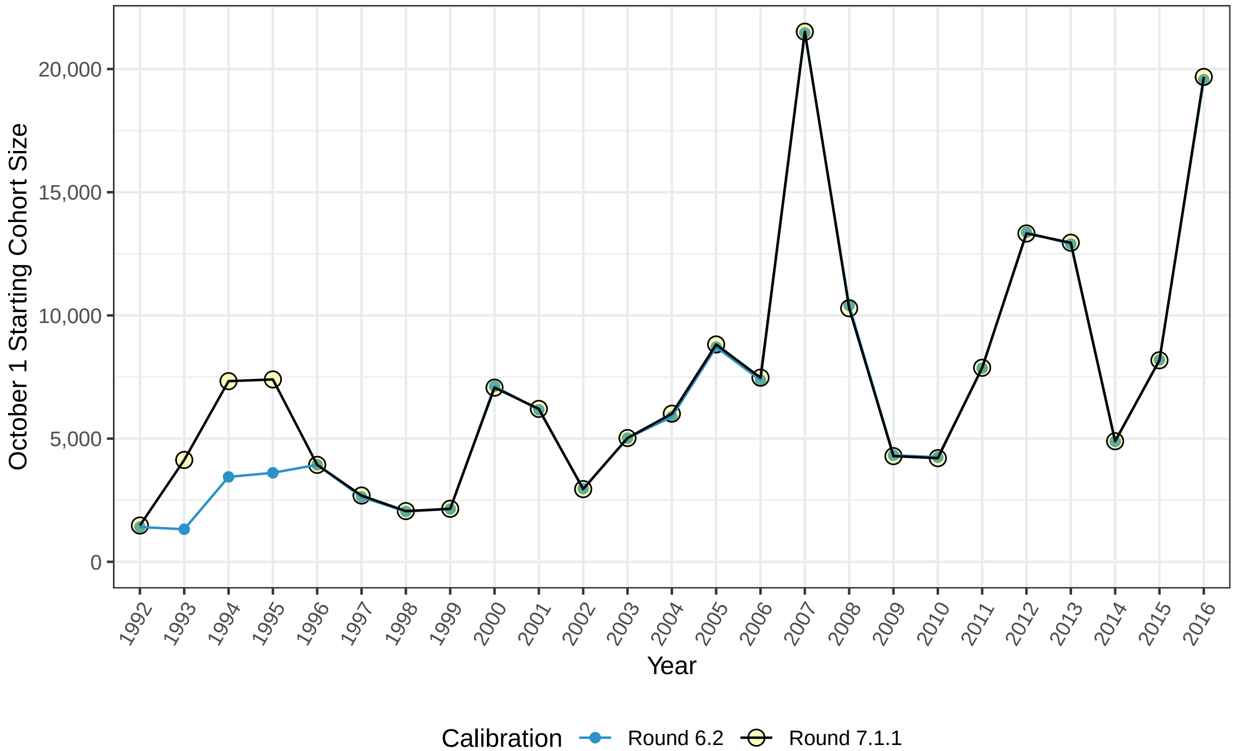


Figure A.15. Hood Canal Fall Fingerling

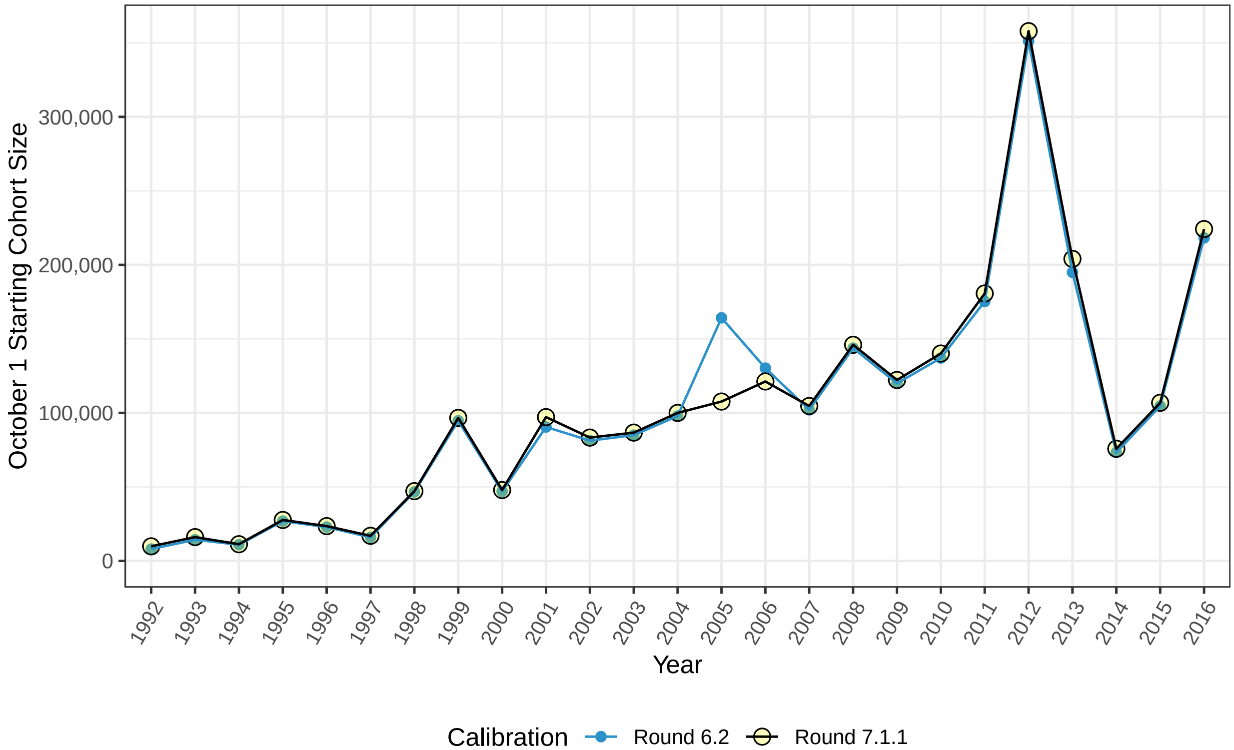


Figure A.16. Hood Canal Fall Yearling

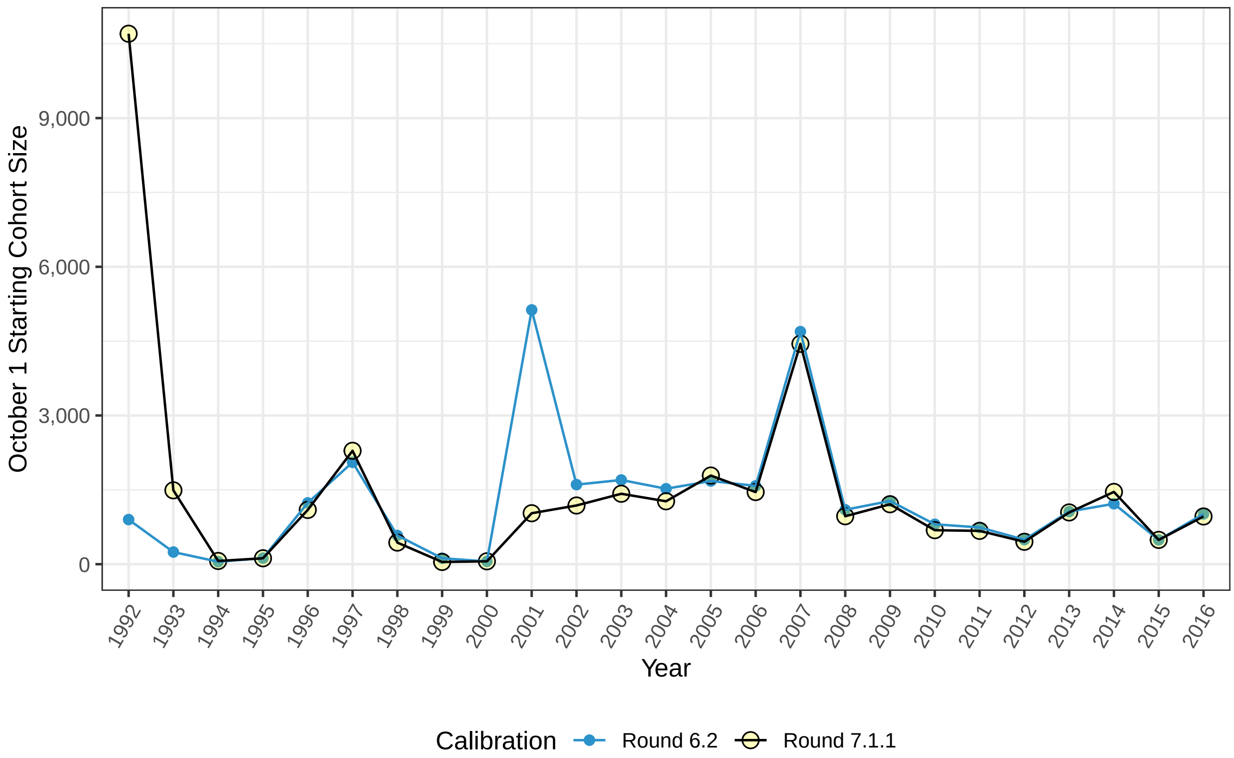


Figure A.17. JDF Tributaries

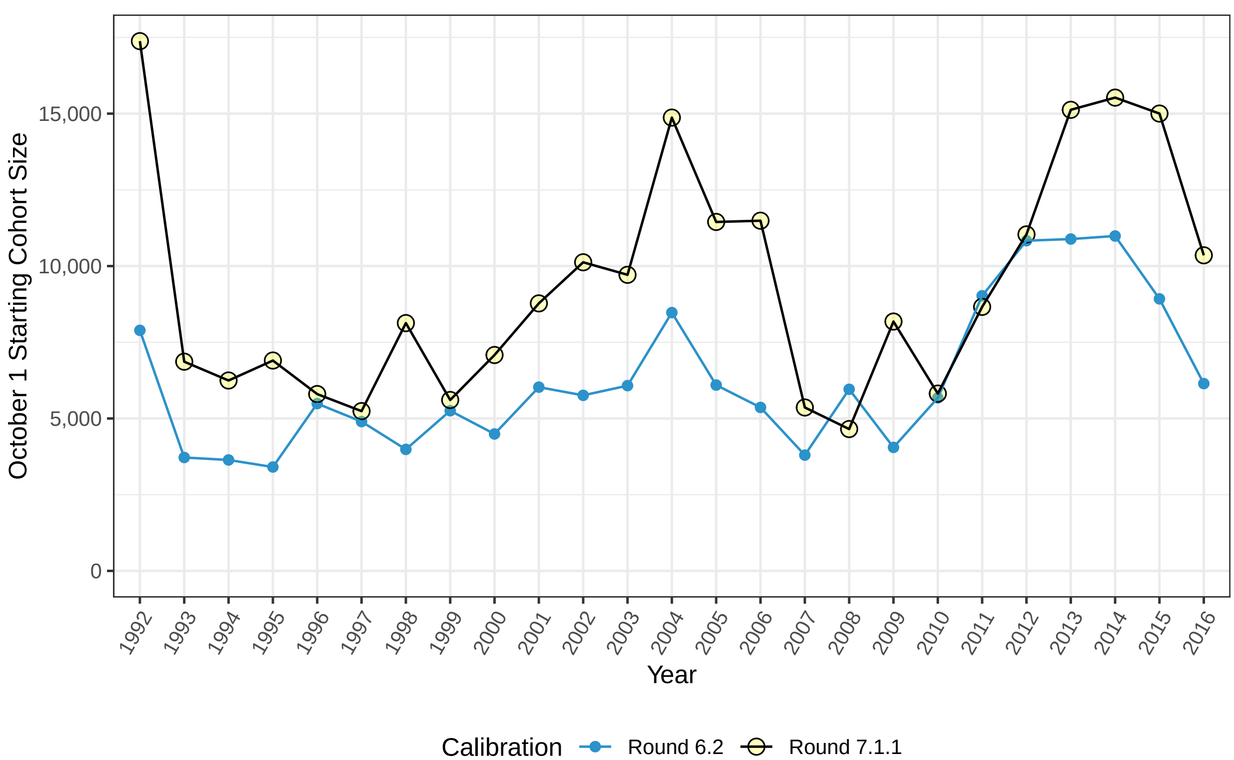


Figure A.18. Col R OR Hatchery Tules

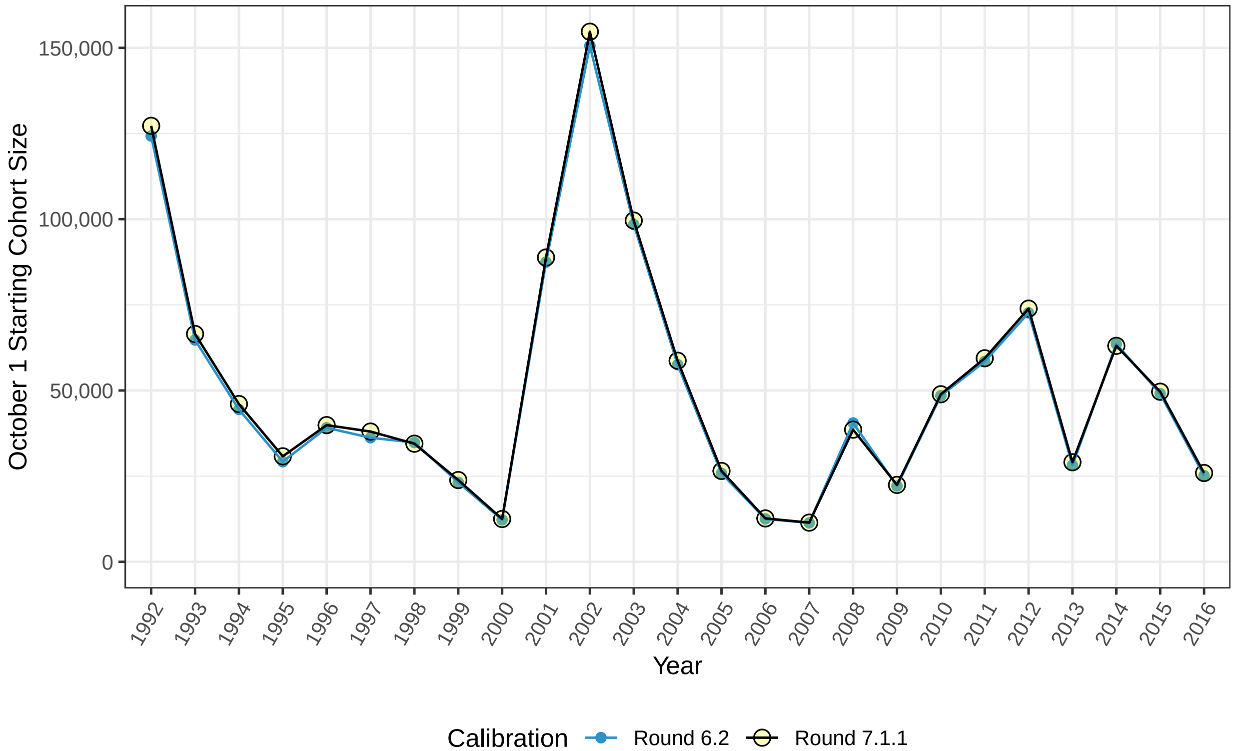


Figure A.19. Col R WA Hatchery Tules

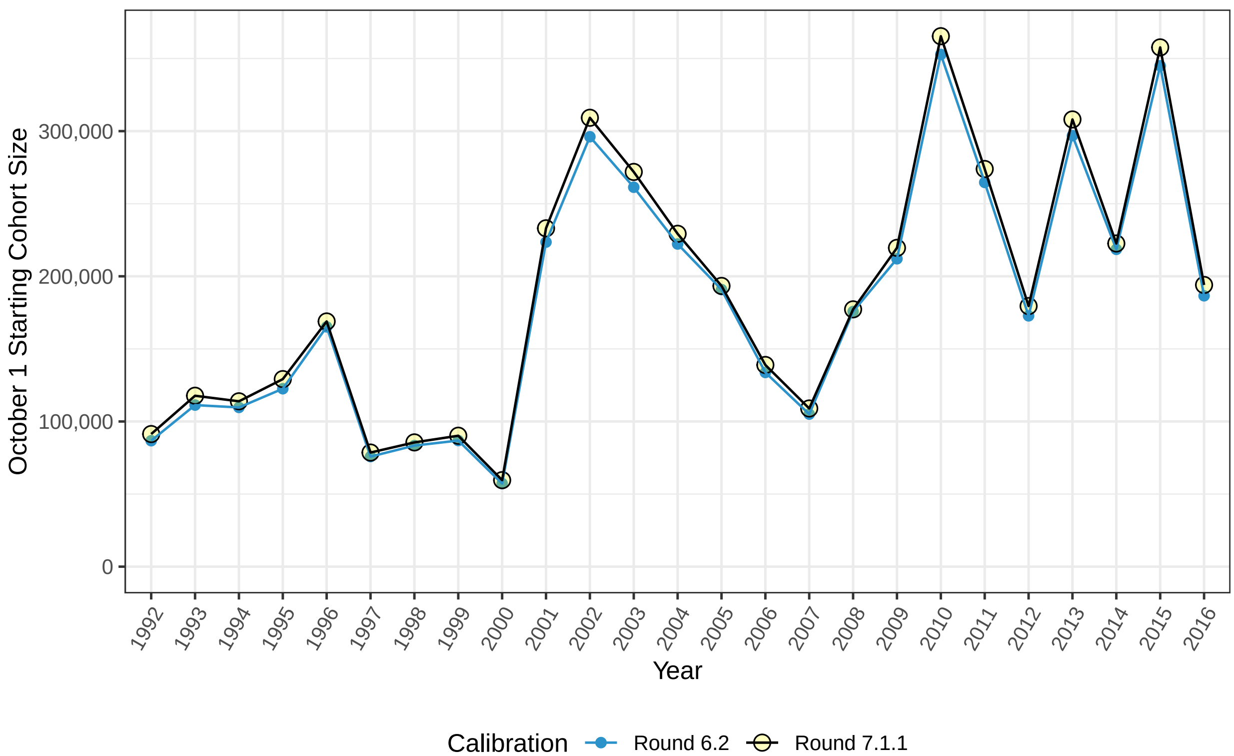


Figure A.20. Lower Columbia River Wild

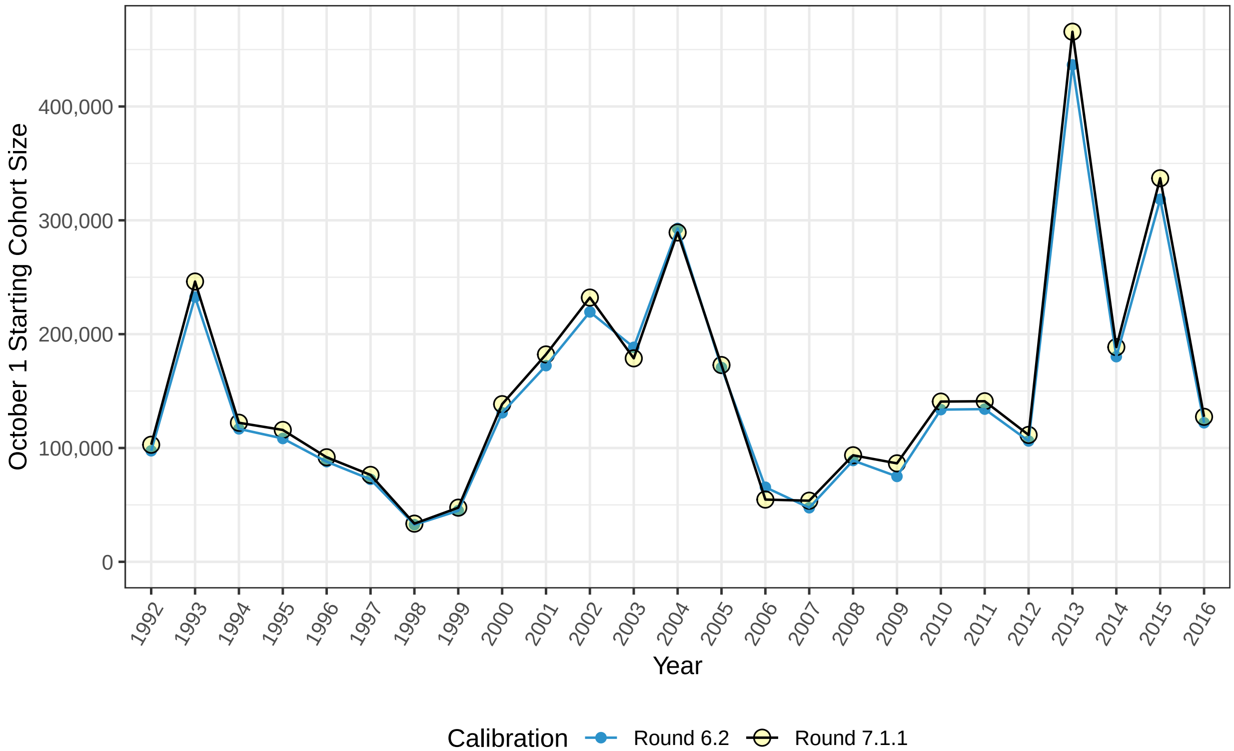


Figure A.21. Col R Bonneville Pool Hatchery

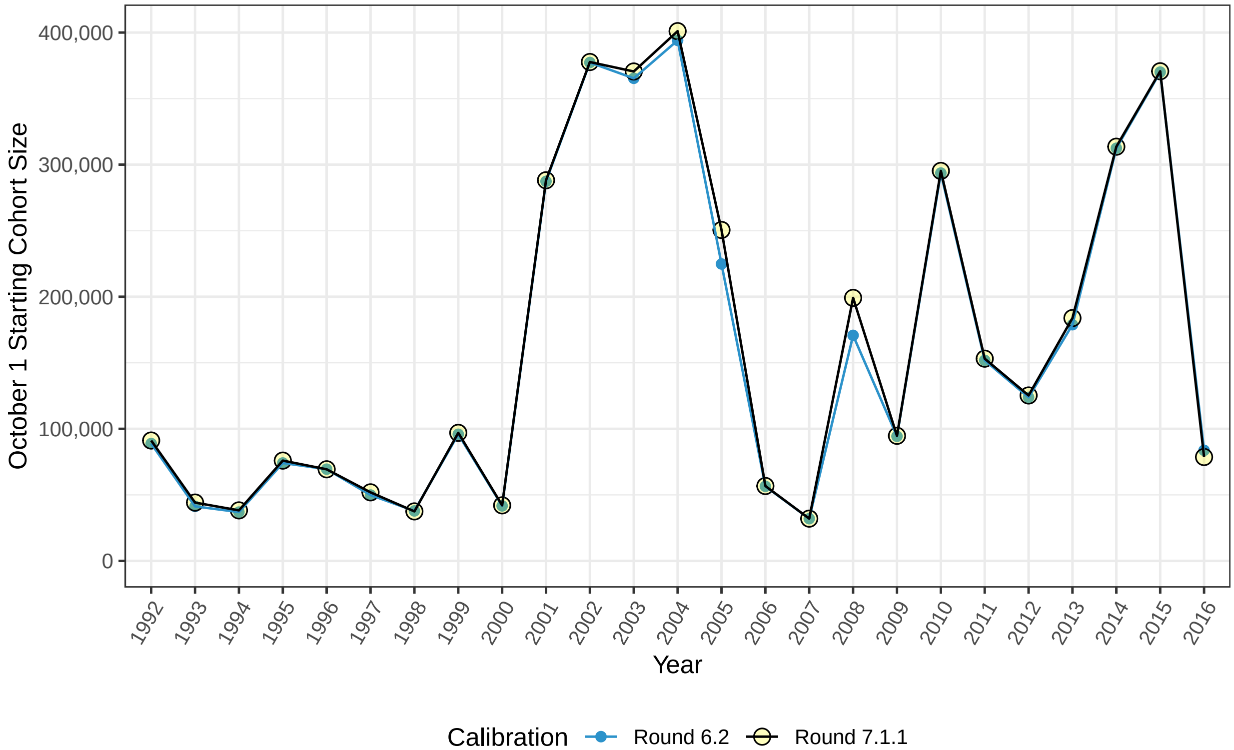


Figure A.22. Col R Upriver Summer

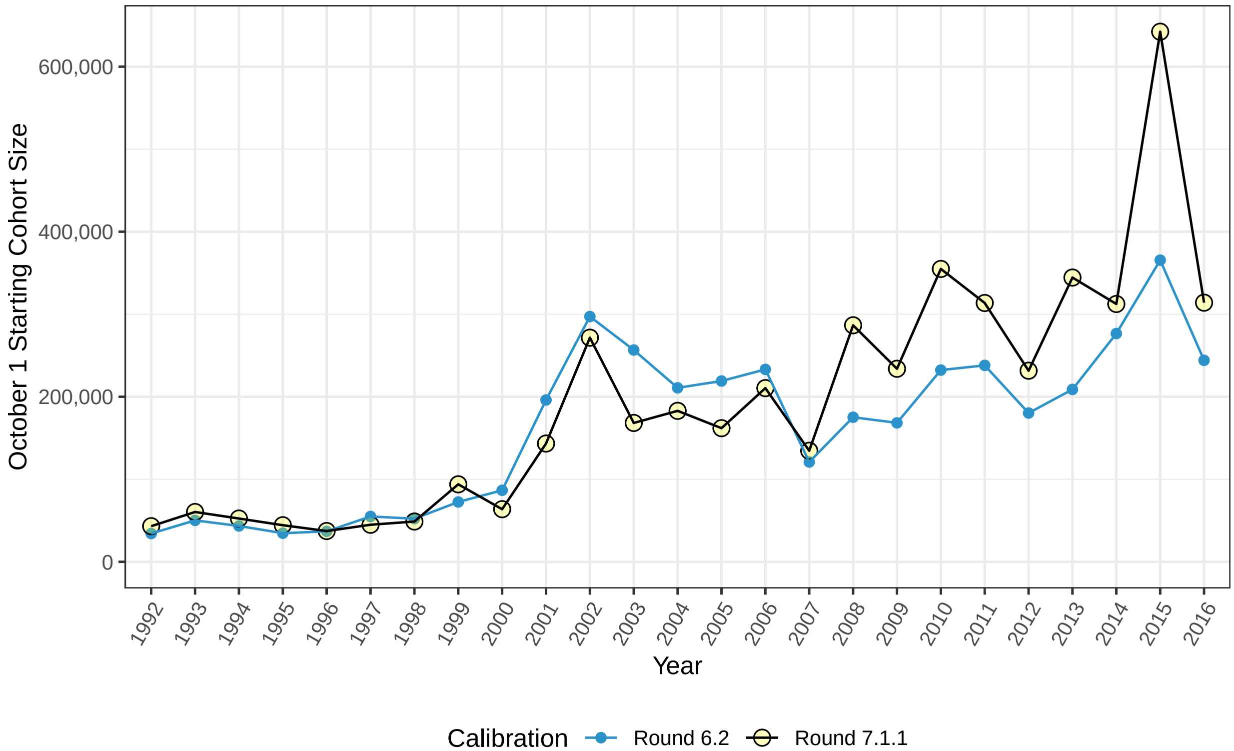


Figure A.23. Col R Upriver Bright

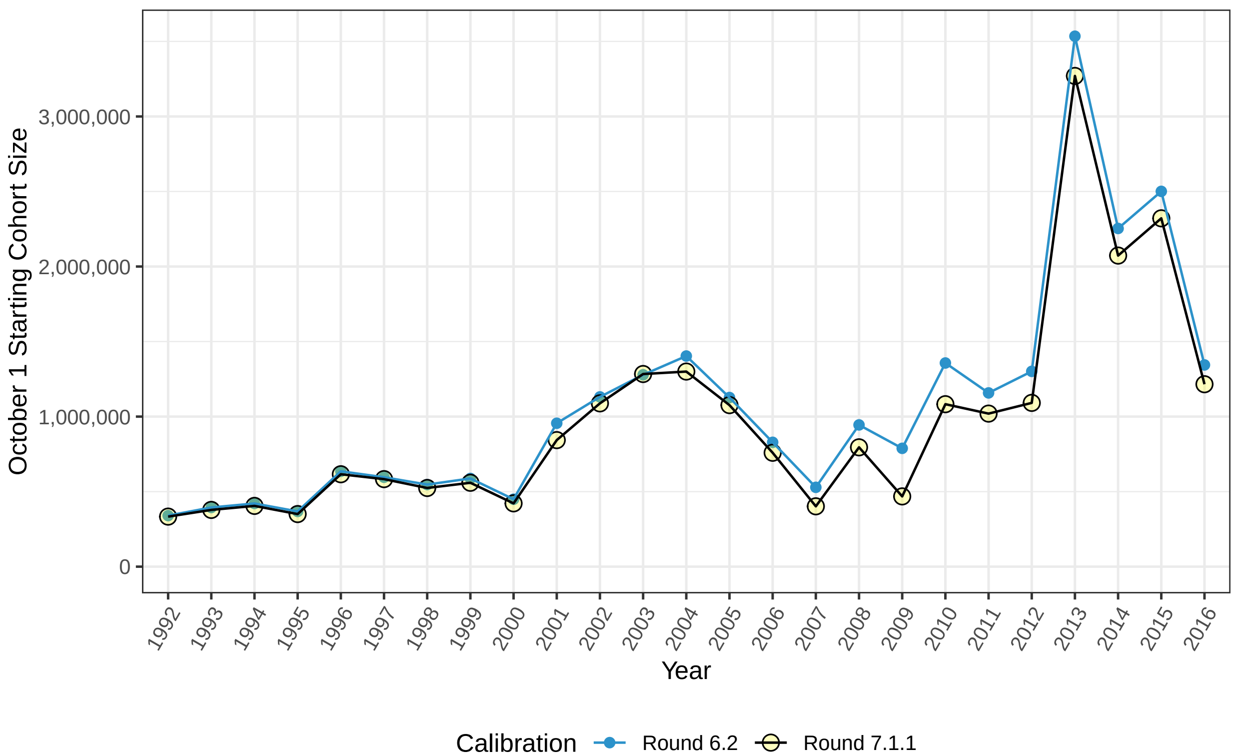


Figure A.24. Cowlitz River Spring

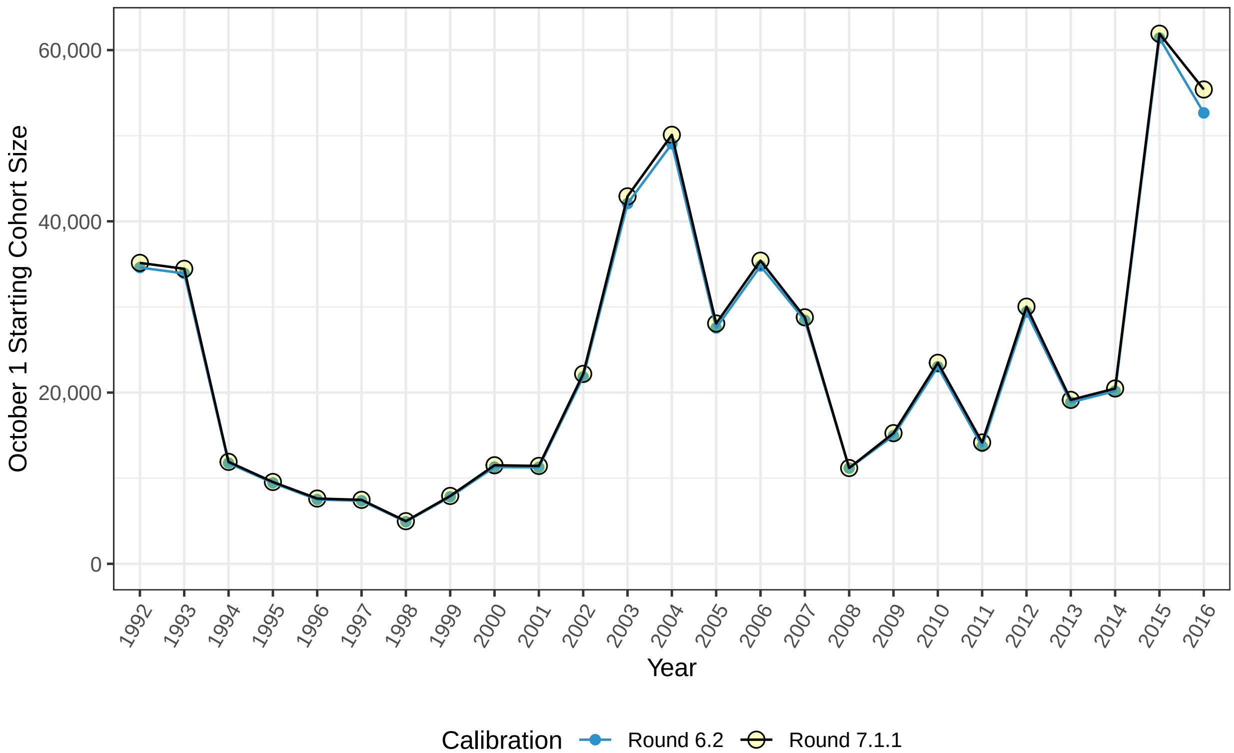


Figure A.25. Willamette River Spring

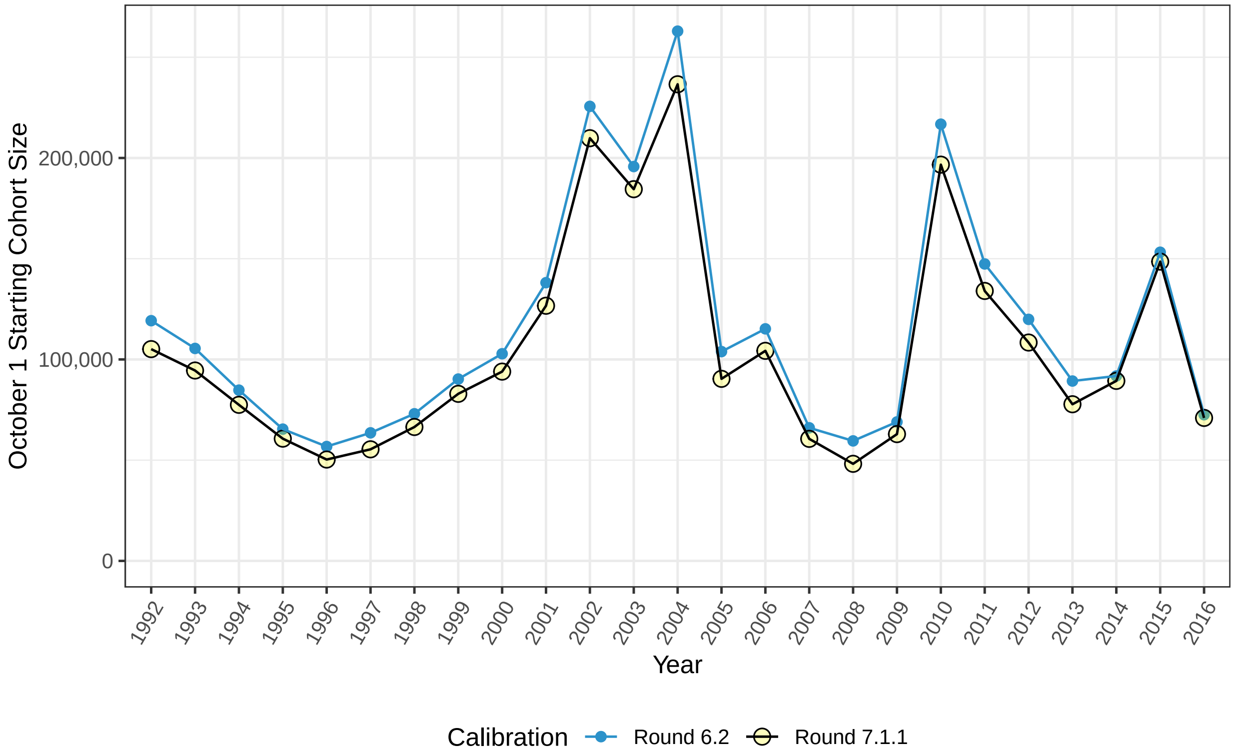


Figure A.26. Snake River Fall

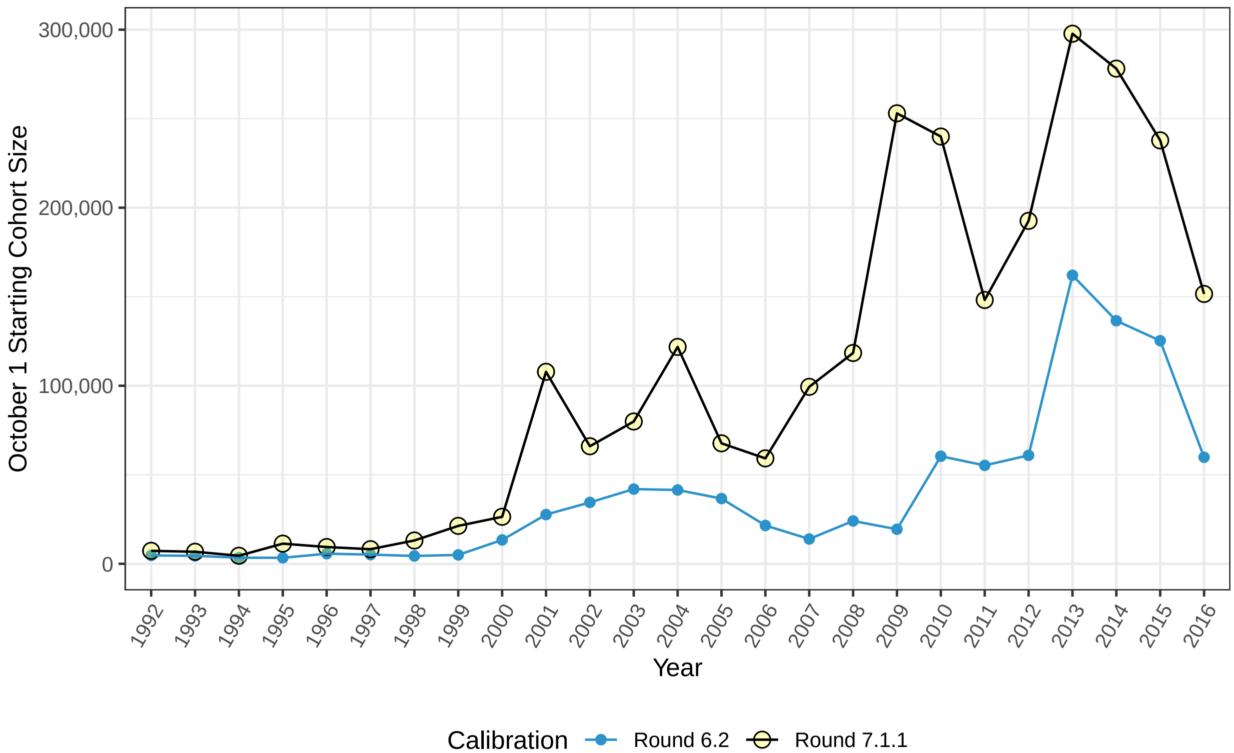


Figure A.27. Oregon North Coast Fall

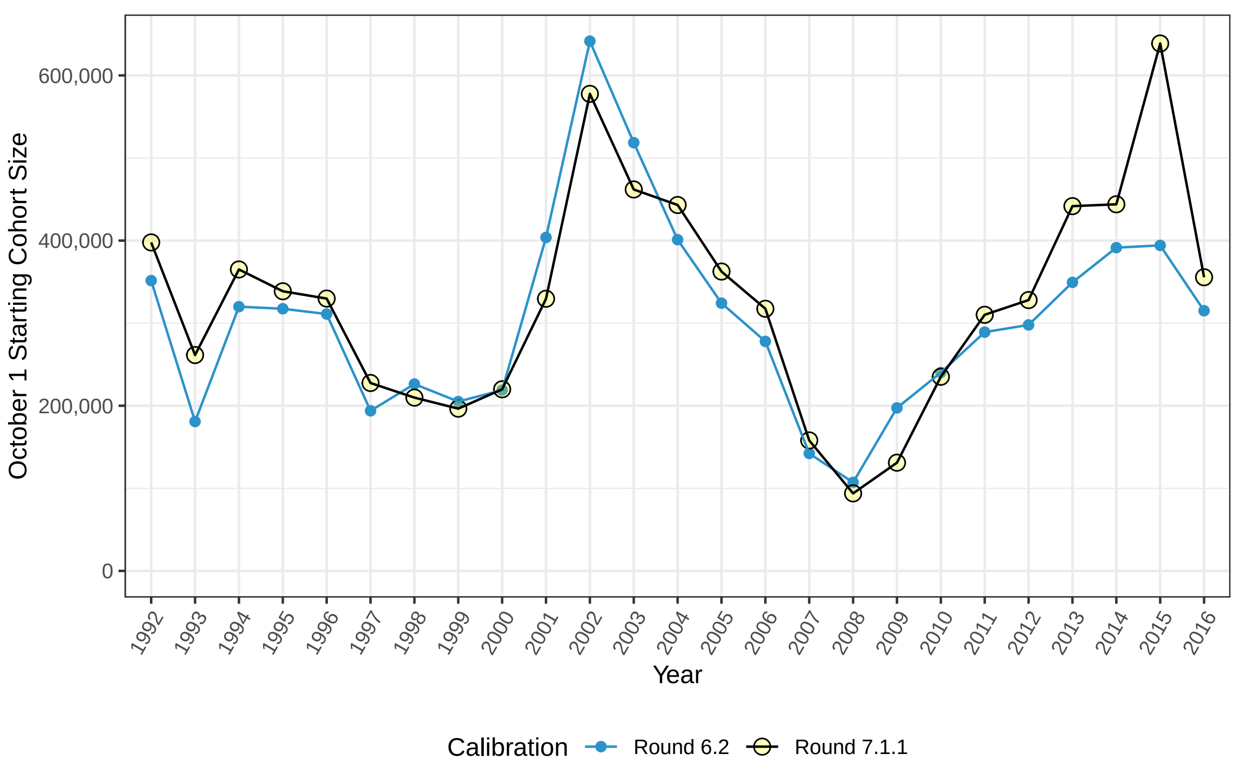


Figure A.28. WCVI Fall

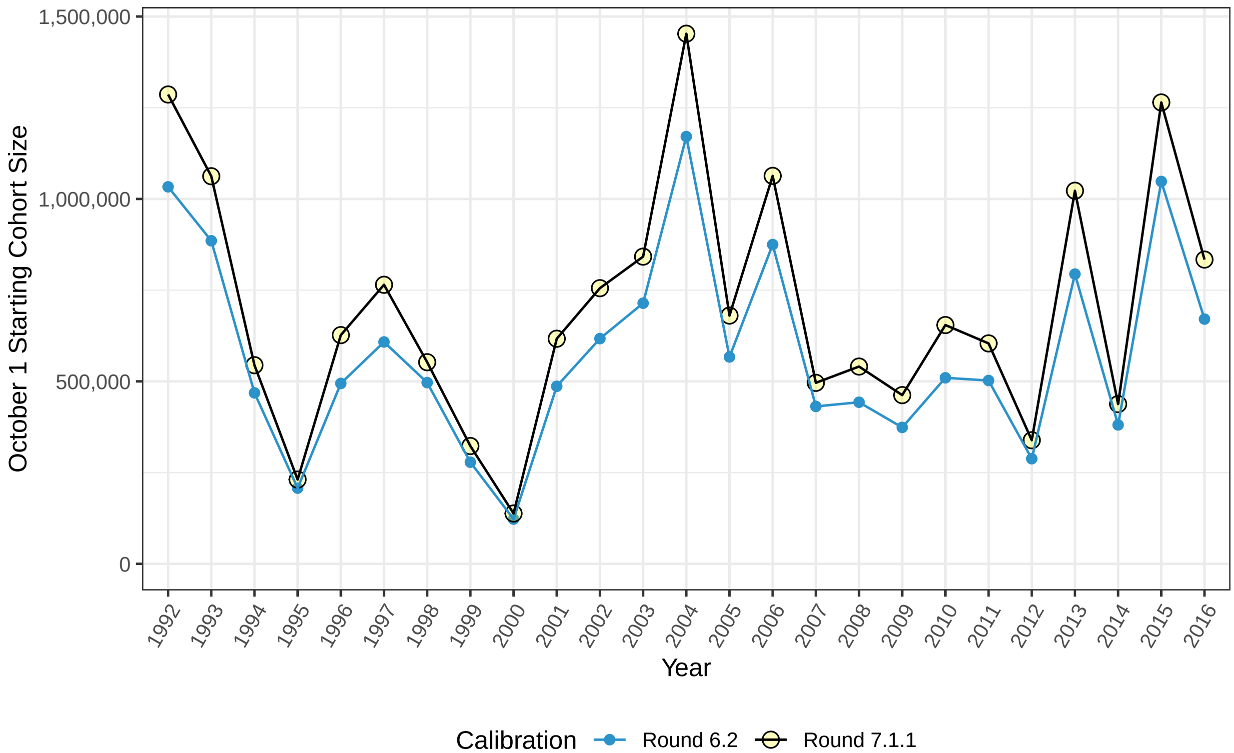


Figure A.29. Fraser River Late

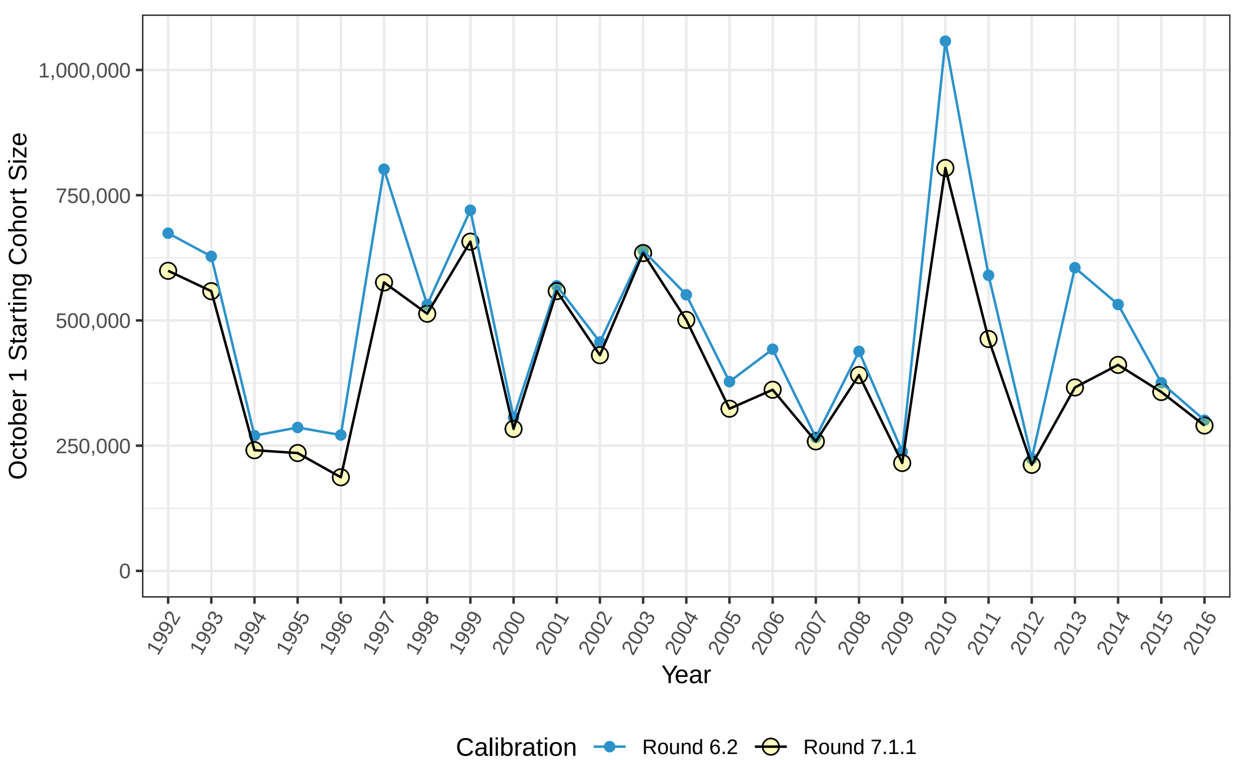


Figure A.30. Fraser River Early

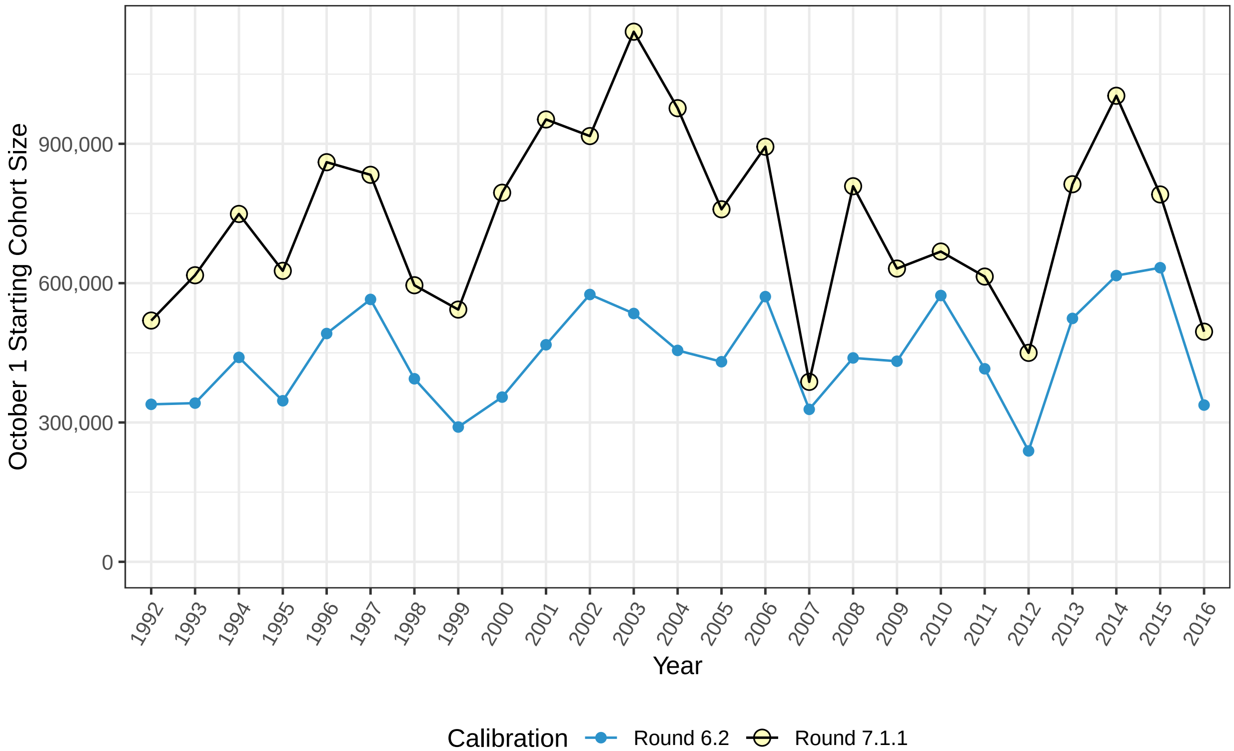


Figure A.31. Lower Georgia Strait

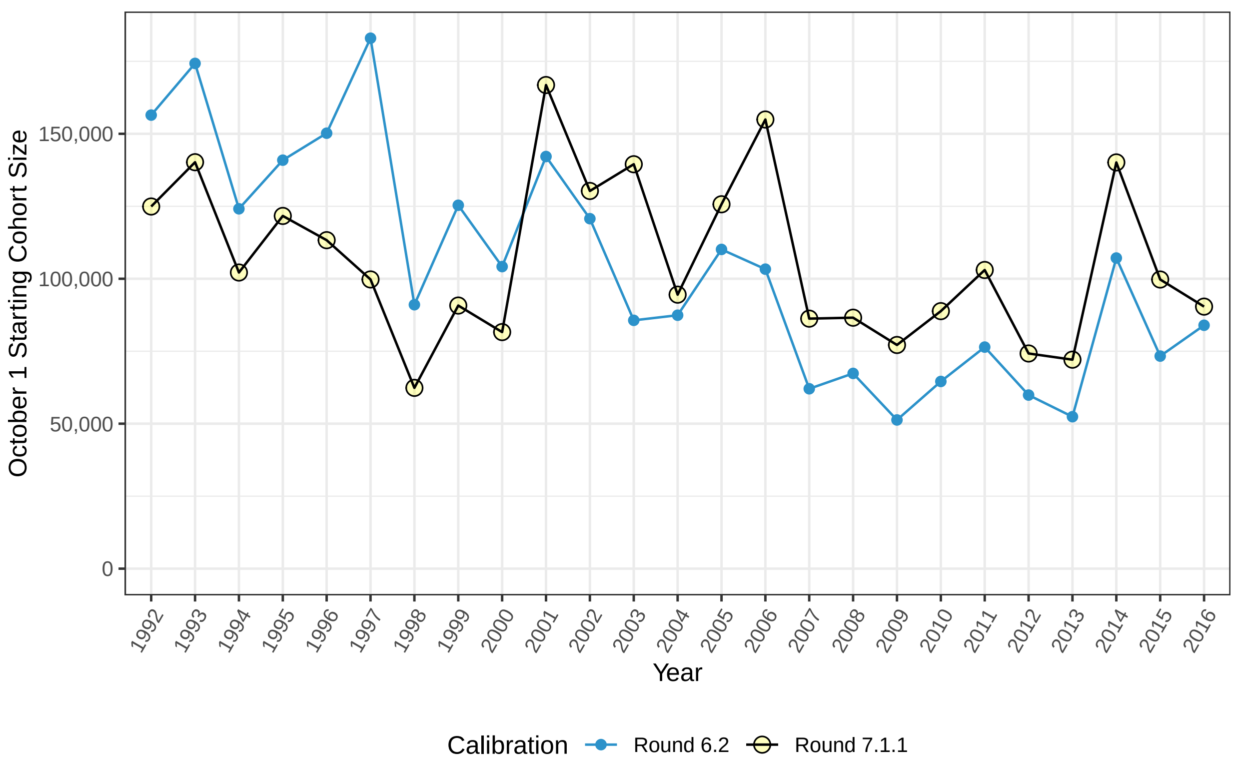


Figure A.32. White River Spring Yearling

