Spring-run Workshop Fact Sheet

Developing a Juvenile Production Estimate for Spring Run Chinook Salmon

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Introduction

The juvenile production estimate (JPE) required by the Incidental Take Permit (ITP[1]) is an annual forecast of the number of natural-origin spring-run Chinook salmon juveniles that will enter the Sacramento-San Joaquin Delta in any given year. This abundance forecast will be used to determine the allowable 'take' by the state water project (SWP), and therefore must be calculated prior to spring-run entering the Delta each year. For this reason, the JPE cannot simply be estimated from real-time monitoring of spring-run at the point of Delta entry, but instead must be based on monitoring data for earlier life history stages and transitions preceding spring-run juvenile immigration into the Delta.

A spring-run JPE may involve multiple existing and emerging data sources, run identification tools, and an understanding of spring-run distribution and life history. These resources are summarized in other fact sheets. In addition, the multiple forms that the Central Valley winter-run Chinook Salmon JPE has taken (Oppenheim 2014, Poytress et al. 2014, Voss & Poytress 2017, O'Farrell et al. 2018) may be instructive in the development of a spring-run JPE approach.

Here we describe:

- elements of selected winter-run JPEs;
- the challenges to developing a spring-run JPE;
- potential difficulties of applying a winter-run JPE approach to spring-run; and
- recent work comparing three JPE methods as applied to natural-origin Central Valley winter-run Chinook salmon (O'Farrell et al. 2018).

JPE Elements

Winter-run JPEs have largely employed the same basic model structure: The number of natural-origin winter-run smolts from the upper Sacramento River is estimated each year and then multiplied by a probable survival rate for their migration down the mainstem Sacramento to the Delta (Figure 1).

Figure 1: Basic winter-run JPE model structure

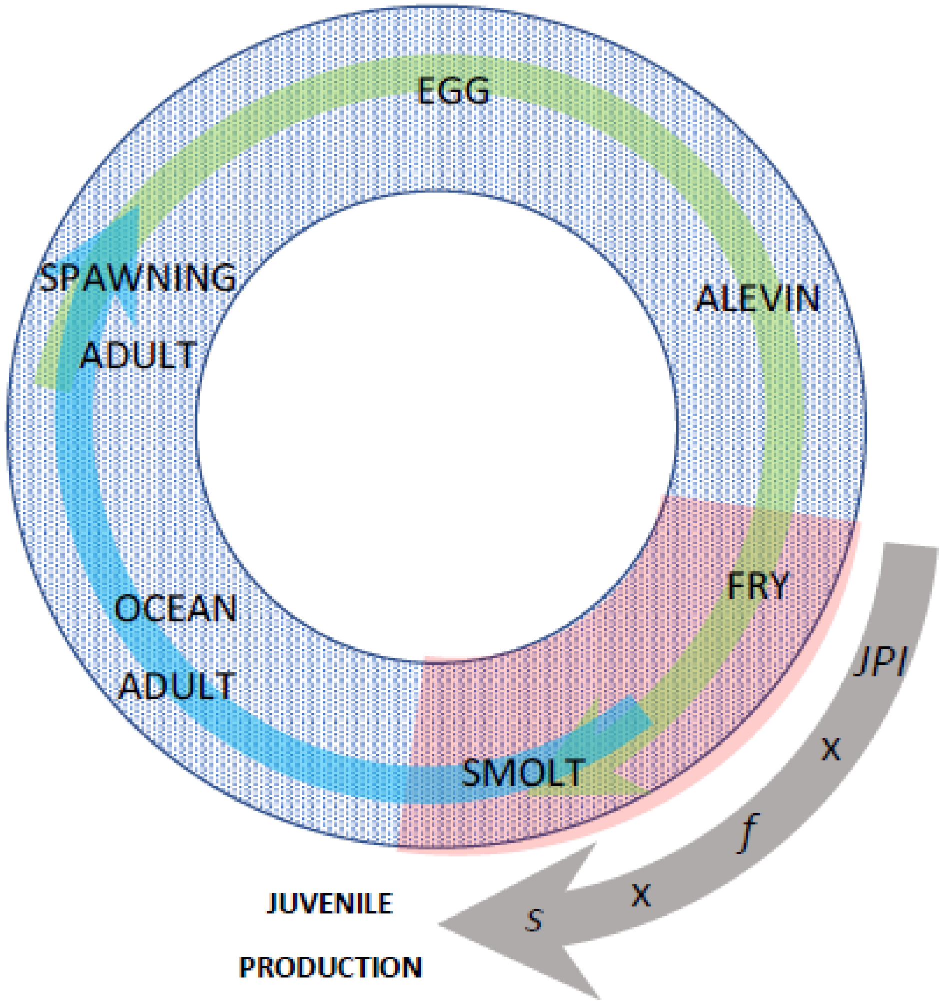
Additional factors, reflecting a greater proportion of the life cycle (Figure 2), that may be used include:

