Appendix 2C
Winter-run Chinook Salmon Juvenile Production Estimates

This document provides background information about the winter-run Chinook Salmon Juvenile Production Estimate (JPE) and describes how it is calculated, the process for producing an annual JPE, and how it will be utilized to manage Long-term Operations of the State Water Project (SWP) and Central Valley Project (CVP).

2C.1 Background

The winter-run JPE is a forecast of the number of winter-run Chinook Salmon (winter-run) juveniles expected to reach the Sacramento–San Joaquin Delta (Delta) each year. It is used to set loss thresholds that will adjust flow management in Old and Middle River (OMR) to minimize impacts of the State and Federal water project pumping facilities on outmigrating winter-run.

Using a JPE to scale allowable take was first introduced in the 1993 National Marine Fisheries Service (NMFS) Biological Opinion for Long-term Operations of the CVP and SWP, and was used to reduce take. JPE letters are available on the NMFS website.

2C.1.1 Early JPE Methods

The winter-run JPE has been calculated several different ways since its inception, based on the best information available to make an estimate at that time. When new or better information was available to calculate a JPE, the method and/or inputs were updated. Early JPE methods all had a similar structure, starting with estimates of female spawners and fecundity and including various survival factors to account for mortality between the egg and smolt stages. Below is a timeline of changes made to the JPE inputs and calculations since 1993 (years shown are BYs), summarized from annual JPE letters:

- 1993: The first JPE was issued. Escapement was estimated based on counts at the fish ladder at Red Bluff Diversion Dam (RBDD). Pre-spawn mortality (5%), sex ratio (50:50), and fecundity (3,353–3,859) were estimated from literature or best professional judgement. Egg mortality due to temperature and dewatering were estimated using a linear regression temperature model and aerial redd surveys. Egg-to-fry survival (25%) was assumed based on U.S. Fish and Wildlife Service (USFWS) studies in the Tehama–Colusa spawning channel from 1975–1980, and fry-to smolt survival (59%) was assumed based on Hallock (undated). The number of smolts released from the Livingston Stone National Fish Hatchery (LSNFH) was added to the JPE without differentiation from natural production. There was not a separate factor for survival to the Delta.
- **2000:** Fecundity was estimated from winter-run females spawned at LSNFH. No other factors changed.

- **2001:** Escapement, number of females, and pre-spawn mortality were estimated by carcass surveys, using the Jolly-Seber model. A factor was added to estimate smolt survival between RBDD and the Delta (52–56%) for natural-origin juveniles; this factor is based on average differential ocean recovery rates of paired releases of coded-wire-tagged late-fall-run Chinook Salmon in Battle Creek and the Delta and was updated with new data when available.
- **2002:** NMFS began developing separate JPE forecasts for hatchery-origin and natural-origin winter-run. The same smolt survival term (52-56%) was applied to releases of winter-run smolts from LSNFH to account for survival between release and the Delta.
- **2010:** Egg-to-fry survival was based on the long term average juvenile passage estimate, calculated at the juvenile monitoring stations at RBDD, divided by female spawners, calculated from carcass surveys.
- **2013:** Smolt survival rates were estimated using the weighted average of late-fall-run and winter-run acoustic tag studies for natural-origin smolts, and winter-run acoustic tag studies for hatchery-origin smolts.
- **2014:** Shift to the JPI Method, which calculated the JPE from estimates of juvenile production from monitoring at RBDD, rather than carcass surveys (see section below).

2C.1.2 JPI-based JPE Method (BY 2014-2018)

The method for calculating the JPE shifted in BY 2014, after a review by the Interagency Ecological Program's winter-run Chinook Salmon Project Work Team (Winter-run PWT) found that the previous method overestimated the number of juveniles entering the Delta on average by 400 percent (National Marine Fisheries Service 2014). The Winter-run PWT also recommended that the JPE be revisited annually and updated as needed with any new or improved information. The equation for calculating the JPE using the JPI-based method is shown in Equation 2C-1.