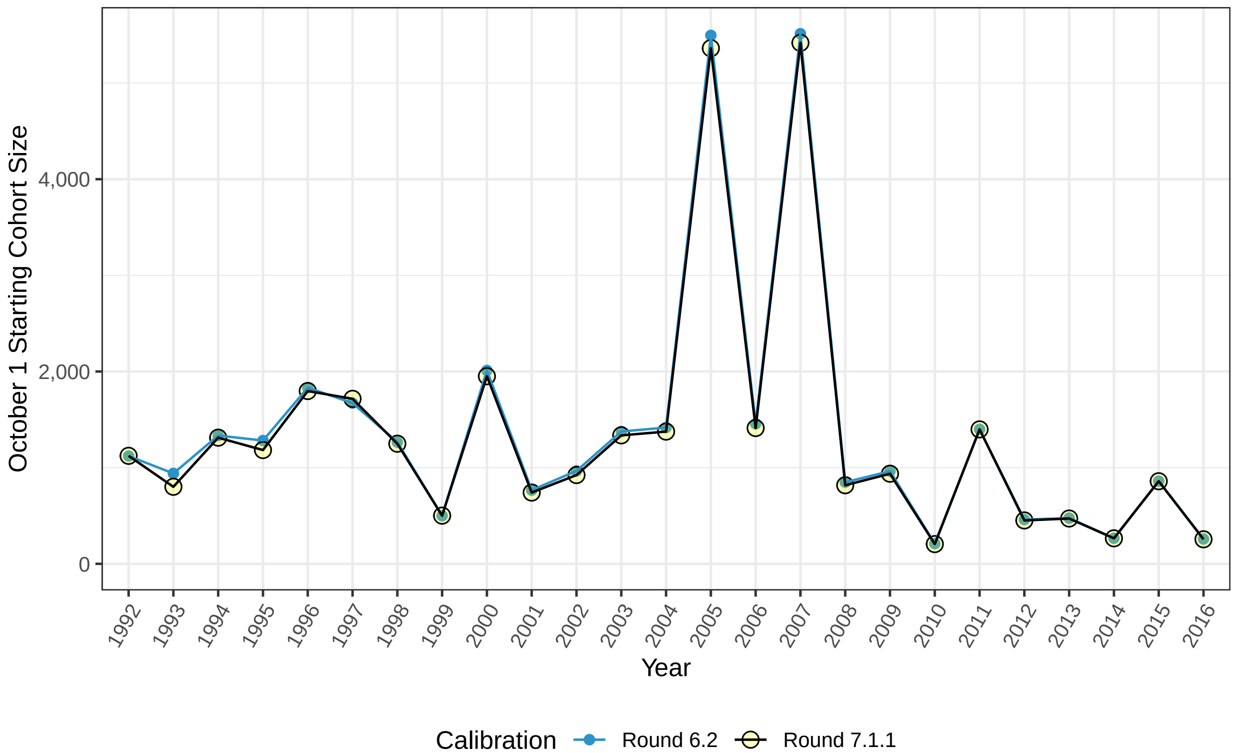


Figure A.33. Lower Columbia Naturals

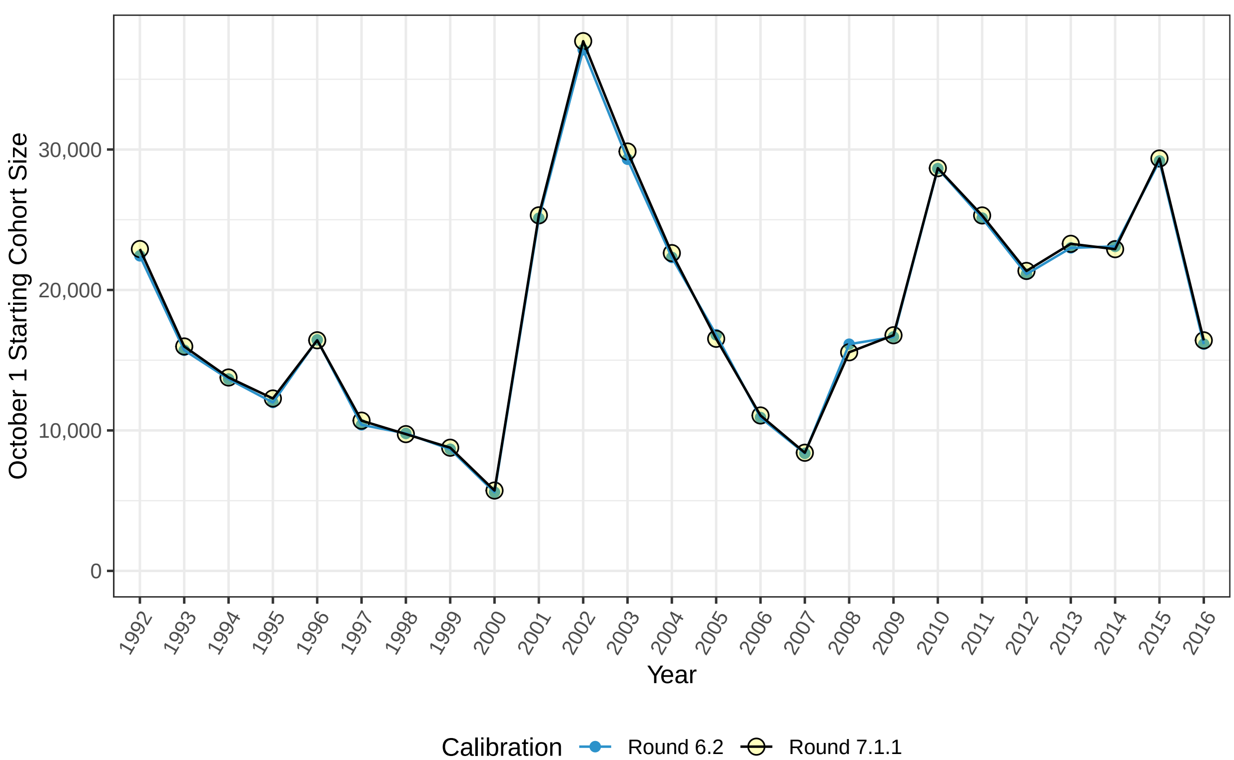


Figure A.34. WA North Coast Fall

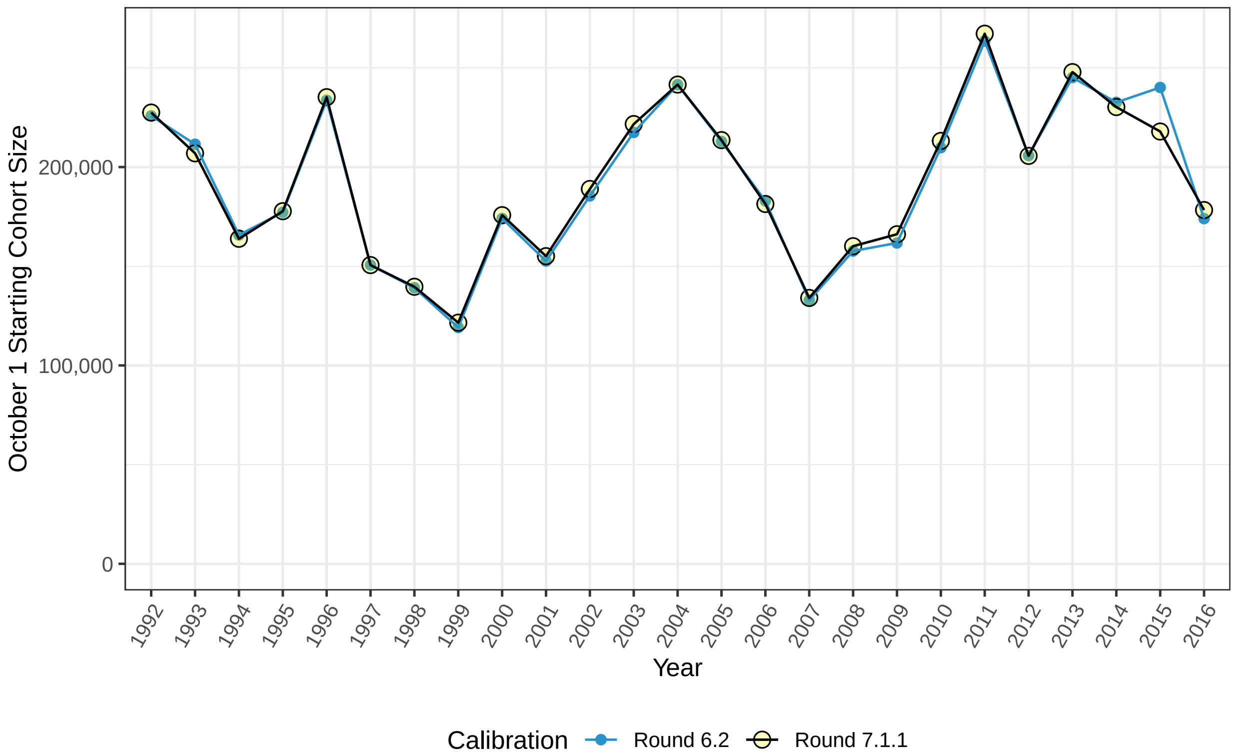


Figure A.35. Willapa Bay Fall

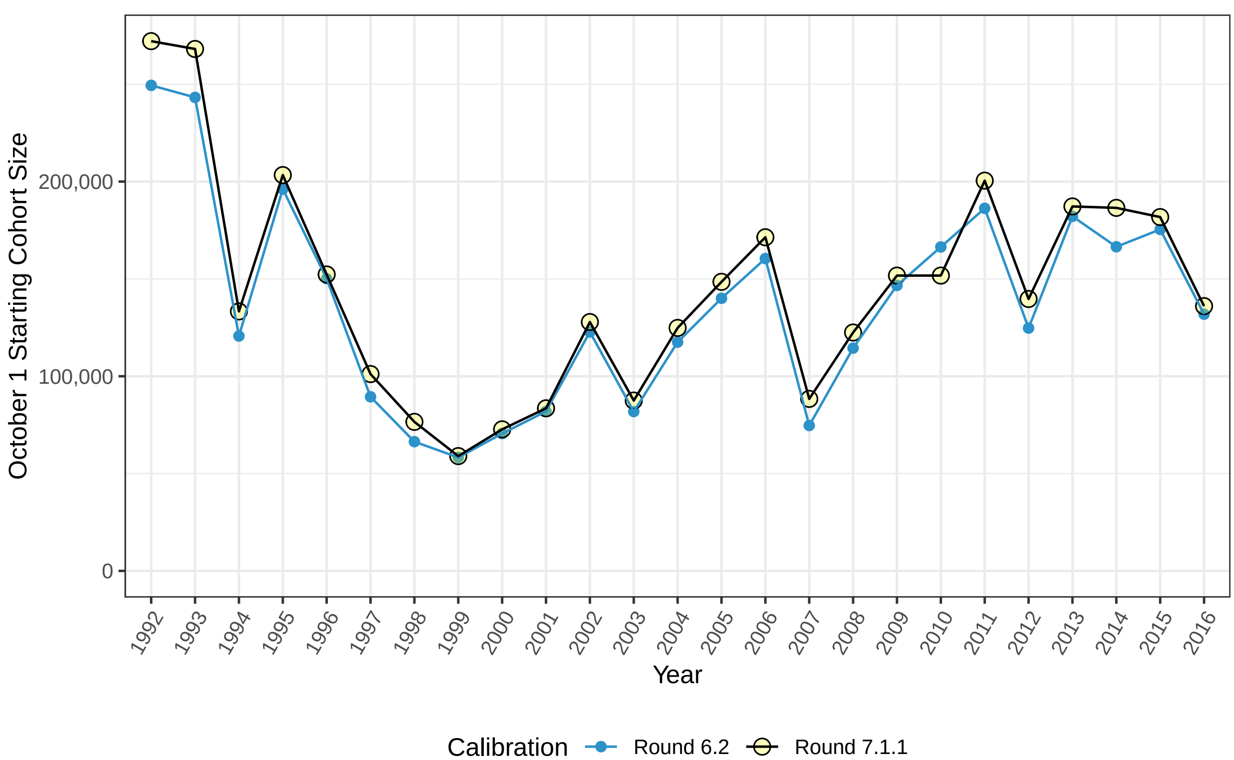


Figure A.36. Hoko River

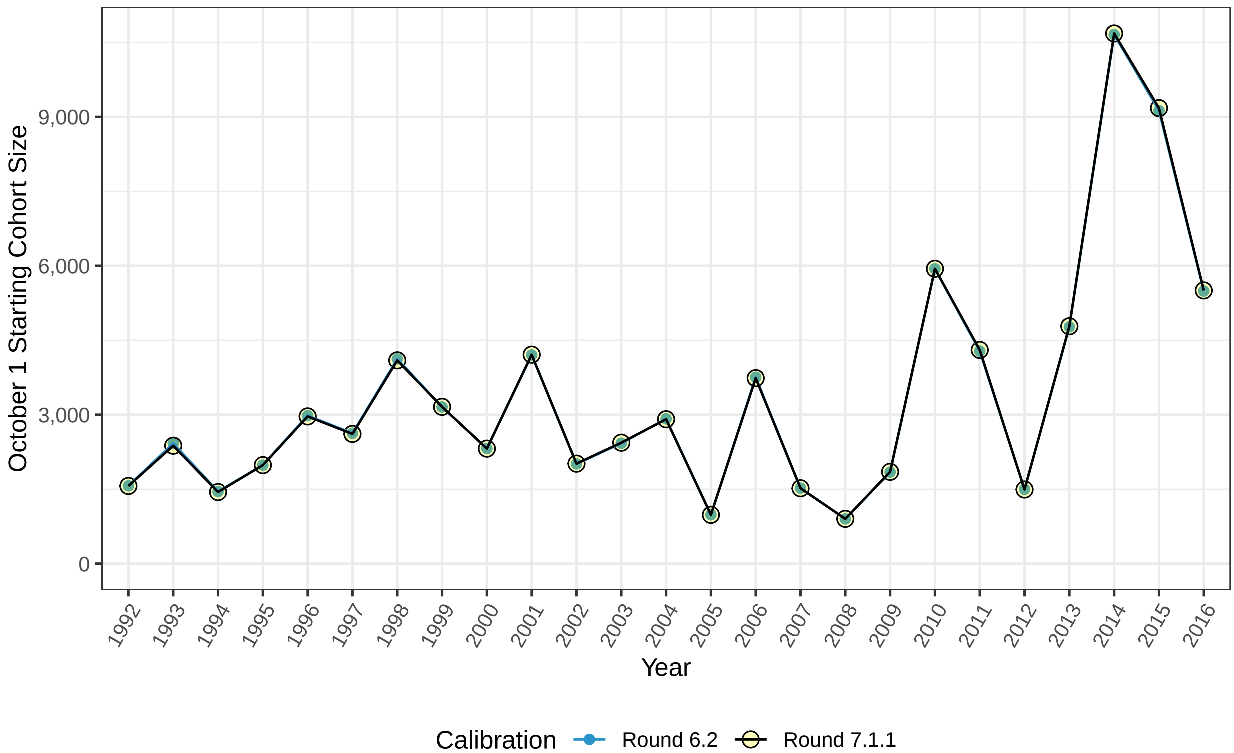
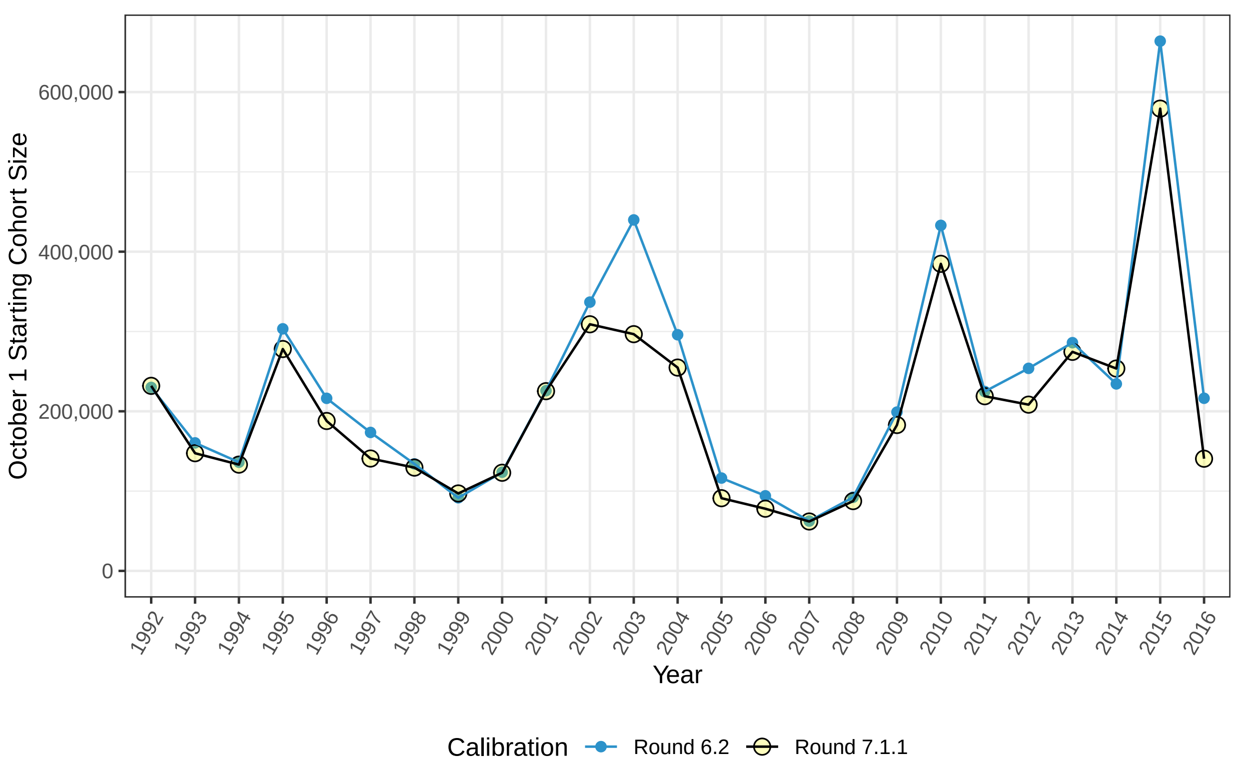


Figure A.37. Mid Oregon Coast Fall



Description of Chinook Salmon Ocean Distribution Models

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Chinook salmon stocks from rivers in California, Oregon, and Washington, live and are captured in mixed-stock ocean fisheries from California to Alaska. Different stocks have distinct spatial distributions in the ocean. This document briefly describes the methodologies and differences between two recently published papers that use code-wire tag (CWT) recoveries to estimate stock-specific ocean distributions of fall-run Chinook salmon (Shelton et al. 2019, 2021). Both papers are relatively long (~ 15 print pages, each with approximately 50 pages of supplementary material). This document is a high-level overview of the data and methodological differences between the papers. Please see the respective documents for detailed technical descriptions of the statistical models. Table 1 provides guidance on where to find key material in each paper.