- adult escapement or the number of spawning adults;
- egg production;
- the quality and availability of habitat for spawning;

[1] Incidental Take Permit for Long-Term Operation of the State Water Project in the Sacramento-San Joaquin Delta (2081-2019-066-00)

- incubation and rearing; and
- the survivorship of migrating juvenile salmon to the Delta.

Figure 2: Representation of salmon life stages



The current winter-run JPE includes three life history stages to estimate annual juvenile production (Figure 2):

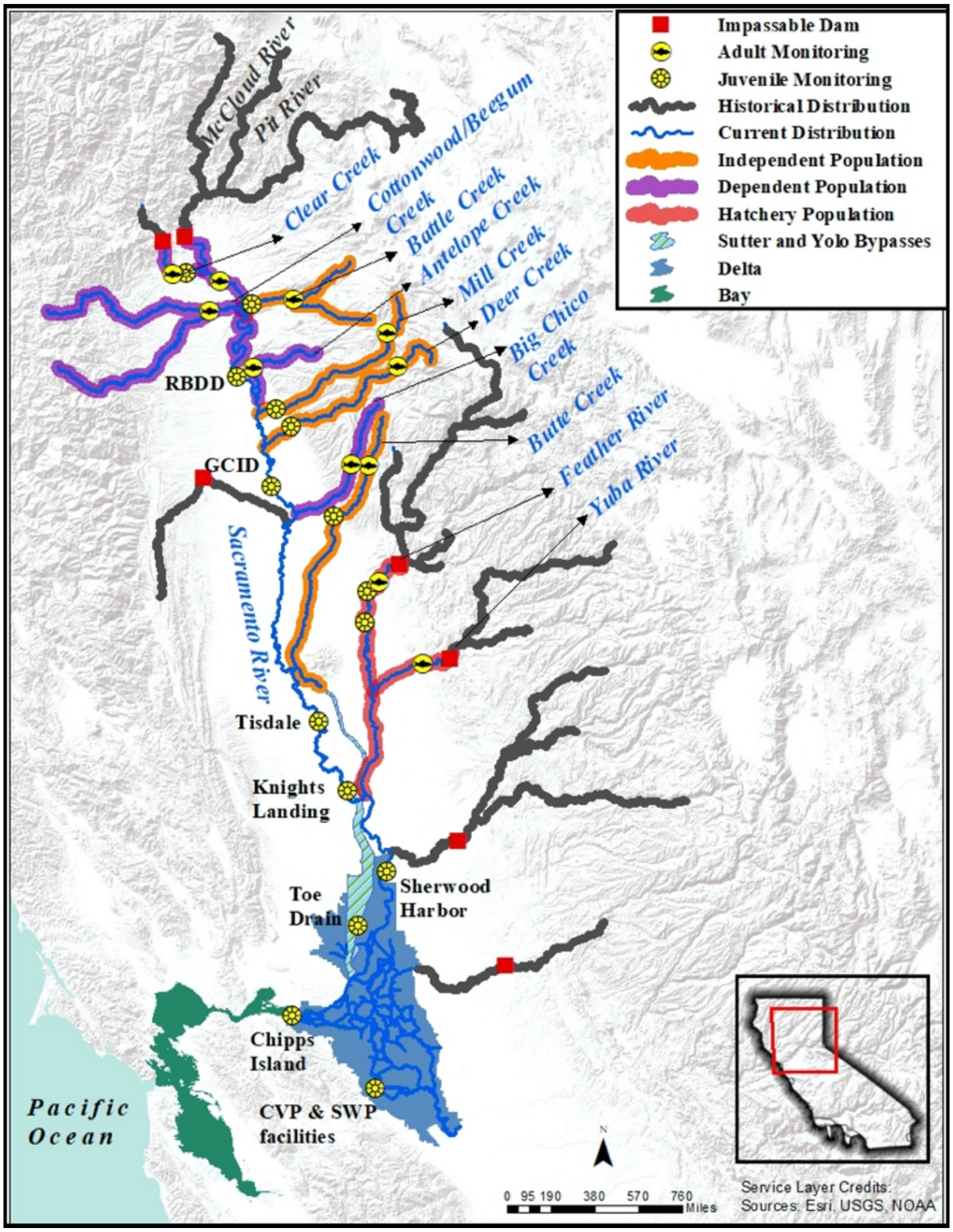
1. fry production (e.g., juvenile production index, *JPI*) in natal streams
2. fry-to-smolt transition success (*f*)
3. smolt survival rate (*s*) from mainstem Sacramento River to the Delta

