Incidental Take Permit
Spring-Run Chinook Salmon
Juvenile Production Estimate
Science Plan

2020–2024

December 1, 2020

Developed collaboratively by
California Department of Water Resources,
California Department of Fish and Wildlife, NOAA Fisheries,
U.S. Bureau of Reclamation, Metropolitan Water District, and
State Water Contractors,
with support from AECOM and ICF

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Acronyms and Abbreviations

AMP	Adaptive Management Program
AT	acoustic tagging
CAMT	Collaborative Adaptive Management Team
CDFW	California Department of Fish and Wildlife
CSAMP	Collaborative Science and Adaptive Management Program
CVP	Central Valley Project
CWT	coded wire tags
Delta	Sacramento-San Joaquin Delta
DJFMP	Delta Juvenile Fish Monitoring Program
DNA	deoxyribonucleic acid
DUWG	Data Utilization Work Group
DWR	California Department of Water Resources
DSP	Delta Science Program
FRFH	Feather River Fish Hatchery
GCID	Glenn-Colusa Irrigation District
IEP	Interagency Ecological Program
ITP	incidental take permit
JPE	juvenile production estimate
LAD	length at date

NGO	nongovernmental organization
NOAA	National Oceanic and Atmospheric Administration
PIT	passive integrated transponder
PLAD	probabilistic length at date
PWT	project work teams
RBDD	Red Bluff Diversion Dam
Reclamation	U.S. Bureau of Reclamation
RST	rotary screw trap
SHERLOCK	Specific High-sensitivity Enzymatic Reporter unLOCKing
SIT	Science Integration Team
SJRRP	San Joaquin River Restoration Program
SNP	single nucleotide polymorphism
SWFSC	Southwest Fisheries Science Center
SWP	State Water Project
USFWS	U.S. Fish and Wildlife Service
YOY	young-of-the-year

Executive Summary

Spring-run Chinook salmon (*Oncorhynchus tshawytscha*; "spring-run") are listed as threatened under both the California Endangered Species Act and the Federal Endangered Species Act. In March 2020, the California Department of Fish and Wildlife (CDFW) issued incidental take permit (ITP) number 2081-2019-066-00 to the California Department of Water Resources (DWR) for the operation of the State Water Project (SWP), which describes the necessary conditions to minimize impacts of the SWP on spring-run Chinook salmon, among other covered species. Condition of Approval 7.5.2 of the ITP requires DWR to convene an interagency team (JPE Team) to support development and implementation of an annual spring-run juvenile production estimate (JPE). The first priority of the JPE Team, and the first deliverable required under Condition of Approval 7.5.2, is a science plan describing the monitoring necessary to inform development of an annual JPE for spring-run. Once developed and approved by CDFW, the annual JPE may be used to support new entrainment minimization measures which would augment or replace current entrainment protective measures for spring-run Chinook salmon, as described in Condition of Approval 8.6.6. This document fulfills the first deliverable of Condition of Approval 7.5.2, the development of a multi-year JPE research and development science plan (JPE Science Plan). The ITP refers to this plan as a "Monitoring Plan"; but, since the plan necessarily includes much more than simply a plan for monitoring, it has been titled a "Science Plan."

The scientific and management purpose of this document is to outline the research and monitoring that will be needed to meet the goal of developing a spring-run JPE ready for implementation in 2025. The JPE Science Plan provides a basic framework and details about the highest priority activities. But it is expected that these research and monitoring activities will be highly adaptive. Although DWR is responsible for meeting the requirements of the ITP and developing a spring-run JPE collaboratively with CDFW, the process for developing, implementing, and subsequently revising the JPE will be guided by the JPE Team, which will in turn rely on advice from regional and subject matter experts throughout the Central Valley and science community.

The JPE Science Plan was developed based on multiple steps with input from diverse organizations. As a first step in the process, DWR requested help from the Delta Science Program (DSP) to organize a large scoping workshop to solicit input on the current understanding of Central Valley spring-run science in the context of the development of a spring-run JPE for the Sacramento River Basin. The DSP organized the scoping workshop under the guidance of a multi-agency steering committee to review the current state of knowledge about spring-run, identify monitoring gaps, evaluate potential race identification tools, and consider potential approaches to develop a spring-run JPE. In addition to DWR, CDFW, and DSP, agencies represented on the steering committee were National Oceanic and Atmospheric Administration (NOAA) Fisheries, U.S. Bureau of Reclamation (Reclamation), U.S. Fish and Wildlife Service (USFWS), California State Water Contractors, and Metropolitan Water District. The scoping workshop was attended by approximately 300 registrants representing more than 50 different organizations including State, federal, and local governments, public water agencies, universities, nongovernmental organizations (NGOs), consultants, and Tribal representatives.

Following the scoping workshop, the JPE Team was formed to develop the current work plan. The JPE Team is chaired by DWR and includes staff from CDFW, Reclamation, NOAA Fisheries, Metropolitan Water District, and California State Water Contractors. Technical support, including group facilitation and document production, is provided by two consulting representatives, AECOM and ICF.

Based on input from the scoping workshop, and upon further consideration by the JPE Team, there are several general expectations for the science program leading to the development of the JPE. These include a focus on entrainment management, a need for multiple tools, some degree of redundancy within the approach, and comparability across JPE methods with the means for seasonal and annual adaptation in the program coupled with regular evaluation steps.

To help frame the science effort, the JPE Team considered three potential approaches to calculate a JPE based on estimated abundance at four key salmonid life stages and locations: (1) adults during passage into, or holding within, tributaries; (2) rearing juveniles in tributaries; (3) tributary outmigrants; and (4) juveniles at Delta-entry. For each approach, the team developed conceptual models with a schematic illustrating a life-stage that would be monitored as the abundance input for a JPE model, the geographic location where that monitoring would occur, and the subsequent transition parameters that would be needed (e.g., fecundity, survival) to calculate a JPE from that input abundance.

Below are descriptions of the broad elements of the JPE Science Plan. These elements were identified during the scoping workshop, and subsequently refined by the JPE Team, as being needed to move forward quickly and efficiently to develop the potential JPE approaches above. Each of these elements will require subsequent detailed planning by the JPE Team with help from subject matter experts. Most of these elements will be initiated and proceed in tandem or with substantial overlap.

- **Additions to Existing Programs and New Monitoring**: To test the efficacy of the potential JPE approaches, there is a need to refine and augment existing monitoring programs as well as add new monitoring programs during the JPE research and development phase. Because it is not feasible to conduct comprehensive sampling in all tributaries, we plan to focus initially on a subset of "representative" streams selected by the JPE Team to represent unique geographies and monitoring challenges (see Section 4.5). Once selected, the JPE Team will draft detailed plans for augmented and new monitoring with the help of regional experts.
- **Special Studies**: In addition to the use of historical data, augmentation of existing monitoring programs and the addition of new monitoring programs, the development and implementation of a spring-run JPE will also require targeted research. Essential to the JPE program will be development of genetic approaches to successfully identify spring-run at multiple locations in the system, and to differentiate between spring-run originating from the San Joaquin River and Sacramento River basins. Other examples of targeted research include studies to determine sampling efficiency, life-history diversity (yearling versus young-of-year), and telemetry estimates of reach-specific survival.
- **Historical Data**: A priority in the science program will be to use available information to develop initial quantitative JPE models and estimates as early as possible. For example, there is existing information from telemetry studies, coded-wire fish releases,

escapement surveys, screw trapping surveys, and genetic results that could be used to inform initial JPE approaches. The JPE Team will evaluate all historical data to determine its applicability for informing the JPE.

- **Long-term Monitoring**: Implementation of the steps outlined above may indicate a need for a continuation of some augmented monitoring in representative streams, and expansion of these monitoring changes into other spring-run streams, as part of a long-term monitoring program to support a spring-run JPE. Decisions regarding these changes to long-term monitoring programs will not be determined until there is reasonable clarity about the most appropriate JPE approach. As a result, broad scale changes to spring-run monitoring are unlikely to occur until the latter part of the four-year study effort.
- **Structured Decision-Making**: We propose that the selection of a JPE approach and monitoring program at the end of the research and development process include a rigorous evaluation using structured decision-making to ensure the decision process and outcomes are transparent and objective, and based on shared, clearly articulated, fundamental objectives. As much as possible given constraints of time and requirements of ITP conditions, the JPE Team will also use structured-decision-making processes and tools to help guide planning and implementation decisions for all JPE Science Plan elements.

The JPE Science Plan provides details about priority needs for each of the key elements described above. After the JPE Science Plan is reviewed and approved by CDFW (winter 2021), the JPE Team will implement research and monitoring activities over a three-year period (2021 to 2024). During this time, a review panel will be organized to examine and compare JPE approaches and results, culminating in selection of a final JPE approach and monitoring plan to develop a JPE for Water Year 2025 (brood year 2024). The final JPE approach will be selected based on multiple factors (e.g., feasibility, accuracy, timeliness, management value, scientific value, cost) and subject to CDFW approval by October 2024.

1.0 Introduction

A juvenile production estimate (JPE) for spring-run Chinook salmon is intended to be a forecast of the abundance of spring-run juveniles expected to enter the Sacramento-San Joaquin Delta (Delta) each year from the Sacramento River. The Spring-run Chinook Salmon JPE Science Plan outlines the research and monitoring that will be needed to develop an approach for calculating a JPE by Water Year 2025 (brood year 2024). The plan provides a basic framework and details about the highest priority activities. This introductory section presents the incidental take permit (ITP) requirements for developing a JPE, the purpose of the JPE Science Plan, JPE Team organization, coordination and outreach, the relationship of the JPE Science Plan to the ITP Adaptive Management Program, the timeline for the JPE Science Plan, and the development of JPE science priorities.

1.1 Incidental Take Permit Requirement

Spring-run Chinook salmon (*Oncorhynchus tshawytscha*; “spring-run”) are listed as threatened under the California Endangered Species Act and the Federal Endangered Species Act. Accordingly, they are considered a focal point for management in the Bay-Delta and its watershed. In particular, spring-run are a major management issue in the Delta, where spring-run are at risk of exposure to the pumping facilities of the State Water Project (SWP) and the Central Valley Project (CVP), which provide water to millions of Californians, including municipal and industrial use, and to a multi-billion-dollar agricultural industry. Operation of these facilities requires permits for take of the species under the State and federal endangered species acts.

On March 2020, the California Department of Fish and Wildlife (CDFW) issued ITP number 2081-2019-066-00 to the California Department of Water Resources (DWR), authorizing take of winter- and spring-run Chinook salmon, delta smelt, and longfin smelt as a result of long-term operations of the SWP. Relevant to the current document, the ITP requires DWR to develop a method for estimating an annual JPE (Condition of Approval 7.5.2). Specifically, Condition of Approval 7.5.2 and a spring-run JPE is intended to help manage SWP operations to minimize spring-run entrainment and help achieve other management objectives including a spring-run performance objective (see below) and life cycle model. This requirement provides the foundation of the current work plan.

The ITP requires these specific steps and timelines for developing and implementing a spring-run JPE.

1. Form an inter-agency JPE Team to help draft a JPE Science Plan.
2. Design and implement a four-year JPE Science Plan for development and testing of JPE approach(es), including necessary monitoring and analytical needs.
3. Use the results of the four-year research and development phase to prepare a draft plan for calculating an annual JPE, including necessary long-term monitoring.
4. Submit the draft plan for review and approval by the JPE Team and CDFW (October 2024).
5. Establish a long-term spring-run monitoring program and annual calculation of a spring-run JPE by the JPE Team (January 2025).

After the final JPE approach is approved by CDFW, DWR may request an amendment to the ITP to modify or replace the current spring-run hatchery surrogate daily loss threshold (Conditions of Approval 8.6.4 and 8.6.5) with a new entrainment minimization measure that incorporates new information from the JPE.

Separate from the ITP requirements, the biological opinion for long-term operations of the SWP and CVP, issued in 2019 by NOAA Fisheries, requires DWR and the U.S. Bureau of Reclamation (Reclamation) to assess a Delta performance objective for young-of-the-year (YOY) Central Valley spring-run Chinook salmon. The JPE approach developed to meet the requirements of the ITP may also meet the Delta performance objective requirement under the biological opinion.

For the purposes of the JPE effort, this report is using the federal Endangered Species Act terminology "Central Valley spring-run Chinook salmon Evolutionary Significant Unit," although the State listing designates the fish as "spring-run Chinook salmon of the Sacramento River drainage." This is being done because most of the scientific literature uses the federal terminology, and it is recognized that this evolutionary significant unit includes naturally spawned spring-run Chinook salmon originating from the Sacramento River and its tributaries, and also hatchery-spawned spring-run Chinook salmon from the Feather River Fish Hatchery (FRFH). Spring-run Chinook salmon originating from the San Joaquin River as well as hatchery fish used to supplement the San Joaquin River Restoration Program will not be included in the calculation of the JPE. But, as will be described further, these fish are a relevant topic as they will need to be differentiated from Sacramento-origin fish during salvage operations at the pumping facilities.

1.2 Purpose of the Spring-Run JPE Science Plan

The regulatory purpose of the current document is to fulfill the requirement of Condition of Approval 7.5.2 in the ITP to form a team to develop a JPE approach, and to describe a science plan for the effort. These goals correspond to Steps 1 and 2, above. Additional details are available in Appendix A.

The scientific and management purpose of this document is to outline the research and monitoring that will be needed to meet the goal of developing a spring-run JPE by Water Year 2025, and to summarize the highest-priority activities. It is expected that these research and monitoring activities will be highly adaptive. In other words, initial research and monitoring projects described below will be reviewed and evaluated on an annual basis by the JPE Team. The expectation is to learn from initial results and propose refinements and new study objectives to continue to fill information gaps in subsequent years. As a result, implementation of the JPE Science Plan will be an adaptive and collaborative process that may not follow the traditional linear pathway of a focused scientific study.

This document may also help to provide the scientific community with an understanding of some of the major science needs for understanding abundance trends and managing spring-run. Although we expect the science activities described in this plan will be planned, coordinated, and implemented through the JPE Team, it is hoped that the plan stimulates others to propose new projects that enhance, or build off of, JPE research activities. Put another way, the hope is that the JPE Science Plan will help catalyze a broader effort for spring-run science and management.

Overall, it is expected that the proposed research and monitoring to support the spring-run JPE will be integrated with region-wide salmon monitoring, and more coordinated research and management. This program will help support spring-run life cycle modeling (required in Condition of Approval 7.5.3) and other scientific efforts used for recovery planning. As described in Section 1.5 below, the program will also contribute to monitoring information for adaptive management of spring-run habitat restoration and resource planning processes such as voluntary settlement agreements, Delta Conveyance Project, and the Central Valley Project Improvement Act.

1.3 Team Organization

The proposed research effort will be implemented by the JPE Team. The JPE Team includes scientists from DWR, CDFW, NOAA Fisheries, U.S. Fish and Wildlife Service (USFWS), Reclamation, Metropolitan Water District of Southern California, and State Water Contractors. Additional experts will be consulted throughout planning and implementation based on specific topics and need. Some of the key roles and responsibilities for planning and implementation are listed below.

- **Team Chair**: DWR.
- **Funding**: DWR, with potential additional support from project partners.
- **Technical Input**: JPE Team.
- **Contract Management**: DWR will have the primary responsibility to manage the contracts for JPE Science Plan work directly identified in the ITP, and to contract or coordinate additional work in the JPE Science Plan, some of which may occur under other funding and contract mechanisms (e.g., State Water Contractors).
- **Reporting**: DWR, with input from the JPE Team.
- **Outreach**: DWR will have the primary responsibility, but it is expected that all team members work to promote communication with the broader scientific and resource management community.

1.4 Coordination and Outreach

Development of a JPE for spring-run will require an unusually high level of coordination and outreach, given the broad geographic area in which spring-run reside, the complex life history of spring-run, and the need for a strong multi-disciplinary approach. For example, the September 2020 JPE Scoping

Workshop (see below and Section 1.7) illustrates the high degree of input and coordination needed to establish a suitable management solution.

The JPE Team, and particularly its chair, DWR, will have the primary responsibility for JPE coordination.