Both papers use a Bayesian state-space model to describe the abundance and distribution of CWT Chinook salmon released from Chinook salmon stocks since 1978 (release years 1978-1990 in Shelton et al. 2019; 1978-2010 in Shelton et al. 2021). Both models also use the same basic data: recoveries of CWT from multiple ocean fisheries, fishing effort from each fishery (including Chinook size limits and retention rules), sampling effort within each fishery, and CWT recoveries from freshwater fisheries and spawners. These data enable the estimation of the abundance-at-age and ocean distribution (divided into 17 areas between California and southeastern Alaska) of each stock in each of three seasons (winter-spring, summer, and fall). Winter and spring seasons were combined due to a limited fishery and fishery sampling data during the winter in the northeastern Pacific.

While the basic structure and approach of the two papers are the same, Shelton et al. (2021) is a larger and more extensive analysis. It includes a wider set of release years (see previous paragraph) and recovery years (1979-2015 in Shelton et al. 2021 versus 1977-1995 in Shelton et al. 2019). The 2021 paper includes 16 Chinook stocks (2019: 12 stocks), 8,279 individual CWT tag codes representing 353 million Chinook salmon released (2019: 2,196 codes representing 83 million releases), and CWT recovery data from five fishing gear types fleets (commercial troll, treaty troll, recreational, hake at-sea, and hake shoreside). Shelton et al. (2019) did not included information from either hake fleet. Finally, the two papers use slightly different spatial regions. Shelton et al. (2019) used a single area that encompassed both Puget Sound and the Strait of Juan de Fuca while Shelton et al. (2021) split them into two separate regions. For the coast of Oregon, Shelton et al. (2019) used three regions (southern, central, and northern) but Shelton et al. 2021 used only two (southern and northern with the central area being merged into the southern region).

In addition to these data changes, there are two major differences in the statistical models used in the two papers. First, Shelton et al. (2021) derived and used a new likelihood function for connecting the observed data with the parameters of the biological model (see Shelton et al. 2021 Supplement S1 pp. 12-16). This new likelihood improved both the biological interpretability of model parameters and the computational speed of model fitting. Second, Shelton et al. (2021) allowed the ocean distribution of salmon stocks to vary year-to-year as a function of localized sea surface temperature (SST). The model provides an estimate of the long-term average ocean distribution corresponding to the long-term average SST pattern for each season (1981-2015) as well as estimated distributions for each year. Shelton et al. (2019) provided a single estimate of ocean distribution for each stock in each season. In addition to these major changes there are a number of smaller technical changes between the models including such things as the slight modifications to determining which ocean locations are considered close enough for fish in that region immediately prior to the time of spawning to migrate into rivers, and allowing for spatial variability in catchability of the commercial troll fleets (see Supplement S1, Shelton et al. 2021 for a full description).

While the results between the two papers are largely comparable – the estimated distribution for each stock provided by 2019 are quite similar to the average ocean distribution estimated in 2021 – the data and model changes do result in different estimated distributions in some cases. Cases with substantial changes in estimated ocean distribution occurred when stock definitions changed substantively between the two papers. Specifically, Shelton et al. (2019) only modeled three groups of fall-run Chinook salmon in the Columbia basin (lower-, middle-, and upper- Columbia fall runs; codes “LCOL”, “MCOL”, and “UPCOL”, respectively) whereas the 2021 paper separates UPCOL into Snake river fall run stock (code “SNAK”) and upriver Columbia bright fall-run stock (code “URB”) and adds an additional lower Columbia fall run corresponding to the hatchery stock derived from Rogue river brood stock released in the Columbia estuary (code “SAB”). The 2021 paper estimated substantial differences between in the ocean distribution of SNAK and URB stocks with both differing substantially from the single UPCOL distribution estimated in Shelton et al. 2019 (see Fig. 2 in Shelton et al. 2021 and Fig. 3 in Shelton et al. 2019). Note that the Columbia upriver bright stock and Snake fall stock are considered a single stock in other management models (e.g. the Pacific Salmon Commission’s Chinook Technical Committee model; CTC 2022).

The two additional stocks added in 2021 were also derived from a single stock used in 2019. The Puget Sound stock in 2019 (PUSO) was divided into Puget Sound, north (PUSO_N) and Puget Sound, south (PUSO_N) groups in 2021. Similarly, the Strait of Georgia (SGEO) stock from 2019 was divided into a Strait of Georgia, north (SGEO_N) and Strait of Georgia, south (SGEO_S) groups for 2021. These divisions were made based on input from regional experts during model development and do result in moderate changes to ocean distribution estimates for each stock (Supplement S5; Fig. 55.13 in Shelton et al. 2021).

Table 1: A road map for finding relevant information in Shelton et al. 2019 and Shelton et al. 2021.

Information	Shelton et al. 2019	Shelton et al. 2021
Spatial regions used in analysis	Figure 1	Figure 1
Stocks considered and description of associated CWT releases	Supplement S1 Table S1.1	Supplement S2, Table S2.1
Summary of CWT releases from each stock	Not in published manuscript	Supplement S2, Table S2.3
Complete list of CWT release groups used in analysis	Supplement S1, Table S1.6	Supplement S2, Table S2.4
Full model description	Supplement S2	Supplement S1
Estimation procedures and diagnostics of model fit	Main text (pg. 101)	Main text (Sections 2.1 and 3.2) and Supplement S5 (pgs. 4-10)
Examples of CWT recovery data used in model estimation for select stocks in select brood years	Figure 2	Supplement S5, Figures S5.1, S5.2, S5.3
Summary of average ocean distribution for six focal stocks and year-to-year variation	N/A	Figure 2, Figure 3
Summaries of ocean distributions for all stocks	Figure 3	Figure S5.13 (summer season only)

Citations

CTC (Chinook Technical Committee) (2022) 2021 PSC Chinook Model Calibration. Pacific Salmon Commission Joint Chinook Technical Committee Report TCCHINOOK(2022)–02, Vancouver, BC. https://www.psc.org/download/35/chinook-technical-committee/14338/tcchinook-22-02.pdf

Shelton, A. O., Satterthwaite, W. H., Ward, E. J., Feist, B. E., & Burke, B. (2019). Using hierarchical models to estimate stock-specific and seasonal variation in ocean distribution, survivorship, and aggregate abundance of fall run Chinook salmon. Canadian Journal of Fisheries and Aquatic Sciences, 76, 95–108. https://doi.org/10.1139/cjfas -2017-0204

Shelton, A.O., Sullaway, G.H., Ward, E.J., Feist, B.E., Somers, K.A., Tuttle, V.J., Watson, J.T., Satterthwaite, W.H. (2021) Redistribution of salmon populations in the northeast Pacific Ocean in response to climate. Fish and Fisheries. 22:503–517. https://doi.org/10.1111/faf.12530

Use of Mean Versus Median in Converting Sacramento Index Forecast from Logarithmic to Arithmetic Scale

Prepared for Pacific Fishery Management Council's Salmon Methodology Review
October 12-13,2022

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Background

Ocean abundance (or potential escapement in the absence of fishing, assuming no adult natural mortality and 100% adult maturation rate) of adult Sacramento River Fall Chinook (SRFC) salmon is characterized using the Sacramento Index (SI, O'Farrell et al. 2013) derived as the sum of estimates of adult (age-3 and older) escapement, ocean harvest, river harvest, and impacts of certain non-retention fisheries.

Since 2014, the SI has been forecasted as a function of estimated jack escapement the previous year using a log-log regression with an autocorrelated error term fitted to the relationship between estimated jack escapements and subsequent SI estimates for previous pairs of years (PFMC 2022, p. 13; discussed in more detail in Appendix E of PFMC 2014). Although a different forecasting method was used for management purposes in 2013 and earlier, sufficient records of jack escapement and SI estimates exist to retrospectively apply the current approach as far back as 1995 using inputs that would have been available at the time[1] (Winship et al. 2015, their Model 8). R code to produce the forecast is appended as Supplement S1, with the input file provided in Supplement S2.

The formulation of the SI forecast (notation here is chosen to match PFMC 2022) implicitly assumes that prior years' jack escapements and SI values are observed without error, and that the natural logarithm (hereafter the qualifier "natural" is dropped from all references to log[arithm]s) of the true value of the current year's SI (*logSI*) is a random variable following a normal distribution with log-scale mean $logSI_t$ and innovation variance σ^2. The log-scale mean $logSI_t$ is the sum of an intercept term (β_0), a slope term (β_1) times the estimated jack escapement the previous year (J_{t-1}), and the estimated autocorrelation of past deviations from the fitted line (ρ) times the deviation of the previous year's postseason SI estimate from the fitted line prediction (ϵ_{t-1}):

$$logSI_t = \beta_0 + \beta_1 logJ_{t-1} + \rho\varepsilon_{t-1}$$

Table 1 shows the parameter estimates from annual Preseason Report 1 documents corresponding to each forecast for management years 2014-2022.

[1] In retrospective evaluations presented later in this document, for forecast years prior to 2014, the current forecast approach was applied using inputs from years up to a certain date; but the inputs used reflected the current estimates of record for those years and may not exactly match the estimates available at the time due to subsequent revisions. The effects of these revisions are expected to be minor. For 2014-2022 I used the forecasts of record for the mean-based forecast, and calculated median-based forecasts using the parameter estimates reported in the Preseason Report 1 accompanying each forecast of record, fixing one transcription error in the 2020 intercept estimate.

On the logarithmic scale, the mean (probability-weighted expected value), median (midpoint of the distribution, i.e. expected to be above 50% of values and below 50% of values), and mode (most likely value) for *logSI* are all equal.

However, management is based on fish counted on the arithmetic scale, requiring a conversion of the SI forecast to the arithmetic scale, resulting in a lognormal distribution (Figure 1). The mean, median, and mode of a lognormal distribution are not equal on the arithmetic scale. Rather, if all assumptions are met, *SI* for the current year will follow a lognormal distribution with arithmetic-scale median equal to exp($logSI_t$) and arithmetic-scale mean equal to exp($logSI_t$+0.5σ^2). Table 1 reports the forecasts resulting from use of the mean or median each year 2014-2022, along with postseason SI estimates for comparison when available. Figure 2 provides a visual comparison of mean- and median-based forecasts for 2014-2021 (2022 is not shown since a postseason abundance estimate was not available at the time of writing).

Current practice is to set the forecast used to inform management equal to the arithmetic-scale mean. During the SSC's review of preseason forecasts in March of 2022, questions were raised as to whether the median might be more appropriate as a risk-neutral point estimate (there were no proposals to consider the mode, nor other quantiles of the distribution).

Theoretical considerations

Differences between the true[2] and forecasted SI on the log scale represent proportional errors. If all model assumptions are met, using the log-scale mean (which is equivalent to the log-scale median and mode[3]) represents using the expected value on the log scale. Thus, using the arithmetic-scale median as the point estimate for the forecast would result in expected proportional error of zero (i.e., the sum across all possible logged ratios, weighted by their respective probability, would be zero; corresponding to a ratio between forecasts and true values of 1.0 on the arithmetic scale), and would be expected to be equally likely to be an over-forecast or an under-forecast (since it is the median). These characteristics may be desirable and/or qualify as "risk-neutral", however strictly speaking a "risk-neutral" approach might need to integrate across the consequences of varying amounts of forecast errors in different directions at different abundances weighted by their respective probabilities; somehow quantifying both conservation harm and lost fishing opportunity using a common currency.

The arithmetic-scale expectation (i.e., the arithmetic-scale mean) for SI_t is not equal to the median (nor mode), rather it is greater than the median. Therefore, using the arithmetic-scale median would lead to an expected (probability-weighted sum across all possible errors in numbers of fish) error of too few fish in the forecast of potential adult escapement in the absence of fishing, in contrast with an expected error of zero fish if using the mean. If it is assumed that the consequences of forecast error scale linearly with the error in numbers of fish, regardless of true abundance or proportional error, this would not be risk-neutral.

The true consequences of forecast error are likely a very complicated function of the magnitude and direction of forecast error along with the true abundance. For example, some

[2] And current practice is to assume that the postseason SI estimate represents the true SI.

[3] Note however that the arithmetic-sale mode of a lognormal does not match either the median or mean.

parts of the control rule allow the same expected exploitation rate across a range of forecasted abundances (PFMC 2022, p. 113), and errors at high abundance may not affect the exploitation rate achievable in practice due to mixed-stock constraints and/or the constraint that expected exploitation rates may never be higher than F_{ABC} regardless of abundance. Conversely, errors at low abundance are more likely to affect the achievable exploitation rate, potentially leading to conservation harm in the case of over-forecasts or unwarranted fishery constraints in the case of under-forecasts. This suggests that proportional error may be more important than error in the number of fish, and might favor the median as closer to risk-neutral than the mean.

Further, note that several assumptions implicit in the SI forecast model are not expected to be met. Jack escapement is not estimated without error, nor are the components of the postseason SI estimate, and the SI does not fully reflect ocean abundance nor potential escapement in the absence of fishing due to factors it neglects (e.g., non-landed fishing mortality is mostly not accounted for, nor is natural mortality nor the fact that some fish harvested in the ocean might not have matured that year; and adults consist of multiple age classes). The relationship between jacks and adults may not be stationary nor linear on the log scale, and errors may not be lognormally distributed with a simple lag-1 autocorrelation structure. Thus, the SI forecast is inherently uncertain and may be intrinsically biased, which may be exacerbated or ameliorated by different choices with respect to use of the arithmetic-scale mean or median (or other quantiles – see Satterthwaite and Shelton [2023], but that is beyond the scope of this document).

Retrospective evaluation of forecast error

To explore the consequences of using the mean versus median on forecast error, I calculated the forecast that would have been obtained using either the mean or median when applying the SI forecast method to estimates of jack escapement and postseason SI estimates from 1983 (adult return year, uses jack returns from 1982) through the start of each management year 1995-2021, and compared these to the postseason estimates of the SI for each year. I then calculated several commonly-used metrics of forecast performance including the mean error (ME), mean absolute error (MAE), mean percent error (MPE), mean absolute percent error (MAPE), and root mean squared error (RMSE) as described in Winship et al. (2015). Following the sign convention used in Winship et al. (2015) based on postseason estimates minus forecasts, positive values of ME and MPE indicate under-forecasting (forecasts less than observed) and negative values indicate over-forecasting. For the other metrics the sign is always positive and does not reveal the direction of bias. Note that using the sign convention defined here, annual percent error (PE) associated with under-forecasting can never be more than +100%, but annual PE values can (and in some cases did) take on values less than -100%. As a result, MPE may be disproportionately sensitive to instances of over-forecasting.

Therefore, I also fit a lognormal distribution to the ratio between annual postseason estimates versus preseason forecasts and calculated the approximate 95% confidence interval on the log-scale mean of these ratios using the normal approximation, then exponentiated the log-scale mean and confidence interval bounds to estimate *C*, the median of a lognormal distribution describing the postseason:preseason ratio, and its approximate 95% confidence interval. Values of *C* greater than 1.0 indicate under-forecasting and values less than 1.0

indicate over-forecasting. Because proportional errors are symmetric on the log scale, this metric is equally sensitive to proportional over- versus under-forecasting.

Table 2 compares performance of the mean- versus median-based forecast for 1995-2021 as evaluated by each of these metrics. The median-based forecast scores slightly better by all metrics evaluated. Both approaches, but especially the mean-based approach, appear to be biased toward proportional overforecasting (negative MPE and *C*<1.0). The approximate 95% confidence interval on *C* does not exclude 1.0 (i.e., unbiased performance) in either case, although statistical power to confidently identify bias is limited due to the limited number of years and substantial inter-annual variation in forecast performance (Satterthwaite and Shelton 2023).

Note that the analysis presented here assumes stationary forecast performance over the entire time series.

Retrospective evaluation of management consequences

Given the complicated nature of the consequences of forecast error, I performed a retrospective analysis of the expected consequences of using the median in place of the mean for forecasts in 2014-2021, comparing the expected outcome from a forecast based on the median to the outcome observed historically. This analysis began with adult return year 2014 because that is when the current forecast method was first applied for use in management, and comparisons to realized management outcomes in earlier years based on a different forecast method would not be appropriate. This analysis attempted to account for not just the differences in forecast values and resultant application of the control rule, but also 1) any supplemental Council guidance (i.e. in some years the Council issued guidance to target an expected escapement higher than the minimum that the control rule would allow[4]), 2) mixed-stock constraints (i.e. in some years the exploitation rate expected at the end of the preseason planning process was less than would have been allowed based on the control rule and guidance, presumably because it was impossible to design an acceptable season with higher expected exploitation rates that still met constraints imposed by other stocks and allocation considerations), and 3) proportional implementation error (i.e. mismatch between exploitation rates predicted under the regulations ultimately adopted and the postseason estimates of exploitation rates actually achieved).

To implement this approach, for each year of record I first determined what the median-based forecast would have been and the exploitation rate allowed under the control rule applied to that alternative forecast value. If the Council issued supplemental guidance to target a higher escapement that year, I adjusted the allowable exploitation rate downward if required to meet that escapement goal given the median forecast. I then compared the allowable exploitation rate to the exploitation rate expected at the end of the preseason planning process that year. If the expected exploitation rate at the end of the preseason planning process was lower than my projection of the allowable exploitation rate, I assumed that mixed stock

[4] Specifically, the Council issued guidance to target escapement of at least 151,000 in 2018 and 160,000 in 2019. Higher escapement was also targeted in 2022, but no postseason estimates for 2022 were available at the time this document was written, so fishery performance in 2022 was not modeled.

constraints would lead to the same planned exploitation rate and assumed that the resulting exploitation rate, harvest, and escapement for that year would be the same as the estimates of record. However, if the allowable exploitation rate corresponding to the median forecast was lower than the exploitation rate expected at the end of the preseason planning process, I assumed that the median forecast would have led to a lower planned exploitation rate, and thus less harvest and more escapement, than was observed. I assumed that the proportional error in exploitation rate would have been the same as the error of record – i.e. I assumed the alternative exploitation rate would have been equal to the allowable exploitation rate times the historical ratio between the postseason estimate of exploitation rate and the expected exploitation rate at the end of the preseason planning process. I then calculated the harvest and escapement expected given this adjusted exploitation rate applied to the postseason SI estimate of record. Individual steps in this process are described in more detail and in equation form in Satterthwaite and Shelton (2023).

I then tracked how the postseason estimates of record versus the potentially adjusted outcomes compared in mean harvest of SRFC, mean escapement, frequency of escapement below S_{MSY} or MSST, and whether the running three-year geometric mean escapements in the different scenarios would have led to different outcomes in terms of the overfishing determination based on 2015-2017 escapement, the speed of achieving not overfished/rebuilding status, and the speed of achieving rebuilt status (as defined in PFMC 2021). I also compared mean harvest to the mean harvest that would have occurred if the exploitation rates allowed by the control rule applied to the postseason SI estimate had been achieved without error (i.e., modeling a hypothetical management scenario where there is no forecast error, no implementation error, and no mixed-stock constraints) and if the exploitation rates expected at the end of the preseason planning process had been achieved without error (i.e., modeling a hypothetical management scenario without implementation error, but using the forecasts of record and accounting for mixed-stock constraints and supplemental guidance to target increased escapement). These calculations were performed in the "ManagementConsequences.xlsx" spreadsheet available at https://dx.doi.org/10.17632/5zncg9bhkr.1, and the annual results are presented in Table 3.

Note that use of the median-based forecast rather than the mean-based forecast was only predicted to change the harvest achieved in 2018 and 2019. For 2014, 2015, 2020, and 2021 both the median- and mean-based forecasts were high enough to allow $F=F_{ABC}$. For 2016 and 2017, although the control rule outputs differed for the median- versus mean-based forecasts, the F expected at the end of the preseason planning process was lower than the output of either control rule, presumably because of mixed-stock constraints. Note also that for the years included in this analysis, the mean-based forecast was never less than 229,432 and thus the control rule output of allowable F was never less than 47%. The SRFC control rule (PFMC 2022, p. 113) is steeper at lower forecasted abundances, and so differences in management outcomes resulting from changes to forecasts could be larger at forecasted abundances lower than the ones informing this analysis.

Table 4 compares the results expected from using the mean versus median forecast for 2014-2021 as evaluated by each of these metrics. Note that if the median forecast led to a lower targeted exploitation rate and thus higher escapement, this could lead to increased abundance in the future and thus higher harvests and/or escapements in future years, but this is not accounted for here. The effects of neglecting the relationship between escapement and future production may be minor, since SRFC are often considered a hatchery-dominated stock (PFMC 2021, p. 7). However, natural-origin fish contribute a larger proportion to SFRC escapement than seems widely appreciated (e.g., 16%-40% with median 25% for 2010-2019: Kormos et al. 2012, Palmer-Zwhalen and Kormos 2013, 2015, and 2020; Palmer-Zwahlen et al. 2018 and 2019a,b, Letvin et al. 2020 and 2021a,b) and natural-origin contributions to ocean harvest are likely similar to if not slightly higher than natural-origin contributions to escapement (Davison and Satterthwaite 2017[5]). This level of natural production has been achieved with management that generally targets a combined hatchery- and natural-area escapement of 122,000 spawners, however natural production is predicted to increase with natural-area escapements substantially higher than this combined target according to multiple studies with different timeframes and methods (e.g., Reisenbichler 1986, PFMC 2019, Munsch et al. 2020) and across a range of flow regimes (Munsch et al. 2020). In addition, hatcheries may not meet their production goals in years of low escapement, for example Coleman National Fish Hatchery (the largest in the system) met only 41% of its production goal in 2017 due to a combination of low escapement and excessive straying (Austing and Niemela 2018). Thus, this analysis likely over-estimates the fishery costs and under-estimates the conservation benefits of using the median rather than the mean, though by an unknown amount.

Overall, use of the median rather than the mean in converting 2014-2021 forecasts to the arithmetic scale would be predicted to have reduced mean annual harvest by 4,469 SRFC[6] (about 2% of mean annual harvest), increased mean escapement by the same[7] 4,469 fish (about a 4% increase), and resulted in one less year with escapement below S_{MSY} and one less year in overfished status (predicting that 2019 would have been "not overfished, rebuilding" instead of "overfished"). Note that harvest reductions from using the median instead of the mean would not have been evenly distributed across years (Table 3). Instead, use of the median-based forecast would be predicted to result in no change in harvest for 6/8 years 2014-2021, but reduce harvest by 15% in 2018 and 5% in 2019 (both years when the stock was

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[5] Davison and Satterthwaite (2017) lays out the theoretical argument why natural-origin fish may disproportionately contribute to ocean harvest and hatchery-origin fish may disproportionately contribute to escapement if hatchery-origin fish mature faster, as is often the case. The CWT recovery reports cited in the previous sentence are empirically consistent with this prediction, but multiple stocks contribute to natural-origin ocean catch and cannot be separated out to isolate the natural-origin SRFC contribution to ocean catch.

[6] Note that a reduction in SRFC harvest would be expected to reduce the harvest of stocks that co-occur with SRFC but are not actively managed, such as San Joaquin Fall Chinook, Sacramento Late Fall Chinook, Central Valley Spring Chinook, California Coastal Chinook, Klamath-Trinity Spring Chinook, and Rogue River Chinook. However, accepted models to estimate harvest of these stocks do not exist, and in many cases the data required to develop models are not routinely collected. Thus it is impossible to quantify the expected reduction in total harvest, but the contributions of these stocks relative to SRFC are expected to be small, especially in the areas where most SRFC are harvested.

[7] This equality reflects the SI not accounting for adult natural mortality or delayed maturation (i.e. some harvested fish might have otherwise died of natural causes rather than survived all the way to spawning). However, reductions in landed harvest would also reduce nonlanded (release and dropoff) mortalities, which are not accounted for by the SI calculation either (except for coho-only fisheries and certain non-retention GSI sampling programs). So, it is not clear whether the expected increase in escapement should be less than or greater than the decrease in landed harvest.

determined to be overfished). Notably, the greatest reduction in harvest was modeled for 2018, a year of only a small over-forecast (229,432 forecasted, 220,366 postseason estimate) but high implementation error (exploitation rate of 34% planned, 52% estimated in the postseason). This was also a year where the Council issued supplemental guidance to target higher escapement than the control rule would have allowed – the output of the control rule as applied to the mean versus median for that year differed by relatively little (47% versus 43%, see Table 3), and the larger difference in projected harvest reflects both the supplemental guidance to target a higher escapement (reducing the target F to 34% for the mean versus 29% for the median) and the large (and assumed proportional) implementation error. Note that guidance to target a higher escapement may have differed if the median forecast had been in effect, but there is no empirical basis for assuming different guidance would have been issued.

Preventing overfished status would have required reductions in exploitation rates for one or more of the years 2015-2017, which were all years of substantial over-forecasting (mean-based forecast exceeding the postseason estimate by 156%, 46%, and 68%, respectively) but also years where mixed-stock constraints reduced the planned exploitation rate relative to the control rule output corresponding to those large forecasts. The differences between the forecasts associated with using the median rather than the mean are not large enough to compensate for forecast errors on the order of 46%-156%. Note also that the exploitation rate achieved in 2017 was 60% higher than the exploitation rate planned in the preseason (and in 2015 and 2016 it was 16% or 14% higher, respectively), but adjustments to the forecast would not address implementation error.

For comparison with the expected reduction in harvest resulting from use of the median versus mean, annual harvest would have averaged 38,674 less SRFC (about 20%) if the exploitation rate expected at the end of the preseason planning process had been achieved without error, or 7,315 less (about 4% less) if forecasts and implementation were error-free and there were no mixed stock constraints or supplemental guidance to target higher escapement in some years[8].

Conclusions

Overall, the analyses presented here suggest that using the median rather than the mean to transform the SI forecast across scales would have had a small cost to the fishery (about 2% fewer SRFC harvested annually, but this does not account for the expected benefits of increased escapement for future production and thus future harvest, and also does not account for how the reduction in harvest is distributed across years) while improving conservation outcomes by boosting mean 2014-2021 escapement above the S_{MSY} reference point (which is also the lower bound of the conservation objective), resulting in one less year in

[8] No attempt was made to model the effects of forecast error alone because there was no obvious way to infer whether or how much mixed-stock constraints would have limited the extent to which the fishery could have fully utilized a larger forecast for 2019. The Sacramento Winter Chinook forecast for 2019 led to a limit on the planned age-3 impact rate for winter run of 15.7%, versus a limit of 20% in years of higher forecasts. The Klamath River Fall Chinook ocean abundance forecast was within the range of forecasts for the last decade, although the forecasted age-4 component was the largest since 2013. The other case of under-forecasting was 2021, where it appears mixed-stock constraints were in effect even using the under-forecast of record.

overfished status[9], and one less year with escapement below S_{MSY}. Using the median also improved forecast performance for 1995-2021 according to all metrics considered, only slightly for some metrics but from -27% to -21% for MPE. Notably, even the median-based forecast tended to be biased high (MPE of -21% and *C* of 0.93 with 95% confidence interval 0.78-1.12) in proportional terms, though the median-based forecast was biased low in number of fish (ME of 11,014); and over-forecasting appeared most common and proportionally most severe at low abundance (Figure 2). While use of the median-based forecast for 2014-2021 was not predicted to have avoided overfished status nor reduced the frequency of escapements below MSST, a lower quantile (analogous to the Council's choice of P*<0.50 for setting groundfish and coastal pelagic species ABCs) might be expected to do so in some cases (see also Satterthwaite and Shelton [2023]).

The cost to the fishery of using the median rather than mean is estimated to be substantially less than the overages the fishery has experienced relative to what it would have harvested in the absence of forecast and implementation error, but implementation error might ideally be addressed through the harvest model rather than preseason forecasts.

In theory, in the unlikely event that all statistical assumptions were met, use of the mean would lead to an expected error of zero fish, but over-forecasting more than half of the time (a theoretical expectation of 57% of the time for a lognormal distribution with log-scale σ^2=0.14 as estimated for the 2022 forecast[10], this may vary slightly from year-to-year based on the value estimated for σ^2) and an expected ratio of forecast versus postseason estimate larger than 1.0. Using the median would lead to an expected proportional (log-scale) error of 0, with equal frequency of over- or under-forecasting; but the mean difference between the forecast and postseason estimate would be negative.

Acknowledgments

Arliss Winship provided helpful background information and feedback on an earlier draft of this report. Owen Hamel provided helpful clarification on concerns raised by the SSC during its March 2022 meeting. The discussion of the retrospective analysis benefited from comments by Carrie Holt and an anonymous reviewer on a similar analysis in a related paper.

Data and Code Availability

Data and code to reproduce all of the analyses in this report are available at https://dx.doi.org/10.17632/5zncg9bhkr.1.

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[9] It may be worth noting that 2019 was very close to meeting the criteria for "not overfished/rebuilding" under the status quo, with a 3-year geometric mean just 17 fish below MSST. However, current management is based on point estimates and strict cutoffs.