The current winter-run JPE also incorporates an estimate for observation error (O'Farrell et al. 2018).

Challenges

The challenges to developing a spring-run JPE include run identification, data availability, data quality, error estimation, model complexity, and changing environmental conditions (Anderson et al. 2014; see also the "Monitoring of Central Valley spring-run Chinook salmon" fact sheet). Winter-run juvenile production is sourced from one location, but spring-run have multiple independent sources, including Battle Creek, Butte Creek, Mill Creek, Deer Creek, and the Feather River (Figure 3). The number of fry produced by each of these systems differs (NMFS 2014), as does their timing and rearing success (fry-to-smolt), and their likelihood of surviving their migration from their natal stream to the Delta (see the "Life history variation in Central Valley spring-run Chinook" fact sheet). For the purpose of developing a spring-run JPE that determines take in the SWP, we do not expect to account for spring-run from the San Joaquin River (see also, the "Identifying Spring-run" fact sheet).

Figure 3: Current and historical Central Valley Spring-run Chinook distribution[2]



An annual estimate of the total number of juveniles produced[3] by each of these independent populations depends on data availability and quality. Fry-to-smolt survival rates and the predicted survivorship of juveniles as they migrate to the Delta are expected to vary among populations. Additional challenges include distinguishing spring-run from other Central Valley Chinook, spring-run life cycle variability and differences (e.g., migration timing), sources of

[2] Historically, independent populations were not dependent on the migration of individuals from other populations; without straying spawners from other watersheds, dependent populations would probably not have persisted (see "Monitoring of Central Valley spring-run Chinook salmon" fact sheet).

[3] Estimates likely to be based on monitoring efforts through the fall and winter of the calendar year prior to the year of the JPE, possibly in terms of 'fry-equivalents' (*sensu* Voss & Poytress 2017).

error, time required to complete JPE to serve management needs, a shifting baseline due to climate change, and the suitability of surrogates (e.g., Feather River Hatchery fish).

Applying the winter-run approach

Prior JPEs and the alternative models considered for the winter-run JPE range from a basic budget model used in the 2014 migration season (Anderson et al. 2014, Oppenheim 2014) to the alternative methods reviewed by (O'Farrell et al. 2018), among others. These approaches employ the same basic model structure of estimating JPE on the basis of the number of fry produced and modified by survival estimates including entry into the Sacramento mainstem and migration down the Sacramento to the Delta.

Previously developed models for a winter-run JPE may offer a useful basis for developing a spring-run JPE. Table 1 summarizes several winter-run JPE models including basic model elements and input data. Note that the JPE results differ substantially depending on both the survival estimates used and on the application of real-time monitoring data, for example, using real-time monitoring data at RBDD for juveniles passing the dam (JPI, Scenario 3) instead of the estimated value (Scenarios 1 & 2), reduces the JPE from 708,970 to 397,726 juvenile salmon (Table 1).