To facilitate expedient and efficient implementation of the JPE Science Plan, the JPE Team will coordinate the research and monitoring activities included in the JPE Science Plan with current spring-run research and monitoring activities that may contribute to the spring-run JPE effort but are not directly under the purview of DWR. Coordination will be particularly important for the building and maintenance of the spring-run database to support JPE models. For example, the Interagency Ecological Program (IEP) organizes research and monitoring centered in the Bay-Delta, a key component of the study area for the JPE effort. The IEP also has several relevant project work teams (PWTs) including the Spring-Run PWT, Biotelemetry PWT, and Juvenile Salmon PWT, that will be important forums for coordination and outreach.

A second venue for coordination will be the Collaborative Science and Adaptive Management Program (CSAMP), which includes the CSAMP Policy Group and the Collaborative Adaptive Management Team (CAMT). These coordination teams include water agencies, fisheries agencies, regulators, water users, and environmental groups. CAMT recently finalized a Coordinated Salmonid Science Planning Assessment for the Delta, which is likely to have several important areas of shared interest with the JPE effort. It is anticipated that that these forums will be a primary venue to discuss collaborative science for spring-run.

A third target venue for JPE coordination is the Central Valley Improvement Act’s Science Integration Team (SIT). The SIT has conducted extensive outreach to salmon scientists, comprehensive data synthesis, and salmon race-specific life cycle modeling to support habitat restoration decisions. It is expected that one or more members of the JPE Team will continue to be on the SIT, providing an opportunity to coordinate.

In addition to the previous efforts, the JPE Team will coordinate with other key salmon groups, including the Central Valley Salmon Habitat Partnership and the Sacramento River Science Partnership. The JPE effort will continue to keep strong linkages to Delta Science Program (DSP), who were instrumental in organizing the original Scoping Workshop used as the basis for this work plan. For example, future external peer review efforts for JPE products and proposals may be managed through DSP’s review process.

Finally, our intention is that the JPE effort continue to be vetted through the broader science community. One approach may be similar to the recent public JPE scoping workshop, where a focused event is organized on this topic. Another likely venue for sharing progress on and results of JPE Science Plan activities will be large meetings, such as the Bay-Delta Science Conference and the Annual Meeting of the American Fisheries Society CAL-NEVA Chapter.

1.5 Relationship to ITP Adaptive Management Program

Throughout implementation of the ITP, DWR, CDFW, and the State Water Contractors will convene regular meetings of the ITP Adaptive Management Program (AMP) to consider and address scientific uncertainty regarding the Bay-Delta ecosystem and covered species ecology. The AMP is intended to improve understanding of take of covered species, impacts of the taking, and minimization associated with operating criteria in the ITP. The AMP’s role in the ITP is described in the Draft Adaptive Management Plan (ITP Attachment 2). This plan defines adaptive management as “a science-based approach to evaluate management actions and address uncertainties associated with those actions to achieve specific objectives and to inform subsequent decision-making. When correctly designed and executed, adaptive management provides a means to evaluate management actions and their underlying scientific basis using formal science programs to assess their efficacy in achieving conservation objectives by comparing the outcomes to predicted responses, and providing the scientific basis for continuing, modifying, or abandoning the action or implementing an alternative action.”

After reviewing results from ongoing monitoring, science, and syntheses, the AMP may recommend amendments to the operational components of the ITP. The spring-run JPE is a significant part of the new science and monitoring requirements included in the ITP that will inform the AMP process (ITP Attachment 2, Section J.2.1). The AMP process is also intended to inform future adaptive management efforts including the Delta Conveyance Project and voluntary settlement agreements.

Throughout the term of the ITP, the AMP will convene to review syntheses of science required by the ITP and other science, as available, to consider and address scientific uncertainty regarding the Bay-Delta ecosystem. Over time, the AMP may expand to incorporate or collaborate with adaptive management efforts being conducted as a part of voluntary agreements or the CSAMP.

As described in more detail below, the primary purpose of the spring-run JPE, once developed and approved by CDFW, will be to inform the development of protection measures to minimize entrainment of spring-run into the central and south Delta and the SWP export facilities. Until there is an effective approach to estimate a JPE for spring-run, entrainment at the SWP will continue to be managed using a surrogate approach. Specifically, each year fry-sized fall-run and spring-run hatchery Chinook salmon will be tagged with coded wire tags (CWTs) and released from several Sacramento Valley hatcheries to coincide with the spring migration of natural YOY spring-run (Conditions of Approval 8.6.4 and 8.6.5). A cumulative entrainment loss threshold (0.25 percent) was established in the ITP for each release group. The details of this surrogate program are summarized in a separate, annual plan developed by CDFW. Ultimately, it is expected that the proposed JPE approach produced by this JPE Science Plan will be evaluated by the AMP and then used to develop alternative protection measures to minimize entrainment of spring-run into the central and south Delta and SWP export facilities. This change will require DWR to submit an application to CDFW for an amendment to the ITP requesting a change to the ITP Conditions of Approval.

1.6 Timeline

The development of a JPE approach will take place from December 2020 through January 2025, with a timeline consisting of the following milestones:

1. December 1, 2020: JPE Team submits a draft spring-run JPE Science Plan to CDFW.
2. Winter 2021: Draft JPE Science Plan is reviewed and approved by CDFW.
3. January 2021 to May 2024: JPE Team and subteams implement research and monitoring activities as outlined in the JPE Science Plan.

4. January 2024: Results of JPE research and monitoring, culminating in a recommended JPE approach and initial calculation, are included as part of activities reviewed by an external panel for the ITP 4-year review.
5. October 2024: A final JPE approach is selected based on multiple factors (e.g., feasibility, accuracy, timeliness, management value, scientific value, and cost) and subject to CDFW approval.
6. January 2025: Approved JPE approach is implemented each year with ongoing evaluation by the JPE Team
7. 2028: Four years of implemented JPE calculations are included as part of activities reviewed by an external panel for the second ITP 4-year review.

More detail regarding the implementation timeline of JPE Science Plan element are provided below in Section 4.0, Figure 23.

1.7 Development of JPE Science Plan

The JPE Science Plan was developed based on multiple steps, with input from diverse organizations, as discussed in the following paragraphs.

1.7.1 JPE Scoping Workshop

As a first step in the process, DWR asked DSP for help in organizing a scoping workshop to solicit input on the current understanding of spring-run science in the context of the development of a JPE. The DSP organized a scoping workshop steering committee with representatives from multiple organizations.

The objective of this public, virtual scoping workshop was to convene subject-matter experts to develop the best possible approach to accurately estimate the population of spring-run Chinook salmon in the Sacramento River drainage as a means to evaluate, manage, and minimize the impact of SWP operations on spring-run.

With that objective, the scoping workshop broadly tackled four themes:

1. The state of knowledge of spring-run distribution and life history.

2. The extent and nature of spring-run adult and juvenile monitoring and gaps.
3. Spring-run identification tools, including genetic and length-at-date (LAD) tools, and their tradeoff.
4. Current approaches to producing and using JPEs, including identifying knowledge gaps for producing a JPE for spring-run.

The scoping workshop was informed by five “fact sheets.” The first fact sheet was prepared by DWR and CDFW and provides background information on the management context related to the scoping workshop and the ITP. The other four fact sheets served as background documents for the four workshop themes described above. These four thematic fact sheets were written exclusively for the scoping workshop by scientists with expertise in the system and in various aspects related to spring-run ecology. The fact sheets described offered an overview of each of the workshop themes, including the state of scientific knowledge and potential discussion questions, as food for thought for the breakout sessions. Similarly, the information from these fact sheets has been incorporated into the JPE Science Plan nearly verbatim to provide background and context. It is important to note that the information from these fact sheets is not comprehensive for each topic.

Besides the fact sheets, outcomes from the scoping workshop included video recordings of the workshop presentations. In addition, a manuscript is being prepared for publication describing information gathered for the fact sheets and outcomes of workshop discussions.

1.7.2 Spring-Run JPE Science Team

A spring-run JPE Team was formed in September 2020 to develop the current work plan. The JPE Team was chaired by DWR and included staff from CDFW, Reclamation, NOAA Fisheries, Metropolitan Water District, and State Water Contractors (see Section 1.3). Technical support, including group facilitation and document production was provided by two consulting representatives: AECOM and ICF.

To maximize communication, the group was intentionally small (fewer than 12 team members) and consisted of staff who were able to actively participate in the rapid drafting process.

In developing the JPE Science Plan, the team considered the input from the scoping workshop with respect to multiple factors, including management relevance (e.g., use for entrainment management and the speed with which information could be made available), scope (e.g., ability to fit in a conceptual model and geographic area), resource needs (e.g., staff, equipment, and cost), and feasibility (e.g., permits, take considerations, ability to leverage existing programs, and safety).

2.0 Background Information

2.1 Spring-Run Chinook Salmon and JPE Approaches

The following summarizes some of the key background information on spring-run Chinook salmon, including life history, sampling programs, race identification methods, as well as current and considered JPE approaches for winter-run Chinook salmon. As mentioned above, these sections are based on fact sheets prepared for the previously described 2020 JPE Scoping Workshop, with updated information provided by the JPE Team. It bears repeating that this information is not intended as a comprehensive review of these topics; rather, these sections are intended as a basic introduction to some of the most relevant information needed to understand spring-run life history, sampling, identification, and potential approaches to population estimates.

2.2 Life History and Diversity

2.2.1 Overview

Life-history diversity has emerged as an important mechanism for salmonid population resilience in changing environments (Hilborn et al. 2003). The link between increased spatial variation in habitat use and decreased interannual variation in production is apparent for both juvenile (Thorson et al. 2014) and adult (Schindler et al. 2010) salmonid life stages. There are many indicators of life-history diversity, including genetic diversity (Gustafson et al. 2007), patterns in the timing of estuarine or ocean entry (Beechie et al. 2006), and fish size and occurrence (Miller et al. 2010; Sturrock et al. 2015). Furthermore, these life history metrics can be linked to habitat and hydrology. Wetland restoration on the Salmon River, Oregon, expanded juvenile life-history variation by allowing greater expression of estuarine resident behaviors (Bottom et al. 2005). Sturrock et al. (2019) showed that the expression and successful return of varying juvenile migratory phenotypes to the Stanislaus River were correlated with hydrologic regime. Data collected in the Yolo Bypass (seasonal floodplain and tidal slough of the Sacramento River) revealed that habitats and hydrology that enhanced habitat complexity supported aspects of life-history diversity for juvenile salmon (Goertler et al. 2017). Section 2.2 provides a review of Central Valley spring-run Chinook salmon life-history diversity, with an emphasis on the juvenile life stage, relevant tools, and emerging studies that advance the identification of life-history variants.

Central Valley spring-run historically comprised 19 independent populations (McElhany et al. 2000). Three of these populations Mill, Deer, and Butte creeks, have persisted to the present time. The Endangered Species Act lists four known independent populations: Battle, Mill, Deer, and Butte creeks. The independent population in Battle Creek reestablished recently, presumably from strays, and this same process may also be occurring on Clear Creek (National Oceanic and Atmospheric Administration 2016a, 2016b). Spring-run were listed as both State and federally (Federal Register 1999) threatened in 1999. Approximately 28 percent of historic spawning and holding habitat remains accessible to Central Valley salmon (Yoshiyama et al. 2001). Spring-run were extirpated from tributaries in the San Joaquin River Basin, which represented a large portion of the historic range and abundance (Fisher 1994; Lindley et al. 2004). The federal ESU also includes smaller dependent populations, which are unlikely to have persisted without immigration from other streams (e.g., they are sink populations or part of a metapopulation). The Battle Creek population was extirpated from its historical habitat and started repopulating in the 1990s (Johnson and Lindley 2016). Big Chico, Cottonwood, Beegum (a tributary of Cottonwood), and Antelope creeks and some San Joaquin River tributaries have seen signs of spring-run intermittent use for spawning repopulation, although they are generally considered "dependent" populations, while Clear Creek has had more consistent returns, and many interpret this a "repopulated" stream (Johnson and Lindley 2016, California Department of Fish and Wildlife personal communication), and a new population is being reintroduced on the San Joaquin River below Friant Dam as part of the San Joaquin River Restoration Program . The ESU also includes populations from the Feather and Yuba rivers; the Feather River population includes hatchery-origin and naturally spawned fish (Figure 1).

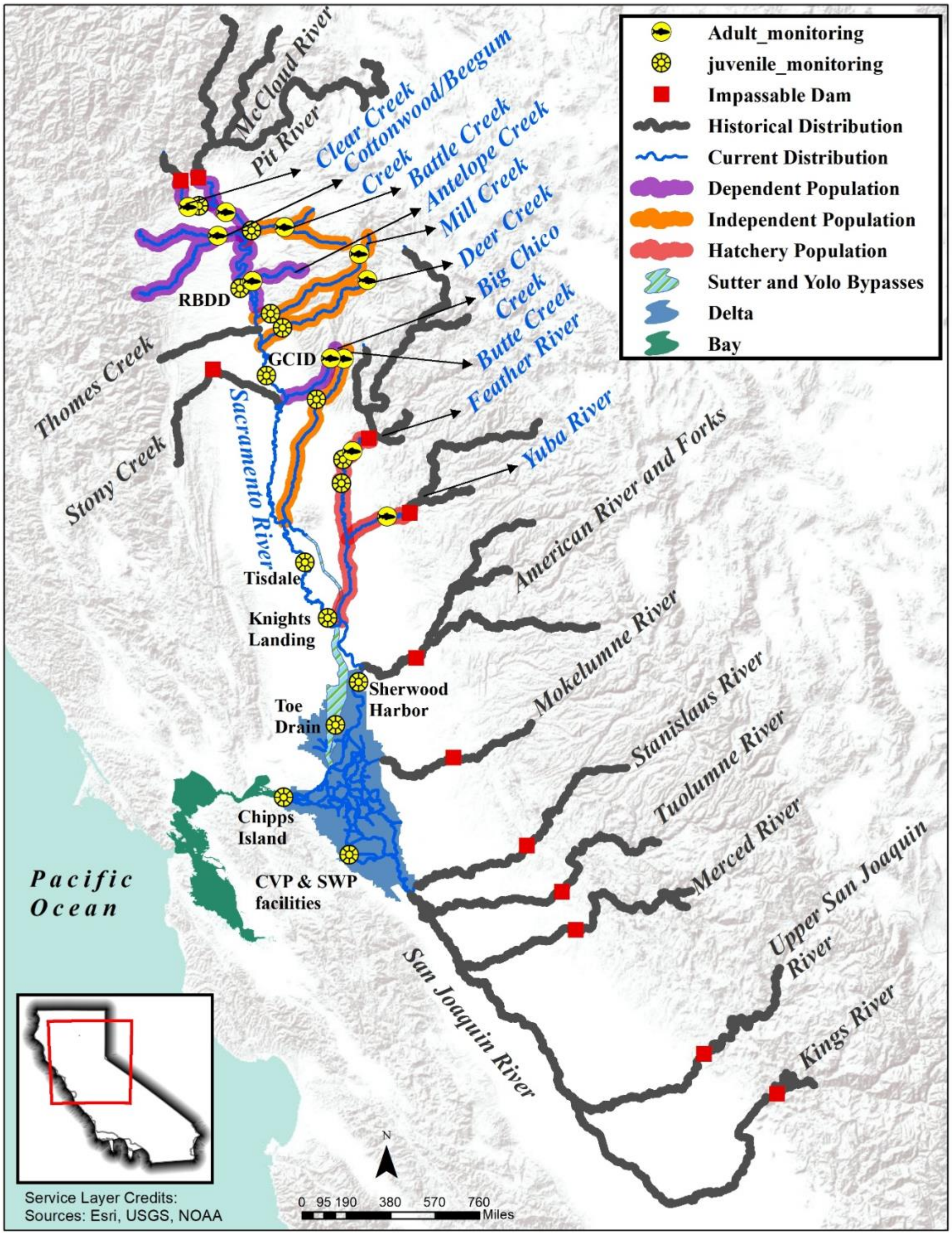
Spring-run adults migrate, hold, or spawn in the Sacramento River Basin from January through October. Fry emerge from late November through March and juveniles can rear for three to fifteen months in freshwater habitat before emigrating to the ocean. Juvenile migration occurs in all but the warmest summer and early fall months (Table 1). Juvenile spring-run exhibit a range of life history variants (Figure 2; note that the entire salmon life cycle is represented, but differences among the timing of juvenile phases [fluvial rearing, tidal rearing, and migration to sea] are emphasized). Juveniles can migrate from natal streams as fry, parr, or smolts, entering the ocean the spring immediately following emergence as YOY, or over-summer and migrate to the ocean the subsequent fall, winter, or spring as yearlings. All spring-run juveniles may rear in the Sacramento River and its tributaries, Sutter and Yolo bypasses, and the San Francisco Estuary (Delta and bays).