[10] Calculated in R as "plnorm(exp(0.5*0.140084),meanlog=0,sdlog=sqrt(0.140084))"

References Cited

Austing S, Niemela K., 2018. Harvest, hatchery returns and straying of fall Chinook Salmon from Coleman NFH. Delta Science Conference, Sacramento, CA. https://mavensnotebook.com/2019/01/17/bay-delta-science-conference-hatchery-returns-and-straying-of-fall-run-chinook-salmon-from-coleman-national-fish-hatchery-released-at-bay-and-delta-sites-during-californias-drought/

Davison, R.J., Satterthwaite, W. H., 2017. Life history effects on hatchery contributions to ocean harvest and natural-area spawning. Can J. Fish. Aquat. Sci. 74, 1575-1587. http://dx.doi.org/10.1139/cjfas-2016-0457

Kormos, B. Palmer-Zwahlen, M., Low, A., 2012. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement and Ocean Harvest in 2010. Cal. Depart. Fish and Game Fisheries Branch Admin. Rep. 2012-02. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=162355

Letvin, A., Palmer-Zwahlen, M., Kormos, B., 2020. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2017. Cal. Depart. Fish and Wildlife and Pacific States Marine Fisheries Comm. CDFW Ocean Salmon Project, 3637 Westwind Blvd Santa Rosa, CA 95403. https://www.calfish.org/Portals/2/Programs/CentralValley/CFM/docs/2017_CFM_CWT_Report.pdf

Letvin, A., Palmer-Zwahlen, M., Kormos, B., 2021a. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2018. Cal. Depart. Fish and Wildlife and Pacific States Marine Fisheries Comm. CDFW Ocean Salmon Project, 3637 Westwind Blvd Santa Rosa, CA 95403. https://www.calfish.org/Portals/2/Programs/CentralValley/CFM/docs/2018_CFM_CWT_Report.pdf

Letvin, A., Palmer-Zwahlen, M., Kormos, B., McHugh, P., 2021b. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2019. Cal. Depart. Fish and Wildlife and Pacific States Marine Fisheries Comm. CDFW Ocean Salmon Project, 3637 Westwind Blvd Santa Rosa, CA 95403. https://www.calfish.org/Portals/2/Programs/CentralValley/CFM/docs/2019_CFM_CWT_Report.pdf

Munsch, S.H., Greene, C.M., Johnson, R.C., Satterthwaite, W.H., Imaki, H., Brandes, P.L., O'Farrell, M.R., 2020. Science for integrative management of a diadromous fish stock: interdependencies of fisheries, flow, and habitat restoration. Can J. Fish. Aquat. Sci. 77, 1487-1504. https://dx.doi.org/10.1139/cjfas-2020-0075

O'Farrell, M.R., Mohr, M.S., Palmer-Zwahlen, M.L., Grover, A.M., 2013. The Sacramento Index (SI). US Department of Commerce, NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-512. https://repository.library.noaa.gov/view/noaa/4449

Palmer-Zwahlen, M., Kormos, B., 2013. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement and Ocean Harvest in 2011. Cal. Depart. Fish and Wildlife Fisheries Branch Admin. Rep. 2013-02. https://www.rmpc.org/files/mark-mtg-2014-docs/2011_CFM_CWT_Recovery_Report_FAR_2013(Melodie_Palmer-Zwahlen).pdf

Palmer-Zwahlen, M., Kormos, B., 2015. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2012. Pacific States Marine Fisheries Comm. and Cal. Depart. Fish and Wildlife Fisheries Branch Admin. Rep. 2015-4. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=112524

Palmer-Zwahlen, M., Gusman, V., Kormos, B., 2018. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2013. Pacific States Marine Fisheries Comm. and Cal. Depart. Fish and Wildlife. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=162355

Palmer-Zwahlen, M., Gusman, V., Kormos, B., 2019a. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2014. Pacific States Marine Fisheries Comm. and Cal. Depart. Fish and Wildlife. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=166077

Palmer-Zwahlen, M., Gusman, V., Kormos, B., 2019b. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2015. Pacific States Marine Fisheries Comm. and Cal. Depart. Fish and Wildlife. CDFW Ocean Salmon Project, 3637 Westwind Blvd Santa Rosa, CA 95403. https://www.calfish.org/Portals/2/Programs/CentralValley/CFM/docs/2015_CFM_CWT_Report.pdf

Palmer-Zwahlen, M., Gusman, V., Kormos, B., 2020. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2016. Pacific States Marine Fisheries Comm. and Cal. Depart. Fish and Wildlife. CDFW Ocean Salmon Project, 3637 Westwind Blvd Santa Rosa, CA 95403. https://www.calfish.org/Portals/2/Programs/CentralValley/CFM/docs/2016_CFM_CWT_Report.pdf

PFMC (Pacific Fishery Management Council), 2014. Preseason Report I: Stock Abundance Analysis and Environmental Assessment Part 1 for 2014 Ocean Salmon Fishery Regulations. (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384. https://www.pcouncil.org/documents/2014/02/2014-preseason-report-i.pdf/

PFMC (Pacific Fishery Management Council), 2019. Salmon Rebuilding Plan for Sacramento River Fall Chinook. PFMC, Portland, OR. https://www.pcouncil.org/documents/2019/07/sacramento-river-fall-chinook-salmon-rebuilding-plan-regulatory-identifier-number-0648-bi04-july-2019.pdf/

PFMC (Pacific Fishery Management Council), 2021. Pacific Coast Salmon Fishery Management Plan for Commercial and Recreational Salmon Fisheries Off the Coasts of Washington, Oregon, and California as Amended Through Amendment 21. PFMC, Portland, OR. https://www.pcouncil.org/documents/2016/03/salmon-fmp-through-amendment-20.pdf/ [sic]

PFMC (Pacific Fishery Management Council), 2022. Preseason Report I: Stock Abundance Analysis and Environmental Assessment Part 1 for 2022 Ocean Salmon Fishery Regulations. (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon

97220-1384. https://www.pcouncil.org/documents/2022/03/2022-preseason-report-i.pdf/

Reisenbichler, R.R., 1986. Use of spawner-recruit relations to evaluate the effect of degraded environment and increased fishing on the abundance of fall-run Chinook salmon, *Oncorhynchus tshawytscha*, in several California streams. Ph.D. dissertation. University of Washington, Seattle, WA.

Satterthwaite, W.H., Shelton, A.O., 2023. Methods for assessing and responding to bias and uncertainty in U.S. West Coast salmon abundance forecasts. 257:106502. https://doi.org/10.1016/j.fishres.2022.106502

Winship, A.J., O'Farrell, M.R., Satterthwaite, W.H., Wells, B.K., Mohr, M.S., 2015. Expected future performance of salmon abundance forecast models with varying complexity. Can J. Fish. Aquat. Sci. 72, 557-569. https://cdnsciencepub.com/doi/10.1139/cjfas-2014-0247

Table 1. Parameter estimates for the SI forecast each year 2014-2022 obtained from corresponding Preseason Report 1 documents, along with corresponding mean- and median-based forecasts. In most cases, the mean and median forecast were calculated from the parameter estimates reported in the corresponding Preseason Report 1. Cases where the mean forecast as calculated here did not match the forecast of record to the nearest fish were re-run to obtain parameter estimates at full precision and matching forecasts. There was a transcription error in the $\beta_0$value reported in the 2020 Preseason Report 1, the corrected value is reported here. Postseason SI estimates are provided for comparison with forecasts (no estimate for 2022 was available at the time of writing this document).

Year	J_{t-1}	β_0	β_1	ρ	ε_{t-1}	σ^2	**Forecast -Mean**	**Forecast -Median**	**SI (post-season)**
2014	20,248	7.681651	0.5508747	0.7216483	0.2062387	0.1359515	634,650	592,942	551,055
2015	25,359	7.637828	0.5545396	0.7188465	0.08393418	0.1321773	651,985	610,289	254,240
2016	19,954	7.619956	0.548526	0.7147045	-0.7215839	0.1498808	299,609	277,977	205,289
2017	15,056	7.611279	0.5455785	0.740155	-0.7896613	0.1477123	230,700	214,275	139,997
2018	24,375	7.571421	0.5425872	0.778056	-1.006827	0.1489286	229,432	212,968	223,854
2019	41,184	7.53758	0.5466653	0.7726405	-0.740665	0.1457727	379,632	352,946	505,535
2020	29,944	7.368991	0.5669711	0.7474764	-0.2916186	0.144809	473,183	440,133	352,109
2021	13,995	7.319135	0.5696732	0.7529011	-0.4235552	0.1422386	270,958	252,357	322,137
2022	17,003	7.46197	0.5579154	0.7478184	-0.102194	0.140084	396,458	369,639	NA

Table 2. Performance metrics for 1995-2021 SI forecasts based on the mean (status quo) or median (alternative) when transforming from logarithmic to arithmetic scales. Negative ME, negative MPE, and *C*<1.0 all indicate bias toward over-forecasting (forecasts larger than postseason estimates), other metrics are positive by definition and do not indicate the direction of bias. For ME, MAE, MPE, MAPE, and RMSE, values closer to zero indicate better performance. For *C*, values closer to 1.0 indicate better performance.

Method	**ME**	**MAE**	**MPE**	**MAPE**	**RMSE**	***C***	**(95% CI)**
Mean	-14,452	204,801	-27%	49%	257,482	0.89	0.74-1.06
Median	11,014	201,670	-21%	46%	253,953	0.93	0.78-1.11

Table 3. Annual management performance achieved in 2014-2021 based on the status quo, mean-based forecast and projected alternate performance expected if the median-based forecast had been used instead. SI_{post} is the postseason estimate of potential escapement in the absence of fishing, and is assumed to apply to both scenarios (even though parent spawning escapement giving rise to the 2021 cohort would have been greater in the median-based scenario). SI_{pre} is the preseason forecast, F_{con} is the allowable F based on applying the control rule to the forecast, F_{guid} includes the effects of supplemental guidance to target a higher escapement than the control rule would allow (if applicable that year), F_{plan} is the F expected at the end of the preseason planning process under the status quo (so including mixed-stock constraints and allocation considerations), F_{mix} is the minimum of F_{plan} (from the status quo) or F_{guid} based on the median forecast (to assess whether it is likely that mixed-stock constraints would override the effects of forecast adjustments in a particular year), F_{ach} is the F estimated in the postseason (for the status quo) or expected to have been achieved (for the median-based scenario), H and E are the resulting harvest and escapement (with orange denoting escapement below S_{MSY} and red denoting escapement below MSST), E_{3yr} is the three-year geometric mean escapement, and status is the resultant status (with overfished status highlighted in red and not overfished/rebuilding highlighted in orange).

		Mean-based forecast									Median-based forecast								
Year	SI_{post}	SI_{pre}	F_{con}	F_{guid}	F_{plan}	F_{ach}	H	E	E_{3yr}	status	SI_{pre}	F_{con}	F_{guid}	F_{mix}	F_{ach}	H	E	E_{3yr}	status
2014	551,183	634,650	0.700	0.700	0.504	0.615	338,707	212,476	291,125	OK	592,942	0.700	0.700	0.504	0.615	338,707	212,476	291,125	OK
2015	254,949	651,985	0.700	0.700	0.477	0.555	141,481	113,468	214,061	OK	610,289	0.700	0.700	0.477	0.555	141,481	113,468	214,061	OK
2016	205,317	299,609	0.593	0.593	0.496	0.563	115,618	89,699	129,317	OK	277,977	0.561	0.561	0.496	0.563	115,618	89,699	129,317	OK
2017	137,063	230,700	0.471	0.471	0.422	0.677	92,734	44,329	76,698	overfished	214,275	0.431	0.431	0.422	0.677	92,734	44,329	76,698	overfished
2018	220,366	229,432	0.468	0.342	0.342	0.521	114,900	105,466	74,851	overfished	212,968	0.427	0.291	0.291	0.444	97,757	122,609	78,705	overfished
2019	507,155	379,632	0.679	0.579	0.578	0.677	343,388	163,767	91,483	overfished	352,946	0.654	0.547	0.547	0.640	324,777	182,378	99,708	rebuilding
2020	352,109	473,183	0.700	0.700	0.507	0.608	214,018	138,091	133,609	rebuilt	440,133	0.700	0.700	0.507	0.608	214,018	138,091	145,620	rebuilt
2021	322,137	270,958	0.550	0.550	0.506	0.676	217,654	104,483	133,192	OK	252,357	0.517	0.517	0.506	0.676	217,654	104,483	138,058	OK

Table 4. Historical versus projected alternative (if forecasts had been based on medians rather than means) harvest, escapement, and management performance for SRFC in 2014-2021. The potential benefits of higher escapement in earlier years leading to higher production in later years are not captured in this analysis, thus it over-states costs to the fishery and under-states conservation benefits of using the median instead of the mean, by an unknown amount.

Method	**Mean Harvest**	**Mean Escapement**	**Years Overfished**	**Years Rebuilding**	**Years Esc < S_{MSY}**	**Years Esc < MSST**
Mean	197,313	121,472	3/8	0/8	5/8	2/8
Median	192,843	125,942	2/8	1/8	4/8	2/8

Figure 1. Distributions corresponding to the 2021 SI forecast on the log scale (left) or arithmetic scale (right). The mean is denoted with a solid vertical line and the median is denoted with a dashed vertical line (because the log-scale mean and median are equal, the lines overlap on the log-scale plot). If all statistical assumptions were met, the area under the curve corresponding to a particular range of SI or log(SI) values would represent the frequency with which the postseason observation of the SI or log(SI) fell within that range.

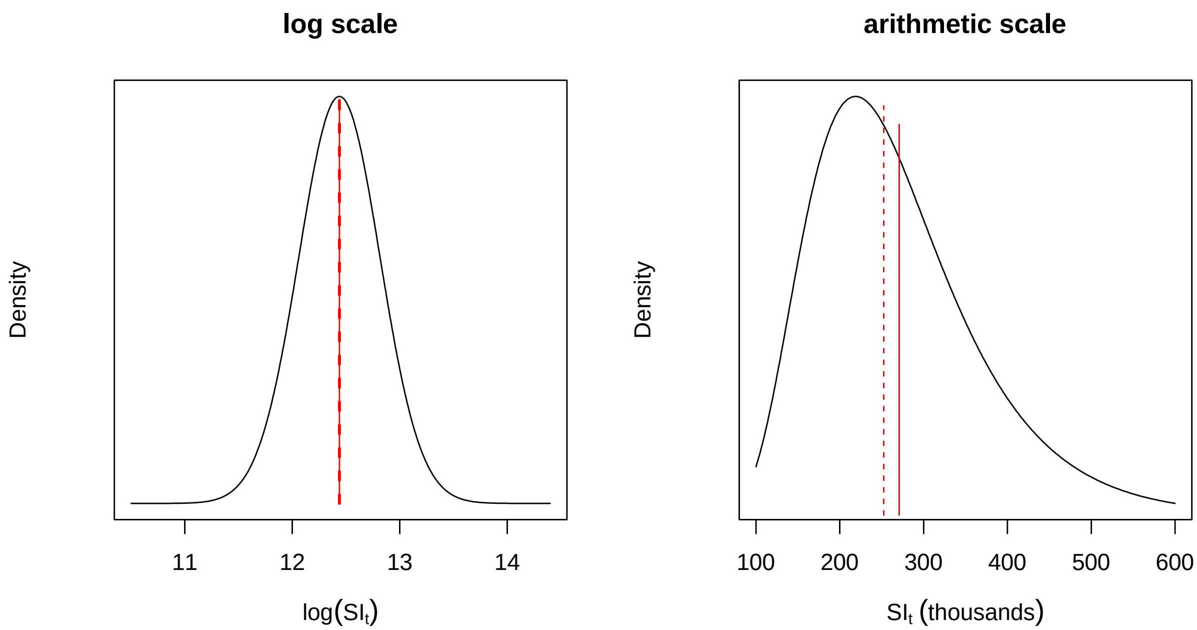
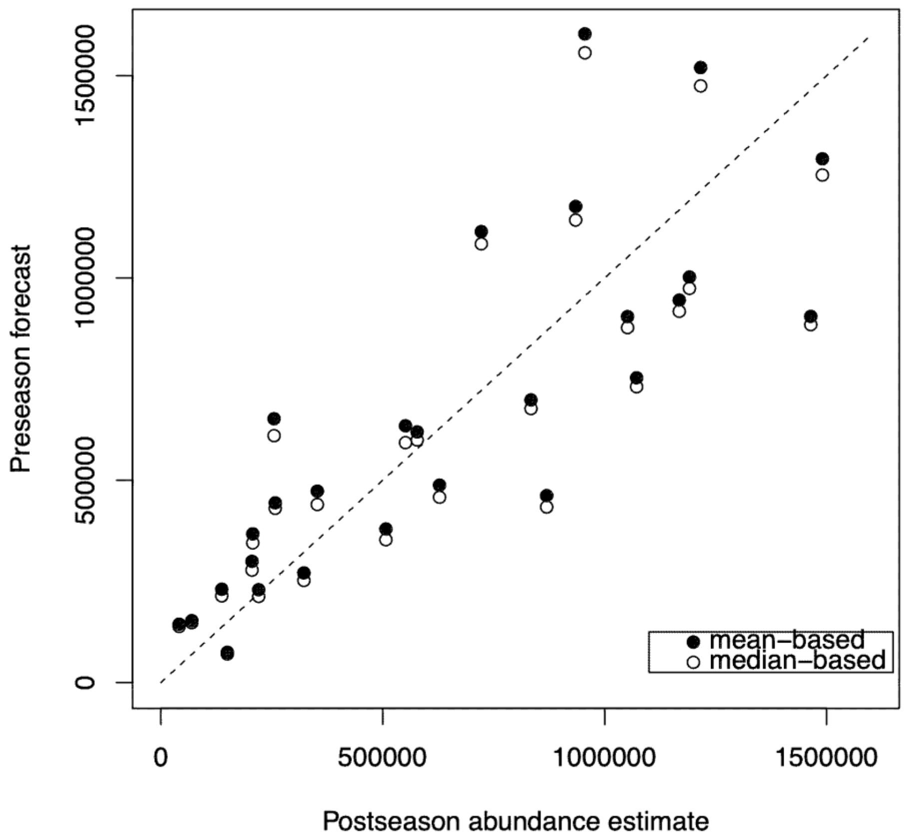


Figure 2. Comparison of mean-based (filled circles) and median-based (open circles) SI forecasts for 1995-2021 (based on the current methodology), plotted against the postseason SI estimate for the same year. Note that for years prior to 2014, the forecasts presented here do not match the forecasts of record, due to changing methods. The dashed line is the 1:1 line, points above the line indicate over-forecasting and points below the line indicate under-forecasting.



Supplement S1. R code to implement SI forecast. Must be run from the same directory as the "SI.forecast.2022.inputfile.csv" file provided in Supplement S2 (or the first line should be altered with the appropriate file path for the host machine).

```
dat.all=read.csv("SI.forecast.2022.inputfile.csv") #input file
for SI forecast
#provided by Mike O'Farrell in email "SI input files: 14, 15,
22" sent 5/2/22 at 2:10pm
# I changed the 2022 SI value (not observed yet) from 0 to NA,
it is not used either way
#note that the jacks (j) reported in the year Y row are the Y-1
jack returns, no further adjustment needed to align properly
# PFMC 2014 and Winship et al 2015 are a bit lacking in details
on how the log-log autoregressive model was actually
implemented.
# code below is an independent replication of the described
methods
# and was adapted from
https://stats.stackexchange.com/questions/6469/simple-linear-
model-with-autocorrelated-errors-in-r


#confirm I can reproduce 2022 forecast parameters as reported in
2022 Pre-1
forecast.yr=2022
train.dat=dat.all[dat.all$year<forecast.yr,]

y=log(train.dat$si)
x=log(train.dat$j)

(si.model <- arima(y, xreg=x, order=c(1,0,0)))
#Coefficients:
#         ar1  intercept       x
#      0.7478     7.4620  0.5579
#s.e.  0.1054     1.0902  0.1054

#sigma^2 estimated as 0.1401:  log likelihood = -17.42,  aic =
42.84

beta0=coef(si.model)[2]
#7.46197
beta1=coef(si.model)[3]
#0.5579154
rho=coef(si.model)[1]
#0.7478184
epsilon_lastyr=y[length(y)]-(beta0+beta1*x[length(y)])
#-0.102194
```

```
s2=si.model$sigma #note that "sigma" is in fact sigma^2
#0.140084
jacks.this.year=dat.all$j[length(y)+1]
#17003
forecast.mean=exp(beta0+beta1*log(jacks.this.year)+rho*epsilon_l
astyr+0.5*s2)
#396457.6
#Matches 2021 Pre-1 perfectly.
forecast.median=exp(beta0+beta1*log(jacks.this.year)+rho*epsilon
_lastyr)
#369639.1

#Perform forecasts for 1995-2013
hindcast.yrs=c(1995:2013)
dat.all=read.csv("SI.forecast.2022.inputfile.csv")
write(c("Year","Forecast.Mean","Forecast.Median"),file="SIhindca
sts.csv",append=FALSE,sep=",",ncolumns=3)
for (forecast.yr in hindcast.yrs)
{#loop over forecast years
     train.dat=dat.all[dat.all$year<forecast.yr,]
     y=log(train.dat$si)
     x=log(train.dat$j)
     (si.model <- arima(y, xreg=x, order=c(1,0,0)))
     beta0=coef(si.model)[2]
     beta1=coef(si.model)[3]
     rho=coef(si.model)[1]
     epsilon_lastyr=y[length(y)]-(beta0+beta1*x[length(y)])
     s2=si.model$sigma #note that "sigma" is in fact sigma^2
     jacks.this.year=dat.all$j[length(y)+1]
     forecast.mean=exp(beta0+beta1*log(jacks.this.year)+rho*epsi
lon_lastyr+0.5*s2)
     forecast.median=exp(beta0+beta1*log(jacks.this.year)+rho*ep
silon_lastyr)
     write(c(forecast.yr,forecast.mean,forecast.median),file="SI
hindcasts.csv",append=TRUE,sep=",",ncolumns=3)
}#loop over forecast years
```

Supplement S2. Inputs to the SI forecast code. Contents below should be saved to a file called "SI.forecast.2022.inputfile.csv". Note that the "j" column reflects jack escapement the previous year, i.e. it is the escapement that informs the forecast for the specified year, not the escapement estimated to have occurred in the specified year.

```
year,si,j
1983,461133,47112
1984,538062,45736
1985,792752,40606
1986,1035731,40011
1987,1086103,33692
1988,1616130,80230
1989,937346,22685
1990,780003,27609
1991,534580,13862
1992,397632,14608
1993,623208,25851
1994,666741,22050
1995,1464552,46797
1996,934683,34970
1997,1191101,41876
1998,722052,40464
1999,833996,33841
2000,1051648,39557
2001,1072040,23039
2002,1490791,42751
2003,1216333,53253
2004,1168169,33623
2005,955544,75745
2006,577563,19862
2007,257671,8446
2008,69634,1904
2009,41148,4122
2010,149788,9467
2011,207020,27288
2012,627927,85543
2013,869325,36023
2014,551183,20402
2015,254949,24627
2016,205317,19870
2017,137063,16997
2018,220366,25078
2019,507052,43606
2020,352410,30151
2021,322137,13916
2022,NA,17003
```

Literature Review for Sacramento River Fall Chinook Conservation Objective and Associated S_{MSY} Reference Point

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Basis for current conservation objective and S_{MSY} reference point

As described on p. 21 of the Pacific Coast Salmon Fishery Management Plan for Commercial and Recreational Salmon Fisheries off the Coasts of Washington, Oregon, and California as Revised through Amendment 22 (PFMC 2022a, hereafter "the FMP"), the current conservation objective for Sacramento River Fall Chinook (SRFC) is 122,000-180,000 "adult" spawners returning to natural areas and hatcheries combined in the Sacramento River basin, regardless of origin. When used by the PFMC in reference to SRFC, "adult" is typically interpreted as any spawner of age-3 or older. This objective was derived (PFMC 1984, Section 3.5.2.1, pp. 3-16 to 3-19) as the sum of contributions from spawners in different natural areas and hatcheries, with PFMC (1984) rejecting the idea of formally establishing area-specific goals.

The hatchery contributions were based on "mitigation requirements or hatchery capacities, whichever is higher" and were set equal to 9,000 for the Upper-River hatchery (i.e., Coleman National Fish Hatchery), 5,000 for Feather River Hatchery, and 6,000 for Nimbus Hatchery on the American River[1]. Contributions for natural areas were initially set equal to 99,000 for the Upper-River, 27,000 for the Feather River, 10,000 for the Yuba River, and 24,000 for the American River. "Upper-River" is not explicitly defined in PFMC (1984) although in recent usage in other documents it typically refers to the mainstem and tributaries upstream of Red Bluff Diversion Dam (RBDD, see map on p. 6 of SRFCRT 1994). However, there is also a reference to "upper Sacramento River (above Feather River)" in the description of other run timings (PFMC 1984, p. 3-16). There is no discussion of minor tributaries in the Lower-River, nor the Lower-River mainstem[2].

PFMC (1984, p. 3-19) further states that natural-area escapement of 99,000 to the Upper-River is unlikely to be achieved until "problems caused by the Red Bluff Diversion Dam are rectified"[3] and so establishes an "interim" (p. 3-19) alternative contribution of 50,000 for

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[1] According to PFMC 2022b Table B-1, current fall-run Chinook goals are 12,000 adults for Coleman National Fish Hatchery, 6,000 adults for Feather River Hatchery, and 4,000 adults for Nimbus Hatchery (totaling 22,000 hatchery adults, compared to a total of 20,000 for the goals stated in PFMC [1984]).

[2] According to Azat (2021), the mainstem and tributaries between RBDD and Princeton Ferry (39°24'43.3"N, upstream of Feather River and Butte Creek) have had spawner estimates in the tens of thousands, although estimates from 2006-2020 were all below 10,000. It is unclear whether this area was included in PFMC (1984)'s Upper-River.

[3] The specific problems with RBDD and how they would be rectified are not clearly stated on p. 3-19 of PFMC (1984), although p. 3-18 refers to passage problems. Construction of RBDD was completed in 1964 (https://www.usbr.gov/projects/index.php?id=244). RBDD was decommissioned and its gates were permanently locked in the open position in 2013 (and had been fully open since May 2011), although the structure has not been

natural areas and the hatchery in the Upper-River combined, based on Upper-River fall Chinook runs "fall[ing] from 81,700 to 51,500 adult[s]" from 1979-1983[4] (PFMC 1984, p. 3-19) and an expectation that returns would stabilize at about 50,000. In fact, returns to the Upper-River were much higher than this for the late 1980s and the late 1990s through the early 2000s (Figure 1).

The contributions to the Lower-River sum to 72,000 and thus the lower bound of the conservation objective is set equal to 72,000+50,000 = 122,000 while the upper bound of the conservation objective is set equal to the sum of 72,000 for the combined Lower-River, 9,000 for the Upper-River hatchery, and 99,000 for the Upper-River natural areas = 180,000 total. The S_{MSY} reference point is set equal to the lower bound of the conservation objective at 122,000.

PFMC (1984) states that the natural-area contributions were based on "averages of previous years' run sizes" and initially states that these averages were from 1953-1960 on p. 3-16. However, the description of the Yuba River contribution on p. 3-17 states that it is based on the 1971-1981 average. According to values reported in Azat (2021), in-river escapement to the mainstem Sacramento River and its tributaries above RBDD had a mean of 197,207 for 1953-1960, although this includes jacks as well as adults. However, it seems unlikely that the inclusion of jacks[5] is the sole reason this number is so much larger than the 99,000 reported in PFMC (1984). Additionally, Azat (2021) reports escapements with a mean of 39,640 to the mainstem and tributaries between Princeton Ferry and RBDD (i.e., above the confluence with the Feather River) for 1953-1960, which might need to also be accounted for in the Upper-River total. For the Feather River, the mean of the 1953-1960 in-river fall Chinook escapements reported by Azat (2021) is 51,131. Again, the discrepancy with the 27,000 reported in PFMC (1984) seems larger than could be explained by the inclusion of jacks alone. For the American River, Azat (2021) yields a 1953-1960 mean of 17,267 in-river spawners, once again at odds with the 24,000 reported in PFMC (1984), although lower in this case. For the Yuba River, the 1971-1981 mean escapement from Azat (2021) is 11,023, reasonably close to the stated contribution of 10,000, especially after factoring in likely jack contributions[6]. Changing the period for calculation of the mean to 1971-1981 does not reconcile the numbers for other natural areas with the values reported in Azat (2021), yielding 43,478 for the Upper-River (not

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removed and its removal is not planned (Duda 2013). Efforts to improve passage occurred prior to this as well (USBR 2008). Since 1964, natural-area escapements above RBDD exceeded 100,000 in 1965-1966, 1968-1969, 1988, 1995-1997, and 1999-2003 (Azat 2021), and in some additional years escapement to Coleman National Fish Hatchery far exceeded 9,000 and brought total Upper-River escapement above 100,000.

[4] According to PFMC (2022b, Table B-1) adult fall Chinook escapement to the Upper Sacramento was 81,332 for natural areas and 4,766 for Coleman Hatchery in 1979 and 42,570 for natural areas and 5,367 for Coleman Hatchery in 1983, however this is only the Upper Sacramento above RBDD whereas PFMC (1984) may have included more of the watershed.

[5] For 1970-2021, natural area SRFC escapement ranged from 2%-35% jacks with median 13% (PFMC 2022b Table B-1). Note also that Azat (2021) refers to "adult" salmon, but Azat (2021) uses "adult" in the biological sense of sexually mature fish returning to freshwater, rather than denoting age-3+ as in many PFMC documents (confirmed via email exchange with Jason Azat, 19 September 2022).

[6] According to PFMC 2022b Table B-1, 1971-1981 mean adult fall run escapement to the Yuba River was 9,397 and the mean for jacks was 1,625 for a sum of 11,022.

including areas upstream of Princeton Ferry but downstream of RBDD), 43,843 for the Feather River, and 38,167 for the American River.

Consistency with definitions and stated goals in the FMP

The FMP (p. 14) defines S_{MSY} as "The abundance of adult spawners that is expected, on average, to produce MSY." Maximum Sustainable Yield (MSY) is defined on page 13 as "the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions and fishery technological characteristics, and distribution of catch among fleets". PFMC (1984) does not attempt to quantify expected yield.

The FMP further states that "Often, data are insufficient to directly estimate S_{MSY}. In these cases, the Council may use MSY proxies derived from more general estimates of productive capacity" (p. 13). The 50,000 contribution toward S_{MSY} assigned to the Upper-River is not based on an estimate of productive capacity. No argument is presented for why the reported average run size over a particular time period in the past (which does not represent current prevailing ecological and environmental conditions) constitutes an estimate of productive capacity for the Lower-River.

The FMP (p. 19) states that "The Council's conservation objectives for natural stocks may (1) be based on estimates for achieving MSY or an MSY proxy, or (2) represent special data gathering or rebuilding strategies to approach MSY and to eventually develop MSY objectives." There is no data gathering or rebuilding strategy built into the conservation objective.

The FMP (p. 21) states that the SRFC conservation objective "is intended to provide adequate escapement of natural and hatchery production", but "adequate" is not defined. PFMC (1984) rejected the idea of formally establishing area-specific subgoals. However, if the individual hatchery and natural area contributions identified are considered to represent adequate[7] levels of spawners in the respective areas, total escapement equal to their sum is exceedingly unlikely to lead to adequate escapement to all areas, since some level of variation is expected in the proportion of escapement returning to each area, and there is no reason to expect the proportions escaping to different areas to exactly equal their proportional contributions to the total objective. Table 1 reports annual total adult escapement as well as adult escapements to the individual areas described in PFMC (1984), using values from PFMC (2022b, Table B-1), and assuming that Upper-River signifies above RBDD (since PFMC 2022b does not report escapements to the mainstem downstream of RBDD). Out of 52 years 1970-2021, only 11 years had all area-specific escapement estimates above their respective

[7] Presumably, "adequate" hatchery performance entails meeting the mitigation requirement. However, "adequate" escapement might be less than the optimal spawning escapement in a given natural area, with the idea that successful management would sometimes miss the optimum above and sometimes below. However, the contributions reported in PFMC (1984) are far below the levels estimated to maximize production or yield, as described in the review of other literature later in this report. Nevertheless, it might make sense to assess the probability of all subareas being above some percentage of their optimal contribution, similar to setting MSST equal to 75% of S_{MSY}.

contributions to the low end of the conservation objective[8]. In 7/11 of those years the Upper-River natural-area adult escapement estimate was above 99,000, and in two more of those years it was close (96,716 in 2005 and 90,119 in 2013). For the 7 years above the full contributions to the current conservation objective, estimated total adult escapement ranged from 239,307 to 769,868 with median 417,537. Expanding to include the 4 years where estimated Upper-River natural-area escapement was below 99,000 but estimated combined Upper-River escapement was above 50,000 reduced the minimum to 164,641 and the median to 399,830.

A logistic regression modeling the probability of meeting or exceeding all contributions as a function of total adult escapement suggested that a total escapement of at least 312,000 (lower end of Upper-River contribution) or 386,000 (upper end) adults would be required for at least a 50% probability of meeting or exceeding all contributions (Figure 2). The logistic regression model requires several unrealistic assumptions and a more sophisticated model may be more appropriate (e.g., Appendix D of PFMC 2007, DFO 2022).

Page 51 of the FMP states that “With respect to California stocks, ocean commercial and recreational fisheries operating in this area[9] are managed to maximize natural production consistent with meeting the U.S. obligation to Indian tribes with federally recognized fishing rights, and recreational needs in inland areas.” However, the current SRFC conservation objective does not include any quantification of production, and it does not distinguish natural- from hatchery-origin fish, nor does it distinguish fish spawning in hatcheries versus natural areas.

PFMC (1984, p. 3-19) rejected the idea of separate hatchery and natural[10] objectives. Part of the argument states “The only major tributary with a truly natural run is the Yuba River. Runs in this river have been remarkably stable from 1971-1981, averaging about 10,000 adults. The run increased sharply in 1982 to 23,000. The stability of the Yuba River escapement suggests that present and past management practices have not reduced the productivity of natural stocks.” However, it is not clear why stable run size necessarily represents management actions stabilizing run size at the escapement that would maximize yield or production. In addition, while “remarkably stable” is a qualitative judgment that cannot be quantitatively validated or refuted, examination of Yuba River escapement estimates reported by Azat (2021) reveals substantial variation, including periods of substantially higher escapement but also escapements as low as 1,600 with multiple years below 4,000 (Figure 3). In addition, the assertion that the Yuba River has a “truly natural run” is incorrect. Synthesis of Coded Wire Tag

[8] Note however that three years (1986, 1995, and 1997) only missed the established Nimbus Hatchery goal of 6,000 (PFMC 1984) but met the updated Nimbus Hatchery goal of 4,000 (PFMC 2022b Table B-1) while meeting all other contributions including the high end of the Upper-River contribution. These years had estimated total adult escapements of 239,307, 344,841, and 301,663, respectively.