Table 1. Calculations of winter-run JPE for three scenarios (adapted from Anderson et al. 2014)

Scenario	AE, Adult Escape-ment	E, viable Eggs per adult	viable egg estimate	S1, Survival to RBDD	JPI, juveniles passing RBDD	S2, Survival RBDD to Delta	JPE[a], juveniles to Delta
1. NOAA method	5,958	2,755	16,411,348	0.27	4,431,064	0.27	1,196,387
2. Use WR S2	5,958	2,755	16,411,348	0.27	4,431,064	**0.16**[b]	708,970
3. Use JPI & WR S2	5,958	2,755	16,411,348	0.15[d]	**2,485,787**[c]	**0.16**	397,726

[a] JPE is calculated as the product of the JPI and S2
[b] Winter-run Chinook salmon acoustic tag estimated survival for 2013
[c] JPI for 2014 based on real-time rotary screw trap catch at Red Bluff Diversion Dam (RBDD)
[d] Calculated S1 based on JPI and viable egg estimate

To estimate survival from RBDD to the Delta (S2, Table 1), scenario 1 estimates survival based on both late fall- and winter-run fish, while scenario 2 limits this estimate to the use of winter-run data only. For the first two scenarios, the number of juveniles passing RBDD (the juvenile production index, JPI) is estimated by multiplying the viable egg estimate by the expected survival (egg to fry-equivalent units passing RBDD, S1, calculated from rotary screw trap (RST) data). However, in scenario 3, JPI is estimated directly from RST catches at RBDD and S1 is calculated from this figure (JPI / viable egg estimate). Note that these three alternatives result in substantially different estimates for juvenile production with real implications for management.

O'Farrell et al. (2018) compared three different methods for estimating winter-run juvenile production, all based on a similar model structure to Oppenheim (2014). O'Farrell et al. (2018) used the estimated number of fry-equivalent units (JPI) observed from RST data at the RBDD, modified by two survival estimates: fry-to-smolt survivorship and survival of outmigrating smolts between RBDD and the Tower Bridge where the Delta officially begins (Figure 1, Table 2). One of the three methods compared did not account for potential errors and produced a point-estimate while the other two quantified potential sources of error (O'Farrell et al. 2018). A more detailed, technical review of results from Table 2 can be found in Appendix 1.

Table 2. Estimates used to forecast the 2018 winter-run Juvenile Production Estimate (JPE) (O'Farrell et al. 2018, Table 4)

	Methods		
	1	**2**	**3***
juveniles passing RBDD (JPI)	54,132	606,039	606,794
fry-to-smolt survival	0.5900	0.4725	0.4733
RBDD-to-Delta survival	0.5129	0.4378	0.4721
methodological differences	point estimate; no error estimation	accounts for observation error	mean & variance estimates; accounts for observation & process error
JPE	164,963	125,378	135,472

*Note that, for Method 3, the estimates are the means of the distribution for each factor.

Potential Questions for the Development of a JPE

1. Are the data available sufficient for a basic spring-run JPE model? If not, what else is minimally necessary and what would be ideal?
2. How should the spring-run JPE incorporate the complex life history strategies (e.g., young-of-the-year vs. yearling) of Central Valley spring-run Chinook?
3. Should data from dependent spring-run populations be used to inform the JPE? If so, how?
4. How can Feather River Hatchery spring-run best be used to parameterize and support a spring-run JPE?
5. There are other data sources that are not currently used in the winter-run JPE that might be used for the spring-run JPE (e.g., trawl efficiency study, Clear Creek carcass surveys, etc.). Which of these are useful and how?
6. Are the recommendations that Johnson et al. (2017) suggested for the estimation of the number of winter-run entering the Delta applicable to spring-run?
7. O'Farrell et al. (2018) raised multiple suggestions for improvement (e.g., consider interaction of $\hat{f}$ (fry-to-smolt survival) and $\hat{s}_n$ (RBDD-to-Delta survival))—to what extent are these applicable here?