Table 1 Natural Spring-Run Life History Timing

Life Stage Event	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Adult Spawning Migration	-	Active	Peak	Peak	Peak	Active	Active	-	-	-	-	-
Adult Holding	-	-	-	-	Active	Peak	Peak	Peak	Active	-	-	-
Spawning	-	-	-	-	-	-	-	Active	Peak	Peak	Active	-
Incubation	Peak	Active	Active	-	-	-	-	-	Peak	Peak	Peak	Peak
Fry Emergence	Peak	Peak	Active	Active	-	-	-	-	-	-	Active	Active
Juvenile Rearing	Active	Active	Active	Active	Active	Active	Active	Active	Active	Active	Active	Active
Young-of-the-year Outmigration	Peak	Peak	Peak	Active	Active	Active	-	-	-	-	Active	Peak
Yearling Outmigration	Active	Active	Active	Active	Active	Active	-	-	-	Peak	Peak	Peak

Source: Cordoleani et al., in press; Williams 2006 and 2012 (adapted from Interagency Ecological Program Tech Rep 91 and Bottom et al. 2009)

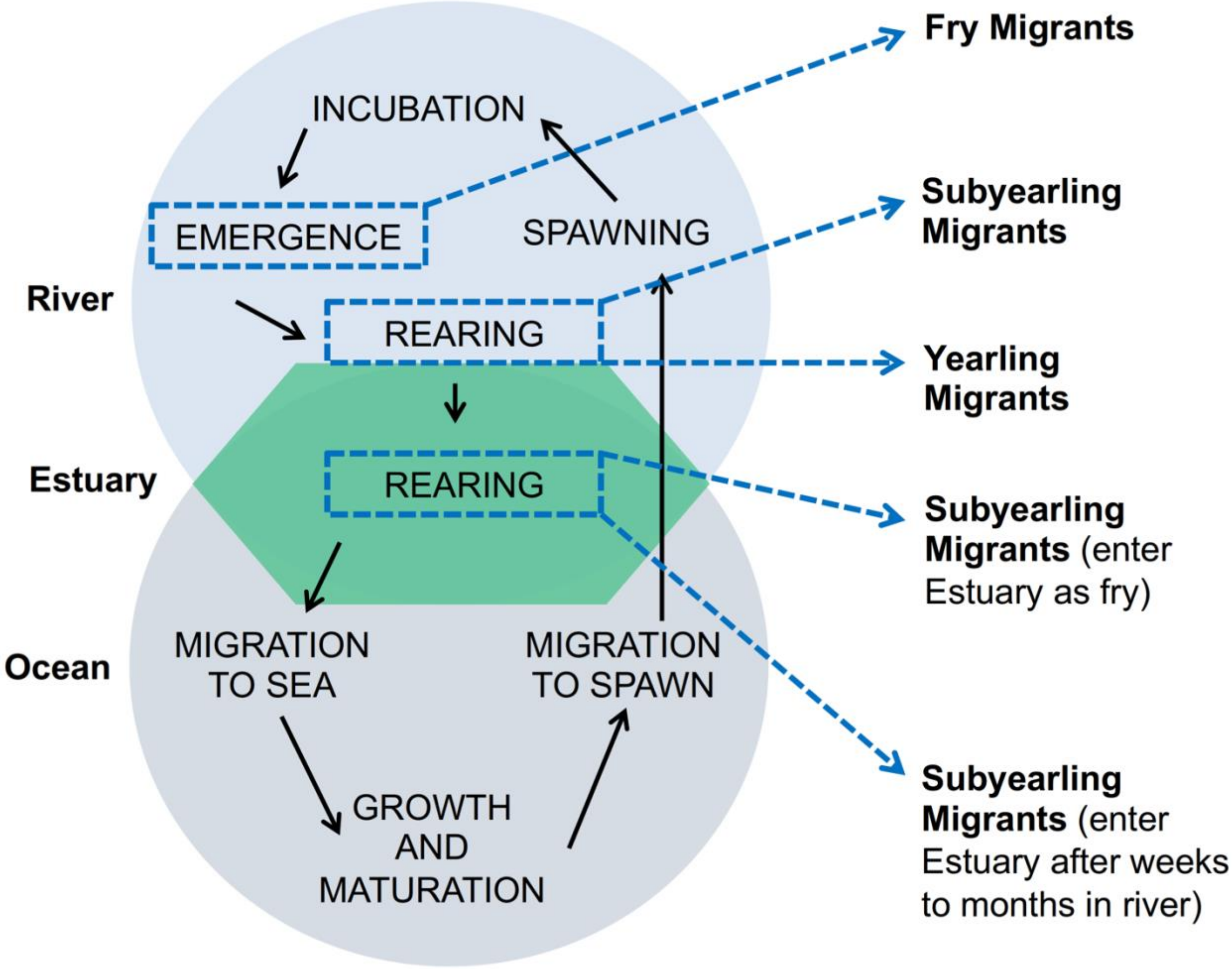
Figure 1 **Current and Historical Central Valley Spring-Run Chinook Salmon Distribution**



Service Layer Credits:
Sources: Esri, USGS, NOAA

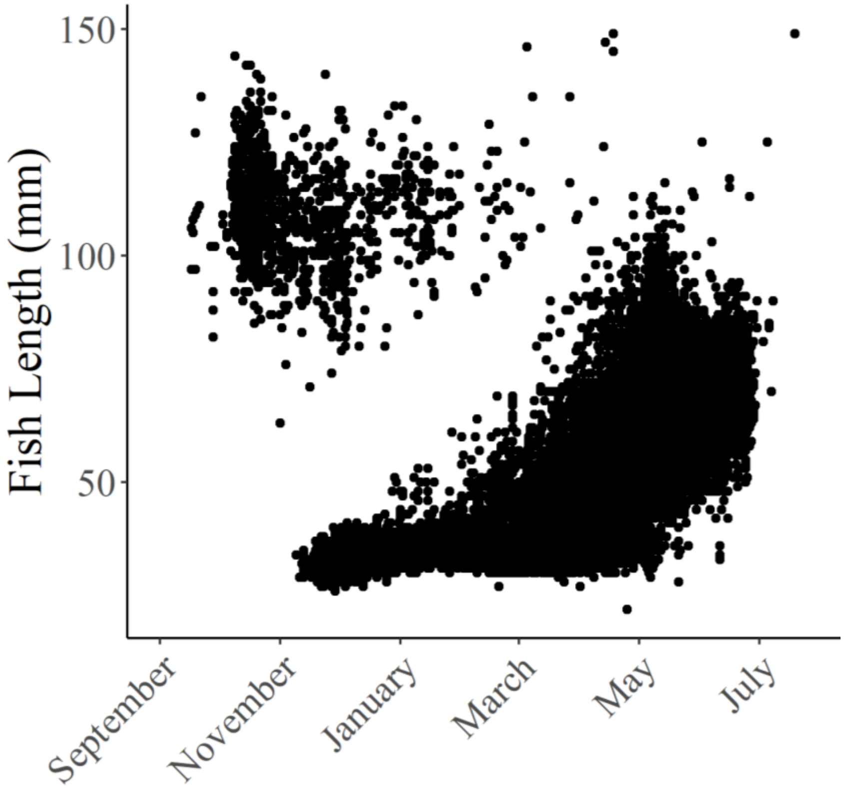
Figure 1 notes: USGS = U.S. Geological Survey, NOAA = National Oceanic and Atmospheric Administration

Figure 2 Conceptual Depiction of Central Valley Chinook Salmon Juvenile Life History Variation



Traditionally, juvenile life-history diversity has been difficult to integrate into real-time salmon management. Commonly, juvenile spring-run life-history diversity is described by the size and timing of juvenile Chinook salmon captured at rotary screw traps (RSTs) using the length at date (LAD) approach (a description of the LAD approach is provided in Section 2.4). For example, Figure 3 shows the length and capture day of juvenile Chinook salmon collected in the Butte Creek RST between 1995 and 2004. In addition to variation in size and timing, trapping data can be used to describe presence in a location within the landscape and differentiate YOY from yearlings. Data from Figure 3 show a clear bimodal distribution in size of salmon occupying Butte Creek, especially from November through March; these were assumed to be yearlings and YOY progeny of Butte Creek spring-run spawners. In addition to life-history diversity, Chinook salmon commonly

Figure 3 **Length and Capture Day of Juvenile Chinook Salmon Collected in the Butte Creek Rotary Screw Trap, 1995–2004**



show diversity in their migration and rearing behavior. For example, work by Phillis et al. (2018) shows that winter-run juveniles use non-natal intermittent streams and tributaries as stop-over rearing habitat during outmigration. Thus, tributary catch data alone does not fully describe the transitions used to define all life history variants present within the spring-run juvenile population (Figure 2). In addition, catch data may not identify population of origin, confirm race identity of spring-run, describe residence time across habitats and life-stages, distinguish individual variation in migration behavior, or estimate apparent or individual growth rates.

Below is a discussion of several monitoring advancements that provide these additional metrics of juvenile life-history diversity in spring-run: otolith microchemistry, acoustic telemetry, and CWT. Examples are provided of spring-run data from studies in progress (Cordoleani et al., in prep; Goertler et al., in prep; Notch et al., 2020) to inform possible discussions regarding the potential to integrate these data into a spring-run JPE approach that addresses life history variation.

2.2.2 Otolith Isotopes

Otoliths are ear stones with daily growth rings, similar to rings on a tree, which can be used to determine the age, growth, stress, migratory behavior, and habitat use of spring-run. The chemical analysis of otoliths recovered from adult spring-run enables an examination of the entire life histories of successful spring-run returns. Strontium isotope ratios are an excellent geographic marker in the California Central Valley, because they vary across the watershed, and those variations are recorded in the growing layers of the otolith (Ingram and Weber 1999; Barnett-Johnson et al. 2008). Otolith strontium isotope analyses can be used to reconstruct movement and life-history patterns of individual salmon across habitats and life stages (Johnson et al. 2017; Phillis et al. 2018; Sturrock et al. 2019), although the resolution is poor for the adult migration stage because adults have stopped feeding and have reduced otolith accrual (Rachel Johnson National Oceanic and Atmospheric Administration, personal communication).

For example, Figure 4 shows the results from a study of adult spring-run otoliths collected between 2003 and 2018 during annual snorkel (Deer Creek, N = 59), redd (Mill Creek, N = 60), and carcass (Butte Creek, N = 286) surveys (Cordoleani et al., in prep). Specific 87Sr/86Sr threshold values, from a Central Valley isoscape database (Barnett-Johnson et al. 2008; Sturrock et al. 2015; Phillis et al. 2018), were used to identify spring-run juvenile movements from one rearing location to another (i.e., natal tributary, Sacramento River, and the Delta). Cordoleani et al. (in prep), observed that Mill Creek and Deer Creek spring-run adult survivors exhibited three distinct life-history types during their juvenile rearing phase, identified as “early,” “intermediate,” and “late” outmigrants (Figure 4). Conversely, juvenile rearing and outmigration for Butte Creek spring-run adult survivors corresponded to a single intermediate outmigrant type. Early, intermediate, and late outmigrants correspond to the fry, sub-yearling, and yearling migrants in the conceptual depiction of juvenile life history variation (Figure 2). Although rearing and migration strategies based on size and timing can be observed in trapping data, otolith microchemistry analysis provides an additional source of information on the relative importance of each of these life history types in different spring-run streams, which would help guide the efforts of spring-run monitoring programs.

Figure 4 **Otolith Radius (Proxy for Fish Size) Distributions at Natal Exit and Otolith Increment Number (Proxy for Fish Age in Days) Distributions at Natal Exit**

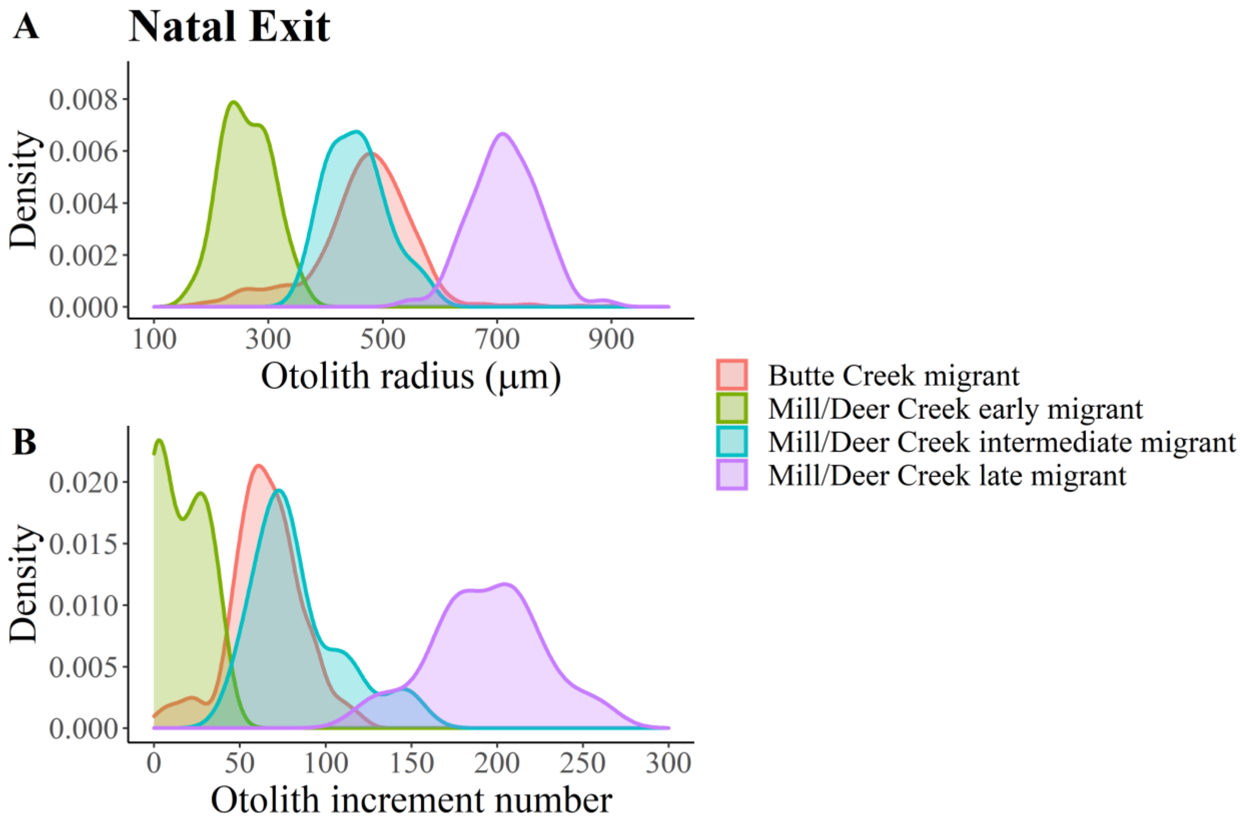


Figure 4 note: µm = micrometer (0.001 of a millimeter)

2.2.3 Acoustic Telemetry

Acoustic telemetry coupled with miniature tags is another high-resolution tool, which can be used to track the timing, location, migration routing, migration rates, and survival of individuals across landscapes. A synthesis of telemetry studies from the Central Valley has shown broad variation in juvenile migration timing and routing (Goertler et al., in prep). Acoustical study results from Cordoleani et al. (2017) and Notch et al. (2020) (natural Butte [n = 194], Mill, and Deer Creeks [n = 147]), as well as Singer et al. (2020) (FRFH [n = 902]) are shown in Figure 5. Across these studies, migration began between March 18 (FRFH) and April 17 (Mill Creek). All fish completed their migration or perished by June 2. Natural Butte Creek spring-run outmigrated to the San Francisco Estuary through the Sacramento River and its sloughs, while Feather River spring-run also outmigrated through the Central Delta (Central Delta and all sloughs; Sacramento River sloughs and

Central Delta sloughs). Acoustic tagging (AT) studies generally target the largest individuals; juvenile Chinook salmon tagged in recent acoustic telemetry studies (2007 through 2017) ranged from 73 to 136 millimeters in fork length (Goertler et al., in prep).