[9] This quote is from a section titled “South of latitude 40°10' N” and similar wording appears in the section describing fisheries in the rest of California.

[10] The terms “natural” and “wild” appear somewhat interchangeably throughout the FMP, with no specific definition provided for either, although each term appears more often in association with some stocks than others. “Natural” is typically used in association with California stocks. In this document, no special significance should be attributed to the use of “natural” versus “wild”.

Recovery Reports (Kormos et al. 2012, Palmer-Zwhalen and Kormos 2013, 2015, and 2020; Palmer-Zwhalen et al. 2018 and 2019a,b, Letvin et al. 2020 and 2021a,b) indicates that escapement to the Yuba River in 2010-2019 (Figure 4) ranged from 37%-87% hatchery-origin with median 58%. In comparison, natural-area spawning in the Sacramento River above RBDD was 5%-68% hatchery-origin with median 37% for the same time period; so the Yuba River is not even the part of the system closest to being mainly natural. However, it is possible that hatchery strays made up a smaller proportion of Yuba River escapement at the time PFMC (1984) was written, since there was less downstream transport of hatchery production and thus probably less straying prior to the mid-1980s (Sturrock et al. 2019).

PFMC (1984, p. 3-19) further states that “the distinction between hatchery and natural fish has become lost in these parts of the river” (apparently intending to exclude the Yuba from “these parts”, though this is not entirely clear). Williamson and May (2005) documented extensive hybridization and homogenization among Central Valley fall Chinook at the seven microsatellite loci they examined, which they attributed to extensive hatchery straying and introgression with fish spawning in natural areas. However, Meek et al. (2020) performed a broader genomic study and found greater population structure than previously documented, including evidence for differentiation and adaptation. A comprehensive review of comparisons between hatchery- and natural-origin fish in genetic and phenotypic aspects is beyond the scope of this paper, but the articles cited in the previous sentence may provide good entry points to the literature, along with CA HSRG (2012).

Additionally, PFMC (1984) argued that hatcheries on the Feather and American Rivers close their ladders once capacity is reached and additional fish that would have returned to the hatchery remain in the river and are counted as natural spawners. However, in reality spawners collected at individual hatcheries have often been far above capacity (see Table 1) and following the practice described in PFMC (1984) could have unintended consequences like inadvertent selection on return timing or even age at return.

Other documents relevant to the SRFC conservation objective cited in the FMP

The FMP (p. 21) cites four other documents in association with the SRFC conservation objective (ASETF 1979, SRFCRT 1994, Hallock 1977, and Reisenbichler 1986), and these are discussed in turn.

ASETF (1979) discusses Sacramento River Chinook abundances and goals on pp. 5-7. It states that “Estimates of the number of salmon spawning in the Sacramento River drainage are not based on solid data. The average annual escapement might have been 300,000 to 500,000 chinook [sic] salmon, and an escapement of 400,000 adults is used in this report.” This refers to all run timings combined. ASETF (1979) goes on to state “a catch-to-escapement ratio (C/E) of 1.17/1.0 was used to estimate the proportion of the [harvested] fish originating from the Sacramento system prior to water developments”, although the basis of the 1.17 value is not stated. A C/E ratio of 1.17 along with escapement of 400,000 adults implies a total catch of 468,000 and total production of 868,000. ASETF (1979) goes on to state “the goal for the Sacramento River system is 935,000 adult salmon” although no clear basis for this goal is given. Table 1 of ASETF (1979) describes this number as representing “with enhancement”. At the assumed C/E ratio of 1.17, this would require escapement of 400,000*935,000/868,000 = 431,000 adults of all run timings combined. ASETF also states “The present (1972-1976) spawning escapement in the Sacramento River system has averaged 254,000[11] fish annually, with a goal of 340,000 when the problems in the upper river are solved.” The basis for the 340,000 goal is not provided[12], while loss of spawning gravel, heavy metal contamination, fish passage at RBDD, and streamflow manipulations are listed as problems with the upper river. Table 1 of (ASETF) lists 340,000 under “Fill present habitat”, suggesting it may reflect an estimate of habitat capacity, which could serve as a proxy for S_{MSY} under the alternative definition on p. 13 of the FMP. It would need to be adjusted to represent fall run rather than all run timings combined, which might be done based on proportional run sizes (Azat 2021, PFMC 2022b) or ratios among goals proposed for the different run timings by Hallock (1977, 1978, see below).

SRFCRT (1994) had the goal of “determin[ing] why the escapement goal for [SRFC] was not met in 1990-1992, and to recommend actions to assure future productivity of the stock”, where “the escapement goal” refers to the conservation objective established by PFMC (1984). SRFCRT (1994) did not explore alternative conservation objectives nor did it examine the basis of the current objective.

Hallock (1977) is no longer publicly available, but a copy from Chuck Tracy’s (retired PFMC) personal archive was obtained and compared to the publicly available Hallock (1978) and judged to be substantially equivalent with respect to information and arguments relevant to the SRFC conservation objective. Hallock (1978, p. 3) states that “Defining spawning levels to serve as management goals is a difficult and largely subjective process” and goes on to recommend “an ‘average’ escapement goal, which is a desirable level around which escapement will fluctuate” (p. 4). Hallock (1977 his Table 4, 1978 his Table 1) suggested SRFC escapement goals of 150,000 for the Upper Sacramento (which he defines as the mainstem and tributaries above the confluence with the Feather River), 40,000 for the Feather River, 25,000 for the Yuba River[13], and 30,000 for the American River, totaling 245,000 spawners (the FMP reports 240,000 as the basin capacity identified by Hallock 1977, but both Hallock 1977 and Hallock 1978 actually report 245,000). The basis for these goals is not clear. The goals for the Upper Sacramento and Yuba River are higher than the 1967-1976 averages reported by Hallock (1977, 1978), while the Feather River and American River goals are lower. Hallock (1977, 1978) does not state whether these goals are for adults only or include jacks, however his area-specific reported averages for 1967-1976 closely (within 1,000 fish) match means calculated for

[11] Values reported in Azat (2021) yield a mean Sacramento Chinook (all run timings and all ages) escapement of 260,468 for this period, a fairly close match (and the adult-only number would be expected to be slightly lower).

[12] However, while this may be coincidence, Hallock (1977, p. S-13-Cs) reports a 1953-1960 average escapement of 340,00 “fall-spawning” Sacramento Chinook, where “fall-spawning” refers to both fall and spring run timings (Hallock [1977] uses “spring-spawning” to refer to late-fall and winter runs). Hallock (1977, p. S-12-Cs) also suggests a goal of 340,000 for all run timings combined, although its derivation is not clear, see discussion of Hallock (1977) below.

[13] Hallock (1977, p. S-21-Cs; 1978, p. 9) refers to “A combination of hatchery production and improvements in spawning and nursery habitat” being planned for the Yuba River, but there is no Chinook hatchery located on the Yuba (although numerous hatchery fish, largely from Feather River Hatchery, do spawn there [Figure 4]).

the same period from Azat (2021) using combined jack plus adult escapement and including hatchery returns. As with PFMC (1984), setting a total goal equal to the sum of goals for individual areas makes it unlikely that all goals will be met simultaneously, although Hallock (1977, 1978) seems to accept this possibility since he states that fluctuations around the goals are expected. As these values are not linked to projections of yield or production, and not explicitly linked to capacity, it is not clear that they would satisfy any of the definitions or goals in the FMP for use as conservation objectives or S_{MSY}, although they might be regarded as implicit estimates of capacity.

Reisenbichler (1986) is a PhD thesis that does not seem to be available online, but a hard copy was located in the SWFSC Salmon Assessment Team archives. Resienbichler (1986) estimated Ricker stock-recruit relationships for Chinook salmon on several rivers in California, including fall Chinook in most but not all of the Sacramento River basin. Reisenbichler (1986) attempted to avoid confounding from hatchery-origin fish by excluding Battle Creek (the site of Coleman National Fish Hatchery) from most[14] of his analyses of the Upper Sacramento (which looked at various time periods between 1950 and 1979[15]), and analyzed data from the Feather River (1953[16]-1966) and American River (1945-1955) prior to the establishment of their major rim dams and hatcheries. Reisenbichler (1986) does not specifically discuss the Yuba River[17] or other tributaries in the main text. The FMP (p. 21) states that Reisenbichler (1986) found that 118,000 natural-area spawners would maximize production, but it is not clear how this number was extracted from Reisenbichler (1986); nor how it could have been given that Reisenbichler (1986) did not consider the entire Sacramento Basin and used different time periods for the parts he did consider. However, the stock-recruit parameters reported by Reisenbichler (1986) for the Upper Sacramento for 1954-1963 do imply an S_{MSY} (so maximizing yield rather than production) for just the Upper Sacramento River of approximately 118,000 natural-area spawners if it is assumed that there is a typo in Table 6 of Reisenbichler (1986) such that it reports Beta x 1000 rather than Beta x 100 as stated (see below).

Combining the separate stock-recruit relationships estimated by Reisenbichler (1986) into an implied total SRFC escapement goal is challenging, if not impossible, because they cover different time periods, differ in whether they include jacks, and omit part of the system. In addition, Resienbichler (1986) excluded putative "outlier" years (p. 42), depends on questionable inferences about ocean harvest (p. 46) along with limited information on age structure (p. 49), and noted simulations showing that estimates of stock-recruit parameters are

[14] Resienbichler (1986, p. 37) but see Resienbichler, (1986 pp. 69-70).

[15] There is some inconsistency among different table and figure legends in Resienbichler (1986) as to whether the last year included in analyses for the Upper Sacramento is 1978 or 1979.

[16] The current Feather River Hatchery was established in 1967 (although the earliest stages of Oroville Dam construction began in 1961), but a Feather River Hatchery on another site operated from 1924-1953, potentially contributing to spawner returns for the first few years of this period. https://wildlife.ca.gov/Fishing/Hatcheries/Feather-River/History

[17] The Yuba River downstream of Englebright Dam is depicted (with no label) in Reisenbichler's Figure 3, and his Appendix A gives the date of Englebright Dam's establishment while labeling the Yuba as a tributary to the Feather, but it is not explicitly stated whether escapement on the Yuba was included in his estimates of Feather River escapement.

"imprecise (have large standard deviations) and often highly biased" (p. 82). Nevertheless, because Reisenbichler (1986) reported the parameters of his fitted Ricker stock-recruit relationships, values for S_{MSY} for subsets of the basin for particular time periods can be calculated using the approach described in Scheuerell (2016), as reported in Table 2. However, the values resulting from the reported parameter estimates seem implausibly small, and are inconsistent with the values displayed in the figures in Reisenbichler (1986), unless it is assumed that Reisenbichler (1986) reported Beta x 1000 rather than Beta x 100 in his Table 6.

To provide information relevant to the goal stated on page 51 of the FMP, Table 3 reports the natural-area escapements predicted to maximize production (S_{MSP}, calculated as 1/Beta, Quinn 2013) for each of the area-year combinations reported by Reisenbichler (1986), assuming that Reisenbichler (1986) reported Beta x 1000 rather than Beta x 100.

Other documents relevant to the SRFC conservation objective not cited in the FMP

This document is not meant to represent a comprehensive review of all recent literature potentially relevant to the SRFC conservation objective. Adkison (2022) provides a wealth of general guidance on the fitting of spawner-recruit relationships and how they can inform management, but not all of the approaches from that document can be applied given currently-available data for SRFC. For SRFC in particular, there are two highly relevant documents that have been seen by the Council and/or its advisory bodies in other contexts.

PFMC (2019) was adopted by the Council and includes a Ricker stock-recruit relationship fitted to fry-equivalent juvenile production as a function of natural-area female spawners in the Upper Sacramento (above RBDD) for brood years 2002-2015 (pp. 24-25). This analysis indicated that maximum production would occur for an escapement of approximately 80,000 females to natural areas above RBDD, or approximately 160,000 spawners assuming a 50:50 sex ratio[18]. This could be scaled to a basin-wide target based on typical proportions escaping to different parts of the system (Azat 2021), or a model could be developed identifying the probability of meeting or exceeding an Upper Sacramento natural-area spawner goal defined from this stock-recruit relationship at different levels of total escapement to the system. The number could be refined further to provide a total adult spawner goal given typical age structures for males versus females. This would not meet the FMP's stated definition of S_{MSY} but could inform the stated goal of maximizing natural production. An estimate of escapement maximizing natural production (S_{MSP}) might be scaled to an estimate of escapement maximizing natural yield (i.e., meeting the definition of S_{MSY}) based on meta-analysis of ratios between escapement levels maximizing production and maximizing yield for suitably-estimated salmon stock-recruit relationships. For example, S_{MSY}/S_{MSP} ratios for the Ricker relationships fitted to SRFC populations by Reisenbicher (1986) ranged from 0.73 to 0.83 with median 0.79. Applying such a multiplier would implicitly assume the absence of compensatory or over-compensatory density dependence after the fry stage, which could be reasonable given that natural-origin juveniles

[18] Note that PFMC 2019 does not specify whether the numbers refer to total female natural-area spawners, or total adult female natural-area spawners. Because the number reported is females, it is likely to be largely adults. However, a 50:50 sex ratio may not be appropriate for extrapolating to total adults but may be closer to appropriate for total spawners.

constitute only a fraction of ocean abundance, and potentially less mechanistic basis to assume strong density dependence in less physically constrained habitats.

While PFMC (1984) stated that it would be difficult to meet an Upper-River goal without over-escapement to the Lower-River, there is considerable variability in the proportion of total escapement (including escapement to hatcheries) which occurs to natural areas of the Upper-River (Table 1), ranging from 3% to 64% with median 38% for the years reported in Table 1. In addition, the proportion of total escapement returning to the Upper-River would be expected to be higher on average if production there was higher, as would be expected in response to higher Upper-River escapements.

Munsch et al. (2020) has been described in presentations to the Council under various NMFS Science Center Reports, and was included in background materials on the Central Valley Fall Chinook Indicator reviewed by the SSC Ecosystem Subcommittee. However, it has never been reviewed by the Council's other technical advisory bodies nor adopted by the Council. Munsch et al. (2020) modeled a Chinook fry production index for the Sacramento River basin as a function of flow and natural-area spawners, using data from outmigration years 1999-2016. Due to the size and timing cutoffs in the fry production index, Munsch et al. (2020) argued that the analysis largely excludes hatchery-origin fish and the late-fall life history, but includes fall, spring, and winter run timings. Thus Munsch et al. (2020) considered the natural-area escapement of these three run timings combined, although fall-run predominates by a very large margin (Azat 2021). Munsch et al. (2020) found that fry production was maximized at a natural-area escapement of around 400,000[19] spawners. This analysis has an advantage over tributary-specific studies in that Munsch et al. (2020) examined basin-wide escapement that was actually achieved given historical variation in how spawners were distributed across the landscape, implicitly incorporating the effects of expected proportional over-escapement to some areas relative to others and finding the optimal expected tradeoff.

While Munsch et al. (2020) found strong effects of flow, they also found that even at the lowest flow levels included in the study, fry production tended to increase with increases in natural-area spawner abundance well above 200,000 (Figure 5). The natural-area spawning escapement of fall, winter, and spring runs combined found by Munsch et al. (2020) to maximize natural production could be converted to a natural-area S_{MSP} for SRFC alone based on typical ratios among run sizes reported in Azat (2021) or PFMC (2022b) or the ratios among run timings in escapement goals developed by Hallock (1978); and if needed could be converted from total spawners to adults based on typical jack contributions. This would not meet the FMP's stated definition of S_{MSY} but could inform the stated goal of maximizing natural production. Additionally, an estimate of escapement maximizing natural production might be scaled to an estimate of escapement maximizing natural yield (i.e., meeting the definition of S_{MSY}) based on meta-analysis of ratios between escapement levels maximizing production and maximizing yield, as described previously for PFMC (2019).

[19] According to Stu Munsch, the GAMs fitted in Munsch et al. (2020) indicate production is maximized at 459,863 natural-area spawners (excluding late-fall) and the best-fit Ricker Beta implies maximum production at 449,663 natural-area spawners (excluding late-fall). Because Munsch et al. (2020) used fry rather than adults as the measure of recruits, the fitted Alpha value is not suitable for estimating S_{MSY}.

Other components of the Central Valley Fall Chinook Stock Complex

SRFC are the indicator stock for the Central Valley Fall Chinook Stock Complex, which also includes San Joaquin Fall Chinook and Sacramento Late Fall Chinook. Sacramento Late Fall Chinook are not mentioned in PFMC (1984), aside from an acknowledgment of their existence on p. 3-16. For San Joaquin Fall Chinook, p. 3-16 of PFMC (1984) states that in 1977 a goal was established based on 1972-1977[20] run sizes, but neither the run sizes nor the goal are reported. PFMC (1984, page 3-19) states, without further explanation, that "management for Sacramento River chinook [sic] within the escapement range adopted will provide adequate escapement of San Joaquin stocks to achieve spawning requirements".

For 1970-2021, the correlation between Sacramento River Fall Chinook adult escapement and San Joaquin Fall Chinook adult escapement was 0.38 (PFMC 2022b, Tables B-1 and B-2). For 1971-2021, the correlation between Sacramento River Fall Chinook adult escapement and Sacramento Late Fall Chinook adult escapement was 0.41 (PFMC 2022b, Tables B-1 and B-3).

ASETF (1979) listed an escapement of 11,000 San Joaquin Chinook under "fill present habitat" and refers to a goal of 15,000 fish. It is not clear whether these numbers include jacks and/or hatchery spawners. Estimated adult San Joaquin spawners in natural areas exceeded 11,000 in 1/11 years 2011-2021 and never exceeded 15,000 during that period; while including adults returning to hatcheries boosted returns above 15,000 in 4/11 years and above 11,000 in 7/11 years (PFMC 2022b, Table B-2). Total (including jacks) San Joaquin Fall Chinook spawners in natural areas and hatcheries combined exceeded 15,000 in 9/11 years 2011-2021 and exceeded 11,000 in one more year, but were well below 11,000 in the other year (PFMC 2022b, Table B-2).

Hallock (1977, 1978) proposed a Sacramento Late Fall Chinook escapement goal of 25,000, although it is unclear whether this includes jacks and/or hatchery returns. Total estimated returns of Sacramento Late Fall Chinook (adults and jacks, to natural areas and hatcheries combined) last exceeded 25,000 in 2002 and were below 10,000 in 9/11 years 2011-2021 (PFMC 2022b, Table B-3).

Comparability Among Different Sources in the Literature

Although there is considerable literature relevant to S_{MSY} and the conservation objective for SRFC, the different documents vary in the currency used (e.g. adults versus total spawners, fall run versus multiple run timings, treatment of hatchery spawners) and in the basis of any stated or implied goal (e.g. maximizing yield, maximizing production, filling available habitat, or "adequacy"). They also differ widely in the age, quantity, and quality of data included. Nevertheless, with some simplifying assumptions, it is possible to convert values from the

[20] It seems unlikely that an estimate of 1977 run size would be available in time to inform the choice of a goal in 1977, but this is what it is reported.

different documents to something like a common currency for a coarse comparison[21] (Table 4), although these comparisons rely on several assumptions and simplifications.

The current S_{MSY} reference point of 122,000 includes fish returning to both hatcheries and natural areas. In recent years (2012-2021), a median 69% of total adult SRFC spawners returned to natural areas (PFMC 2022b Table B-1), suggesting this reference point is roughly equivalent to a goal of 84,000 natural-area spawning adults in practice. For 1970-2021, a median 82% of SRFC adults spawned in natural areas (PFMC 2022b Table B-1), such that the S_{MSY} reference point would roughly correspond to 100,000 natural-area adult SRFC spawners.

As written, PFMC (1984) implies an upper-end natural-area adult fall run escapement "goal" (i.e., the sum of natural area contributions to the defined overall goal) of 160,000 adults (99,000 for the Upper-River, 27,000 for the Feather River, 10,000 for the Yuba River, and 24,000 for the American River, where the Yuba River contribution is based on mean 1971-1981 escapement and the other contributions are said to be based on mean 1953-1960 escapements but cannot be reproduced). Using numbers reported by Azat (2021) (which include jacks) for the stated periods yields contributions of 197,207 (excluding areas downstream of RBDD but upstream of Princeton Ferry), 51,131, 11,023, and 17,267, respectively; for an implied natural-area fall run escapement goal (including jacks) of about 277,000 at the upper end, or approximately 316,000 spawners after accounting for spawners between RBDD and Princeton Ferry. If the Upper-River contribution to the lower end is arbitrarily lowered to 50,000 (for comparability, this number should be slightly larger to include jacks, but might need to be reduced to reflect Coleman Hatchery's inclusion in the 50,000 low-end contribution), this would yield an implied lower end natural-area spawner goal of about 126,000 spawners. Including updated hatchery goals would increase all of these goals by a further 22,000.

Hallock (1977) stated a goal of 245,000 fall run spawners. Hallock (1977) is not explicit about whether this goal is for total spawners or natural-area spawners, nor about whether this includes jacks. However, average escapements reported by Hallock (1977) for various reference periods could be closely reproduced using escapement estimates from Azat (2021) including jacks and hatchery returns, so it likely includes both. For 1970-2021, 40%-94% with median 82% of total SRFC adult escapement was to natural areas (PFMC 2022b Table B-1), although this proportion has been lower in recent years. For 2012-2021, a median 69% of total SRFC adult spawners were in natural areas. Thus, the 245,000 spawner goal identified by Hallock (1977) might equate to about 200,000 or 169,000 natural-area SRFC spawners.

Various parts of ASETF (1979) imply goals of 340,000 to 431,000 adults of all runs combined. For 1971-2021 (PFMC 2021 Tables B-1 and B-3) adult SRFC natural-area spawners made up a median 69% of all adult Chinook spawners (jacks included in spring run tributary estimates) in the Sacramento Basin (including hatchery spawners). This could imply SRFC natural-area adult goals of 235,00 to 298,000 for each of the all-run goals stated previously. For 1970-2021 (PFMC 2022b Table B-1), natural area SRFC escapement ranged from 2%-35% jacks with median 13%, implying total natural-area SRFC spawner goals of 272,000 to 344,000.

[21] The calculations that follow were carried out at full precision, and so products may not exactly match the products of the rounded intermediate values reported here.

Reisenbichler (1986) analyzed multiple areas over multiple time periods. However, the 1954-1963 analysis of the Upper Sacramento uses a time period similar to the stated basis of PFMC (1984), and seems to be the source of the S_{MSY} value that appears (mislabeled as the basin-wide natural-area escapement maximizing production) in the FMP, although Resienbichler (1986) included everything above the confluence with the Feather River compared to recent practice typically referring to the Upper Sacramento above RBDD. Reisenbichler's (1986) implied S_{MSY} for the Upper Sacramento of 118,247 natural-area spawners (including jacks) implies a Sacramento basin-wide S_{MSY} of about 163,000 natural-area spawners based on a median of 72% of SRFC natural-area escapement occurring to the Upper Sacramento mainstem and tributaries above Princeton Ferry for 1954-1963 according to Azat (2021). Reisenbichler's (1986) implied S_{MSP} for the Upper Sacramento of 161,290 spawners implies an escapement of about 223,000 fall Chinook (including jacks) to natural areas for the Sacramento Basin as a whole would maximize production.

PFMC (2019) found that Upper Sacramento natural fall Chinook production was maximized at approximately 80,000 female spawners based on data from the 1998-2015 spawner years. 80,000 females implies about 160,000 spawners (which, to be consistent with assuming a 50:50 sex ratio would likely include jacks) in natural areas to maximize production, or about 126,000 Upper Sacramento fall run spawners to maximize yield given typical S_{MSY}/S_{MSP} ratios (S_{MSY}/S_{MSP} ratios for the Ricker relationships fitted to SRFC populations by Reisenbicher [1986] ranged from 0.73-0.83 with median 0.79). For the 1998-2015 spawning years used in PFMC (2019), a median 45%[22] of natural-area SRFC escapement was to the Upper Sacramento (calculated from PFMC 2022 Table B-1), implying that maximum production could be achieved with about 359,000 natural-area fall-run spawners and maximum sustainable yield for SRFC could be achieved with Sacramento Basin natural-area fall run spawning escapement (including jacks) of around 283,000, close to the level implied by Munsch et al. 2020

Munsch et al. (2020) found that a natural-area Sacramento Basin spawning escapement of around 400,000[23] fall/spring/winter runs combined would maximize production, and this number includes jacks[24]. For 1998-2015 (matching outmigration years 1999-2016 used in Munsch et al. 2020), fall run made up 76%-98% of combined fall/spring/winter run escapement to natural areas in the Sacramento Basin with median 93% (calculated from PFMC 2022 Tables B-1 and B-3, using adults only when possible), implying maximum production at 371,000 fall-run spawners. Given typical S_{MSY}/S_{MSP} ratios, this could imply an S_{MSY} of about 400,000 x 0.93 x 0.79 = about 293,000 natural-area SRFC spawners (including jacks). Despite using different measures of juvenile production, different measures of spawners, and different modeling methods, the

[22] However, this proportion is exceedingly variable, ranging from 26%-76% for 1998-2015 and from 9% to 77% for 1970-2021.

[23] According to Stu Munsch, the GAMs fitted in Munsch et al. (2020) indicate production is maximized at 459,863 natural-area spawners (excluding late-fall) and the best-fit Ricker Beta implies maximum production at 449,663 natural-area spawners (excluding late-fall).

[24] Despite some references to "spawning adults" in Munsch et al. 2020 – the intent there was to simply distinguish reproductively mature returning spawners from sexually immature juveniles in freshwater. Munsch et al. (2020) used spawner numbers from GrandTab, an earlier iteration of Azat (2021).

natural-area SRFC spawners corresponding to S_{MSY} implied by PFMC (2019) and Munsch et al. (2020) are remarkably similar[25].

Note that these calculations of MSY are based on yield of natural-origin fish (consistent with the approach employed for Klamath River Fall Chinook). Setting reference points for composite hatchery- and natural-origin stocks has long been recognized as a challenging task that risks over-harvesting the natural-origin component (Kope 1992, CA HSRG 2012 [their section 2.3]).

Errors in the FMP

Based on this literature review, several errors were identified in the FMP's description of the SRFC conservation objective and S_{MSY} derivation in Table 3-1. Suggested corrections to result in factual accuracy (assuming no changes to current management practices) are provided below in track-changes form (deletions in ~~strikethrough~~, additions in underline):

> 122,000-180,000 natural and hatchery adult spawners (122,00 is the MSY proxy adopted 1984). ~~This~~ The upper end of this objective is intended to provide adequate escapement of natural and hatchery production based on the sum of previous hatchery goals and reports of average fall Chinook escapements for various parts of the Sacramento Basin (which are inconsistent with current estimates for those years) during various reference periods (PFMC 1984). The lower end of the objective and S_{MSY} are based on a reduction from the average Upper Sacramento escapement, meant to be used until "problems caused by the Red Bluff Diversion Dam are rectified".~~ for Sacramento and San Joaquin fall and late-fall stocks based on habitat conditions and average run-sizes as follows: Sacramento River 1953-1960; San Joaquin River 1972-1977 (ASETF 1979; PFMC 1984; SRFCRT 1994).~~ The objective is less than ~~the~~ an estimated basin capacity of 24~~0~~5,000 fall-run spawners (Hallock 1977), but greater than the 118,000 spawners for maximum ~~production~~ yield estimated for natural areas in the Upper Sacramento alone, based on data from 1954-1963~~ on a basin by basin basis before Oroville and Nimbus Dams~~ (Reisenbichler 1986).

The references to late-fall and San Joaquin spawners should be removed because they are not considered in PFMC (1984). The year ranges should be removed because they are incorrect for the Yuba River portion of the Sacramento basin and averages for the named

[25] Note however that the Munch et al. (2020) calculation started from the rounded value of 400,000 total spawners and the PFMC (2019) calculator started from the rounded value of 80,000 female spawners in natural areas of the Upper Sacramento, calculations starting from full precision model estimates would be slightly different.

periods could not be even approximately reproduced for the rest of the Sacramento basin, and no run sizes for the San Joaquin were reported or used in PFMC (1984). 240,000 is not the correct number for Hallock 1977, 245,000 fall-run spawners is (the fall-run modifier is suggested because Hallock [1977] also offers numbers for other run timings and their sum). The original description of Resienbichler (1986) was inaccurate in multiple respects (production versus yield, entire basin versus Upper Sacramento) and could either be revised for accuracy, or simply dropped because as corrected it may not be a particularly useful comparison. The reference to SRFCRT (1994) should be dropped because it does not present information or analyses relevant to the choice of a specific value for S_{MSY} or the conservation objective. If the reference to ASETF (1979) is retained, it could be appropriate to point out that various parts of ASETF (1979) imply a Sacramento Basin Chinook escapement goal of 340,000-467,500 adults of all run timings combined.

In addition, p. 51 of the FMP states that salmon fisheries in California are "managed to maximize natural production consistent with meeting the U.S. obligation to Indian tribes with federally recognized fishing rights, and recreational needs in inland areas" but this is incorrect. As described earlier in this document, the current SRFC conservation objective and S_{MSY} reference point are based on an analysis that explicitly rejected an objective for natural fish, and does not attempt to quantify production. For Klamath River Fall Chinook, although natural-area fish are specifically considered, S_{MSY} and the conservation objective are based on maximizing yield, not production. Other salmon stocks in California are either managed under Endangered Species Act requirements or not actively managed.

Data and Code Availability

Grey literature or open access references cited in this report, along with data and code for calculating the summary statistics and other quantitative analyses presented here, are available at https://drive.google.com/drive/folders/1q3yBGqT4RCBZ-Q2xzS7R2_xHBs0LevF3 (access will be granted upon request if needed). Email will.satterthwaite@noaa.gov for help with access options for paywalled journal articles.

References cited

Adkison, 2022. A review of salmon spawner-recruitment analysis: The central role of the data and its impact on management strategy. Reviews in Fisheries Science & Aquaculture 30:391-427. https://www.tandfonline.com/doi/full/10.1080/23308249.2021.1972086

ASETF (Anadromous Salmonid Environmental Task Force), 1979. Freshwater habitat, salmon produced and escapements for natural spawning along the Pacific Coast of the U.S. PFMC, Portland, Oregon. 68 p. https://www.pcouncil.org/documents/2021/05/freshwater-habitat-salmon-produced-and-escapements-for-natural-spawning-along-the-pacific-coast-of-the-u-s-june-1979.pdf/

Azat, J., 2021. GrandTab 2021.06.30. California Central Valley Chinook Population Database Report. California Department of Fish and Wildlife, Sacramento, CA. https://www.calfish.org/ProgramsData/Species/CDFWAnadromousResourceAssessment.aspx

CA HSRG (California Hatchery Scientific Review Group), 2012. California Hatchery Review Report. Prepared for the US Fish and Wildlife Service and Pacific States Marine Fisheries Commission. https://swfsc-publications.fisheries.noaa.gov/publications/CR/2012/2012California.pdf

DFO (Department of Fisheries and Oceans, Canada), 2022. Proceedings of the Pacific regional peer review on methodologies and guidelines for developing Limit Reference Points for Pacific Salmon in British Columbia; March 2-4, 2022. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2022/029. https://www.dfo-mpo.gc.ca/csas-sccs/Publications/Pro-Cr/2022/2022_029-eng.html

Duda, C., 2013. Red Bluff Diversion Dam to be permanently decommissioned for salmon's benefit. Record Searchlight (newspaper article). https://archive.redding.com/news/red-bluff-diversion-dam-to-be-permanently-decommissioned-for-salmons-benefit-ep-299376979-353718741.html/

Hallock, R.J. 1977. Status of Sacramento River system salmon resource and escapement goals. California Department of Fish and Game. Prepared for PFMC, Portland, OR. 26 p.

Hallock, R.J., 1978. A description of the California Department of Fish and Game management program and goals for the Sacramento River system salmon resource. Report to the Pacific Fishery Management Council, Portland, OR. https://www.pcouncil.org/documents/1978/05/a-description-of-the-california-department-of-fish-and-game-management-program-and-goals-for-the-sacramento-river-system-salmon-resource.pdf/

Kope, R., 1992. Optimal harvest rates for mixed stocks of natural and hatchery fish. Canadian Journal of Fisheries and Aquatic Science 49:931-938. https://cdnsciencepub.com/doi/abs/10.1139/f92-103

Kormos, B. Palmer-Zwahlen, M., Low, A., 2012. Recovery of Coded-Wire Tags from Chinook Salmon in California’s Central Valley Escapement and Ocean Harvest in 2010. Cal. Depart. Fish and Game Fisheries Branch Admin. Rep. 2012-02. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=162355

Letvin, A., Palmer-Zwahlen, M., Kormos, B., 2020. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2017. Cal. Depart. Fish and Wildlife and Pacific States Marine Fisheries Comm. CDFW Ocean Salmon Project, 3637 Westwind Blvd Santa Rosa, CA 95403. https://www.calfish.org/Portals/2/Programs/CentralValley/CFM/docs/2017_CFM_CWT_Report.pdf

Letvin, A., Palmer-Zwahlen, M., Kormos, B., 2021a. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2018. Cal. Depart. Fish and Wildlife and Pacific States Marine Fisheries Comm. CDFW Ocean Salmon Project, 3637 Westwind Blvd Santa Rosa, CA 95403. https://www.calfish.org/Portals/2/Programs/CentralValley/CFM/docs/2018_CFM_CWT_Report.pdf

Letvin, A., Palmer-Zwahlen, M., Kormos, B., McHugh, P., 2021b. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2019. Cal. Depart. Fish and Wildlife and Pacific States Marine Fisheries Comm. CDFW Ocean Salmon Project, 3637 Westwind Blvd Santa Rosa, CA 95403. https://www.calfish.org/Portals/2/Programs/CentralValley/CFM/docs/2019_CFM_CWT_Report.pdf

Meek, M.H, Stephens, M.R., Goodbla, A., May, B., Baerwald, M.R., 2020. Identifying hidden biocomplexity and genomic diversity in Chinook salmon, an imperiled species with a history of anthropogenic influence. Canadian Journal of Fisheries and Aquatic Science 77:534-547. https://dx.doi.org/10.1139/cjfas-2019-0171

Munsch, S.H., Greene, C.M., Johnson, R.C., Satterthwaite, W.H., Imaki, H., Brandes, P.L., O'Farrell, M.R., 2020. Science for integrative management of a diadromous fish stock: interdependencies of fisheries, flow, and habitat restoration. Can. J. Fish. Aquat. Sci. 77, 1487–1504. https://doi.org/10.1139/cjfas-2020-0075.