From BY 2014–2019, the JPE calculation was calculated using estimates of the number of "fry equivalents" passing RBDD (Juvenile Production Index or JPI_{Fry}), an estimated fry-to-smolt survival rate of 0.59 (Hallock, undated), and an estimated smolt migration survival rate based on average survival from acoustic tagged smolts from LSNFH (Figure 2C-1). By starting with an estimate of fry production rather than female spawners, this method reduced uncertainty related to the large number of survival factors that need to be estimated. It also better represented survival differences due to environmental conditions during spawning, egg incubation, and rearing upstream of RBDD.

2C.1.3 Current "Method 2" JPI-based JPE Calculation Method (BY 2019-present)

Since BY 2019 (JPE applied in water year 2020), the winter-run JPE has consistently been calculated using the same method, although the factors used to calculate it are updated each year to include new available data. Described in O'Farrell et al. (2018) as "Method 2," this JPE method (Equation 2C-1) has a similar structure to the method used from 2014-2018, but it uses different methods to estimate survival rates for fry-to-smolt ($Survival_{Fry\text{-}to\text{-}Smolt}$) and smolt migration ($Survival_{Smolt}$).

Equation 2C-1:

$$JPE_{Natural} = JPI_{Fry} \times Survival_{Fry-to-Smolt} \times Survival_{Smolt}$$

The Juvenile Production Index (JPI_{Fry}) is an estimate of the number of juveniles passing the monitoring stations at RBDD, extrapolated for the remainder of the season and converted to "fry equivalents" to account for mortality between the fry and smolt stage. The fry-to-smolt survival rate ($Survival_{Fry\text{-}to\text{-}Smolt}$) is the estimated slope of a zero-intercept linear model fitted to estimates of hatchery-origin juvenile survival rates and natural-origin juvenile survival rates (O'Farrell et al. 2018). $Survival_{Fry\text{-}to\text{-}Smolt}$ is also the factor used to convert juvenile passage estimates at RBDD to "fry equivalents" for JPI_{Fry}, based on the peak of fry catch (generally in October) and the smolt life-stage for natural-origin winter-run at RBDD. The survival rate for smolt migration ($Survival_{Smolt}$) from RBDD to the Delta (i.e., Sacramento at the I-80/I-50 Bridge) is estimated using the variance-weighted mean of survival estimates from acoustic tagged LSNFH smolts released (2013-present) and uses the Cormack-Jolly-Seber model which accounts for variation in detection probabilities. Both survival parameters ($Survival_{Fry\text{-}to\text{-}Smolt}$ and $Survival_{Smolt}$) are updated annually to incorporate new data collected since the previous year (Table 2C-1).