Figure 5 Individual Movement Described by Acoustic Telemetry Detections Across Space and Time

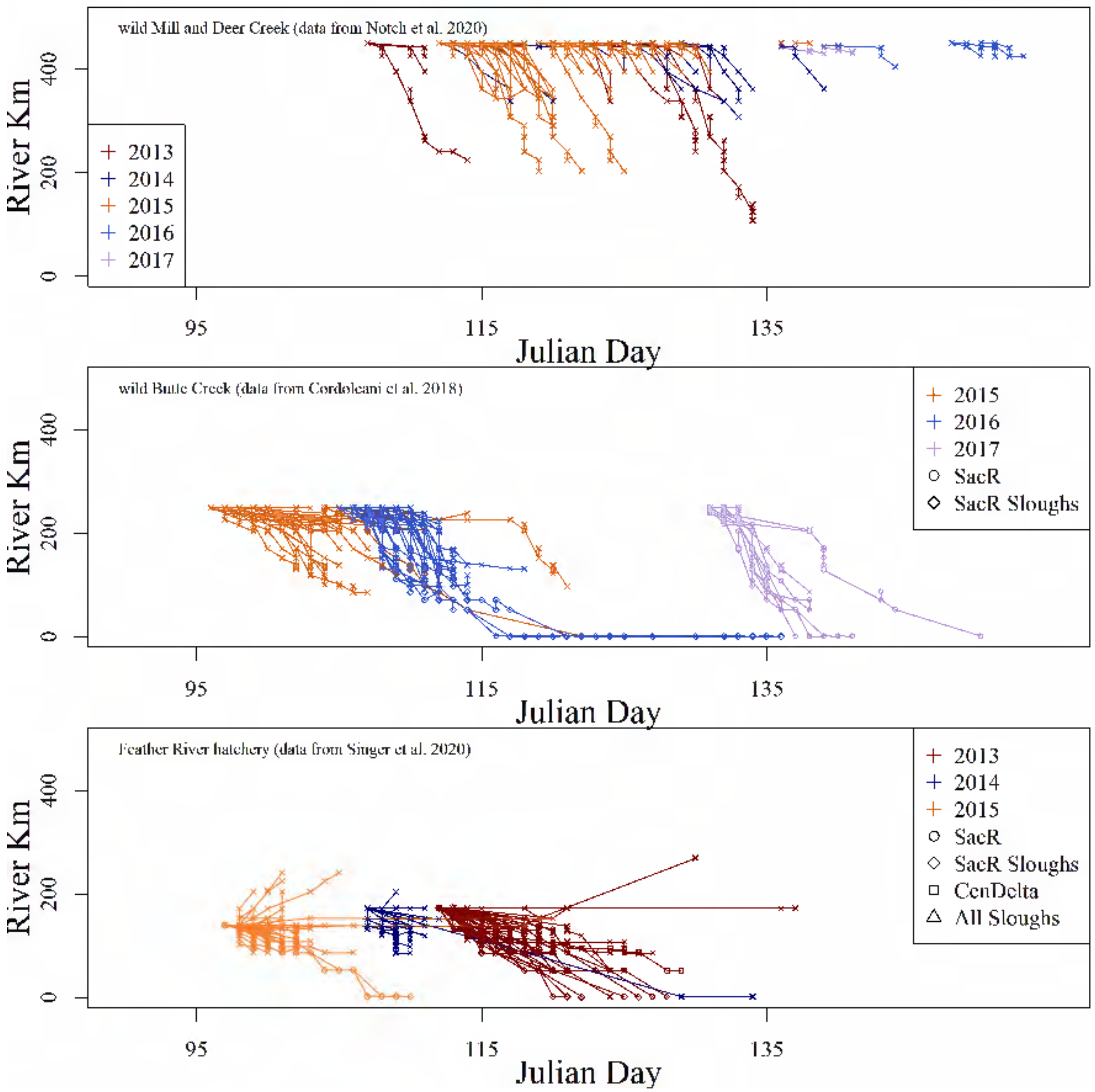


Figure 5 notes: Space measured in river kilometers, time in Julian days. Year is denoted by color; routing is denoted by shape for those fish detected in the estuary.

2.2.4 Coded Wire Tags

CWTs have been used to study the residence time, movement, and survival of salmon for many decades (Nandor et al. 2010). Small fish can be tagged by hand or with an automated tagging trailer; large sample sizes can be obtained because CWTs are relatively inexpensive. Another advantage of CWTs is their longevity; CWTs can be recovered from adult salmon to describe ocean distribution, reconstruct spawner age structure, and evaluate the impacts of ocean harvest (Satterthwaite et al. 2018).

The CDFW marked juvenile Chinook salmon with CWTs near the spawning grounds in Butte Creek and recaptured those individuals downstream in the Sutter Bypass from 1996 through 2008 (Figure 6), (Ward and McReynolds 2004). This study provided the first glimpse of two juvenile rearing strategies exhibited in lower Butte Creek and the Sutter Bypass: fish that reared for extended periods of time prior to recapture in the Sutter Bypass (72 days ± 13.5 days), and fish that outmigrated quickly after tagging (11 days ± 5.6 days). These life-history types are indicated in Figure 6 by the dotted vertical lines. Recaptured juveniles were more likely to rear for extended periods (83 percent) than to outmigrate quickly (17 percent), with rearing taking place in the Sutter Bypass and upstream in the Butte Sink wetland area.

Figure 6 Fork Length at Recapture Date Compared with "Days at Large"

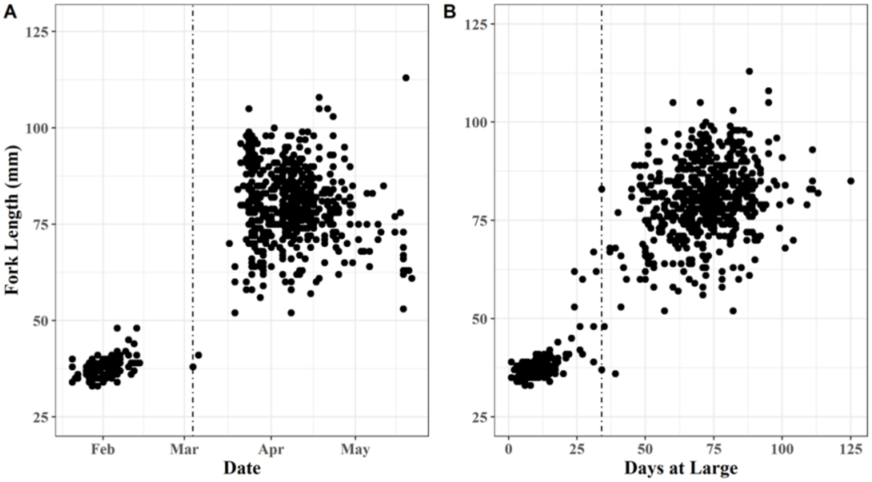


Figure 6 notes: Graph A shows fork length (in millimeters) at recapture date. Graph B shows fork length (in millimeters) compared with "days at large" or residence time (days between release in Butte Creek spawning grounds and recapture at Sutter Bypass [juvenile Chinook tagged with coded wire tags; the dotted line delineates the life history]).

2.3 Monitoring Programs

Long-term monitoring of spring-run populations at critical life stages is performed by a variety of State and federal resource agencies. There are current and historical monitoring programs at multiple sites within the freshwater and estuarine range of Central Valley spring-run Chinook salmon (Figure 1), including adult and juvenile monitoring efforts. The independent populations referenced in Figure 1 correspond to populations that, historically, were not sustainably altered by exchanges of individuals with other populations, noting that regional experts disagree about the status of Battle Creek. In contrast, dependent populations likely would have not persisted without immigration from other streams (Lindley et al. 2004). Feather River and Yuba River populations were historically independent populations, but because of the proximity of FRFH a large presence of hatchery fish occurs among in-river spawners (Lindley et al. 2004). This population is considered to be dependent because of the high proportion of hatchery-origin fish in from FRFH. Because spring-run likely did not spawn in the mainstem Sacramento River before the construction of Keswick and Shasta dams, and it is believed that hybridization has occurred with fall-run fish, this population is considered to be dependent.

2.3.1 Adult Monitoring

Spring-run adult monitoring has several goals, including (1) quantifying the total escapement number, which corresponds to the number of adults returning to the spawning ground; (2) monitoring summer holding and spawning, which includes timing, success, and spatial distribution; and (3) quantifying the number of eggs and fry generated per spawner (Table 2). Spring-run escapement inventories in the upper Sacramento River Basin have been sporadically conducted since the 1940s, but were incomplete, inconsistent, and not replicable. Since the early 1990s, there has been an effort to standardize sampling methods to provide consistent and reproducible spring-run adult escapement estimates. Various watershed-specific challenges and uncertainties in adult collection and escapement estimation remain. Overcoming those challenges would improve the accuracy of a spring-run JPE. In the following sections, some of those challenges are identified.

2.3.1.1 HOLDING AND PRE-SPAWNING MORTALITY

Adult holding and pre-spawn mortality during the summer months could be an important driver of spring-run dynamics in certain years and watersheds. But this source of mortality is not always properly evaluated or accounted for when developing estimates of escapement. For instance, if abundance estimates come only from adult sampling performed during their upstream migration in the spring and early summer (e.g., video monitoring at downstream trap), this could create a discrepancy between escapement and actual spawner numbers, with a potential overestimation of the spawner abundance and further overestimation of the total number of eggs produced. In Butte Creek, where large pre-spawning mortality events have been observed in the past, the estimation of pre-spawning mortality is performed by using a variety of sampling methods. Snorkel surveys conducted in early summer and video monitoring provide an escapement estimate before any pre-spawn mortality. Additionally, a carcass survey is conducted in late summer and early fall. The snorkel survey and carcass survey are used to evaluate pre-spawning mortality and provide alternative spawner estimates. When extended carcass surveys are challenging to implement, an alternative approach is to complement video monitoring with redd counts to provide an additional abundance estimate that only includes returning adults that successfully spawned. This approach has been used in Mill and Battle creeks.

Table 2 Spring-Run Adult Monitoring Summary

Watershed	Monitoring Method	Variable Measured[1]	Sampling
Upper Sacramento River[A]	Aerial redd survey	Escapement	Efficiency Estimate: No Tissue: No Otolith: No
Clear Creek[B]	Snorkel, redd, and carcass surveys; video monitoring	Escapement and successful spawner estimates, summer holding/spawning distribution	Efficiency Estimate: Yes (partially) Tissue: Yes Otolith: Yes
Cottonwood Creek[A]	Snorkel survey and video monitoring	Escapement	Efficiency Estimate: No Tissue: No Otolith: No

Watershed	**Monitoring Method**	**Variable Measured**[1]	**Sampling**
Battle Creek[C]	Fish trapping/ sorting, video monitoring, snorkel and carcass surveys	Escapement and successful spawner estimates, summer holding/spawning distribution	Efficiency Estimate: Yes Tissue: Yes Otolith: Yes
Antelope Creek[A]	Snorkel survey and video monitoring	Escapement	Efficiency Estimate: No Tissue: No Otolith: No
Mill Creek[A]	Redd survey and video monitoring	Escapement and successful spawner estimates, summer holding/spawning distribution	Efficiency Estimate: No Tissue: No Otolith: Yes
Deer Creek[A]	Snorkel survey and video monitoring	Escapement, summer holding/ spawning distribution	Efficiency Estimate: No Tissue: No Otolith: Yes
Big Chico Creek[D] (not currently surveyed)	Snorkel survey (historical)	Escapement, summer holding/ spawning distribution	Efficiency Estimate: No Tissue: Yes Otolith: Yes
Butte Creek[D, E]	Carcass and snorkel surveys, Vaki Riverwatcher	Escapement and successful spawner estimates, summer holding/spawning distribution	Efficiency Estimate: Yes Tissue: Yes Otolith: Yes
Feather River – Natural[2, F]	Redd Survey, Carcass Survey, Adult Telemetry study	Spawning distribution, Escapement (combined with fall-run), summer holding, prespawning mortality	Efficiency Estimate: Yes? Tissue: No Otolith: Yes
Yuba River[G, H]	Carcass and redd surveys, Vaki Riverwatcher	Escapement, summer holding/ spawning distribution	Efficiency Estimate: No Tissue: No Otolith: Yes

Table 2 notes: [1] The variable “Escapement” corresponds to the number of adults that have returned to the spawning ground. [2] Only spring-run adults spawning in the river were considered; Feather River Fish Hatchery production is not included.

Table 2 sources: [A] Killam 2019. [B] Bottaro and Chamberlain 2019. [C] Bottaro and Earley 2020. [D] Garman and McReynolds 2009. [E] Garman and McReynolds 2012. [F] California Department of Water Resources 2011. [G] Yuba River Management Team 2013. [H] Pacific States Marine Fisheries Commission 2015.

2.3.1.2 SAMPLING EFFICIENCY

In most of the spring-run watersheds, adult sampling method efficiency is not assessed and the error in the number of adult spawners observed, related to sampling uncertainty, is not evaluated. This can potentially create a bias in the escapement numbers reported. For example, in Mill and Deer creeks, video monitoring and snorkel or redd surveys are performed. The higher count of the two independent methodologies is used to report the final escapement estimate each year in the main data repository (GrandTab) and the sampling efficiency is not reported. Video passage estimates in CDFW annual reports provide 90 percent confidence intervals for video passage estimates, and there are few examples where the number of spring-run adult spawners recorded is expanded to account for sampling method uncertainty. In Butte Creek, a Cormack-Jolly-Seber model is used to expand the carcass mark-recapture survey’s raw adult counts to population production estimates (Garman and McReynolds 2009). In Clear Creek, a generalized additive model is sometimes used when escapement is estimated from video monitoring, to derive passage values for days that contain video outages (Bottaro and Chamberlain 2019). In Battle Creek, a passage estimate equation is used to expand adult counts when experiencing video monitoring outages and poor video quality (Bottaro and Earley 2020).

2.3.1.3 SPATIO-TEMPORAL SPAWNING OVERLAP

Extracting and reporting accurate estimates of spring-run escapement numbers is challenging in some watersheds because of overlap between spring- and fall-run spawning in space and time. This is further complicated by the lack of a suitable means of distinguishing between spring- and fall-run adults during the spawning period. In the upper Sacramento River, the traditional process of estimating natural spring-run spawning effort uses the aerial redd data and assigns a spring-run number based on new redds observed in late August through September. There is considerable uncertainty and discussion amongst biologists regarding the exact nature of the spring-run population in the Sacramento River (Pipal 2005). In the Feather River, adult spring-run are included in fall-run Chinook counts. The installation of a fish barrier weir to temporally and spatially separate spring- and fall-run spawners on the Feather River is a required action included in DWR’s Fish Weir Program (National Marine Fisheries Service 2016). A count weir is also required (in DWR’s anticipated Federal Energy Regulatory Commission license) to enumerate all Central Valley spring-run Chinook salmon that enter the Feather River Low Flow Channel. In Clear Creek, a segregation weir is installed every year for the same purpose. In the Yuba River, Vaki passage data are used to develop a statistical model that helps define a demarcation date between the spawning of the two races upstream of Daguerre Dam. But model improvements have been suggested and are ongoing to better separate spring- and fall-run adults. Some level of spawning overlap is also sometimes observed in Mill, Deer, and Butte creeks. In Butte Creek, efforts are made to discourage fall-run passage at the Parrott-Phelan diversion dam fish ladder, and CDFW biologists note any potential fall-run during spring-run adult escapement surveys. Securing reliable funding to collect and analyze carcass tissue samples during the entire spawning time period and genetically identify their race could help improve spring-run escapement estimations. Some genetic information may already exist to make this determination.

2.3.1.4 LENGTH AND SEX DATA

Fish length and sex information are necessary to better estimate the number of female spawners and to evaluate the number of eggs produced per spawner each year. Egg production is then used to estimate a fry equivalent production index for JPE calculations based on spawner abundance. But, this type of information can only be accurately collected when carcasses are recovered, which can be challenging in some spring-run streams in part because of low returning adult numbers in a given year and/or insufficient monitoring funding. Securing reliable funding for carcass surveys or using fish size and sex ratios from other Central Valley spring-run Chinook salmon streams or the FRFH are some alternatives in decreasing order of preference which may be used to improve spring-run egg production estimates.