Palmer-Zwahlen, M., Kormos, B., 2013. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement and Ocean Harvest in 2011. Cal. Depart. Fish and Wildlife Fisheries Branch Admin. Rep. 2013-02. https://www.rmpc.org/files/mark-mtg-2014-docs/2011_CFM_CWT_Recovery_Report_FAR_2013(Melodie_Palmer-Zwahlen).pdf

Palmer-Zwahlen, M., Kormos, B., 2015. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2012. Pacific States Marine Fisheries Comm. and Cal. Depart. Fish and Wildlife Fisheries Branch Admin. Rep. 2015-4. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=112524

Palmer-Zwahlen, M., Gusman, V., Kormos, B., 2018. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2013. Pacific States Marine Fisheries Comm. and Cal. Depart. Fish and Wildlife. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=162355

Palmer-Zwahlen, M., Gusman, V., Kormos, B., 2019a. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2014. Pacific States Marine Fisheries Comm. and Cal. Depart. Fish and Wildlife. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=166077

Palmer-Zwahlen, M., Gusman, V., Kormos, B., 2019b. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2015. Pacific States Marine Fisheries Comm. and Cal. Depart. Fish and Wildlife. CDFW Ocean Salmon Project, 3637 Westwind Blvd Santa Rosa, CA 95403. https://www.calfish.org/Portals/2/Programs/CentralValley/CFM/docs/2015_CFM_CWT_Report.pdf

Palmer-Zwahlen, M., Gusman, V., Kormos, B., 2020. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2016. Pacific States Marine Fisheries Comm. and Cal. Depart. Fish and Wildlife. CDFW Ocean Salmon Project, 3637 Westwind Blvd Santa Rosa, CA 95403. https://www.calfish.org/Portals/2/Programs/CentralValley/CFM/docs/2016_CFM_CWT_Report.pdf

PFMC (Pacific Fishery Management Council), 1984. Framework amendment for managing the ocean salmon fisheries off the coasts of Washington, Oregon and California commencing in 1985. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384. https://www.pcouncil.org/documents/1995/10/final-framework-amendment-for-managing-the-ocean-salmon-fisheries-off-the-coasts-of-washington-oregon-and-california-commencing-in-1985.pdf/

PFMC (Pacific Fishery Management Council), 2007. Final Environmental Assessment for Pacific Coast Salmon Plan Amendment 15: An Initiative to Provide for De Minimis Fishing Opportunity for Klamath River Fall-run Chinook Salmon. (Document prepared by the Pacific Fishery Management Council and National Marine Fisheries Service.) Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384. https://www.pcouncil.org/documents/2007/03/final-environmental-assessment-for-salmon-fmp-amendment-16.pdf/ [sic]

PFMC (Pacific Fishery Management Council), 2019. Salmon Rebuilding Plan for Sacramento River Fall Chinook. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384. https://www.pcouncil.org/documents/2019/07/sacramento-river-fall-chinook-salmon-rebuilding-plan-regulatory-identifier-number-0648-bi04-july-2019.pdf/

PFMC (Pacific Fishery Management Council), 2022a. Pacific Coast Salmon Fishery Management Plan for Commercial and Recreational Salmon Fisheries Off the Coasts of Washington, Oregon, and California as Amended Through Amendment 22. PFMC, Portland, OR. https://www.pcouncil.org/documents/2016/03/salmon-fmp-through-amendment-20.pdf/ [sic]

PFMC (Pacific Fishery Management Council), 2022b. Review of 2021 Ocean Salmon Fisheries: Stock Assessment and Fishery Evaluation Document for the Pacific Coast Salmon Fishery Management Plan. PFMC, Portland, OR. https://www.pcouncil.org/documents/2022/02/review-of-2021-ocean-salmon-fisheries.pdf/ with annual values for some tables only presented as period means in the print version available from https://www.pcouncil.org/documents/2019/06/escapements-to-inland-fisheries-and-spawning-areas-salmon-review-appendix-b-excel-file-format.xlsm

Quinn, T. J. II. 2013.Population Dynamics. In: Encyclopedia of Environmetrics. Wiley Online Library. https://doi.org/10.1002/9780470057339.vap028.pub2

Reisenbichler, R.R., 1986. Use of spawner-recruit relations to evaluate the effect of degraded environment and increased fishing on the abundance of fall-run Chinook salmon, *Oncorhynchus tshawytscha*, in several California streams. Ph.D. dissertation. University of Washington, Seattle, WA.

Scheuerell, M. D., 2016. An explicit solution for calculating optimum spawning stock size from Ricker's stock recruitment model. PeerJ 4:e1623. https://doi.org/10.7717/peerj.1623

SRFCRT (Sacramento River Fall Chinook Review Team), 1994. An assessment of the status of the Sacramento River fall Chinook stock. PFMC, Portland, Oregon. 44 p. Available from: https://www.pcouncil.org/documents/1994/12/sacramento-river-fall-chinook-review-team-report.pdf/

Sturrock, A.M., Satterthwaite W.H., Yoshida, K.M., Huber, E.R., Sturrock, H.J.W., Nusslé, S., Carlson, S.M., 2019. Eight decades of hatchery salmon releases in the California Central Valley: Factors influencing straying and resilience. Fisheries 44:433-444. https://doi.org/10.1002/fsh.10267

USBR (U.S. Department of the Interior Bureau of Reclamation), 2008. Record of Decision (ROD) on Final Environmental Impact Statement for Fish Passage Improvement Project at the Red Bluff Diversion Dam.

Williamson, K.S., May, B., 2005. Homogenization of fall-run Chinook salmon gene pools in the Central Valley of California, USA. North American Journal of Fisheries Management 25:993-1009. https://doi.org/10.1577/M04-136.1

Table 1. Total adult SRFC escapement and escapement to each area contributing to the SRFC conservation objective, relative to their respective contribution to the total objective. Estimates are from Table B-1 of PFMC (2022b) and the qualifiers and caveats provided there apply here as well. For 1971-1986, the reported systemwide total adult escapement was higher than the sum of reported adult escapements to the individual subareas by as much as a few hundred fish, reflecting the inclusion of fish spawning in the since-discontinued Tehama-Colusa Fish Facility. Red cells are below the conservation objective contributions. For Upper-River natural areas, yellow cells meet the 50,000 contribution (though only when combined with Coleman Hatchery in some cases) at the low end of the conservation objective but not the 99,000 natural-area contribution at the high end.

	SRFC Adult Spawners							
		Natural Areas				Hatcheries		
Year	System-Wide	Upper-River	Feather	Yuba	American	Coleman	Feather	Nimbus
GOAL	122,000-180,000	50,000-99,000	27,000	10,000	24,000	9,000	5,000	6,000
1970	156,665	61,160	45,140	11,852	25,238	3,010	2,439	7,827
1971	154,882	67,586	33,582	5,255	35,720	1,503	2,326	8,684
1972	92,157	36,485	27,130	5,555	14,962	1,188	1,414	5,352
1973	220,059	48,948	52,080	22,117	77,225	1,047	7,180	10,830
1974	202,016	66,304	53,558	16,758	51,613	1,305	4,321	7,478
1975	155,621	72,985	34,754	4,699	29,112	1,823	4,170	6,612
1976	167,865	80,263	50,724	3,087	22,163	1,799	4,299	4,313
1977	164,011	60,967	35,672	6,786	39,608	4,741	8,529	6,367
1978	126,948	66,991	29,007	6,363	11,933	1,090	3,864	6,073
1979	172,397	81,332	25,289	10,441	39,523	4,766	3,505	5,900
1980	142,109	45,504	29,077	10,260	32,352	8,800	1,107	13,538
1981	174,958	51,831	40,488	12,047	39,662	4,438	7,255	17,792
1982	164,641	39,694	40,427	23,463	29,391	16,225	6,451	8,097
1983	110,248	42,570	18,441	11,390	19,261	5,367	6,075	6,399
1984	158,972	51,772	35,378	7,104	25,993	18,668	8,842	10,289
1985	239,307	103,698	46,527	10,121	49,707	13,089	5,602	7,784
1986	240,103	113,875	40,566	16,940	46,875	11,283	5,781	4,784
1987	195,065	76,861	51,278	12,352	34,741	9,981	6,510	3,342
1988	227,467	128,725	40,215	7,110	24,646	12,594	6,156	8,021
1989	152,562	67,296	36,487	6,402	17,435	10,212	6,479	8,251
1990	105,090	50,225	25,000	3,500	4,618	13,464	4,258	4,026
1991	118,869	35,259	28,524	11,164	17,892	10,031	9,227	6,772

Year	System-Wide	Upper-River	Feat. R.	Yuba	American	Coleman	Feat. H.	Nimbus
GOAL	122,000-180,000	50,000-99,000	27,000	10,000	24,000	9,000	5,000	6,000
1992	81,545	31,734	19,790	4,517	3,816	6,257	10,324	5,107
1993	137,390	55,144	27,367	5,818	24,435	7,056	10,228	7,342
1994	165,587	66,383	31,013	7,046	30,544	11,585	11,341	7,676
1995	295,313	112,235	56,197	12,998	72,335	24,810	11,566	5,172
1996	301,633	131,268	44,593	23,492	69,761	18,848	6,494	7,177
1997	344,841	167,353	47,009	19,202	48,001	44,590	13,358	5,328
1998	245,907	60,713	39,600	26,737	48,942	42,400	17,567	9,949
1999	399,830	256,629	30,000	18,778	52,199	23,194	12,822	6,207
2000	417,537	152,923	109,924	12,954	94,161	20,793	16,470	10,312
2001	596,775	179,198	169,588	21,567	169,023	23,710	24,001	9,688
2002	769,868	474,812	93,766	18,406	97,242	61,895	17,516	6,231
2003	523,016	164,802	85,578	26,820	137,444	82,882	13,615	11,875
2004	286,885	70,548	48,580	9,260	77,842	52,145	15,769	12,741
2005	396,005	96,716	43,738	16,251	58,155	139,979	20,597	20,569
2006	275,030	89,933	75,545	7,891	23,120	56,819	13,400	8,322
2007	91,374	36,079	21,541	2,523	9,929	11,543	5,169	4,590
2008	65,364	36,274	5,703	3,084	2,255	10,181	5,031	2,836
2009	40,873	12,277	3,950	3,992	4,729	5,433	6,240	4,252
2010	124,276	25,688	40,981	12,074	12,383	8,666	17,215	7,269
2011	119,342	20,466	35,656	6,917	14,815	19,312	15,925	6,251
2012	285,429	67,190	57,507	6,009	35,527	77,318	33,628	8,250
2013	406,846	90,119	145,650	13,830	56,036	67,758	25,152	8,301
2014	212,476	80,407	55,480	9,885	22,895	17,937	18,824	7,048
2015	113,468	40,696	18,069	3,844	11,895	13,861	17,700	7,403
2016	89,699	10,563	34,054	2,143	9,537	8,306	17,594	7,502
2017	44,329	1,526	8,120	1,207	6,998	1,316	16,598	8,564
2018	105,466	18,317	39,210	2,140	12,022	8,207	21,084	4,486
2019	163,767	53,706	43,352	2,677	21,894	13,065	19,731	9,342
2020	138,091	36,447	40,499	3,801	19,422	12,478	20,340	5,104
2021	104,483	52,320	9,203	3,918	7,787	14,555	9,372	7,328

Table 2. Area-specific S_{MSY} values derived from Ricker stock-recruit parameters (arithmetic mean version, excluding grilse [jacks] when available) reported by Reisenbichler (1986) using the analytical solution for S_{MSY} derived by Scheureuell (2016). The values obtained directly from Reisenbichler (1986) seem implausibly small and conflict with his figures, and it seems likely that Reisenbichler's Table 6 reported Beta x 1000 rather than Beta x 100 as stated. The "(fixed)" columns reflect this adjustment.

Spawning Area	Years	includes jacks?	alpha	beta	beta (fixed)	S_{MSY}	S_{MSY} (fixed)
American River	1945-1955	yes	10.7	0.00071	0.000071	1,117	11,174
Feather River	1953-1966	yes	10.6	0.00025	0.000025	3,167	31,671
Feather River	1955-1966	no	13.2	0.00034	0.000034	2,432	24,318
Upper Sacramento	1950-1953	yes	12.5	0.000054	0.0000054	15,159	151,595
Upper Sacramento	1954-1963	yes	7.8	0.000062	0.0000062	11,825	118,247
Upper Sacramento*	1955-1963	no	10.4	0.000086	0.0000086	9,168	91,681
Upper Sacramento*	1955-1965	no	8.3	0.000076	0.0000076	9,815	98,153
Upper Sacramento*	1967-1979	no	10.4	0.00017	0.000017	4,638	46,380

*Excludes Battle Creek.

Table 3. Natural-area spawning escapement to maximize production (1/Beta, Quinn 2012) in areas within the Sacramento Basin based on Ricker parameters estimated by Reisenbichler (1986), assuming that the reported values were Beta x 1000 rather than Beta x 100. Estimates of Beta excluding grilse were used when available.

Spawning Area	Years	includes jacks?	Natural-area escapement to maximize production
American River	1945-1955	yes	14,085
Feather River	1953-1966	yes	40,000
Feather River	1955-1966	no	29,412
Upper Sacramento	1950-1953	yes	185,185
Upper Sacramento	1954-1963	yes	161,290
Upper Sacramento*	1955-1963	no	116,279
Upper Sacramento*	1955-1965	no	131,579
Upper Sacramento*	1967-1979	no	58,824

*Excludes Battle Creek.

Table 4. Stated (bold text) or implied levels of SRFC spawning escapement to achieve various potential objectives, based on the different documents discussed in the main text. Derivations and caveats are described in the main text. For Reisenbichler (1986), the Upper Sacramento stock-recruit relationship estimated for 1954-1963 was used because it appears to be the analysis that yielded the 118,000 figure cited in the FMP. The low end of the PFMC (1984) objective after updating it based on new goals for hatcheries and using estimated mean escapements from Azat (2021) for the years specified in PFMC (1984) is shaded because the conditions for this "interim" adjustment may no longer apply (see main text).

	goals based on unstated or ambiguous criteria				max. production	maximize yield
	adults - hat. & nat.	spawners - hat. & nat.	adults - natural	spawners - natural	spawners - natural	spawners - natural
PFMC 1984 - low end	**122,000**		84,000-100,000			
PFMC 1984 - high end	**180,000**		160,000			
PFMC 1984 - low (updated)		*148,000*		*126,000*		
PFMC 1984 - high (updated)		299,000-339,000		277,000-316,000		
Hallock 1977		**245,000**		169,000-200,000		
ASETF 1979			235,000-298,000	272,000-344,000		
Reisenbichler 1986					223,000	163,000
PFMC 2019					359,000	283,000
Munsch et al 2020					371,000	293,000

Figure 1. Escapement to the Upper Sacramento River above Red Bluff Diversion Dam, including returns to Coleman National Fish Hatchery (PFMC 2022b, Table B-1). The 1979-1983 period referred to in PFMC (1984) is highlighted, as well as the 50,000 level they expected returns to stabilize around.

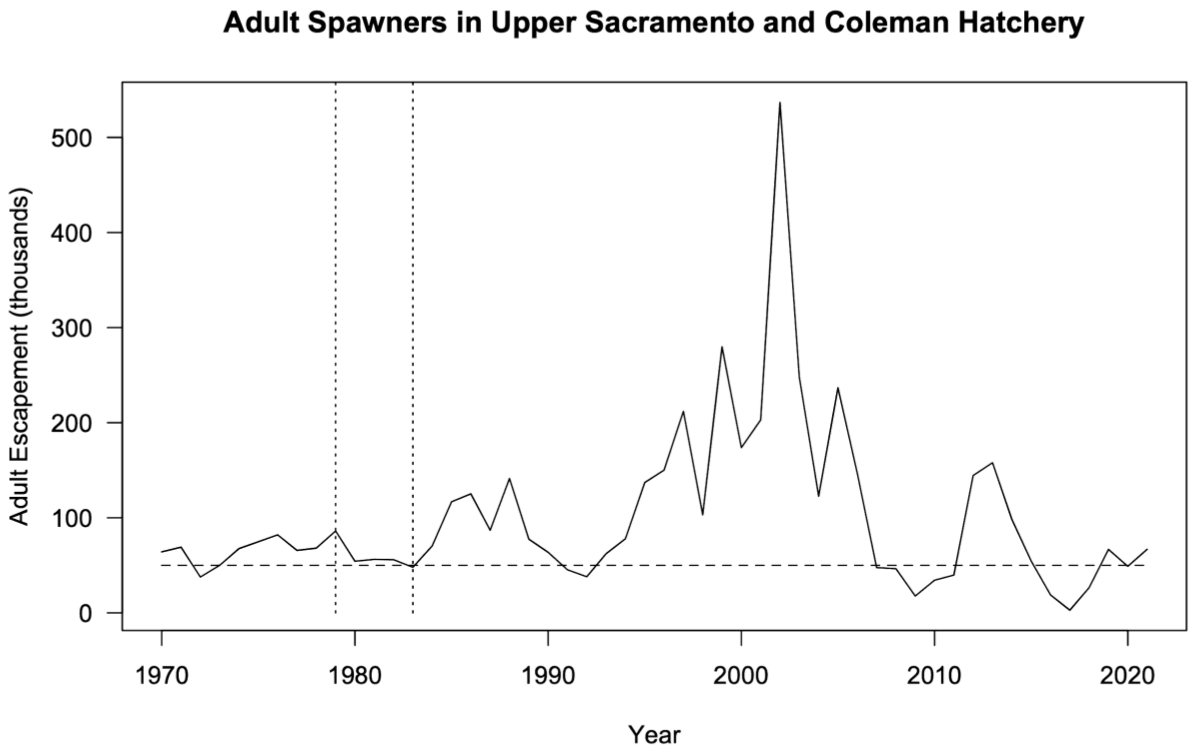
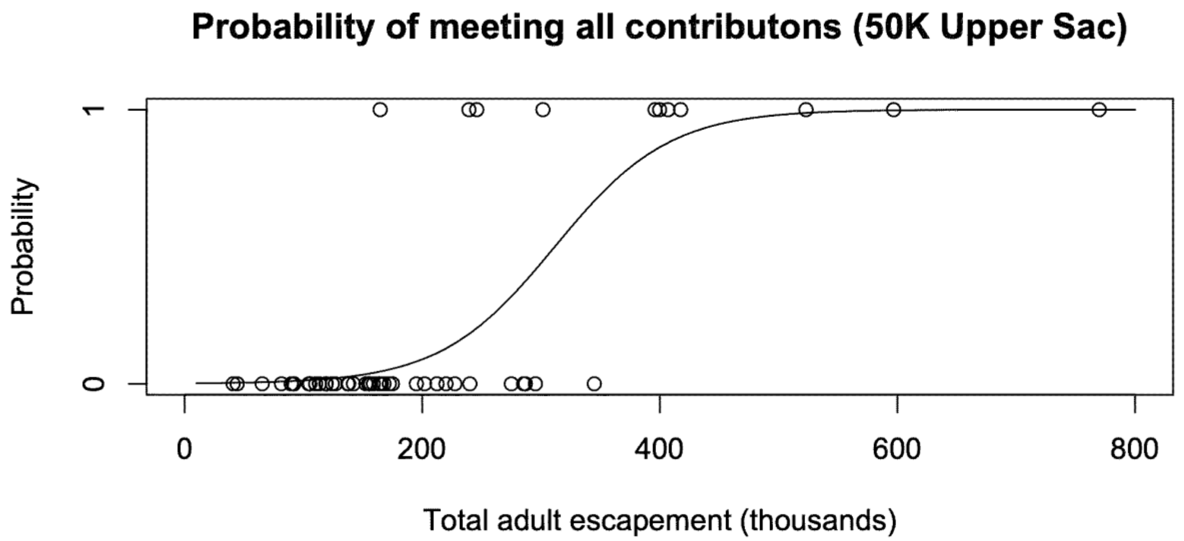


Figure 2. Logistic regression modeled probability of exceeding all areas' contributions to the SRFC conservation objective as a function of total escapement. In the top panel, the Upper-River (natural areas and hatchery combined) has a contribution of 50,000; in the bottom panel the Upper-River natural areas have a contribution of 99,000 and Coleman National Fish Hatchery has a contribution of 9,000. The line is a fitted logistic regression, circles at y=0 indicate years that did not achieve all contributions to the conservation objective, and circles at y=1 indicate years that did.



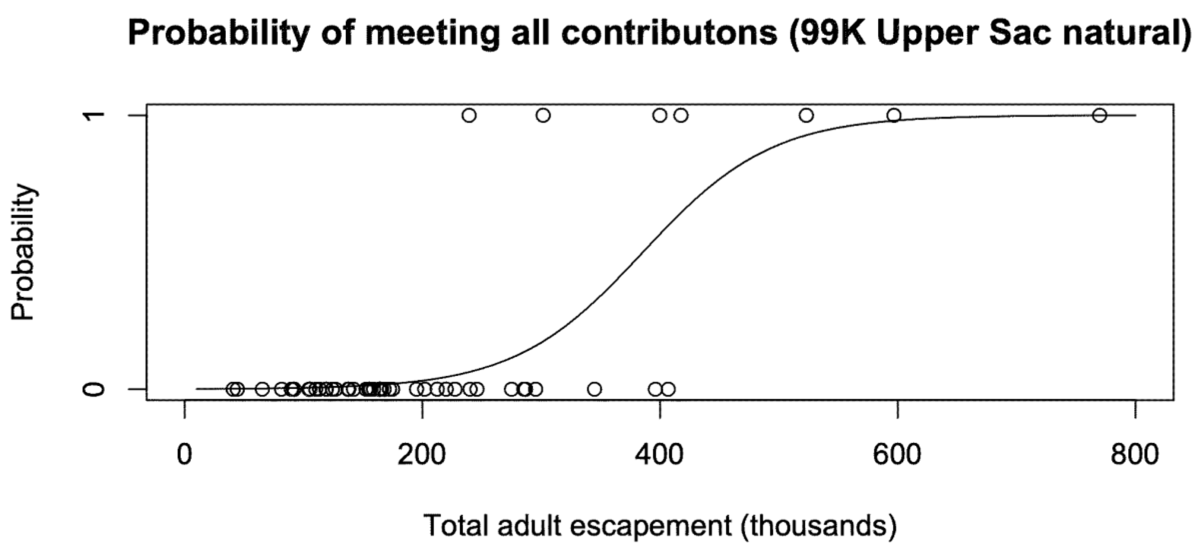


Figure 3. Fall run spawners escaping to the Yuba River (from Azat 2021). The horizontal dashed line represents the 10,000 spawners that PFMC (1984) reports escapement was "remarkably stable" around from 1971-1981, years that are highlighted with vertical dashed lines.

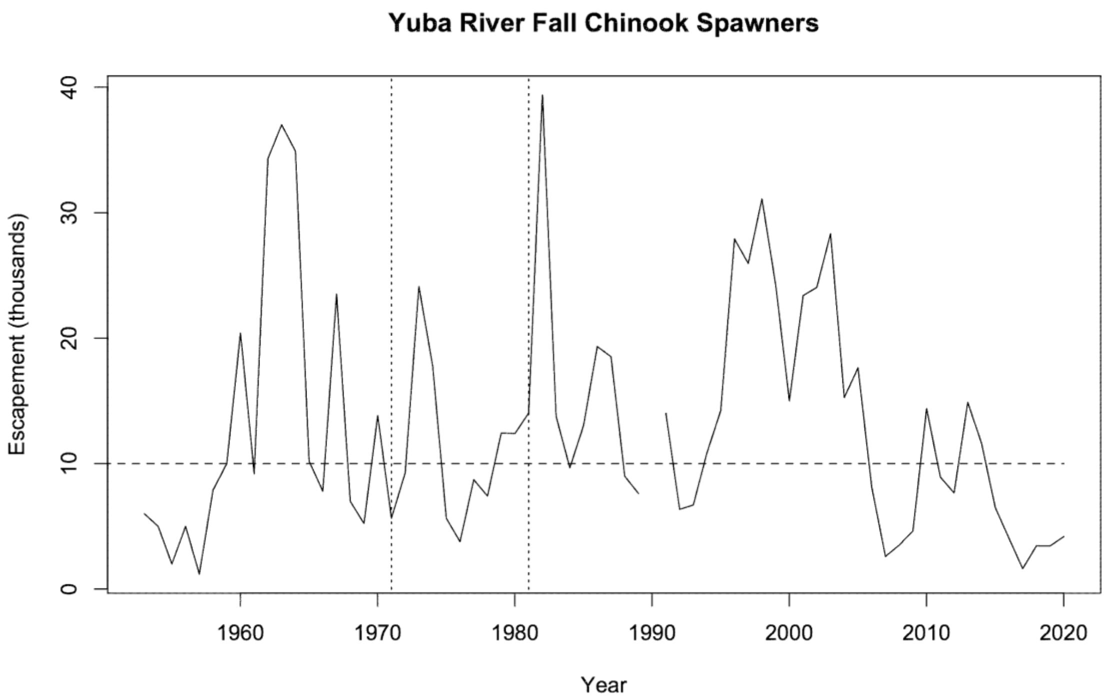


Figure 4. Composition (hatchery-origin versus natural-origin) and abundance of fall run Chinook salmon spawning in the Yuba River according to Coded-Wire Tag Recovery Reports (see citations in main text).

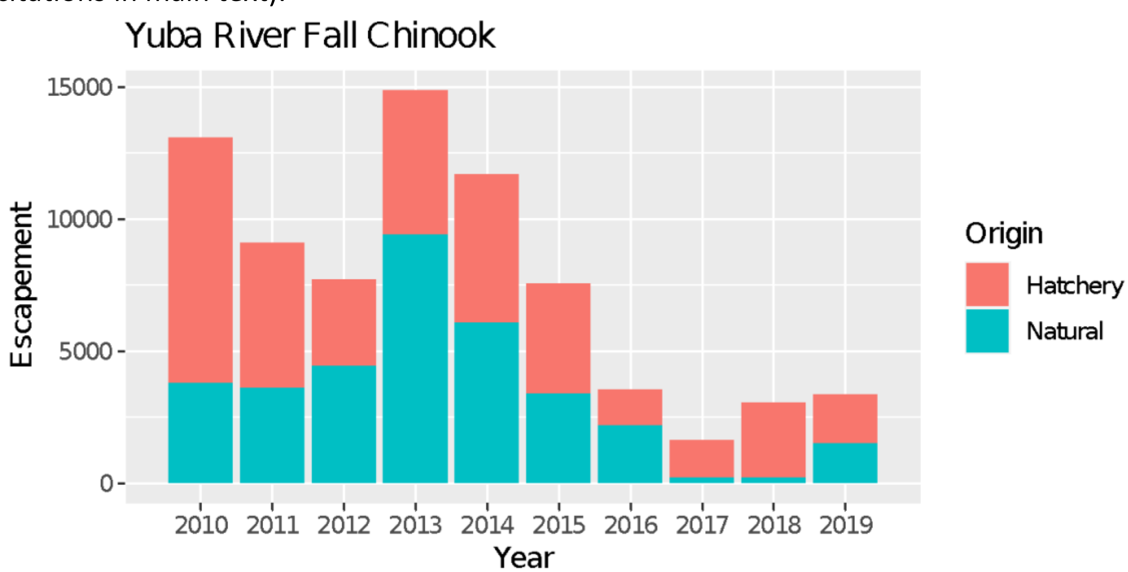
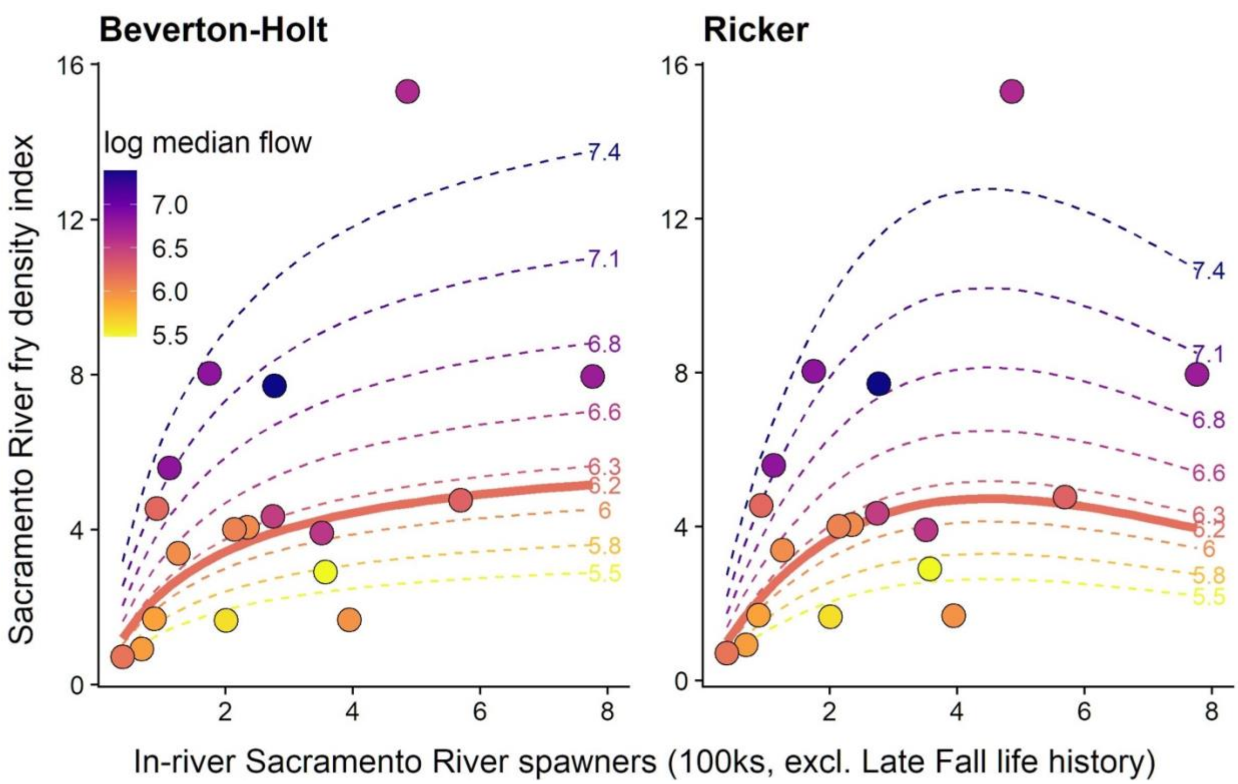
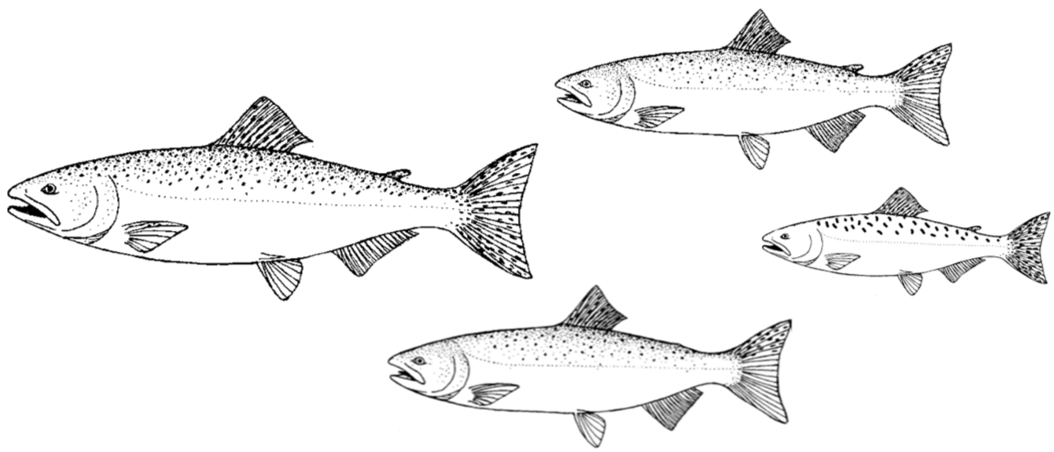


Figure 5. Annual fry density index compared with spawner abundances and flow (median flow between December and May measured at USGS flow gages 11447650 on the Sacramento River and 11303500 on the San Joaquin [two gages summed]) overlaid with predictions from the model describing the relationship among these variables. These models are parameterized by a Beverton–Holt and Ricker stock–recruitment relationships and a linear effect of log-transformed flow. The thick, solid line indicates the median value of median log-transformed flow across all years. Predictions from these top two models were shown because AIC values indicated they fit the data similarly well. Other flow metrics yielded broadly similar results, see Munsch et al. (2020) for details. Reproduced from Munsch et al. (2020) in compliance with the Creative Commons Attribution 4.0 International License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author(s) and source are credited.



PACIFIC COAST SALMON FISHERY MANAGEMENT PLAN

FOR COMMERCIAL AND RECREATIONAL SALMON FISHERIES OFF THE COASTS OF WASHINGTON, OREGON, AND CALIFORNIA AS REVISED THROUGH AMENDMENT 22



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2 ACHIEVING OPTIMUM YIELD

"Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery"

Magnuson-Stevens Act, National Standard I

This chapter explains the Council's means of meeting the requirements of the Magnuson-Stevens Act to achieve the optimum yield from the salmon fishery.

2.1 THEORY

Optimum yield (OY) means the amount of fish that will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities, and taking into account protection of marine ecosystems. It is prescribed on the basis of the maximum sustainable yield (MSY) from the fishery, reduced by any relevant economic, social, or ecological factors, and provides for rebuilding of an overfished stock, taking into account the effects of uncertainty and management imprecision.