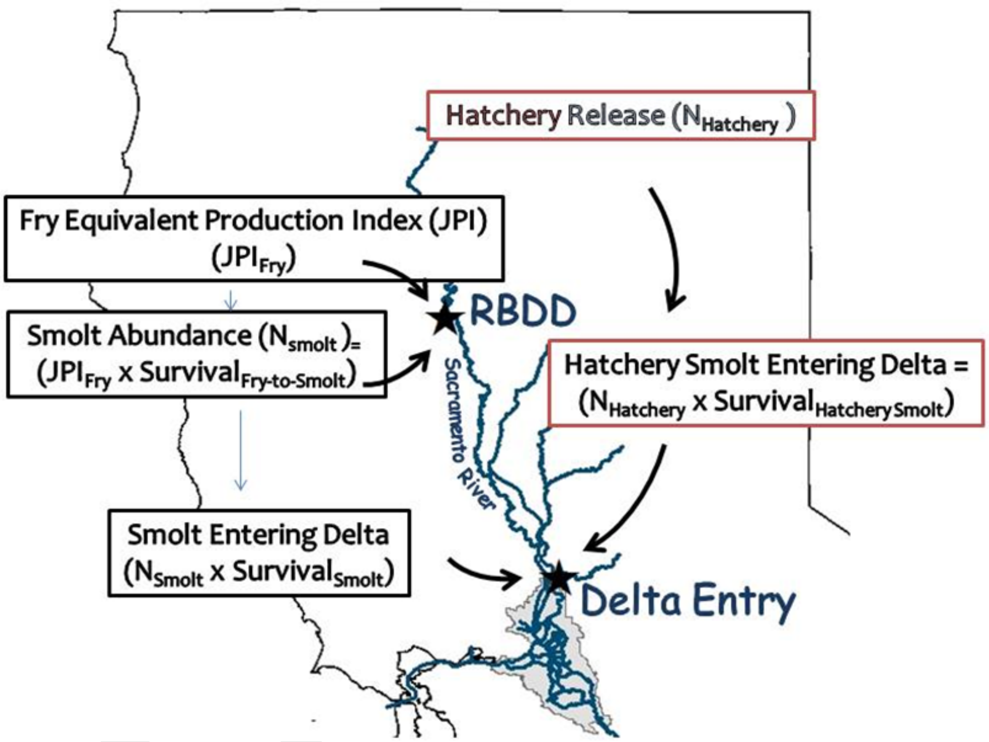

Figure 2C-1. Location and formulas used to calculate the Juvenile Production Estimate from 2014-present

A similar calculation is used to forecast the number of hatchery-origin winter-run Chinook Salmon entering the Delta each year, although it requires fewer parameters because the release numbers are known ($N_{Hatchery}$) and fish are released as smolts. Survival of hatchery smolts from release to the Delta ($Survival_{HatcherySmolt}$) is estimated by the variance-weighted mean of survival rates from LSNFH release to the Delta (2013-present). Separate JPEs are calculated for different release groups and accounted for separately in tracking.

Equation 2C-2:

$$JPE_{Hatchery} = N_{Hatchery} \times Survival_{HatcherySmolt}$$

Beginning in 2019, the Winter-run PWT has also calculated a JPE for hatchery-origin winter-run smolts released in Battle Creek as part of the “Jumpstart” reintroduction. Although there was also natural spawning in Battle Creek, the JPE has not differentiated natural-origin juveniles from Battle Creek from Sacramento River juveniles. As reintroduction efforts continue in Battle Creek and the McCloud River and populations become established, differentiating production sources is expected to become more relevant. Under the current method, unmarked winter-run Chinook Salmon from Battle Creek and the McCloud River are included in JPI estimates and therefore in $JPE_{Natural}$.

Table 2C-1. Parameters used in calculating the winter-run JPEs for brood years 2019-2022. Survival parameters were generated as described in in O’Farrell et al. (2018), Method 2, and updated annually to include the previous year of monitoring data.

Estimate	Parameter	BY 2019	BY 2020	BY 2021	BY 2022
Fry Production [a]	JPI_{Fry}	4,762,142	2,232,811	796,403	311,058
Fry-to-Smolt Survival [b]	$Survival_{Fry\text{-}to\text{-}Smolt}$	0.4651	0.4475	0.4429	0.4946
	Data for Fry-to-Smolt Survival	1998–2014	1998–2015	1998–2016	1998–2017
Natural Smolt Survival, RBDD to Delta [c]	$Survival_{Smolt}$	0.3860	0.3304	0.3537	0.3245
	Data for Smolt Survival	2013–2019	2013–2020	2013–2021	2013–2022
Hatchery Smolt Survival, LSNFH release to Delta [c]	$Survival_{HatcherySmolt}$	0.3687	0.3148	0.2818	0.2577
Hatchery Smolt Survival, Battle Creek to Delta [d]	$Survival_{BCJumpstart}$	NA	0.1570	0.0519	0.0206
Juvenile Production Estimate	$JPE_{Natural}$	854,941	330,130	124,760	49,924
JPE Confidence Interval (C.I.)2	95% C.I.	301,002–1,408,880	145,088–515,172	58,840–190,679	32,298–67,550

[a] Estimated juvenile passage at juvenile monitoring stations at Red Bluff Diversion Dam (RBDD), converted to “fry equivalents” using the fry-to-smolt survival factor for smolt-sized juveniles. This estimate includes an interpolation to account for the remainder of passage for the brood year.