References

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[NMFS] National Marine Fisheries Service (2014) Recovery Plan for the evolutionarily significant units of Sacramento River winter-run Chinook salmon and Central Valley spring-run Chinook salmon and the distinct population segment of California Central Valley steelhead. National Marine Fisheries Service, California Central Valley Area Office.

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Poytress WR, Gruber JJ, Carrillo FD, Voss SD (2014) Compendium report of Red Bluff Diversion Dam rotary trap juvenile anadromous fish production indices for years 2002-2012. U.S. Fish and Wildlife Service, Red Bluff, CA.

Voss SD, Poytress WR (2017) Brood Year 2015 juvenile salmonid production and passage indices at Red Bluff Diversion Dam. U.S. Fish and Wildlife Service, Red Bluff, CA.

Appendix 1. Detailed summary of O'Farrell et al. (2018)

As indicated above, O'Farrell et al. (2018) use the same basic model structure to compare three alternative methods to model winter-run JPE,

$$\widehat{JPE}_{n,t} = \widehat{JPI}_{t-1} \times \hat{f} \times \hat{s}_n$$

where $\widehat{JPE}_{n,t}$ is the natural-origin juvenile production estimate for year *t* Chinook salmon, $\widehat{JPI}_{t-1}$ is the juvenile production index (estimated number of natural-origin juveniles in fry-equivalent units[4]) for the previous calendar year, $\hat{f}$ is the forecast fry-to-smolt survival rate, and $\hat{s}_n$ is the forecast smolt survival rate of natural-origin fish from RBDD to the entrance of the Delta (O'Farrell et al. 2018). The methods differ in terms of their inclusion of sources of error.

[4] Both fry and pre-smolt juveniles pass the Red Bluff Diversion Dam in proportions that vary annually; production is "standardized to the fry stage to facilitate comparisons across years" (O'Farrell et al. 2018).

Method 1 equates $\widehat{JPE}_{n,t}$ to the product of the juvenile production index from the prior calendar year ($\widehat{JPI}_{t-1}$), the forecast of the number of fry-equivalents ($\hat{f}$) passing RBDD and the forecast of the smolt survival rate ($\hat{s}_n$) from RBDD to the Delta entrance. Each component is a point estimate, as is the resultant JPE, with no error estimation.

Method 2 estimates the variance associated with observation error for each component on the right-hand side of the basic equation. In addition, this model uses a new approach to forecasting $\hat{f}$, correlating estimated hatchery- and natural-origin pre-smolt survival rates and using the slope to estimate $\hat{f}$ (Figure 1, O'Farrell et al. 2018). Smolt survival is based on recapture estimates from previous years (see Michel et al. 2015); includes variance estimates and accounts for detection probabilities. Year-to-year variation in $\hat{f}$ and $\hat{s}_n$ are not included, and the model does not consider potential covariance between these rates.

Method 3 employs a probability distribution for each of the components, resulting in a distribution (with mean and confidence intervals) for the $\widehat{JPE}_{n,t}$. Observation and process error are incorporated by the use of a hierarchical Bayesian model to forecast a posterior predictive distribution for $\hat{s}_n$. Partial accounting for annual variability.

Table A1. Alternatives compared by O'Farrell et al. (2018).

	Method		
	1	**2**	**3**
$\widehat{JPI}_{t-1}$	point estimate	estimate of variance based on historical CVs*; dependent on $\hat{f}$	estimate of variance* or historical CV
$\hat{f}$	point estimate	new forecast method	new forecast method
$\hat{s}_n$	point estimate	based on external survival estimates	Bayesian; data-limited
$\widehat{JPE}_{n,t}$	point estimate; no error estimation	accounts for observation error	mean & variance estimates; accounts for observation & process error
model status**	status quo	in use	potential
$\widehat{JPE}_{n,2018}$	164,963	125,378	135,472***

*The variance estimates needed for Methods 2 & 3 may be difficult or impossible to provide in time to complete the JPE (O'Farrell et al. 2018).

**As per O'Farrell et al. (2018).

***Mean of the distribution.