2.3.1.5 OTHER CONSIDERATIONS

Additional sampling is performed in some spring-run streams to obtain biological and environmental information that could also be important for the development of a JPE. For example, carcass otolith sampling is currently ongoing in various spring-run tributaries such as Mill, Deer, Butte, Clear, and Battle creeks, and the Feather River; and isotope analysis can be used to study successful spring-run juvenile rearing and migrating strategy characteristics (Sturrock et al. 2019; Cordoleani et al., in prep). Environmental factors such as water temperature, flow, and redd physical data (e.g., substrate used and redd size) are also monitored in many of the spring-run streams where adult holding and spawning occurs. These environmental factors can be used to investigate the habitat’s suitability for egg incubation and to estimate the likelihood of successful incubation. Reaches where this monitoring takes place include Cottonwood, Antelope, Clear, Mill, Deer, and Battle creeks, and the Yuba and Feather rivers. Finally, the spring-run ESU includes FRFH spring-run production. Adult tagging and spawning efforts at the hatchery might provide opportunities to genetically sample hatchery and natural-origin spring-run, as well as an opportunity to examine interannual variation of hatchery versus natural-origin abundance returning to the hatchery.

2.3.2 Juvenile Monitoring

The goals of spring-run juvenile monitoring include: (1) assessing the relative juvenile abundance; (2) quantifying the total juvenile salmon production (the number of juveniles migrating past a location); and (3) collecting juvenile salmon life history information such as outmigration timing and size distribution (Table 3). Juvenile monitoring is mainly performed using RSTs downstream of the spawning reaches in spring-run tributaries (U.S. Fish and Wildlife Service 2010) or using trawls or beach seines at key locations along the migratory corridor. Currently, JPE estimations are performed in very few spring-run watersheds because of the difficulties identified below.

Table 3 Spring-Run Juvenile Monitoring Summary

Watershed	Monitoring Method	Years of Operation	Season of Operation	Variable Measured[1]	Traits Measured	Tissue Sampling
Clear Creek[A]	RST	1998 – present	November –June	Production, outmigrant size and timing	FL – W – K	Yes
Sacramento River – Balls Ferry	RST	1996 – 1999	October – September	Production, outmigrant size and timing	FL	No
Cottonwood Creek	None	None	None	None	None	None
Battle Creek[B]	RST	1998 – present	November – June; restarting year-round in 2020	Production, outmigrant size and timing	FL – W – K	Yes
Sacramento River – Red Bluff Diversion Dam[C]	RST, telemetry study	1995 – 2000, 2002 – present	January – December	Relative abundance, outmigrant size and timing, smolt survival	FL	Yes (during the fall period)
Antelope Creek	None	None	None	None	None	None
Mill Creek[D]	RST, telemetry study	1996 – 2010, 2013 – 2017	November – June	Relative abundance, outmigrant size and timing, smolt survival	FL	No
Deer Creek[D]	RST, telemetry study	1994 – 2010, 2017 – present	November – June	Relative abundance, outmigrant size and timing, smolt survival	FL	No

Watershed	Monitoring Method	Years of Operation	Season of Operation	Variable Measured[1]	Traits Measured	Tissue Sampling
Sacramento River – GCID Hamilton City[E]	RST	1991-2009, 2013-present	January – December	Relative abundance, outmigrant size and timing	FL	No
Big Chico Creek[F]	RST	1999 – 2003	November – May	Relative abundance, outmigrant size and timing	FL	No
Butte Creek[F]	RST, CWT, and telemetry study	1995 – present	October – June	Relative abundance, outmigrant size and timing, smolt survival	FL	No
Sacramento River – Tisdale[G]	RST	2010 – present	August/September – June	Relative abundance, outmigrant size and timing	FL – W	As needed
Sacramento River – Knights Landing[H]	RST	1995 – present	August/September – June (since 2015)	Relative abundance, outmigrant size and timing	FL – W	Yes (since 2017)
Feather River[I]	RST, beach seining, snorkel survey, CWT, and telemetry study	1998 – present	November/ December – June	Production, outmigrant size and timing, disease monitoring, smolt survival (FRFH fish)	FL	Some
Yuba River[J]	RST	1999 – 2009	October – June	Relative abundance, outmigrant size and timing	FL – W	No

Watershed	Monitoring Method	Years of Operation	Season of Operation	Variable Measured[1]	Traits Measured	Tissue Sampling
Sacramento River – Sherwood Harbor[K]	Trawl	1988 – present	Year-round since 1994	Relative abundance, outmigrant size and timing	FL	Yes
Yolo Bypass[L]	RST, fyke trap, beach seine, telemetry study	1998 – present	January – June (RST), September – Junes (fyke), year-round (seine)	Relative abundance, outmigrant size and timing, spatial distribution, smolt survival	FL	Yes
Delta – various locations (e.g., Chipps Island[K])	Trawl	1976 – present	Year-round since 1996	Relative abundance, outmigrant size and timing	FL	Yes
Delta – various locations[K]	Beach Seine	1970 – present	Year-round since 1995	Spatial distribution	FL	No
Delta – CVP and SWP facilities	Salvage facilities	1968 – present	Year-round	Outmigrant size and timing, fish count	FL	Yes

Table 3 notes: CWT = coded wire tag; FL = Fork Length; FRFH = Feather River Fish Hatchery; GCID = Glenn-Colusa Irrigation District; K = condition factor; RST = rotary screw trap; W = Weight

[1] The variable “Production” corresponds to the juvenile production estimate obtained from the expansion of raw juvenile counts.

Sources: [A] Schraml et al. 2020; [B] Schraml and Earley 2020; [C] Poytress et al. 2014; [D] Johnson and Merrick 2012; [E] Coulon unpublished; [F] Garman and McReynolds 2009; [G] Purdy and Coulon 2013; [H] Julienne 2016; [I] California Department of Water Resources 2019; [J] YRMT 2013; [K] Barnard et al. 2015; [L] Schreier et al. 2018.

2.3.2.1 SAMPLING EFFICIENCY

To expand raw juvenile capture numbers to total abundance values, trap efficiency studies have to be performed throughout the trapping season. But only a few spring-run watersheds currently conduct trap efficiency trials at the levels necessary to reliably expand estimates. This is because of the frequency of high-flow events in these unregulated tributaries which cause dangerous debris loads in and around sampling locations (e.g., Butte, Mill, and Deer creeks), and/or because access is not readily available to the large numbers of fish required for trap efficiency trials. Another constraint is that CWT and AT releases using hatchery fish to estimate trap efficiency for spring-run at key spring-run should be limited to the watershed in which the hatchery resides to preserve the genetic integrity of sensitive populations.

2.3.2.2 RUN IDENTIFICATION

In most spring-run watersheds, sampled juveniles are assigned to race, based on the LAD criteria; LAD criteria have been shown to be inaccurate for spring-run when compared to genetic identification (Harvey and Stroble 2013, Harvey et al. 2014). This is primarily because empirical fall-run and winter-run length distributions and outmigration timing overlap substantially with LAD criteria for spring-run and are classified as spring-run in locations where these runs co-occur (e.g., the Sacramento, Feather, and Yuba rivers).

Similarly, empirical spring-run size distributions overlap LAD criteria for other salmon races, particularly spring-run yearlings, which frequently occur within LAD criteria for winter-run. Developing a more robust juvenile fish race identification methodology and securing reliable funding to implement it would improve spring-run juvenile abundance estimates (see Section 2.4). Race identification is discussed in more detail in Section 2.4.

2.3.2.3 SURVIVAL ESTIMATES

Estimation of fry-to-smolt survival and smolt survival from natal streams to the Delta is required to develop a spring-run JPE. But spring-run fry survival estimates are difficult to obtain because of tracking challenges related to their small size and because large CWT release programs typically used to calculate fry survival rates are expensive and can require high take authorization to obtain adequate sample sizes. One exception is FRFH, where 100 percent of spring-run Chinook juveniles are tagged with CWTs at the hatchery before being released in the river. If a large number of tagged juveniles are recovered in the Delta, this information could be used to estimate in-stream fry survival. An alternative is the use of passive integrated transponder (PIT) tags to mark and track parr-size juveniles (smaller than 50 millimeters) in the spring-run streams, which could help gain insight into fry-to-smolt survival.

With advances in AT technology (e.g., smaller tags and longer battery life), biotelemetry has become a well-established tool in estimating spring-run smolt-sized juvenile survival through their migratory corridor (Cordoleani et al. 2019; Notch et al. 2020; Singer et al. 2020). But most of the tagging studies occurred during the last California drought period and likely do not represent the suite of hydrological conditions and water year types spring-run juveniles experienced during the modeled years. Furthermore, because of the small number of tagged fish in some of these studies, Delta smolt survival estimates were associated with large error margins. Securing reliable funding for the implementation of long-term AT studies throughout the Central Valley could help provide better smolt survival estimates to the Delta for spring-run populations.

2.3.2.4 OTHER CONSIDERATIONS

Additional monitoring efforts are performed in some spring-run watersheds that could also help the development of an accurate spring-run JPE. As an example, a study on disease prevalence and the impact on juvenile health and outmigration success has been conducted in the Feather River (Foott et al. 2019). Juvenile tracking studies of both spring-run natural and hatchery fish, using CWTs or ATs, can also provide valuable information, such as movement and presence of juveniles from various size classes (e.g., fry, sub-yearling, or yearling) at key locations and time periods (e.g., in the Delta during opened Delta Cross Channel gate period), and sub-yearling migration routes throughout the Central Valley.

2.4 Identification Methods

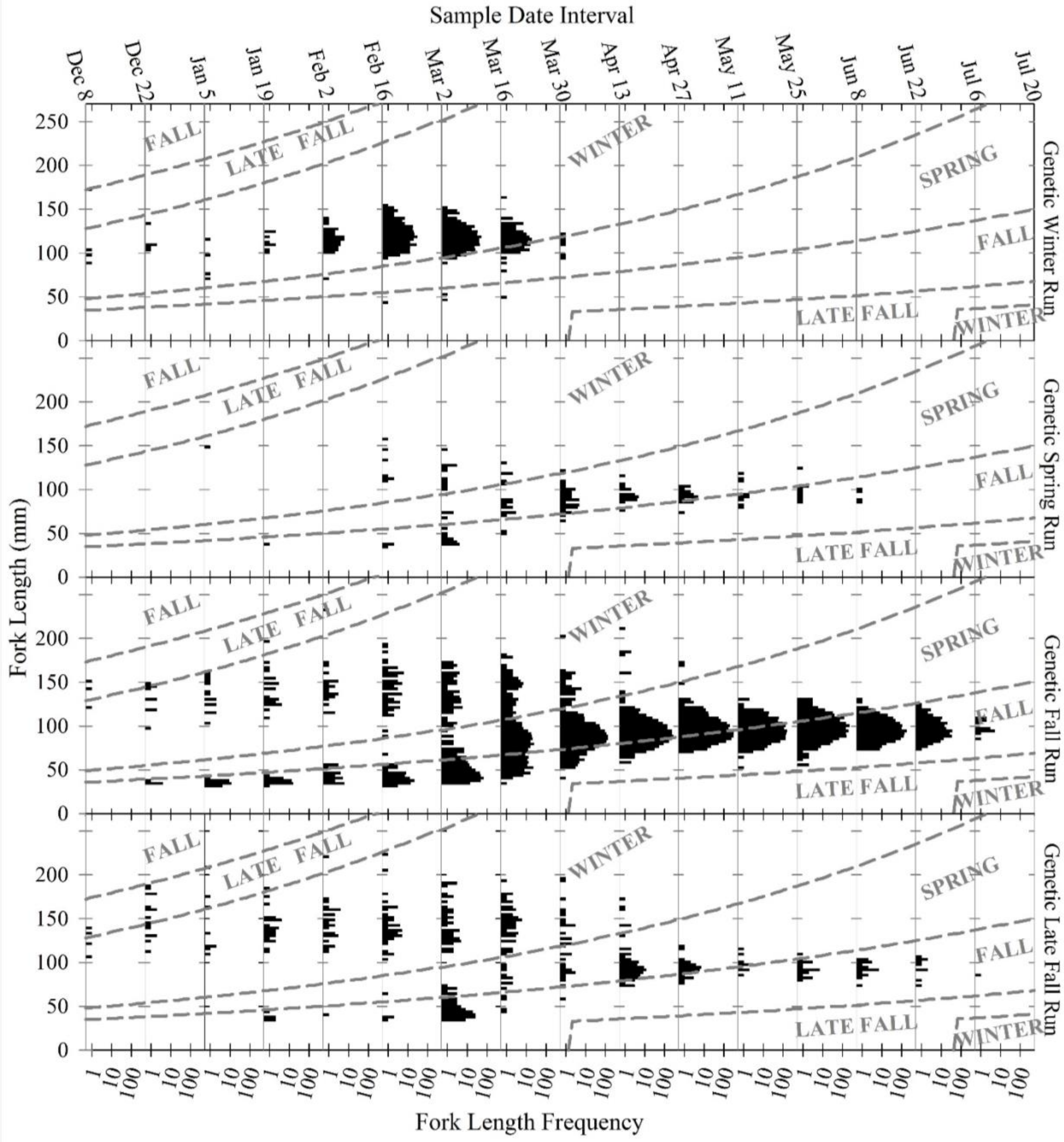
Migrating juvenile spring-run Chinook salmon occur in a mixed population of the four Central Valley salmon races and are morphologically indistinguishable from these other races to the naked eye. But some means of identifying juvenile spring-run from the other salmon races migrating through the Delta will be critical to the development of a robust JPE. Several approaches exist, or are in development, that may be applied. A single approach to identifying spring-run may not be optimal for all possible JPE approaches, and different approaches may need to be applied in combination.

2.4.1 Deterministic Length at Date

The LAD approach assigns a race identification to a juvenile salmon, based on capture date and fork length (Figure 7). The approach was originally proposed in 1989 concurrent with the federal listing of winter-run Chinook salmon under the Endangered Species Act, as a tool to assess take of juvenile winter-run salmon by the State and federal water projects (Harvey 2011). Currently, there are two different LAD criteria applied in the Central Valley. The Delta Model is used for fish sampled at the State and federal water project salvage facilities and in the Yolo Bypass Fish Monitoring Program. The River Model is used for most other locations and sampling programs.