[b] Estimate of fry-to-smolt survival is calculated using estimated slope of a zero-intercept linear model fitted to estimates of hatchery-origin juvenile survival rates and natural-origin juvenile survival rates (O’Farrell et al. 2018).

[c] Variance-weighted mean survival rate of acoustically tagged hatchery winter-run Chinook Salmon between RBDD and I-80/Tower Bridge in Sacramento (based on O’Farrell et al. 2018). Survival is estimated from the release location for hatchery-origin smolts, and from the Salt Creek receiver site, located 3 miles downstream of RBDD, to estimate survival from RBDD for natural-origin smolts.

[d] Variance-weighted mean survival rate of acoustically tagged hatchery winter-run Chinook Salmon between the release location in North Fork Battle Creek and I-80/Tower Bridge in Sacramento (based on O’Farrell et al. 2018). The survival rate of 64 fish on released on May 18, 2020 was not included because fish size and environmental conditions were not consistent with expected conditions during planned releases.

2C.2 Annual JPE Development Process

After the Record of Decision is finalized, the JPE will be developed by the JPE Subteam, consisting of technical representatives from the U.S. Bureau of Reclamation, California Department of Water Resources, NMFS, USFWS, and California Department of Fish and Wildlife. Annual JPE Development will begin in November, and the JPE Subteam will issue the JPE Memo to the Shasta Operations Team (SHOT) by December 31 of the same year. The objective of the JPE Subteam will be to use best available science and work collaboratively to produce JPE forecasts that are transparent, defensible, and unbiased.

2C.2.1 Annual JPE Parameter Updates

During annual JPE development, the JPE Subteam will evaluate and incorporate any new data they agree will improve estimates of JPI_{Fry}, $\text{Survival}_{\text{Fry-to-Smolt}}$, $\text{Survival}_{\text{Smolt}}$, and $\text{Survival}_{\text{HatcherySmolt}}$ for the purposes of generating JPEs for natural-origin and hatchery-origin winter-run Chinook Salmon. This has occurred annually since the current JPE method was adopted in 2019, and is consistent with O’Farrell et al. (2018).

2C.2.2 Potential JPE Calculation Method Updates

Since 2014, the JPE development process has included an annual technical review to determine if there is new or improved information that should be incorporated. Additional years of monitoring data, additional data on fry and smolt survival, and better statistical models could increase accuracy and/or better capture uncertainty, resulting in better JPE forecasts (O’Farrell et al. 2018). If, after evaluation of the alternatives, the JPE Subteam determines that adjusting the method beyond updating parameter estimates for “Method 2” and Equation 2C-1 would improve the JPE forecast, the JPE Subteam will provide a technical memorandum to SHOT for consideration.

2C.3 Winter-run JPE Application

The Proposed Action for Long-term Operations of the SWP and CVP includes loss thresholds for natural- and hatchery-origin winter-run that are scaled to the Winter-run JPE. When triggered by winter-run loss observed in salvage, the loss thresholds require prescribed adjustments to OMR flow management through SWP and CVP exports in the Delta to protect outmigrating winter-run. The Proposed Action includes an annual loss threshold and weekly distributed loss thresholds for natural-origin winter-run and an annual loss threshold for hatchery-origin winter-run. The weekly distributed loss thresholds are calculated separately for early season (November through December) migrating juveniles and for mid- and late-season (January through June) migrating juveniles. The equations for calculating each loss threshold are provided in the Proposed Action and are explained further below.