MSY is a theoretical concept that, for the purposes of the Magnuson-Stevens Act, is defined as the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions and fishery technological characteristics, and distribution of catch among fleets. In Council management of naturally spawning salmon stocks, MSY is usually approached in terms of the number of adult spawners associated with this goal (S_{MSY}). Often, data are insufficient to directly estimate S_{MSY}. In these cases, the Council may use MSY proxies derived from more general estimates of productive capacity and implement harvest strategies that may be expected to result in a long-term average catch approximating MSY.

2.2 IMPLEMENTATION

The optimum yield to be achieved for species covered by this plan is the total salmon catch and mortality (expressed in numbers of fish) resulting from fisheries within the EEZ adjacent to the States of Washington, Oregon, and California, and in the waters of those states (including internal waters), and Idaho, that, to the greatest practical extent within pertinent legal constraints, fulfill the plan's conservation and harvest objectives. On an annual basis, the Council recommends management measures to comply with annual catch limits (ACLs) and to achieve the stock conservation objectives for each stock or stock complex, based on the estimated MSY, MSY proxy, maximum sustainable production (MSP), rebuilding schedule, or ESA consultation standard (Chapter 3), while simultaneously seeking to fulfill, to the extent practicable, the harvest and allocation objectives (Chapter 5) that reflect the Council's social and economic considerations. The subsequent catch and mortality resulting under the Council's management recommendations will embody the optimum yield. The level of total allowable harvest, the relative harvest levels in various management areas, and the species and stock composition of optimum yield will vary annually, depending on the relative abundance and distribution of the various stocks and contingencies in allocation formulas.

The Council's annual Review of Ocean Salmon Fisheries (stock assessment and fishery evaluation; SAFE) document and preseason reports (e.g., PFMC 2021a, 2021b, 2021c, and 2021d) assess and specify the present and historical range of harvests and harvest related mortalities that represent the optimum yield. A similar range of yields can be expected in the future, though further stock declines and listings under the ESA could result in even lower levels than experienced in the past.

3 CONSERVATION

"Conservation and management measures shall be based upon the best scientific information available."

Magnuson-Stevens Act, National Standard 2

Conservation of salmon stocks includes determining and reporting individual stock status and establishing conservation objectives and control rules to manage harvest. To facilitate these processes, reference points, defined by the MSA and/or National Standard 1 (NS1) Guidelines and adapted for salmon stocks are used as benchmarks.

Reference points used in the FMP include:

OFL: Overfishing Limit. Defined in NS1 Guidelines as the annual amount of catch that corresponds to the estimate of MFMT applied to a stock or complex's abundance, expressed in terms of numbers or weight of fish, and is the catch level above which overfishing is occurring.

MFMT: Maximum Fishing Mortality Threshold. Defined in NS1 Guidelines as the level of fishing mortality (F) on an annual basis, above which overfishing is occurring. MFMT is generally less than or equal to F_{MSY}.

F_{MSY}: MSY fishing mortality rate. The fishing mortality rate that results in MSY over the long term. Generally corresponds to MFMT, which is the basis of the OFL.

S_{MSY}: MSY spawner abundance. The abundance of adult spawners that is expected, on average, to produce MSY.

F_{OFL}: OFL fishing mortality rate. The level of fishing mortality (F) on an annual basis, above which overfishing is occurring; equivalent to the MFMT.

S_{OFL}: OFL spawner abundance. The abundance of adult spawners below which overfishing occurs in a given year.

ABC: Acceptable Biological Catch. Required by the MSA and defined in the NS1 Guidelines as the level of a stock or stock complex's annual catch that accounts for the scientific uncertainty in the estimate of OFL and other scientific uncertainty, and should be specified based on the ABC control rule. ABC may not exceed OFL and should be reduced from OFL to prevent overfishing.

F_{ABC}: ABC fishing mortality rate. The annual exploitation rate associated with the ABC.

ACL: Annual Catch Limit. Required by the MSA and defined in the NS1 Guidelines as the level of annual catch of a stock or stock complex that serves as the basis for invoking accountability measures. The ACL cannot exceed the ABC.

F_{ACL}: ACL fishing mortality rate. The annual exploitation rate associated with the ACL; equivalent to F_{ABC}

S_{ACL}: ACL spawner abundance. The annual abundance of adult spawners that achieves the ACL.

MSST: Minimum Stock Size Threshold. Defined in the NS1 Guidelines as level of biomass below which the stock or stock complex is considered to be overfished (see section 3.1.4). The MSST should be no less than one-half of S_{MSY}.

3.1.7 Changes or Additions to Status Determination Criteria

Status determination criteria are defined in terms of quantifiable, biologically-based reference points, or population parameters, specifically, S_{MSY}, MFMT (F_{MSY}), and MSST. These reference points are generally regarded as fixed quantities and are also the basis for the harvest control rules, which provide the operative guidance for the annual preseason planning process used to establish salmon fishing seasons that achieve OY and are used for status determinations as described above. Changes to how these status determination criteria are defined, such as MSST = 0.50*S_{MSY}, must be made through a plan amendment. However, if a comprehensive technical review of the best scientific information available provides evidence that, in the view of the STT, SSC, and the Council, justifies a modification of the estimated values of these reference points, changes to the values may be made without a plan amendment. Insofar as possible, proposed reference point changes for natural stocks will only be reviewed and approved within the schedule established for salmon methodology reviews and completed at the November meeting prior to the year in which the proposed changes would be effective and apart from the preseason planning process. SDC reference points that may be changed without an FMP amendment include: reference point objectives for hatchery stocks upon the recommendation of the pertinent federal, state, and tribal management entities; and Federal court-ordered changes. All modifications would be documented through the salmon methodology review process, and/or the Council's preseason planning process.

3.2 SALMON STOCK CONSERVATION OBJECTIVES

"To the extent practicable, an individual stock of fish shall be managed as a unit throughout its range, and interrelated stocks of fish shall be managed as a unit or in close coordination"
Magnuson-Stevens Act, National Standard 3

To achieve OY, prevent overfishing, and assure rebuilding of salmon stocks whose abundance has been depressed to an overfished level, this plan establishes conservation objectives to perpetuate the coastwide aggregate of salmon stocks covered by the plan (Chapter 1). The Council's stock conservation objectives (to be achieved annually) and other pertinent stock management information are contained in Table 3-1. Specific objectives are listed for natural and hatchery stocks that are part of the Council's preseason fishery alternative development process (Chapter 9), including all relevant stocks listed under the Federal ESA. The objectives may be applicable to a single stock independently or to an indicator stock or stocks for a stock complex. Stocks that are not included in the preseason analyses may lack specific conservation objectives because the stock is not significantly impacted by ocean fisheries or insufficient information is available to assess ocean fishery impacts directly. In the latter case, the stock will be included in a stock complex and the conservation objective for an indicator stock will provide for the conservation of closely related stocks unless, or until, more specific management information can be developed.

3.2.1 Basis

The Council's conservation objectives for natural stocks may (1) be based on estimates for achieving MSY or an MSY proxy, or (2) represent special data gathering or rebuilding strategies to approach MSY and to eventually develop MSY objectives. The objectives have generally been developed through extensive analysis by the fishery management entities with direct management authority for the stock, or through joint efforts coordinated through the Council, or with other state, tribal, or federal entities. Most of the objectives for stocks north of Cape Falcon have been included in U.S. District Court orders. Under those orders for Washington coastal and Puget Sound stocks (Hoh v. Baldrige No. 81-742 [R] C and U.S. v. Washington, 626 F. Supp. 1405 [1985]), the treaty tribes and WDFW may agree to annual spawner targets or other objectives that differ from the FMP objectives. Details of the conservation objectives in effect at the time the initial framework FMP was approved are available in PFMC (1984), in individual amendment documents (see Table 1 in the Introduction), and as referenced in Table 3-1. Updated conservation objectives and ESA consultation standards are available in Appendix A of the most recent Preseason Report I, and Table 5 of the most recent Preseason Report III produced each year by the STT (PFMC 2021d).

The Council's conservation objectives are generally expressed in terms of an annual fishery or spawning escapement estimated to be optimum for producing MSY over the long-term. The escapement objective may be (1) a specific number or a range for the desired number of adult spawners (spawner escapement), (2) a specific number or range for the desired escapement of a stock from the ocean or at another particular location, such as a dam, that may be expected to result in the target number of spawners, or (3) based on the exploitation rate that would produce MSY over the long-term. Objectives may be expressed as fixed or stepped exploitation or harvest rates and may include spawner floors or substantially reduced harvest rates at low abundance levels, or as special requirements provided in the Pacific Salmon Treaty or NMFS consultation standards for stocks listed under the ESA.

3.2.2 Changes or Additions

Conservation objectives generally are fixed quantities intended to provide the necessary guidance during the course of the annual preseason planning process to establish salmon fishing seasons that achieve OY. Changes or additions to conservation objectives may be made either through a plan amendment or notice and comment rulemaking if a comprehensive technical review of the best scientific information available provides evidence that, in the view of the STT, SSC, and the Council, justifies a modification. Insofar as possible, proposed changes for natural stocks will only be reviewed and approved within the schedule established for salmon estimation methodology reviews completed prior to the preseason planning process. The Council may change conservation objectives for hatchery stocks upon the recommendation of the pertinent federal, state, and tribal management entities. Federal court-ordered changes in conservation objectives will also be accommodated without a plan amendment. The applicable annual objectives of Council-adopted rebuilding programs and the requirements of consultation standards promulgated by NMFS under the ESA may be employed without plan amendment to assure timely implementation. All of these changes will be documented during the Council's preseason planning process.

The Council considers established conservation objectives to be stable and a technical review of biological data must provide substantial evidence that a modification is necessary. The Council's approach to conservation objectives purposely discourages frequent changes for short-term economic or social reasons at the expense of long-term benefits from the resource. However, periodic review and revision of established objectives is anticipated as additional data become available for a stock or stock complex.

TABLE 3-1. Conservation objectives and reference points governing harvest control rules and status determination criteria for salmon stocks and stock complexes in the Pacific Coast salmon FMP. These may change periodically. The most recent values are reported annually in Preseason Reports I and III. (Page 1 of 7)

CHINOOK					
Stocks In The Fishery	**Conservation Objective**	S_{MSY}	MSST	MFMT (F_{MSY})	ACL
Sacramento River Fall Indicator stock for the Central Valley fall (CVF) Chinook stock complex.	122,000-180,000 natural and hatchery adult spawners (MSY proxy adopted 1984). This objective is intended to provide adequate escapement of natural and hatchery production for Sacramento and San Joaquin fall and late-fall stocks based on habitat conditions and average run-sizes as follows: Sacramento River 1953-1960; San Joaquin River 1972-1977 (ASETF 1979; PFMC 1984; SRFCRT 1994). The objective is less than the estimated basin capacity of 240,000 spawners (Hallock 1977), but greater than the 118,000 spawners for maximum production estimated on a basin by basin basis before Oroville and Nimbus Dams (Reisenbichler 1986).	122,000	91,500	78% Proxy (SAC 2011a)	Based on F_{ABC} and annual ocean abundance. F_{ABC} is F_{MSY} reduced by Tier 2 (10%) uncertainty
Central Valley Spring ESA Threatened	NMFS ESA consultation standard/recovery plan: Conform to Sacramento River Winter Chinook ESA consultation standard (no defined objective for ocean management prior to listing).	Undefined	Undefined	Undefined	ESA consultation standard applies.
Sacramento River Winter ESA Endangered	NMFS ESA consultation standard/recovery plan: Recreational seasons: Point Arena to Pigeon Point between the first Saturday in April and the second Sunday in November; Pigeon Point to the U.S./Mexico Border between the first Saturday in April and the first Sunday in October. Minimum size limit ≥ 20 inches total length. Commercial seasons: Point Arena to the U.S./Mexico border between May 1 and September 30, except Point Reyes to Point San Pedro between October 1 and 15 (Monday through Friday). Minimum size limit ≥ 26 inches total length. Guidance from NMFS in 2010 and 2011 required implementation of additional closures and/or increased sized limits in the recreational fishery South of Point Arena. The winter-run management framework and consultation standard is an abundance based age-3 impact rate control rule established in 2018 (NMFS 2018) which sets the maximum allowable age-3 impact rate based on the forecast age-3 escapement in the absence of fisheries: above 3,000, the allowable, impact rate is fixed at 20 percent; between 3,000 and 500, the allowable impact rate declines linearly from 20 percent to 10 percent; between 500 and 0, the allowable impact rate declines linearly from 10 percent to 0 percent.	Undefined	Undefined	Undefined	
California Coastal Chinook ESA Threatened	NMFS ESA consultation standard/recovery plan: Limit ocean fisheries to no more than a 16.0% age-4 ocean harvest rate on Klamath River fall Chinook.	Undefined	Undefined	Undefined	
Klamath River Fall Indicator stock for the Southern Oregon Northern California (SONC) Chinook stock complex.	At least 32% of potential adult natural spawners, but no fewer than 40,700 naturally spawning adults in any one year. Brood escapement rate must average at least 32% over the long-term, but an individual brood may vary from this range to achieve the required tribal/nontribal annual allocation. Natural area spawners to maximize catch estimated at 40,700 adults (STT 2005).	40,700	30,525	71% (STT 2005)	Based on F_{ABC} and annual ocean abundance. F_{ABC} is F_{MSY} reduced by Tier 1 (5%) uncertainty
Klamath River - Spring	Undefined	Undefined	Undefined	Undefined	Component stock of SONC complex; ACL indicator stock is KRFC
Smith River	Undefined	Undefined	Undefined	78% Proxy (SAC 2011a)	

4. Minimize fishery mortalities for those fish not landed from all ocean salmon fisheries as consistent with achieving OY and the bycatch management specifications of Section 3.5.

5. Manage and regulate fisheries so that the OY encompasses the quantity and value of food produced, the recreational value, and the social and economic values of the fisheries.

6. Develop fair and creative approaches to managing fishing effort and evaluate and apply effort management systems as appropriate to achieve these management objectives.

7. Support the enhancement of salmon stock abundance in conjunction with fishing effort management programs to facilitate economically viable and socially acceptable commercial, recreational, and tribal seasons.

8. Achieve long-term coordination with the member states of the Council, Indian tribes with federally recognized fishing rights, Canada, the North Pacific Fishery Management Council, Alaska, and other management entities which are responsible for salmon habitat or production. Manage consistent with the Pacific Salmon Treaty and other international treaty obligations.

9. In recommending seasons, to the extent practicable, promote the safety of human life at sea.

5.2 MANAGEMENT CONSIDERATIONS BY SPECIES AND AREA

Following, are brief descriptions of the stock management considerations which guide the Council in setting fishing seasons within the major subareas of the Pacific Coast.

5.2.1 Chinook Salmon

5.2.1.1 South of latitude 40°10' N

Within this area, considerable overlap of Chinook originating in Central Valley and northern California coastal rivers occurs between Point Arena and lat. 40°10' N. Ocean commercial and recreational fisheries are managed to address impacts on Chinook stocks originating from the Central Valley, California Coast, Klamath River, Oregon Coast, and the Columbia River. With respect to California stocks, ocean commercial and recreational fisheries operating in this area are managed to maximize natural production consistent with meeting the U.S. obligation to Indian tribes with federally recognized fishing rights, and recreational needs in inland areas. Special consideration must be given to meeting the consultation or recovery standards for threatened California Coastal Chinook, for threatened Sacramento River spring Chinook and endangered Sacramento River winter Chinook in the area south of Point Arena, and for threatened Snake River fall Chinook north of Pigeon Point.

5.2.1.2 Latitude 40°10' N to Humbug Mountain (Klamath Management Zone)

Major Chinook stocks contributing to this area originate in streams located along the southern Oregon/California coasts as well as California's Central Valley. The primary Chinook run in this area is from the Klamath River system, including its major tributary, the Trinity River. Ocean commercial and recreational fisheries operating in this area are managed to maximize natural production of Klamath River fall and spring Chinook consistent with meeting the U.S. obligations to Indian tribes with federally recognized fishing rights, and recreational needs in inland areas. Ocean fisheries operating in this area must

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Appendix B and the tables it references provides additional specific information on the fishing communities.

11 SCHEDULE AND PROCEDURES FOR FMP AMENDMENT AND EMERGENCY REGULATIONS

Modifications not covered within the framework mechanism will require either an FMP amendment, rulemaking, or emergency Secretarial action. Depending on the required environmental analyses, the amendment process generally requires at least a year from the date of the initial development of the draft amendment by the Council. In order for regulations implementing an amendment to be in place at the beginning of the general fishing season (May 16), the Council will need to begin the process by no later than April of the previous season. It is not anticipated that amendments will be processed in an accelerated December-to-May schedule and implemented by emergency regulations.

Emergency regulations may be promulgated without an FMP amendment. Depending upon the level of controversy associated with the action, the Secretary can implement emergency regulations within 20 days to 45 days after receiving a request from the Council. Emergency regulations remain in effect for no more than 180 days after the date of publication in the Federal Register. A 186-day extension by publication in the *Federal Register* is possible if the public has had an opportunity to comment on the emergency regulation and the Council is actively preparing a plan amendment or proposed regulations to address the emergency on a permanent basis.

12 LITERATURE CITED

Ames, J., and D. E. Phinney. 1977. 1977 Puget Sound summer-fall Chinook methodology: escapement estimates and goals, run-size forecasts, and in-season run size updates. WDF, Technical Report No. 29. 71 p.

ASETF. 1979. Freshwater habitat, salmon produced and escapements for natural spawning along the Pacific Coast of the U.S. PFMC, Portland, Oregon. 68 p.

Bowhay, C. and P. Pattillo. 2009. Letter to Chuck Tracy, Staff Officer PFMC. September 30, 2009.

Chinook Technical Team (CTC). 1999. Pacific Salmon Commission Joint Chinook Technical Committee Report TCCHINOOK 99-3: Maximum sustainable yield or biologically based escapement goals for selected Chinook salmon stocks used by the Pacific Salmon Commission's Chinook Technical Committee for escapement assessment. Vancouver, British Columbia, Canada. 108 p.

Clark, W. G. 1983. FAB 83-39: Report of William G. Clark, Co-Chairman FAB, to the Honorable Walter E. Craig, U.S. District Judge. U.S. v. Washington #9213.

Cooney, T. D. 1984. A probing approach for determining spawning escapement goals for fall Chinook salmon on the Washington North coast. Pp. 205-213. *In*: J. M. Walton, and D. B. Houston, eds. Proceedings of the Olympic Wild Fish Conference. Peninsula College, Port Angeles, Washington, 1984. 308 p.

Hage, P., R. Hatch, and C. Smith. 1994. Memorandum entitled: Interim escapement goal for Lake Washington Chinook. WDFW Memorandum, March 28, 1994.

Hallock, R.J. 1977. Status of Sacramento River system salmon resource and escapement goals. California Department of Fish and Game. Prepared for PFMC, Portland, OR. 26 p.

Hubbell, P. M. and LB Boydstun. 1985. An assessment of the current carrying capacity of the Klamath River Basin for adult fall Chinook salmon. California Department of Fish and Game, Inland Fisheries Division, Sacramento, California. 17 p.

Johnstone, E., L. Foster, P. Pattillo. 2011. Letter to Pacific Fishery Management Council Chair Mark Cedergreen RE Amendment 16 Comments. May 31, 2011. 4 pp.

KRTT. 1986. Recommended spawning escapement policy for Klamath River fall run Chinook. Southwest Region, NMFS, Terminal Island, California. 73 p.

Lestelle, L. C., G.S. Morishima, and T.D. Cooney. 1984. Determining spawning escapement goals for wild coho salmon on the Washington north coast. Pp. 243-254. *In*: J.M. Walton, and D.B. Houston, eds. Proceedings of the Olympic Wild Fish Conference. Peninsula College, Port Angeles, Washington, 1984. 308 p.

McGie, A. M. 1982. Stock-recruitment relationships for Oregon costal fall Chinook salmon stocks. ODFW, Research and Development Section, draft report. 33 p.

McIsaac, D. O. 1990. Factors affecting the abundance of 1977-1979 brood yield of fall Chinook salmon (*Oncorhynchus tshawytscha*) in the Lewis River, Washington. Ph.D. dissertation. University of Washington, Seattle, WA.

Nickelson, T. and P. Lawson. 1996. Population dynamics of Oregon coastal coho salmon: application of a habitat based life cycle model. Pp. 1-33. *In*: Appendix III of the Oregon coastal salmon restoration initiative. ODFW. Corvallis, Oregon.

NMFS. 2006. Endangered Species Act Section 7 Consultation – Supplemental Biological Opinion. Reinitiation of Section 7 Consultation Regarding the Pacific Fisheries Management Council's Groundfish Fishery Management Plan. March 11, 2006. 34 p.

NMFS. 2018. Endangered Species Act Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat (EFH) Response. Effects on the Pacific Coast Salmon Plan Fisheries on the Sacramento River Winter-run Chinook Salmon Evolutionarily Significant Unit. NMFS West Coast Region. March 30, 2018. WCR-2017-8012.

PFMC. 1984. Framework amendment for managing the ocean salmon fisheries off the coasts of Washington, Oregon and California commencing in 1985. PFMC, Portland, Oregon. 145 p. Available at: https://www.pcouncil.org/actions/amendment-6-framework-amendment/.

PFMC. 1988. Amendment issue 1 - Klamath River fall Chinook salmon escapement goal. Pp. 2-13. *In*: Ninth Amendment to the fishery management plan for commercial and recreational salmon fisheries off the coasts of Washington, Oregon, and California commencing in 1978. PFMC, Portland, Oregon. Available at: https://www.pcouncil.org/actions/salmon-fmp-amendment-9-klamath-river-fall-chinook/.

PFMC. 1993. Final Amendment 11 to the fishery management plan for commercial and recreational salmon fisheries off the coasts of Washington, Oregon, and California commencing in 1978. PFMC, Portland, Oregon. 24 p. Available at: https://www.pcouncil.org/actions/salmon-fmp-amendment-11-ocn-coho-stock/.

PFMC. 1997a. Amendment 12 to the fishery management plan for commercial and recreational salmon fisheries off the coasts of Washington, Oregon, and California commencing in 1978. PFMC, Portland, Oregon. 19 p. Available at: https://www.pcouncil.org/documents/1997/01/groundfish-amendment-10-

1997-this-is-a-joint-amendment-with-amendment-12-to-the-salmon-plan-allowing-for-salmonids-to-be-retained-in-the-pacific-whiting-mid-water-trawl-fishery-the-regulations-im.pdf/.

PFMC. 1997b. The Pacific coast salmon plan. PFMC, Portland, Oregon. 41 p.

PFMC. 1997c. Salmon methodology review and updates, March 1985 through June 1997. PFMC, Portland, Oregon. 73 p.

PFMC. 1999. Final amendment 13 to the Pacific Coast salmon plan. PFMC, Portland, Oregon. 75 p. Available at: https://www.pcouncil.org/actions/salmon-fmp-amendment-13-fishery-management-regime-to-ensure-protection-and-rebuilding-of-oregon-coastal-natural-coho/.

PFMC. 2000a. Amendment 14 to the Pacific coast salmon plan (1997). PFMC, Portland Oregon. 133 p. Available at: https://www.pcouncil.org/actions/salmon-fmp-amendment-14-comprehensive-update-addressing-the-sustainable-fisheries-act-esa-listings-and-other-issues/.

PFMC. 2000b. 2000 Review of Amendment 13 to the Pacific Coast Salmon Plan. Portland, Oregon. 42 p.

PFMC. 2008. Council operating procedure 15 salmon estimation methodology updates and reviews, in: Council Operating Procedures (COP). PFMC, Portland, Oregon. Available at:

PFMC. 2021a. Review of 2020 ocean salmon fisheries-stock assessment and fishery evaluation document for the Pacific Coast Salmon Fishery Management Plan. PFMC, Portland, Oregon. 352 p. Available at: www.pcouncil.org.

PFMC. 2021b. Preseason report I-stock abundance analysis and environmental assessment part 1 for 2021 ocean salmon fishery regulations. PFMC, Portland, Oregon. 126 p. Available at: www.pcouncil.org.

PFMC. 2021c. Preseason report II-Proposed alternatives and environmental assessment part 2 for 2021 ocean salmon fishery regulations. PFMC, Portland, Oregon. 67 p. Available at: www.pcouncil.org.

PFMC. 2021d. Preseason report III- Council adopted management measures and environmental assessment part 3 for 2021 ocean salmon fishery regulations. PFMC, Portland, Oregon. 40 p. Available at: www.pcouncil.org.

PFMC and NMFS. 2006. Environmental Assessment for the Proposed 2006 Management Measures for the Ocean Salmon Fishery Managed Under the Pacific Coast Salmon Plan. (Document prepared by the Pacific Fishery Management Council for the National Marine Fisheries Service.) Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 200, Portland, Oregon 97220-1384. Available at: https://www.pcouncil.org/salmon-management-documents/#stocksmodelsotherkeydocs

PFMC and NMFS. 2007. Final environmental assessment for Pacific coast salmon plan Amendment 15: an initiative to provide *de minimis* ocean fishing opportunity for Klamath River fall Chinook. PFMC, Portland Oregon. 219 p.

PFMC and NMFS. 2011. Environmental assessment for Pacific coast salmon plan amendment 16: classifying stocks, revising status determination criteria, establishing annual catch limits and accountability measures, and *de minimis* fishing provisions. PFMC, Portland, Oregon. 525 p.

Pacific Salmon Treaty (PST). 2020. Treaty Between The Government of Canada and the Government of the United States of America Concerning Pacific Salmon, (Pacific Salmon Treaty), January 28, 1985, at Annex IV, Chapter 5, as revised January 1, 2020. Available at: www.psc.org

PSSSRG. 1997. Puget Sound Salmon Stock Review Group report 1997. PFMC, Portland, Oregon. 67 p.

QDNR (Quinault Department of Natural Resources) and WDFW. 2014. Development of escapement goals for Grays Harbor fall Chinook using stock-recruitment models. WDFW, Olympia, WA. 53 p.

Reisenbichler, R.R. 1986. Use of spawner-recruit relations to evaluate the effect of degraded environment and increased fishing on the abundance of fall-run Chinook salmon, *Oncorhynchus tshawytscha*, in several California streams. Ph.D. dissertation. University of Washington, Seattle, WA. 175 p.

Sacramento River Fall Chinook Review Team (SRFCRT). 1994. An assessment of the status of the Sacramento River fall Chinook stock. PFMC, Portland, Oregon. 44 p.

STT. 1997. Appendix A biological evaluation of 1997 Council ocean salmon fishery impacts on fish species listed under the Endangered Species Act. Pp. A-1 through A-6. *In*: Preseason report III analysis of Council adopted management measures for 1997 ocean salmon fisheries. PFMC, Portland, Oregon.

STT. 2000. STT Report B.2. (Final) “STT Recommendations for Hooking Mortality Rates in 2000 Recreational Ocean Chinook and Coho Fisheries”. Available at www.pcouncil.Org.

STT. 2005. Klamath River fall Chinook stock recruitment analysis. PFMC, Portland, Oregon. 31 p.

Salmon Amendment Committee (SAC). 2011a. Appendix C: Chinook F_{MSY} proxy development. *In*: environmental assessment for Pacific coast salmon plan amendment 16: classifying stocks, revising status determination criteria, establishing annual catch limits and accountability measures, and de minimis fishing provisions. PFMC, Portland, Oregon.

SAC. 2011b. Appendix E: Development of reference points for Washington coastal coho stocks. *In*: environmental assessment for Pacific coast salmon plan amendment 16: classifying stocks, revising status determination criteria, establishing annual catch limits and accountability measures, and de minimis fishing provisions. PFMC, Portland, Oregon.

Smith, C. and B. Sele. 1994. Memorandum entitled: Dungeness River Chinook escapement goal. WDFW and Jamestown S’Klallam Tribe Memorandum. July 12, 1994.

Thompson, J. 1977. Estimate of salmon escapement goals and runs for Oregon coastal streams. Memorandum to John Harville. Dec. 2, 1977, with attachments.

United States Congress. 1982. Northern Pacific Halibut Act of 1982. Available at www.GOVINFO.gov

WDF. 1979. Salmon spawning escapement objectives for Grays Harbor tributaries. WDF, Attachment to Memorandum from Bill Hopley to all concerned coastal Indian tribes. Oct. 5, 1979. 7 p.

Zillges, G.F. 1977. Methodology for Determining Puget Sound Coho Escapement Goals, Escapement Estimates, 1977 Preseason Run Size Prediction and In-season Run Assessment. Washington. Department of Fisheries Technical Report 28. 65 p.

FINAL
FRAMEWORK AMENDMENT FOR MANAGING THE OCEAN SALMON FISHERIES OFF THE COASTS OF WASHINGTON, OREGON, AND CALIFORNIA COMMENCING IN 1985

An Amendment of the "Fishery Management Plan for Commercial and Recreational Salmon Fisheries off the Coasts of Washington, Oregon, and California Commencing in 1978".

Pacific Fishery Management Council
526 SW Mill Street
Portland, Oregon 97201

October, 1984

COVER SHEET

( ) Draft (x) Final

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Title of Proposed Action

Framework Amendment for Managing the Ocean Salmon Fisheries off the Coasts of Washington, Oregon, and California Commencing in 1985.

Abstract

The proposed action is to amend the 1978 ocean salmon management plan to incorporate a flexible framework for setting preseason and inseason management measures. Under this framework amendment, certain principles and measures are fixed and cannot be altered without a plan amendment, to provide a long-term management system. Other measures are flexible and are determined before or during each season according to procedures specified in this document.

Annual natural spawning escapement goal estimates and total escapement objectives are made by the Washington Department of Fisheries and treaty tribes in status reports and distributed for public review under the provisions of U.S. v. Washington and subsequent U.S. District Court orders. After agreement to these goals is reached by the parties in this litigation, ocean fishery escapement objectives are established for each river, or region of origin, which include provisions for providing treaty allocation requirements and inside, non-Indian fishery needs.

3.5.2 Chinook

3.5.2.1 California Chinook

Escapement goals for California chinook, shown in Table 3-2, are for fall run fish. Significant populations of late fall, spring, and winter chinook also occur in the upper Sacramento River (above Feather River), but escapement goals for ocean management purposes have not been established for these stocks.

The Central Valley (Sacramento and San Joaquin Rivers) and Klamath River long-term spawning escapement goals were established in 1977 and 1978 respectively, based on averages of previous years' run sizes. The following base periods were used: Sacramento River 1953-1960, San Joaquin River 1972-1977, and Klamath River early 1960's (circa 1963). In 1980 the Central Valley goals were adjusted to address adults only and to separate hatchery and natural goals. Hatchery goals for Central Valley and Klamath River chinook are based on mitigation requirements or hatchery capacities, whichever is higher.

Sacramento River Fall Chinook

The Council considered three alternative management goals for Sacramento River fall chinook before it adopted Option 3.

Option 1: Achieve a spawning escapement goal of 99,000 natural and 9,000 hatchery chinook of upper Sacramento River origin by 1988 given average environmental conditions and contingent upon solving the problems associated with the Red Bluff Diversion Dam. A specific schedule to achieve the goal is not included in this option.

Option 2: Achieve an average 20 percent increase in spawning escapement every four years until the long-term goal of 99,000 natural spawning chinook is attained, contingent upon solving the problems at the Red Bluff Diversion Dam. The rebuilding schedule listed below is expressed as spawning escapement except for a small in-river harvest.

1983-86	65,800
1987-90	79,000
1991-94	94,800
1995-98	99,000

The following goals would be components of Options 1 and 2 for the upper Sacramento:

	Spawning Escapement Goal		Other
Lower Sacramento			
Feather River	27,000 5,000	natural hatchery	Provide for inside recreational fishery
Yuba River Suboption a: (see below) Suboption b:	20,000 10,000	natural natural	Provide for inside recreational fishery
American River	24,000 6,000	natural and hatchery	Provide for inside recreational fishery

Yuba River Fall Chinook

The Council considered two fall chinook spawning escapement goal options for the Yuba River. The 20,000 spawner goal (Suboption a) used by the state and the Council in recent years was set in 1979 at a level considerably higher than the river run sizes preceding that year. This higher escapement goal was based on recently increased flows from New Ballards Bar Dam. California Department of Fish and Game (CDFG) officials believe these higher flows have not improved production in the Yuba River, because the flows have been provided at times that are not beneficial to salmon. The higher flows soon will be reduced after diversion facilities are completed. Consequently, CDFG recommends the natural spawning escapement goal for the Yuba River be set at 10,000 fish (suboption b) which is the 1971-81 average.

Option 3 (adopted by the Council): Achieve a single river spawning escapement goal range of 122,000 to 180,000 Sacramento River chinook. Within this range annual escapements can be expected to vary. Separate goals for the upper and lower Sacramento stocks are not established. The California Department of Fish and Game has provided the following information on state distribution goals and the rationale for this option:

California Department of Fish and Game Distribution Goals for Sacramento River Fall Chinook Salmon 1/

Upper-River:	Natural	99,000
	Hatchery	9,000
Total Upper-River		108,000
Lower-River:		
Feather -	Natural	27,000
	Hatchery	5,000
Yuba -	Natural	10,000
American -	Natural	24,000
	Hatchery	6,000
Total Lower-River		72,000
Total Sacramento		180,000

1/ Distribution goals will not be used as a basis for ocean management. These will be used as management goals by agencies having in-river management responsibilities. Until passage problems at the Red Bluff Diversion Dam are corrected, the up-river distribution goals are not expected to be achieved.

Rationale for Single Sacramento River System Goal Expressed as a Range

Management of ocean fisheries by the PFMC is limited to the management of ocean harvest. Presently there are no techniques for selective management of different stocks of Sacramento River fall chinook salmon. Ocean harvest management only can provide for a target ocean escapement of Sacramento River fall chinook. Once the fish have entered the river, distribution of fish within the system is dependent on factors such as water flow, habitat, water quality, fish passage barriers, and hatchery practices. It is likely that future increases in water development, increased water export, and stream channelization will reduce the production capacity of portions of the Sacramento River system. Mitigating for these losses may necessitate increasing production in other portions of the system.

The only portion of the system currently not meeting escapement goals is the upper Sacramento River. Lower Sacramento River 1979-82 escapements have averaged 138 percent (99,700) of the new CDFG lower-river goal of 72,000 and 122 percent of the recent state goal of 82,000 chinook.