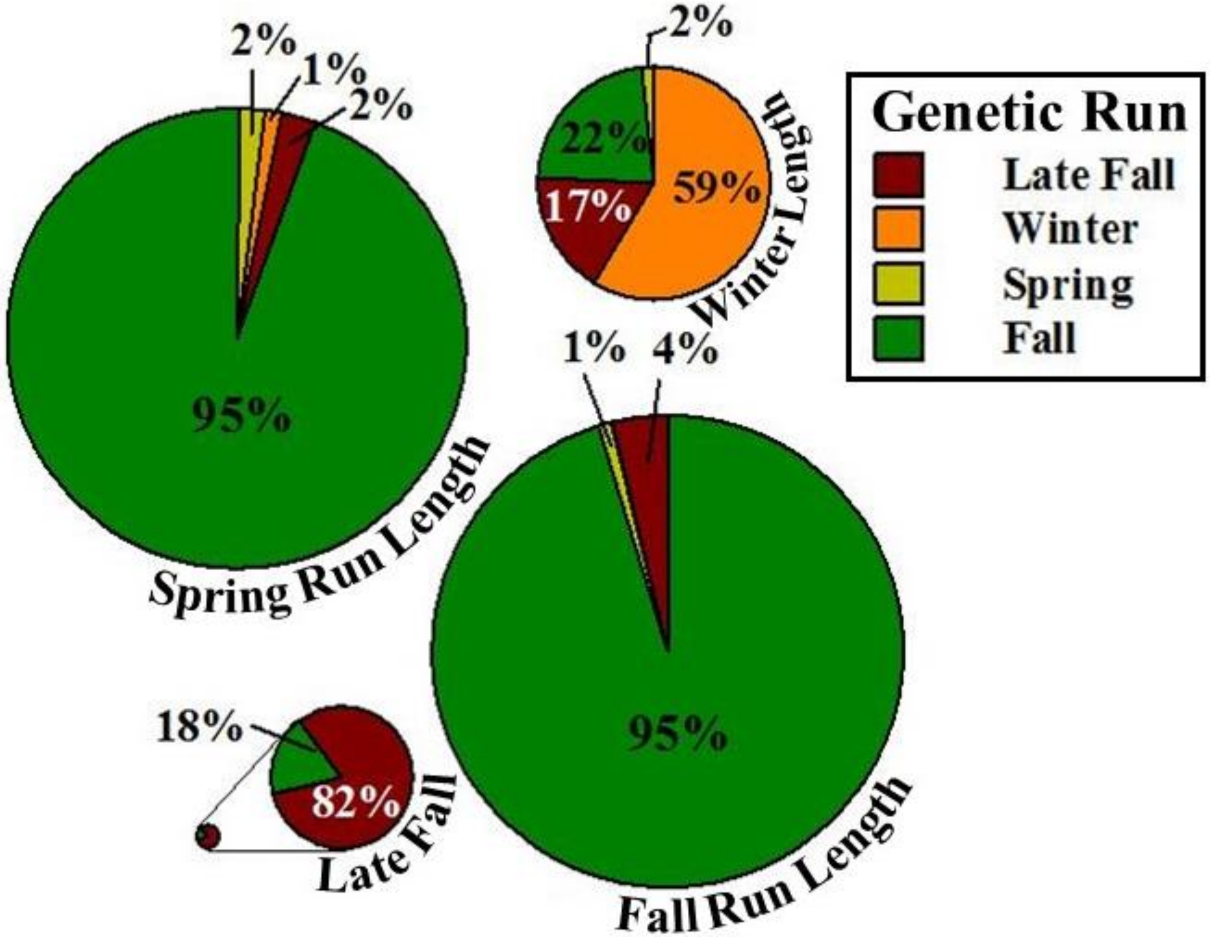
The LAD approach relies on two major assumptions: (1) juvenile salmon of different races hatch during distinct periods of the calendar year; and (2) all juvenile salmon grow at a constant rate. Genetic analyses show that neither of these assumptions are true, and there is large overlap in size distributions between races (Harvey and Stroble 2013; Harvey et al. 2014). Fall-run have considerable size overlap with spring-run for the Delta Model (Figure 7, third panel), and both fall-run and winter-run overlap considerably with spring-run for the River Model. Because of the large abundance of fall-run relative to spring-run, this overlap can lead to a high number of false positive spring-run assignments by LAD (Figure 8, green slice of upper left pie). Nonetheless, the approach continues to be used for race assignment in many, if not most, Central Valley monitoring programs, ostensibly because its speed and simplicity is useful for “real-time” management, and because its application has minimal cost.

Figure 7 **Fork Length Distribution of Genetically Assigned Chinook Salmon and Delta Model Length-at-Date Size Ranges for Fish Sampled at Salvage Facilities, 2004–2010**



Source: Harvey et al. 2014

Figure 8 **Proportion of Genetic Race Sampled within Each Delta Model Length-at-Date Range at the State and Federal Salvage Facilities, 2004–2010**

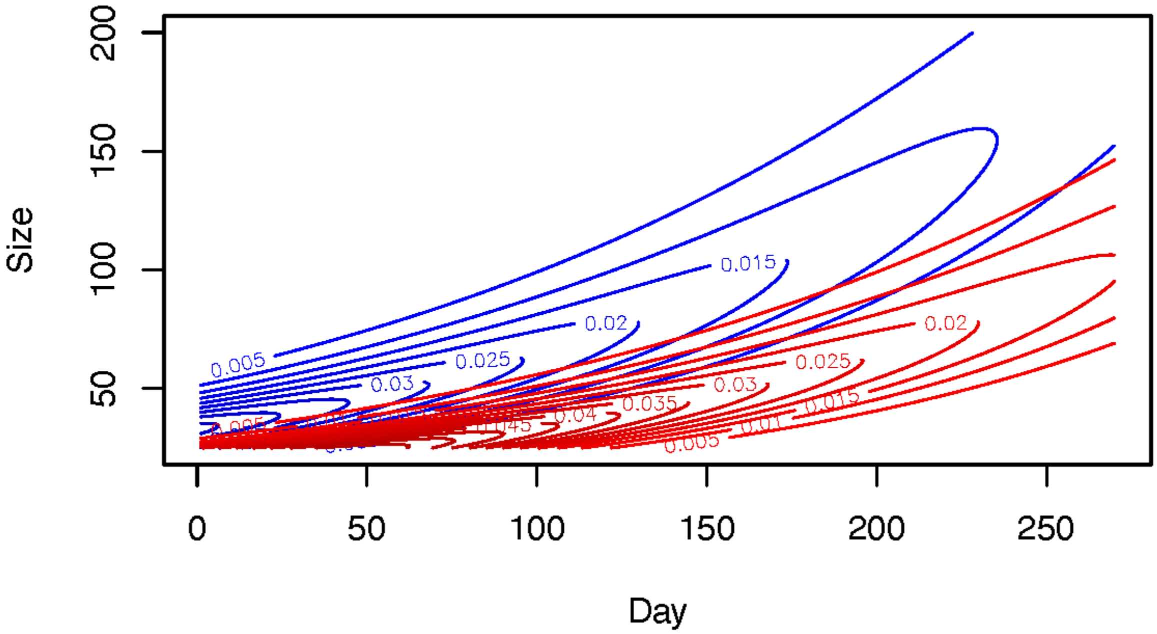


Source: Harvey and Stroble 2013

2.4.2 Probabilistic Length at Date

A Bayesian probabilistic LAD (PLAD) approach for winter-run Chinook salmon was initiated in 2017 and is currently being developed under the guidance of an interagency steering committee (Noble Hendrix, Queda Consulting, personal communication). Similar PLAD models could be developed for spring-run. The probabilistic approach of PLAD has a similar construct to the original deterministic approach of LAD in that it relies on the fork length and sample date of a juvenile salmon to assign a race. Unlike LAD, the PLAD may assign more than one race for a given juvenile salmon along with a probability for each race assignment (Figure 9).

Figure 9 Conceptual Depiction of Probabilistic Length-at-Date Size Ranges for Two Runs



Source: Nobel Hendrix, unpublished

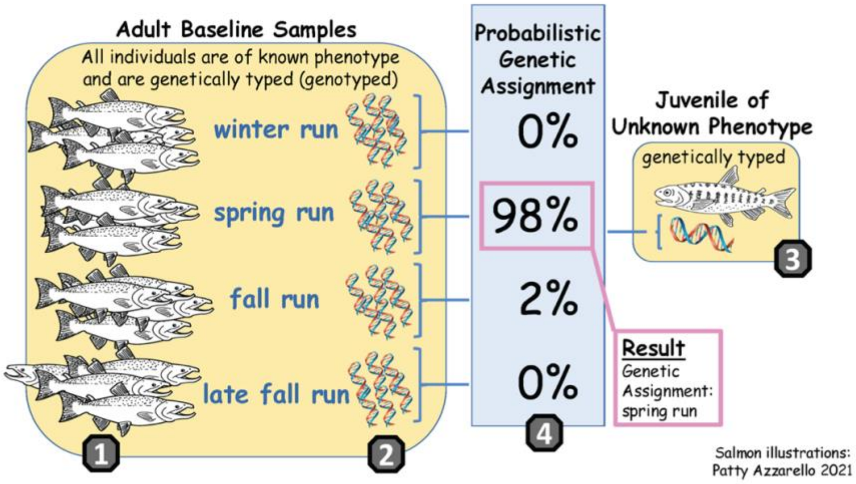
The assignment probabilities are based on genetic identification of catch from the preceding years of various monitoring programs. In addition to genetic information, variables such as geographic area, flow, and temperature may be incorporated as predictive variables into PLAD models. The updated model predictions can be posted for real-time use on an internet platform such as SacPAS, possibly available as an R application, which would allow field crews to use the uncertainty of PLAD identification to determine which juveniles required tissue sampling for genetic race identification. PLAD models can then be updated regularly throughout a migration season as ongoing genetic and other calibration data become available.

The PLAD models under development are focused on winter-run versus non-winter-run identification, and assignment probabilities are calibrated with coupled genetic and length data from key sampling locations along winter-run migration routes. To be most effective, spring-run PLAD models would require genetic, length, and environmental data specific to sampling locations where spring-run PLAD models would be used. In other words, PLAD assignment accuracy for a given sampling location would depend on the site-specificity and accuracy of the data used to calibrate the models, in particular the accuracy of genetic race identification.

2.4.3 Genetic Identification

All salmon races were originally and primarily defined by phenotypic differences among adult Chinook run-timing and spawning periods, and not by differences in genetic composition or morphology. To use genetics to differentiate between salmon races, thousands of genetic samples are collected from adult salmon displaying the different run-timing phenotypes, and from different regions (Figure 10). These adults form a baseline. The genetic composition of a set of genetic markers is characterized for each adult fish in the baseline. Most genetic tests now use genetic markers called single nucleotide polymorphisms (SNPs). For each SNP, the type of nucleotides (the building blocks of deoxyribonucleic acid [DNA]) are identified for a single nucleotide pair at a specific location on the genome (Figure 11). SNPs are grouped into panels tailored for specific applications and objectives. Various laboratory techniques may be employed for genetic typing a SNPs panel; techniques differ in the number of SNPs for a given panel (96 to more than 10,000), sample processing cost, turnaround time, throughput, and other factors (Figure 12). Genetics laboratories constantly harness new technologies and develop new SNPs to update their panels and improve identification accuracy and certainty.

Figure 10 Genetic Identification

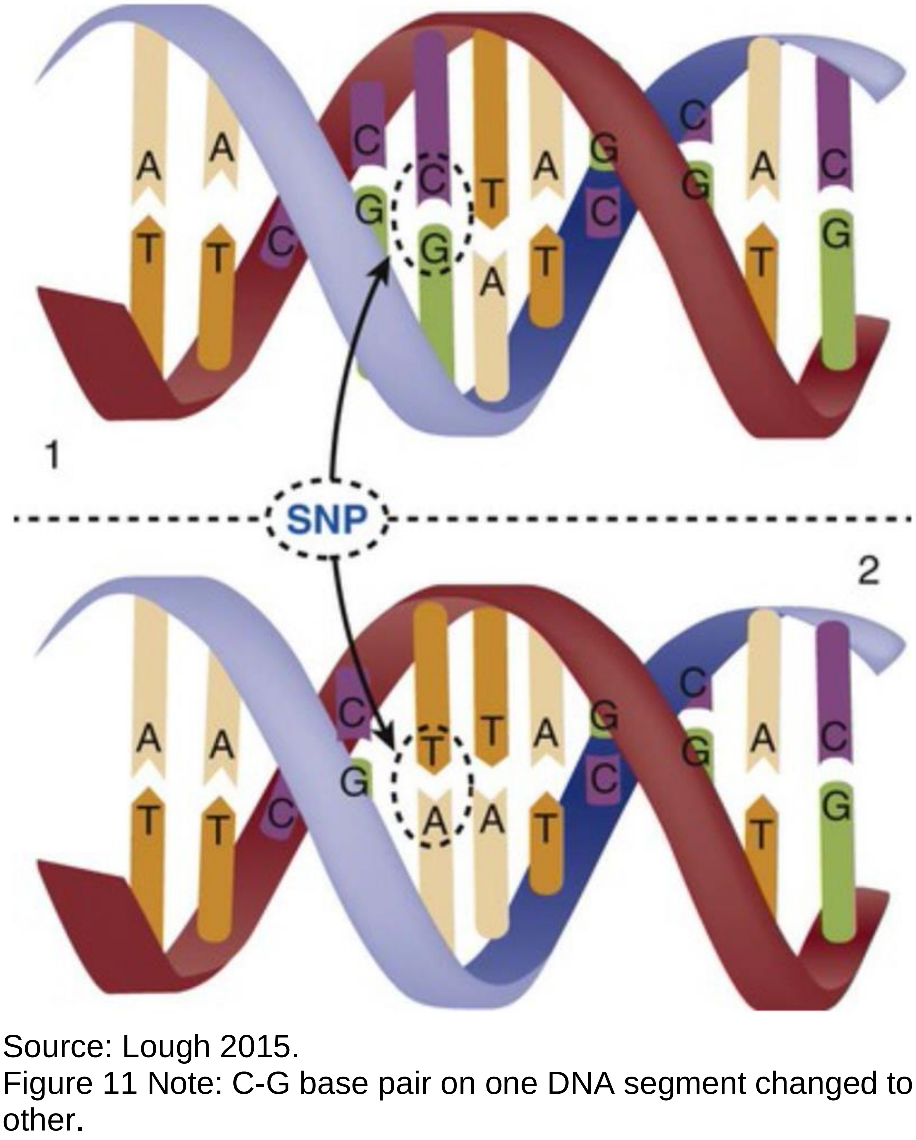


Salmon illustrations: Patty Azzarello 2021

Figure 10 notes: (1) Collecting baseline tissue samples from adult salmon of known race; (2) Analysis of genetic markers (specific locations in genome); (3) Analysis of salmon of unknown race at same genetic markers; (4) Comparison of unknown and baseline samples to derive probabilistic assignment

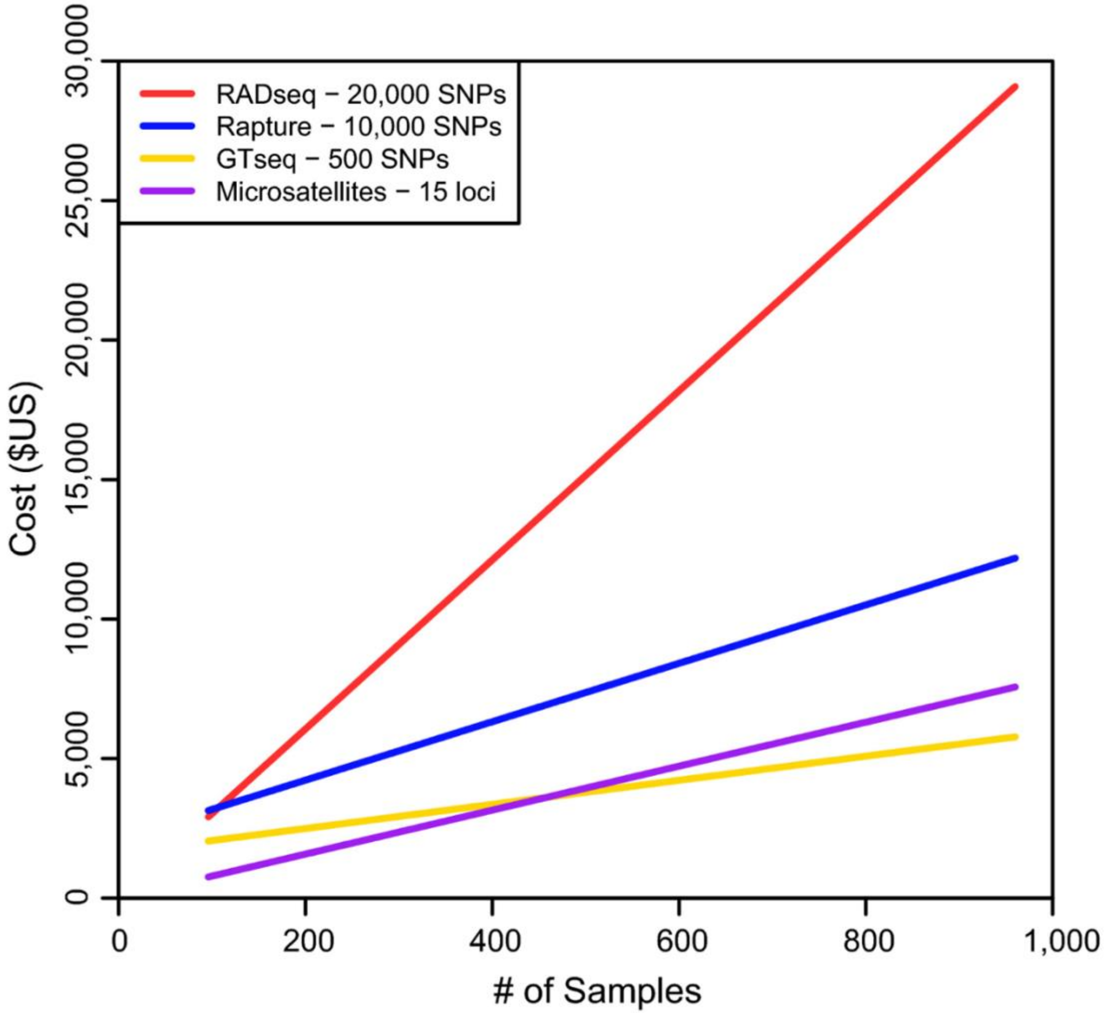
The SNPs for a specific genetic test are selected based on their collective ability to differentiate among populations of interest. In general, increasing the number of genetic markers improves the ability to differentiate among populations with increasing certainty, but the degree of improvement is highly case-specific. Once a genetic test is developed, salmon of unknown origin are genetically typed at the same set of genetic markers as the baseline adults and are assigned a probability of belonging to each race based on their similarity/dissimilarity to the adult fish representing the different phenotypes in the baseline (Figure 10).