2C.3.1 Annual Loss and Mid- and Late-Season Weekly Distributed Loss Thresholds

The winter-run JPE will be used as a factor in the equations to calculate thresholds for mid- and late-season weekly distributed loss and annual loss at the SWP and CVP during the OMR Management Season, as described in the Proposed Action. The JPE Subteam will coordinate with the Salmon Monitoring Team (SaMT) to ensure that SaMT is able to calculate thresholds using the JPE forecasts prior to the start of OMR Management Season for winter-run on January 1 each year.

2C.3.2 Early Season Migration Loss Threshold Multiplier (before a JPE is available)

The early season migration loss threshold is in effect in November and December, prior to development of $JPE_{Natural}$ for the BY. Weekly thresholds are calculated separately for November and December as the product of the cumulative biweekly winter-run passage estimates at RBDD and a Multiplier.[1] The Multiplier, applied to both November and December thresholds ($Multiplier_{Nov}$ and $Multiplier_{Dec}$, is the product of the estimated percent of winter-run juveniles present in the Delta for the given month[2] scaled to week (multiplied by 0.25), fry-to-smolt survival ($Survival_{Fry\text{-}to\text{-}Smolt}$), and smolt survival from RBDD to the Delta ($Survival_{Smolt}$).

Similarly to the JPE, $Survival_{Fry\text{-}to\text{-}Smolt}$ and $Survival_{Smolt}$ will be updated each year to include any new data that are available. If data are not yet available to update the parameters, the JPE Subteam will use the $Survival_{Fry\text{-}to\text{-}Smolt}$ and/or $Survival_{Smolt}$ estimates from the previous BY JPE calculation. Equations 2C-3 and 2C-4 show the calculations for the $Multiplier_{Nov}$ and $Multiplier_{Dec}$, and an example calculation for BY 2023 (as would be applied to water year 2024), which uses survival estimates from the BY 2022 JPE.

Equation 2C-3:

$$Multiplier_{Nov} = 0.0011 \times 0.25 \times Survival_{Fry-to-Smolt} \times Survival_{Smolt}$$

Example for BY 2023: $0.0044\% = 0.0011 \times 0.25 \times 0.4946 \times 0.3245$

Equation 2C-4:

$$Multiplier_{Dec} = 0.0021 \times 0.25 \times Survival_{Fry-to-Smolt} \times Survival_{Smolt}$$

Example for BY 2023: $0.0084\% = 0.0021 \times 0.25 \times 0.4946 \times 0.3245$

2C.4 Cited

National Marine Fisheries Service. 2014. Winter-run Chinook Salmon Juvenile Production Estimate for Water Year 2014. Letter to Mr. Ron Milligan, Operations Manager, Central Valley Project, U.S. Bureau of Reclamation from Marian Rea, Assistant Regional Administrator, California Central Valley Area Office.

---

[1] The November threshold is calculated using the seasonal passage to date from the second biweekly RBDD winter-run passage estimate in October. The December threshold is calculated using the seasonal passage to date from the second biweekly RBDD winter-run passage estimate in November.

[2] The November and December estimated percent of winter-run juveniles present in the Delta are based on Table 15 of the Proposed Action, which includes calculated values for the percent of winter-run present in the Sacramento Trawl (Sherwood Harbor; Delta entry) and the percent of winter-run present in Chipps Island Trawl (Delta exit), as determined by genetic analyses for water years 2017-2022. For the first week of January (January 1-7), Table 15 indicates that 0.32% of winter-run are historically present in the Delta (scaled to 100%; Column E). The November Multiplier assumes that one third of winter-run presence in the Delta by the first week of January occurred as early as November (one third of 0.32% = 0.0011). The December Multiplier assumes that two thirds of winter-run presence in the Delta by the first week of January occurred as early as December (two thirds of 0.32% = 0.0021).

O'Farrell M. R., W. H. Satterthwaite, A. N. Hendrix, and M. S. Mohr. 2018. Alternative Juvenile Production Estimate (JPE) forecast approaches for Sacramento River winter-run Chinook Salmon. *San Francisco Estuary & Watershed Science* 16(4):4.