Fish passage and water quality problems are largely responsible for the upper-river spawning escapement shortfall. Since upper-river fall chinook cannot be selectively managed in the ocean fisheries, attainment of present upper-river escapement goals by reducing ocean harvest would necessitate reducing harvest of abundant lower-river stocks, thereby increasing lower-river escapement still higher over escapement goals. As an example, based on the team analysis, the restrictive USFWS proposal for managing Sacramento stocks in 1983 would have resulted in 92,000 and 193,000 adult fall chinook returning to the Upper and Lower Sacramento River systems, respectively. In 1984, returns would be even higher because two year classes would be impacted by the regulations rather than one, resulting in 130,000 and 271,000 returning to the Upper and Lower Sacramento, respectively. Since the lower-river spawning escapement goal is 72,000 salmon, restrictive regulations designed to meet upper-river goals would result in gross over-escapement into the lower-river.

For these reasons, an interim spawning escapement goal range for the Sacramento River is established until such times as the problems caused by the Red Bluff Diversion Dam are rectified, and the full production of salmon in the Upper Sacramento River can be realized. For the period 1979 to 1983, Upper Sacramento fall chinook runs have fallen from 81,700 to 51,500 adult chinook. The rate of decline appears to be slowing and will likely stabilize at about 50,000 adults. Therefore, the lower end of the aggregated Sacramento River goal range of 122,000 adult chinook is based on 50,000 upper-river adult chinook and 72,000 lower-river adult chinook.

<u>Rationale for Combined Sacramento Hatchery and Natural Escapement Goal</u>

Escapement data for the Sacramento River are grouped into four production units. Salmon stocks in three of these production units, the American River, Feather River, and upper Sacramento River, are enhanced by mitigation hatcheries.

The separation of hatchery and natural fish in these units is artificial. Returns to hatcheries on the American and Feather rivers have exceeded hatchery capacities in recent years. Once capacity is reached, the ladders are closed and fish that would have returned to the hatchery remain in the river and are counted as natural spawners. Also, naturally-produced salmon commonly return to the hatchery, thus becoming hatchery fish. In 1982 Coleman Hatchery took 7,200 fish in excess of its goal and greatly exceeded hatchery capacity. Had these fish not been taken, they would have become natural spawners.

The distinction between natural and hatchery stocks has become lost in these portions of the river. Natural spawners are those that spawn in the wild regardless of their origin. The only major tributary with a truly natural run is the Yuba River. Runs in this river have been remarkably stable from 1971-81, averaging about 10,000 adults. The run increased sharply in 1982 to 23,000. The stability of the Yuba River escapement suggests that present and past management practices have not reduced the productivity of natural stocks.

<u>San Joaquin River Escapement</u>

The San Joaquin River system is degraded severely due to water development and pollution. Increases in water transport out of the Delta will further jeopardize the continuation of these runs.

San Joaquin escapement cannot be selectively managed in the ocean. Ocean management for Sacramento River chinook within the escapement range adopted will provide adequate escapement of San Joaquin stocks to achieve spawning requirements.

Table 3-2. Summary of management goals for stocks in the salmon management unit.

System	Spawning Escapement Goal [a/]	Management Objectives: Other	Management Objectives: Rebuilding Schedule
California Central Valley Fall Chinook Adults			
Total Sacramento [b/]	Range of 122,000 to 180,000 for natural and hatchery	Provide for inside recreational fishery	As determined by the state [c/] for components of the system
Klamath Fall Chinook	97,500 natural 17,500 hatchery	Provide for inside Indian subsistence and recreational fishery	Achieve in-river run sizes (natural and hatchery combined) as follows: 1983-86 68,900 1987-90 82,700 1991-94 99,200 1995-98 115,000+ [d/]
Oregon Coastal Chinook South Coast North Coast	150-200,000 natural not yet established not yet established	Meet hatchery requirements	None
Columbia River Chinook		Manage consistent with U.S./Canada treaty if ratified; meet treaty Indian obligations and provide fish to inside non-Indian fisheries and meet hatchery requirements	The Council recognizes that certain factors at work such as (1) the implementation of the Pacific Northwest Electric Power Planning and Conservation Act, (2) the conclusion and ratification of a U.S./Canada salmon treaty, (3) renegotiation among the parties of a plan for allocation of in-river harvests of Columbia River salmon, could lead to improved status of depressed Columbia River stocks. This will require reassessment and perhaps changes in ocean and spawning escapement goals for the Columbia River as improvements are realized. Estimates of the magnitude of these changes are not possible at this time. It is recognized that current management practices which prevent directed ocean fisheries on up-river chinook stocks will be required until substantial improvements occur.
Upper-River Fall	40,000 bright adults above McNary Dam		
Upper-River Summer	80,000 adults above Bonneville		
Upper-River Spring	100-120,000 adults above Bonneville	" "	
Lower-River Fall	Meet hatchery requirements	Provide for inside net and recreational fisheries	
Lower-River Spring (Willamette)	30,000-35,000	" "	
Washington Coastal Fall Chinook	[e/] [f/]	Meet treaty allocation requirements and inside non-Indian needs	None
Washington Coastal Spring/ Summer Chinook	[e/] [f/]	" "	None
Puget Sound Chinook	[e/] [f/]	Meet treaty allocation requirements and provide fish to inside non-Indian fisheries	None
Columbia River and Oregon Coastal Coho	575,000 OPI ocean escapement 200,000 adult natural coastal spawning escapement	Provide for Columbia River treaty obligations, and inside non-Indian harvest opportunities, and hatchery requirements	Achieve escapement of natural spawning stocks as follows: (see below)

Year	Cycle 1	Cycle 2	Cycle 3
1983		140,000	
1984			135,000
1985	175,000		
1986		170,000	
1987			200,000
1988	200,000		
1989		200,000	

Table 3-2. (continued)

System	Spawning [a/] Escapement Goal	Management Objectives: Other	Management Objectives: Rebuilding Schedule
Washington Coastal Coho	- [e/]	Meet treaty obligation requirements and provide fish to inside non-Indian fisheries	None
Puget Sound Coho	[e/]	" "	
Southern B.C. Coho	not clearly established	Manage consistent with Canadian intent Manage consistent with U.S./Canada treaty, if ratified.	None
Puget Sound Pink	900,000 natural	Meet treaty allocation requirements	None
Fraser River Pink and Sockeye		Manage consistent with chinook and coho escapement needs	None
Lake Washington Sockeye	300,000 to Lake Washington	Meet treaty allocation requirements [h/]	None
Columbia River Sockeye	80,000 over Priest Rapids	[h/]	None

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a/ Represents adult natural spawning escapement goal for viable natural stocks or adult hatchery return goal for stocks managed for artificial production.

b/ The Sacramento River escapement goal is presented as a range within which annual escapements can be expected to vary. Achieving the upper end of the range, especially for the up-river chinook stock, will be contingent upon solving the problems associated with the Red Bluff Diversion Dam.

c/ The State of California has established a distribution goal for each river system which contributes to the aggregated Central Valley fall chinook goal. These distribution goals are not used as a basis for ocean management but will be used as management goals by agencies having in-river management responsibilities. The distribution goals are listed in §3.5.2.1.

d/ The long-term Klamath River escapement goal of 115,000 chinook is spawning escapement to which in-river harvest must be added to calculate the ocean escapement goal.

e/ Annual management objectives (expected hatchery plus natural escapement) for specific rivers or regions of origin are developed through fixed procedures established in the U.S. District Court. The total escapement objective is based upon either maximum sustained harvest spawning escapement goals for stocks managed primarily for natural production (Grays Harbor, Queets, Hoh, Quillayute, Strait of Juan de Fuca, Skagit, Stillaguamish/Snohomish, and Hood Canal) or upon hatchery escapement needs for stocks managed for artificial production. Total escapement objectives for each stock are established annually based on the appropriate goal. Puget Sound procedures are outlined in "Memorandum Adopting Salmon Plan" (U.S. v. Washington, 459 F. Supp. 1020 [1978]). Washington north coastal coho procedures are currently being developed via U.S. District Court order in Hoh v. Baldridge.

f/ These stocks represent a minor component of the Washington ocean harvest although ocean impact relative to terminal run size for each stock can be a management consideration.

g/ Fraser River pink and sockeye are managed primarily under jurisdiction of IPSFC which includes control of ocean harvests between the 48° and 49° parallel. Spawning escapement goals for these fish currently are established by IPSFC and under proposed terms of the draft U.S./Canada salmon treaty, would be established by Canada. State control of landings may be used to control potential impacts on coho or chinook during pink and/or sockeye fisheries.

h/ These stocks represent a negligible component of the Washington ocean harvest.

2022 Updates to Documentation of Fishery Regulation Assessment Model (FRAM)

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October 2022

The Fishery Regulation Assessment Model (FRAM) is one of the main tools used by the Pacific Fishery Management Council to model Chinook (*Oncorhynchus tshawytscha*) and Coho (*Oncorhynchus kisutch*) salmon fisheries on the West Coast of the United States.

Since completion of initial FRAM documentation (2007-2008) the model has undergone functional and design changes in response to management needs and software advancements. In 2019, a web-based, living FRAM documentation project was initiated with the goal of updating the existing documentation and providing a comprehensive repository of FRAM documentation. It can be found at https://framverse.github.io/fram_doc/. The web-based approach provides many beneficial features such as intuitive navigation through refreshed content. It facilitates ongoing development and allows the documentation to stay synchronized with the underlying FRAM application.

This project first updated the FRAM User Manual which was presented at the Methodology Review meeting in October 2019 (Auerbach, Hagen-Breaux, Dapp, Bellman, & Miler, 2019). In 2021, FRAM overview material, describing major FRAM processes, underlying data sources, and equations was added to the documentation (Shrovnal, et al., 2021) and presented in October of 2021. Since then, the SMAWG, composed of staff from the Washington Department of Fish and Wildlife (WDFW), Puget Sound Treaty Tribes, the Northwest Indian Fisheries Commission (NWIFC), and the National Oceanic and Atmospheric Administration (NOAA), has extended documentation available at the website. These efforts demonstrate the group's continued commitment to sharing the model structure and function, and they illustrate the value of a readily revised format for ongoing and timely adjustments.

As described in earlier review documents, the public FRAMverse GitHub account houses a collection of scripts and associated resources that are converted into html output for display (https://github.com/FRAMverse/fram_doc). This approach has begun to meet the goal of increased technical understanding among those interested in FRAM and its outputs. Seeking to further this understanding, several updates were undertaken to clarify existing content and to supplement it with additional descriptions without disrupting the "look and feel" of the existing site.

The top-level menu bar organization remains unchanged, presenting a user with the options of "Overview", "Model Detail", "Pre and Post Season FRAM", "Base Period" and "User Manual". Within the "Model Detail" sections for Chinook and Coho salmon, equation formatting has been revised to illustrate the origin of terms (Figure 1). User input values that are "external" and subject to change on any given model run are shown in bold, in contrast to values calculated by FRAM during forward runs in italics, and during backwards runs in blue. In addition, values calculated during base period calibration are shown as underlined. This may assist a reader conceptually, better indicating how different types and sources of information are combined within the model.

The Chinook and Coho "Model Detail" sections now include new or expanded treatments of non-retention (both species), size limit evaluation (Chinook), and mark selective fishery (MSF) bias correction (Coho). For both species, substantially expanded descriptions of non-retention calculations are within the "Model Calculations - Computational Process" chapter 4.2 subsection 3, addressing fishery-related mortality (Figure 2). The Chinook equations address the additional complexity of representing legal and sublegal portions of cohorts. Chinook salmon fisheries in FRAM can include minimum size limits for retained fish, and the new section "Model Calculations – Size Limit Evaluations" addresses the adjustments involved when model runs include changes from the values that were in place during the base period years (Figure 3). The conceptual basis for and model implementation of bias corrections in Coho MSFs are also included in a significantly expanded section (Figure 4).

The top level "Base Period" section has been supplemented with an appendix containing data from 30 underlying tables used during the Chinook base period calibration process, as well as an extensive log of the modifications made from the first version of the calibration produced in 2016 through the current version produced in 2021, Round 7.1.1 (Figure 5). These complement the assumptions and methods covered in the "Model Detail" sections, providing supporting values for terms in many of the equations throughout the "Calculations".

Beyond incorporating methodology review, user feedback, and minor corrections, the SMAWG anticipates future progress towards fully comprehensive documentation. That progress will likely include additional content regarding Backwards FRAM (i.e., the iterative process by which stock-specific coefficients are adjusted to generate starting cohorts that yield input, target endpoints), more details on Terminal Area Management Modules (TAMM) processes for both species (e.g., WA coastal iterations for Coho and/or river-specific calculations for Chinook), options to perform brood year (rather than fishing year) calculations, and other topics as needed. Future changes may also affect overall site design and functionality, while prioritizing familiar, stable navigation whenever possible.

4.2. Computational Processes

In the following equations, variables are presented with origin specific formatting:

- Variables estimated in FRAM are shown in regular *italics*.
- Variables that are input by a user, including externally estimated values, are shown as **bold**.
- Variables that are estimated during the base period are shown with an underline.
- Variables that are estimated using a BkFRAM run are shown as blue.

Cohort Abundance

Process 1: Cohort abundance at the start of the time step

The starting cohort size in time step 1 is a product of two parameters: (*1*) the base period cohort abundance for stock *s* at age *a* ($BPCohorts_{s,\,a}$) and (*2*) a stock and age-specific recruit scaler ($StockScalers_{s,\,a}$).

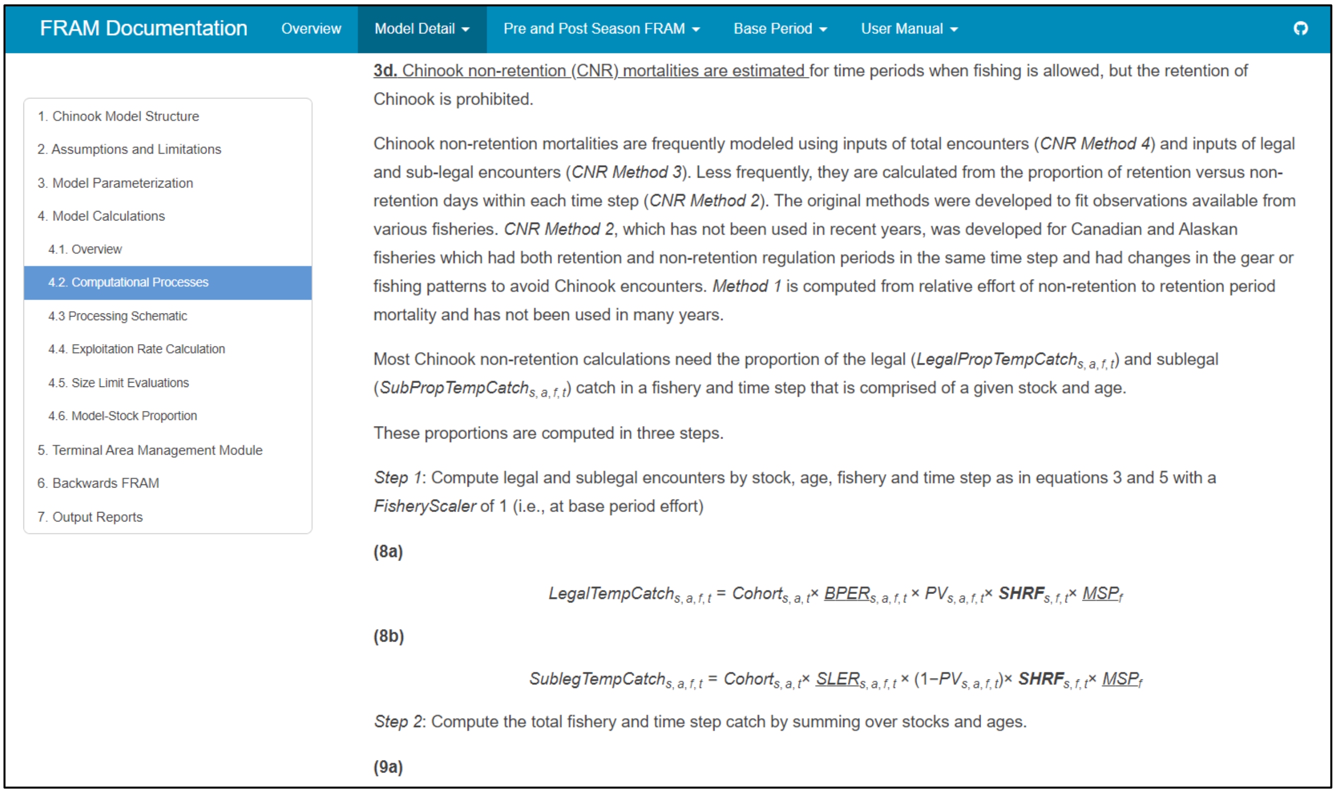
The starting cohort is generally calculated from pre-season forecasts or post-season assessments of terminal run size during Backwards FRAM (BkFRAM) calculations. BkFRAM produces starting cohorts by expanding terminal run sizes for maturation, preterminal fisheries, and natural mortalities (see Backwards FRAM chapter).

(1)

$$Cohort_{s,\,a,\,t=1} = \underline{BPCohort}_{s,\,a} \times StockScaler_{s,\,a}$$

where $Cohort_{s,\,a,\,t=1}$ is the initial cohort size for stock *s*, age *a*, during time step *t*=1.

Figure 1: Updated equation formatting indicates sources of terms.



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3d. Chinook non-retention (CNR) mortalities are estimated for time periods when fishing is allowed, but the retention of Chinook is prohibited.

Chinook non-retention mortalities are frequently modeled using inputs of total encounters (*CNR Method 4*) and inputs of legal and sub-legal encounters (*CNR Method 3*). Less frequently, they are calculated from the proportion of retention versus non-retention days within each time step (*CNR Method 2*). The original methods were developed to fit observations available from various fisheries. *CNR Method 2*, which has not been used in recent years, was developed for Canadian and Alaskan fisheries which had both retention and non-retention regulation periods in the same time step and had changes in the gear or fishing patterns to avoid Chinook encounters. *Method 1* is computed from relative effort of non-retention to retention period mortality and has not been used in many years.

Most Chinook non-retention calculations need the proportion of the legal ($LegalPropTempCatch_{s,a,f,t}$) and sublegal ($SubPropTempCatch_{s,a,f,t}$) catch in a fishery and time step that is comprised of a given stock and age.

These proportions are computed in three steps.

Step 1: Compute legal and sublegal encounters by stock, age, fishery and time step as in equations 3 and 5 with a *FisheryScaler* of 1 (i.e., at base period effort)

(8a)

$$LegalTempCatch_{s,a,f,t} = Cohort_{s,a,t} \times \underline{BPER}_{s,a,f,t} \times PV_{s,a,f,t} \times \mathbf{SHRF}_{s,f,t} \times \underline{MSP}_{f}$$

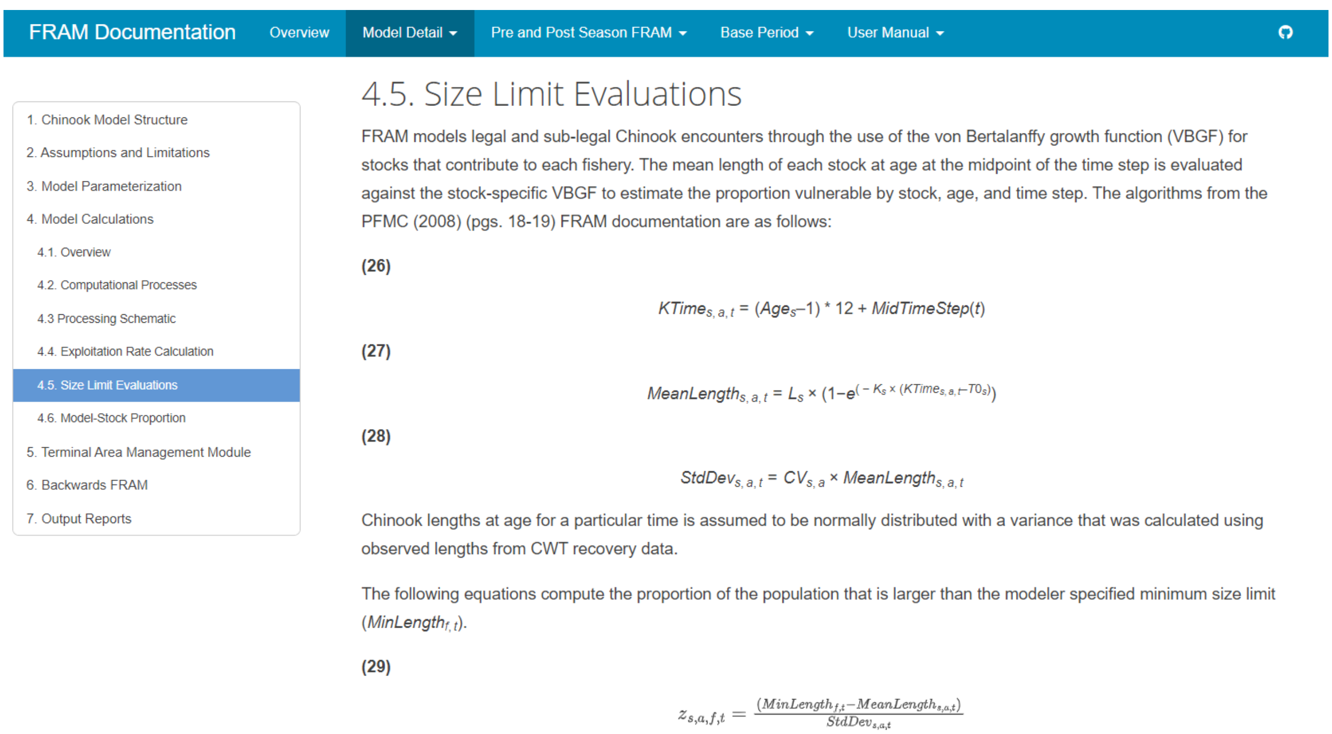
(8b)

$$SublegTempCatch_{s,a,f,t} = Cohort_{s,a,t} \times \underline{SLER}_{s,a,f,t} \times (1-PV_{s,a,f,t}) \times \mathbf{SHRF}_{s,f,t} \times \underline{MSP}_{f}$$

Step 2: Compute the total fishery and time step catch by summing over stocks and ages.

(9a)

Figure 2 An excerpt of the expanded non-retention mortality calculations, here shown for Chinook.



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4.5. Size Limit Evaluations

FRAM models legal and sub-legal Chinook encounters through the use of the von Bertalanffy growth function (VBGF) for stocks that contribute to each fishery. The mean length of each stock at age at the midpoint of the time step is evaluated against the stock-specific VBGF to estimate the proportion vulnerable by stock, age, and time step. The algorithms from the PFMC (2008) (pgs. 18-19) FRAM documentation are as follows:

(26)

$$KTime_{s,a,t} = (Age_{s}-1) * 12 + MidTimeStep(t)$$

(27)

$$MeanLength_{s,a,t} = L_{s} \times (1-e^{(-K_{s} \times (KTime_{s,a,t}-T0_{s})})$$

(28)

$$StdDev_{s,a,t} = CV_{s,a} \times MeanLength_{s,a,t}$$

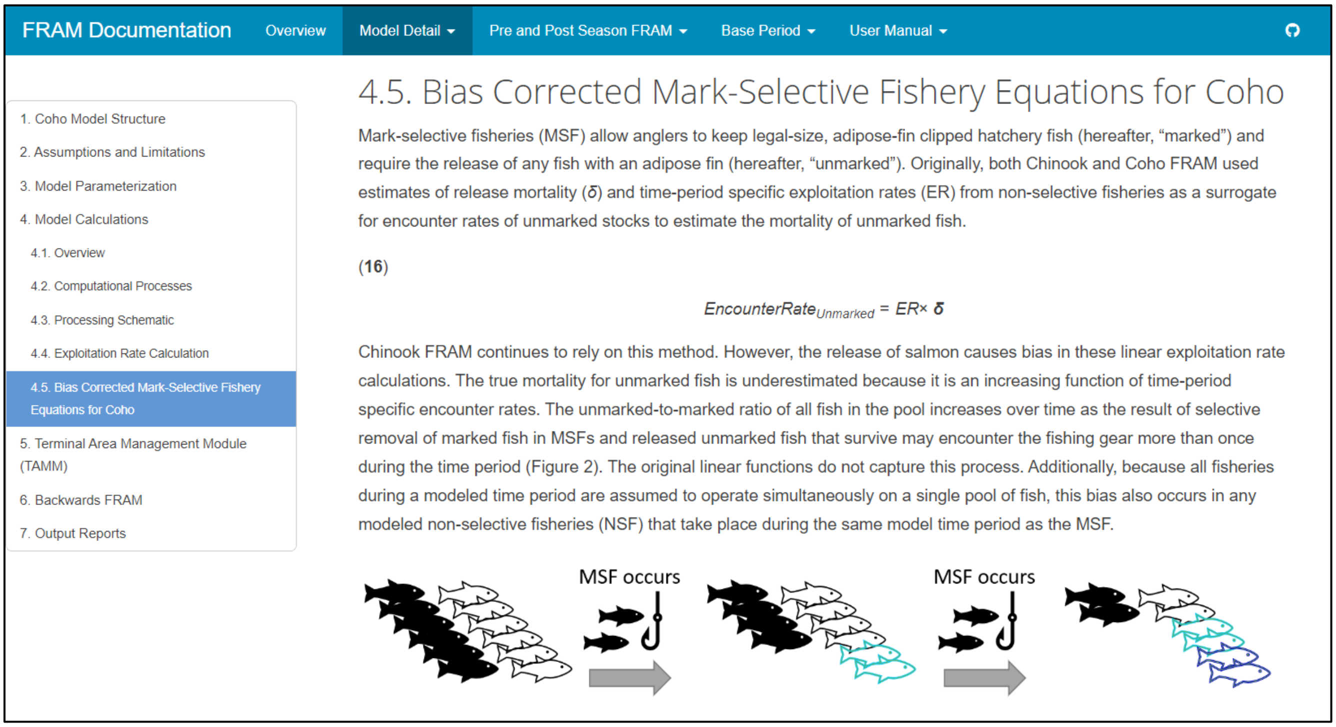
Chinook lengths at age for a particular time is assumed to be normally distributed with a variance that was calculated using observed lengths from CWT recovery data.

The following equations compute the proportion of the population that is larger than the modeler specified minimum size limit ($MinLength_{f,t}$).

(29)

$$z_{s,a,f,t} = \frac{(MinLength_{f,t} - MeanLength_{s,a,t})}{StdDev_{s,a,t}}$$

Figure 3 Start of the new section addressing the process of altered size limits in Chinook fisheries.



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4.5. Bias Corrected Mark-Selective Fishery Equations for Coho

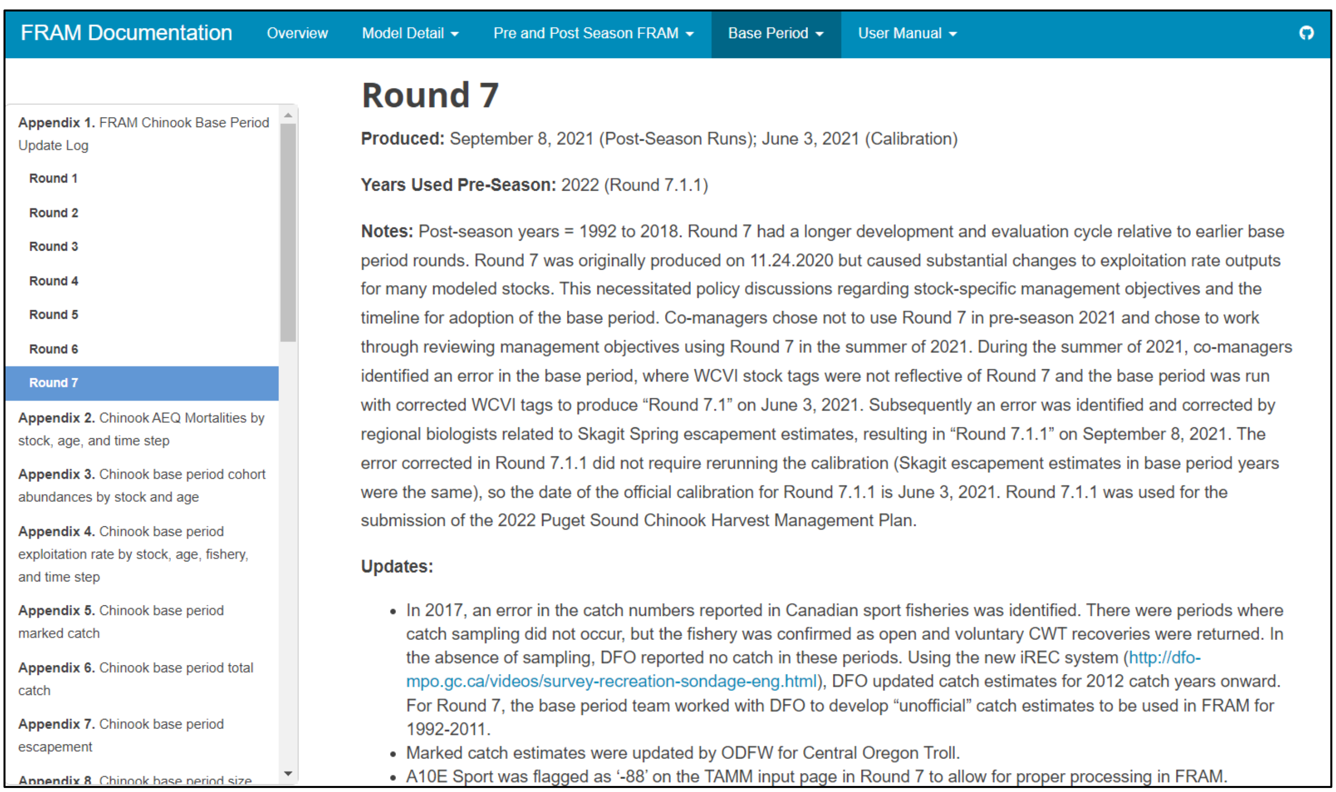
Mark-selective fisheries (MSF) allow anglers to keep legal-size, adipose-fin clipped hatchery fish (hereafter, “marked”) and require the release of any fish with an adipose fin (hereafter, “unmarked”). Originally, both Chinook and Coho FRAM used estimates of release mortality (δ) and time-period specific exploitation rates (ER) from non-selective fisheries as a surrogate for encounter rates of unmarked stocks to estimate the mortality of unmarked fish.

(**16**)

$$EncounterRate_{Unmarked} = ER \times \delta$$

Chinook FRAM continues to rely on this method. However, the release of salmon causes bias in these linear exploitation rate calculations. The true mortality for unmarked fish is underestimated because it is an increasing function of time-period specific encounter rates. The unmarked-to-marked ratio of all fish in the pool increases over time as the result of selective removal of marked fish in MSFs and released unmarked fish that survive may encounter the fishing gear more than once during the time period (Figure 2). The original linear functions do not capture this process. Additionally, because all fisheries during a modeled time period are assumed to operate simultaneously on a single pool of fish, this bias also occurs in any modeled non-selective fisheries (NSF) that take place during the same model time period as the MSF.

Figure 4 The beginning of the expanded section describing the rational for and equations to implement bias corrections for unmarked mortality in Coho mark-selective fisheries.



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Round 7

Produced: September 8, 2021 (Post-Season Runs); June 3, 2021 (Calibration)

Years Used Pre-Season: 2022 (Round 7.1.1)

Notes: Post-season years = 1992 to 2018. Round 7 had a longer development and evaluation cycle relative to earlier base period rounds. Round 7 was originally produced on 11.24.2020 but caused substantial changes to exploitation rate outputs for many modeled stocks. This necessitated policy discussions regarding stock-specific management objectives and the timeline for adoption of the base period. Co-managers chose not to use Round 7 in pre-season 2021 and chose to work through reviewing management objectives using Round 7 in the summer of 2021. During the summer of 2021, co-managers identified an error in the base period, where WCVI stock tags were not reflective of Round 7 and the base period was run with corrected WCVI tags to produce “Round 7.1” on June 3, 2021. Subsequently an error was identified and corrected by regional biologists related to Skagit Spring escapement estimates, resulting in “Round 7.1.1” on September 8, 2021. The error corrected in Round 7.1.1 did not require rerunning the calibration (Skagit escapement estimates in base period years were the same), so the date of the official calibration for Round 7.1.1 is June 3, 2021. Round 7.1.1 was used for the submission of the 2022 Puget Sound Chinook Harvest Management Plan.

Updates:

- In 2017, an error in the catch numbers reported in Canadian sport fisheries was identified. There were periods where catch sampling did not occur, but the fishery was confirmed as open and voluntary CWT recoveries were returned. In the absence of sampling, DFO reported no catch in these periods. Using the new iREC system (http://dfo-mpo.gc.ca/videos/survey-recreation-sondage-eng.html), DFO updated catch estimates for 2012 catch years onward. For Round 7, the base period team worked with DFO to develop “unofficial” catch estimates to be used in FRAM for 1992-2011.
- Marked catch estimates were updated by ODFW for Central Oregon Troll.
- A10E Sport was flagged as ‘-88’ on the TAMM input page in Round 7 to allow for proper processing in FRAM.

Figure 5 The beginning of the newly added Chinook base period update log providing a valuable history of adjustments made over the course of re-developing calibrations (based on fishing years 2007-13).

Auerbach, D., Hagen-Breaux, A., Dapp, D., Bellman, M., & Miler, O. (2019). *Updating the Fishery Regulation Assessment Model (FRAM) User Manual.* Agenda Item E.2 Attachment 4, November 2019. Pacific Fishery Management Council, Portland, OR. https://www.pcouncil.org/documents/2019/10/agenda-item-e-2-attachment-4-updating-the-fishery-regulation-assessment-model-fram-user-manual.pdf/.

Shrovnal, J., Hagen-Breaux, A., Auerbach, D., Dapp, D., Bellman, M., Johnson, G., Miler, O., Thurner, S., Carey, J. (2021). *Updated Documentation of the Fishery Regulation Assemessment Model (FRAM).* Agenda Item F.1 Attachment 1, November 2021. Pacific Fishery Management Council, Portland, OR. https://www.pcouncil.org/documents/2021/10/f-1-attachment-1-updated-documentation-of-the-fishery-regulation-assessment-model-fram.pdf/.