Figure 11 Single Nucleotide Polymorphism



Source: Lough 2015.
Figure 11 Note: C-G base pair on one DNA segment changed to a T-A base pair on the other.

Figure 12 **Cost Analysis for Four Genetic Analysis Approaches Employing Different Numbers of SNPs**



Source: Meek and Larson 2019
Figure 12 note: SNP = single nucleotide polymorphisms

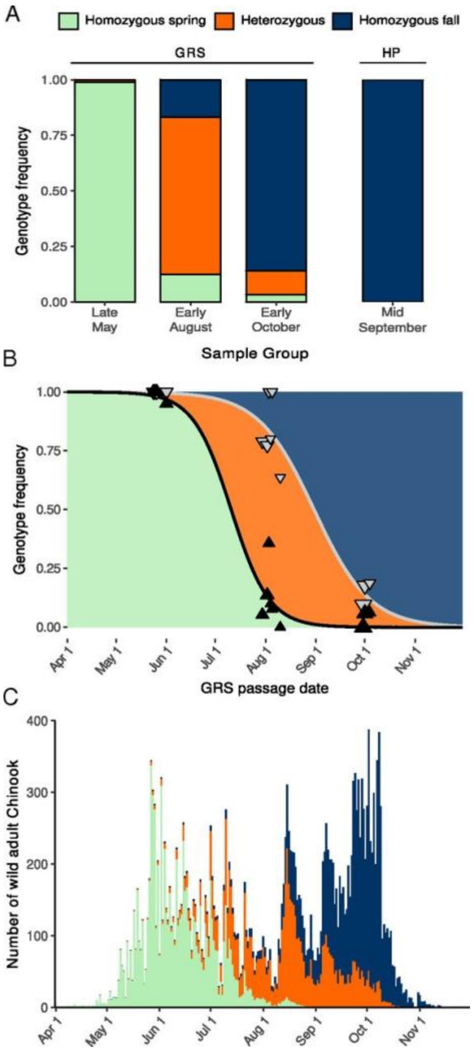
The appropriate genetics test for differentiating among Central Valley salmon populations varies depending on the needs and conditions of a specific application. These needs include the biological question at hand, and the logistical requirements and constraints. Primary among biological questions is the type and level of population differentiation required, such as spring-run versus not spring-run, or spring-run tributary of origin. Logistical considerations and constraints include cost, turnaround time, sample throughput, and the number of genetic markers needed to achieve a given level of identification accuracy (Figure 12). In general, finer-scale population resolution will have higher costs. After these parameters are defined, a geneticist can determine the most appropriate available techniques, and develop an approach or explain the tradeoffs of different potential approaches.

Until recently, the ability to differentiate among Central Valley salmon populations required reproductive isolation, because of either spatial or temporal segregation during spawning. When Oroville Dam was constructed, spring-run access to historical holding and spawning habitat in the upper watershed was eliminated. Feather River spring-run have continued to migrate early and hold in the dam’s cold tailwaters, an area overlapping the historical spawning region of Feather River fall-run. Until recently, interbreeding between these overlapping populations in the Feather River prevented genetic differentiation between Feather River spring-run and fall-run. But advancements in salmon genetics have solved this problem.

The phenotypic trait that defines spring-run salmon, early migration with immature eggs, was recently found to be strongly associated with SNPs located around and within an adjacent pair of genes, Greb1L and Rock1 (Prince et al. 2017; Narum et al. 2018; Thompson et al. 2020). Genetic tests on Rogue River and Klamath River Chinook salmon, using only two SNPs in the region of Greb1L, provided strong evidence that salmon with spring-run genotypes at the SNP locations on both of their paired chromosomes (i.e., salmon with homozygous spring-run genotypes) almost universally express the early-migrating spring-run phenotype in these rivers; homozygous fall-run genotypes express a late-migrating fall-run phenotype; and salmon with a spring-run allele on one chromosome and a fall-run allele on the other chromosome (i.e., heterozygous) display intermediate run-timing that overlaps with the run-timing of homozygous spring and fall-run salmon (Figure 13; Thompson et al. 2019). The degree of overlap for heterozygous salmon appears to vary by watershed. Ongoing work shows that a similarly strong association exists between Greb1L-associated SNPs and phenotypic run-timing for Sacramento River Chinook salmon, including Feather River salmon (Figure 14; Meek et al. 2020; Thompson et al. 2020). As previously discussed, assignment accuracy of current genetic tests varies depending on the level of differentiation a test was designed to resolve, which in turn depends on the purpose, cost, and other constraints that were considered in the design of the test. If the objective is to distinguish spring-run from other races, or to distinguish among the four Central Valley races, a high degree of accuracy can be obtained (Figure 16; Meek et al. 2020; Thompson et al.

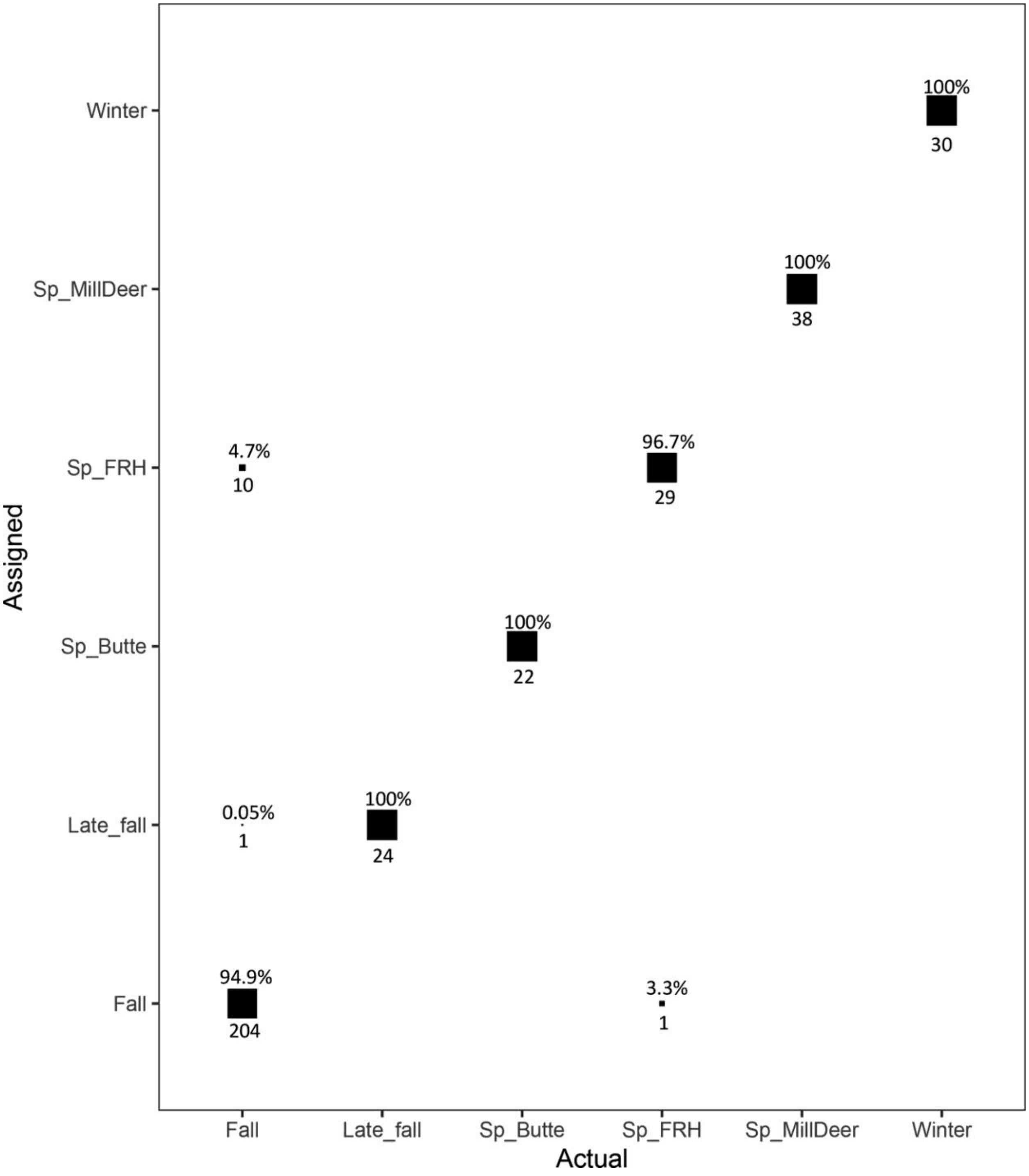
2020). But fine-scale differentiation within a race will likely be associated with higher costs per individual sample and may become prohibitive for large sampling programs. Ford et al. (2020) provide a timely review of the strengths and limitations of several recent genetic studies that examined the association between the GREB1L-ROCK1 genomic region and migration timing in salmonids.

Figure 13 Run Timing Distribution of Rogue River Chinook Salmon Genotyped as Homozygous Spring-Run, Homozygous Fall-Run, or Heterozygous (Fall- and Spring-Run), at Two SNPs in the Region of the Greb1L Gene



Source: Thompson et al. 2019
Figure13 notes: GRS = Gold Ray Fish Counting Station, HP = Huntley Park, SNP = single nucleotide polymorphisms

Figure 14 Matrix Comparing Actual Phenotypic Run Timing with Genetically Assigned Race for Central Valley Salmon Populations Using a Large Number of SNPs



Source: Meek et al. 2020
Figure 14 note: SNP = single nucleotide polymorphisms

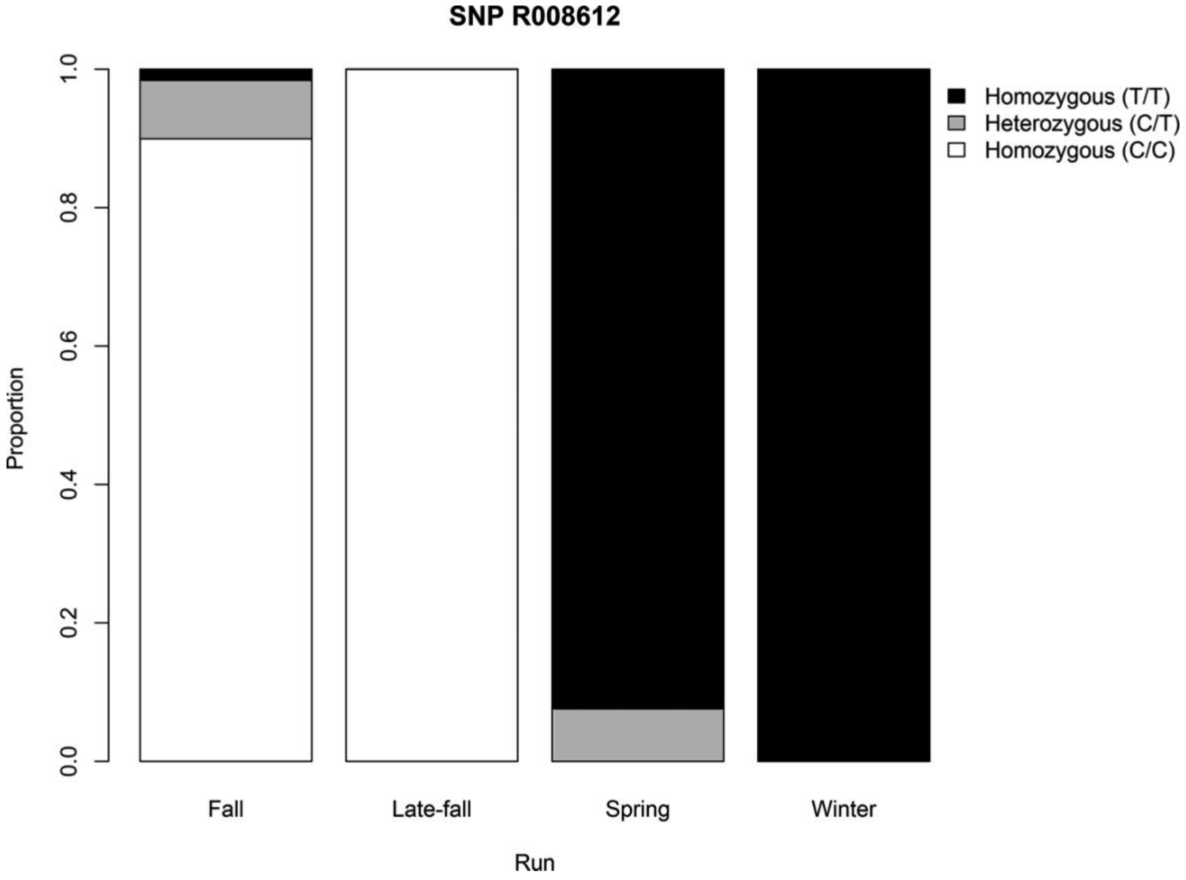
Rapid portable genetic testing tools, first developed in 2017 for human disease detection during outbreaks, are being adapted for potential field-based fish identification (Baerwald et al. 2020). The first of these technologies was SHERLOCK (Gootenberg et al. 2017), followed by DETECTR (Chen et al. 2018), but other similar innovative tools will likely be available in the future. Essentially, these tests search for the presence of a specific DNA nucleotide sequence in a sample of genetic material, such as a swab taken from the mucus of a juvenile salmon. If the nucleotide sequence is in the sample, the detection is indicated by a line on a paper strip (like a home pregnancy test) or a fluorescent reaction (Figure 15). These tests can be carried out anywhere (e.g., field, salvage facility, or laboratory), with minimal equipment and training, and results are returned in as few as 30 minutes. Once a specific test has been developed, test production is very low-cost. For comparison, current “rapid” genetic testing employed for race identification at the salvage facilities requires at least one day for processing, and at considerable expense relative to technologies like SHERLOCK and DETCTR.

Figure 15 Photograph of SHERLOCK Technology Applied Using Test Strips; the Presence or Absence of a Line on Each Strip Visually Indicates Genetic Identification

Photo Credit: Zhang lab, Broad Institute of MIT and Harvard, Broadinstitute.org

Before a genetic identification can be designed and produced, several questions must be addressed: At what life stages and geographic locations would identification be necessary? What existing identification tools or set of tools could be used? Are there specific challenges to identification? What new tools would and could be developed to meet those challenges? One challenge that has been identified is the need to differentiate Sacramento from San Joaquin spring-run at the salvage facilities. Both are early-migrating populations, and because FRFH spring-run are the source stock for reintroduced San Joaquin spring-run, there has been insufficient reproductive isolation to segregate stocks. Several identification approaches have been suggested, relying on tagging or genetics tracking parentage. Any identification solution will have to balance required population resolution, cost turnaround time, and acceptable levels of identification uncertainty.

Figure 16 Proportion of Individuals Among the Four Central Valley Chinook Salmon Runs that Had Each of Three Possible Genotypes at a Single GREB1L Associated SNP



Source: Meek et al. 2020
Figure 16 note: SNP = single nucleotide polymorphisms

2.5 Winter-Run Chinook Salmon JPE Approaches

The multiple forms that the Central Valley winter-run Chinook salmon JPE has taken (Oppenheim 2014; Poytress et al. 2014; Voss and Poytress 2017; O’Farrell et al. 2018) are instructive in the development of a spring-run JPE approach. 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 River to the Delta (Figure 17).

Figure 17 Basic Winter-Run JPE Model Structure

Figure 17 note: JPE = juvenile production estimate

The current winter-run JPE references the following salmonid life cycle components (Figure 18):

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 references an estimate for observation error (O’Farrell et al. 2018). Additional factors, reflecting a greater proportion of the life cycle (Figure 18 [life cycle and model components]), that may be used in a spring-run JPE include:

- Adult escapement or the number of spawning adults.
- Egg production.
- Hatching success.
- The quality and availability of habitat for spawning.
- Incubation and rearing.

- Life history alternatives (i.e., timing of migration and yearling growth and survivorship).

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 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, modified by survival estimates, including those for entry into the Sacramento mainstem and migration down the Sacramento River to the Delta.

Previously developed models for a winter-run JPE may offer a useful basis for developing a spring-run JPE. Table 4 summarizes several winter-run JPE models, including basic model elements and input data. Note that the JPE results differ substantially depending on the survival estimates used and the application of real-time monitoring data. For example, using real-time monitoring data at Red Bluff Diversion Dam (RBDD) for juveniles passing the dam (JPI, Scenario 3) rather than the estimated value (Scenarios 1 and 2) reduces the JPE from 1,196,387 to 397,726 juvenile salmon (Table 4).

Figure 18 **Salmonid Life-Cycle Components**

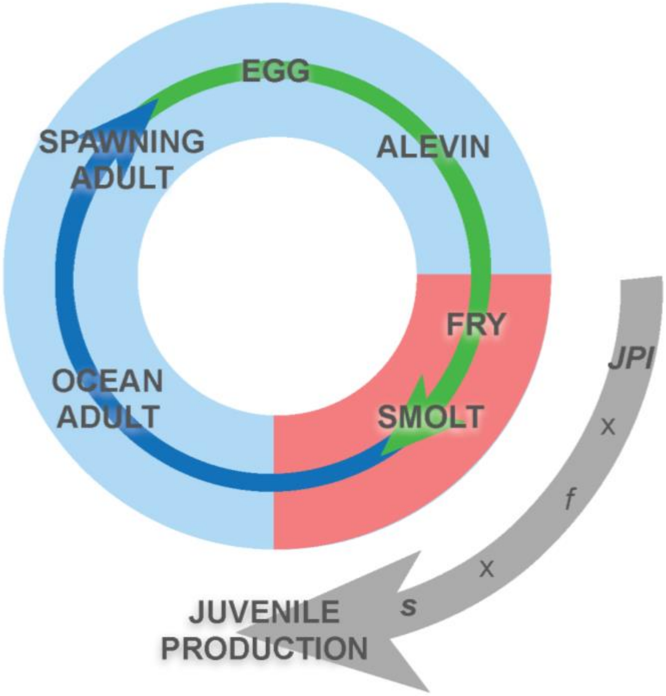


Figure 18 note: JPI = juvenile production index

Table 4 Calculations of Winter-Run JPE for Three Scenarios

Scenario	Adult Escapement	Viable Eggs per Adult	Viable Egg Estimate	S1, Survival to RBDD	JPI, Juveniles Passing RBDD	S2, Survival RBDD to Delta	JPE[1], 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[2]	708,970
3. Use JPI and WR S2	5,958	2,755	16,411,348	0.15[3]	2,485,787[4]	0.16	397,726

Source: Anderson 2014

Table 4 notes: JPE = juvenile production estimate, JPI = juvenile production index, NOAA = National Oceanic and Atmospheric Administration, RBDD = Red Bluff Diversion Dam, RST = rotary screw trap

[1] JPE is calculated as the product of the JPI and S2. [2] Winter-run Chinook salmon acoustic tag estimated survival for 2013. [3] Calculated S1 based on JPI and viable egg estimate. [4] JPI for 2014 based on real-time RST catch at RBDD.

Table 5 Estimates Used by O'Farrell et al. (2018) to Forecast the 2018 Winter-Run Juvenile Production Estimate

Estimate	Method 1	Method 2	Method 3[1]
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 and variance estimates; accounts for observation and process error
JPE	164,963	125,378	135,472

Table 5 notes: RBDD = Red Bluff Diversion Dam

[1] For Method 3, the estimates are the means of the distribution for each factor.

For the first two scenarios, the number of juveniles passing RBDD (the JPI) is estimated by multiplying the viable egg estimate by the expected survival (egg to fry-equivalent units passing RBDD, S1, calculated from RST data).

But, in Scenario 3, the 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.

The survival estimate from RBDD to the Delta (Table 4, S2) is currently based on AT study results using hatchery released winter-run Chinook salmon released at smolt size when they are ready to move quickly down river and through the Delta. Although this is the most relevant current information, it does not address mortality of pre-smolt juveniles obligated to rear for a more extended period during migration from RBDD to the Delta, and results in over-estimation of the winter-run JPE. Assessing survival of pre-smolt juveniles will likely be even more critical for a spring-run JPE given the proportion of spring-run juveniles that migrate from natal streams in a pre-smolt condition.

O’Farrell et al. (2018) compared three different methods for estimating winter-run juvenile production, all based on a model structure similar to that of 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 out-migrating smolts between RBDD and the Tower Bridge where the Delta officially begins (Figure 1). One of the three methods compared did not account for potential errors and produced a point estimate; the other two quantified potential sources of error (O’Farrell et al. 2018). Table 6 summarizes the approaches described by O’Farrell et al. (2018).

Table 6 Alternative Winter-Run JPE Approaches Compared by O'Farrell et al. (2018)

Formula	Method 1	Method 2	Method 3
$\widehat{JPI}_{t-1}$	Point estimate	Estimate of variance based on historical CVs; dependent on $\hat{f}$	Estimate of variance[1] 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 and variance estimates; accounts for observation and process error
Model Status	Status quo	In use	Potential

2.5.1 Challenges of Applying Winter-Run JPE Approach to Spring-Run

There are many differences between winter-run and spring-run Chinook salmon life history and management that make direct application of a winter-run JPE approach to spring-run challenging. Winter-run juvenile production is sourced from one location, but spring-run juveniles come from multiple (and changeable) independent and dependent sources each year (Figure 1). The number of fry produced by each of these systems differs (National Marine Fisheries Service 2014), as does their timing, rearing success (fry-to-smolt), and their likelihood of surviving their migration from their natal stream to the Delta. For the purpose of developing a spring-run JPE that can be used to assess and minimize the impact of SWP operations on the spring-run population, there is no expectation to account for spring-run from the San Joaquin River in the JPE; but identifying and distinguishing San Joaquin River spring-run from Sacramento River spring-run will be a major consideration for sampling at the south Delta diversions.

An annual estimate of the total number of spring-run juveniles produced in different streams 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 salmon races, spring-run life-cycle variability and differences (e.g., migration timing), sources of error, time required to complete JPE to serve management needs, a shifting baseline because of climate change, and the suitability of hatchery surrogates.

3.0 Spring-Run Chinook Salmon JPE Science Plan

3.1 Spring-Run JPE Science Priorities

3.1.1 Guiding Concepts

Based on input from the JPE Scoping Workshop and further consideration by the JPE Team, there are several general expectations for the science program leading to the development of the JPE. These guiding concepts for the JPE Science Plan are summarized below.

Entrainment Focus: Although information gained from implementation of the JPE Science Plan will benefit multiple endeavors, notably development of a spring-run Chinook salmon life cycle model for the Central Valley, the primary goal of the JPE Science Plan is to develop a population estimate that can inform the development of protection measures against entrainment of spring-run at the SWP, such as through management of water operations. As a consequence, it is especially important that future JPE forecasts be estimated early enough to allow time for seasonal management decisions (e.g., winter-spring). Initial estimates in December, for example, would be most useful for initial entrainment management. But such initial estimates are likely to be refined later in the winter or early spring as additional information is incorporated into the JPE to provide a more complete picture of the migration period.

In this context, a critical component of the JPE Science Plan is the ability to identify and quantify Sacramento Valley spring-run at the water diversions. Because of the complex life history of spring-run, the entrainment of both YOY and yearling migration strategies need to be considered. How the JPE data for different life history stages of spring-run will be incorporated into entrainment management remains to be determined. But it is possible that management will focus on separate JPEs for each cohort rather than each calendar year. For example, a JPE estimate for YOY could be used to guide operations in the current water year, and a JPE estimate of yearling fish from the same cohort, which hold throughout the summer before migrating, would inform entrainment management for that life stage the following water year. In other words, it is possible that entrainment management in a given calendar year could be based on JPEs from two different cohorts.

As noted previously, despite the entrainment focus of the current JPE effort, the monitoring and targeted studies will still be of great value to other management efforts, such as development of a spring-run life-cycle model, to inform conservation planning and actions.

Need for Multiple Tools: As described earlier, the broad geographic scope of spring-run, combined with their complex life history, means that multiple tools will be needed to develop a JPE. As a result, it is not expected that one well-designed survey or program will be sufficient. Instead, the science program and subsequent JPE approach will rely on a suite of tools, including monitoring, experiments, modeling, and analysis. Data to be considered will include new data collected as part of the JPE program, but also relevant historical data sources such as adult escapement, RST, Delta sampling, telemetry, tagged fish releases, and water diversion salvage records.

Redundancy: An important recommendation from the scoping workshop was that there should be some level of redundancy in the science effort and the JPE toolbox. As noted previously, multiple tools are needed for JPE development and for the JPE approach selected for implementation, each with its own specific limitations. Having some level of redundancy in techniques will provide different views of the problem and help in understanding some of the potential variability in estimation. For example, O’Farrell et al. (2018) describe the strengths and weaknesses of several different approaches to estimate a JPE for winter-run. The goal is to have a similar range of estimation techniques for spring-run.

Comparability: Related to the previous concepts, an additional goal is to develop multiple JPE approaches that are directly comparable. This will allow the different JPE options to be compared appropriately during the research and development phase (study program), as well as later in the implementation phase.

Progressive Approach: 2020 scoping workshop attendees also recommended that the JPE consider a progressive approach to estimation, both within and across years. Specifically, each year there would be an initial JPE estimate based on early season data (e.g., adult abundance), followed by refined JPE updates using new data from juvenile sampling (e.g., screw trapping and telemetry) and survival studies at progressive life stages. Data across years can then be integrated into JPE models to gradually improve annual estimates from each life stage.

Adaptation in the Research and Development Program: Another guiding concept is to plan for an adaptive process in the initial JPE research and development phase. It is expected that there will be annual refinements to the JPE Science Plan as initial results are observed from each of the study areas. The JPE study effort is sufficiently complex and uncertain that it is not reasonable to map out the entire four-year research and development effort at this time. Instead, the focus in the short-term will be on immediate and obvious science priorities, which will be refined (or expanded) as more is learned from initial research and monitoring. For this reason, it is very likely that the initial components of the JPE Science Plan (e.g., monitoring, experiments, and analyses) will be different than the future approach used during implementation.

Evaluation: An important part of the science program is to incorporate an evaluation step that allows direct comparison of JPE approaches (see above) with respect to multiple considerations (e.g., minimizing take, scientific merit, accuracy, management relevance, feasibility, and cost). Matching the model performance to management goals will be one of the most critical parts of the evaluation. To help facilitate this process, the selection of a JPE approach and monitoring program at the end of the research and development process should include a rigorous evaluation using structured decision-making.

3.1.2 Overview of JPE Science Plan Approach

The following study plan elements are based on the previously described background information, expert input, guiding concepts, and conceptual model. These elements were identified during the scoping workshop, and subsequently refined by the JPE Team, as being necessary to move forward quickly and efficiently to develop the potential JPE approaches above. Each of these elements will require subsequent detailed planning by the JPE Team with help from subject matter experts. Most of these elements will be initiated and proceed in tandem or with substantial overlap.

- **Additions to Existing Programs and New Monitoring**: To test the efficacy of the potential JPE approaches, there is a need to refine and augment existing monitoring programs as well as add new monitoring programs during the JPE research and development phase. Because it is not feasible to conduct comprehensive sampling in all tributaries, the initial focus will be on a subset of “representative” streams selected by the JPE Team to represent unique geographies and monitoring challenges (see Section 4.5). After they are selected, the JPE Team will draft detailed plans for augmented and new monitoring with the help of regional experts.
- **Special Studies**: In addition to the use of historical data, augmentation of existing monitoring programs and the addition of new monitoring programs, the development and implementation of a spring-run JPE will also require targeted research. Essential to the JPE program will be development of genetic approaches to successfully identify spring-run at multiple locations in the system, and to differentiate between spring-run originating from the San Joaquin River and Sacramento River basins. Other examples of targeted research include studies to determine sampling efficiency, life-history diversity (yearling versus young-of year), and telemetry estimates of reach-specific survival.
- **Historical Data**: A priority in the science program will be to use available information to develop initial quantitative JPE models and estimates as early as possible. For example, there is existing information from previous telemetry studies, coded-wire fish releases, escapement surveys, screw trapping surveys, and genetic results that could be used to inform initial JPE approaches. The JPE Team will evaluate all historical data to determine their applicability for informing the JPE.
- **Long-term Monitoring**: Implementation of the steps outlined above may indicate a need for a continuation of some augmented monitoring in representative streams, and expansion of these monitoring changes into other spring-run streams, as part of a long-term monitoring program to support a spring-run JPE. Decisions regarding these changes to long-term monitoring programs will not be determined until

there is reasonable clarity about the most appropriate JPE approach. As a result, broad scale changes to spring-run monitoring are unlikely to occur until the latter part of the four-year study effort.

- **Structured Decision-making**: The selection of a JPE approach and monitoring program at the end of the research and development process should include a rigorous evaluation using structured decision-making to ensure the decision process and outcomes are transparent and objective, and based on shared, clearly articulated, fundamental objectives. As much as possible, given constraints of time and requirements of ITP conditions, the JPE Team will also use structured decision-making processes and tools to help guide planning and implementation decisions for all JPE Science Plan elements.

The JPE Science Plan provides details about priority needs for each of the key elements described above. After the JPE Science Plan is reviewed and approved by CDFW (winter 2021), the JPE Team will implement research and monitoring activities over a three-year period (2021 to 2024). During this time, a review panel will be organized to examine and compare JPE approaches and results, culminating in selection of a final JPE approach and monitoring plan to develop a JPE for Water Year 2025 (brood year 2024). The final JPE approach will be selected based on multiple factors (e.g., feasibility, accuracy, timeliness, management value, scientific value, cost) and subject to CDFW approval by October 2024.

3.2 Conceptual Models for a Spring-Run JPE Approach

The JPE required by the ITP is an annual forecast of the number of natural-origin spring-run Chinook salmon juveniles from the Sacramento River and tributaries that will enter the Delta in any given year. This abundance forecast will be used to set entrainment thresholds governing water operations and must be calculated prior to spring-run entering the Delta from the Sacramento River each year. For this reason, real-time monitoring of spring-run at the point of Delta entry will most likely not provide enough advance warning, and additional monitoring of earlier life history stages and transitions will be needed on a regular basis. But a JPE could be informed by correlative relationships between juvenile abundance records in the Delta and other ecological indicators. A spring-run JPE is likely to involve multiple existing and emerging data sources, race identification tools, and a more refined understanding of spring-run distribution and life history.

To help frame the science effort, the JPE Team developed a set of initial conceptual models describing how a JPE might be implemented (Figure 19 through Figure 22). Each conceptual model illustrates a life-stage that would be monitored as the abundance input for a JPE model, the geographic location where that monitoring would occur, and the subsequent transition parameters that would be needed (e.g., fecundity and survival) to calculate a JPE from that input abundance. In addition, the models account for life-history diversity, specifically the two main migration strategies: yearling and YOY. Following general descriptions and illustrations of the alternative JPE approaches, a more detailed description is provided of the abundance input and transition parameters that make up the models. For each of these model components, existing information is discussed that could be used for initial model building and potential new research or monitoring that could be implemented to reduce JPE uncertainty.

JPE models based on earlier life stages in the reproductive process (i.e., starting with adult passage) necessarily require more transition parameters to calculate a JPE than models based on later life stages, although parameters illustrated in the schematics could be combined for estimation, depending on available and developed information. For example, at the extreme, a JPE could be calculated using adult passage and a single adult-to-smolt transition parameter, combining fecundity and survival across all intervening life stages and locations. It is also important to point out that JPE models based on earlier life stages share many components with models based on later life stages. This redundancy will allow comparison of alternative strategies, testing of multiple tools, and a progressive approach to JPE estimation. These models help to reflect how different estimates could be made at multiple life stages, and how different sampling methods could be applied for different segments of the spring-run population and integrated into an overall JPE framework. Moreover, the transition of primary input variables across models — from adults to juveniles in the tributaries, followed by migrants leaving tributaries and eventually entering the Delta — provides a representation of how monitoring over the course of a juvenile production year could provide an early JPE estimate for planning purposes, and then progressively refined estimates over the course of an entrainment season.

JPE conceptual models will be used to help identify science needs to be targeted for immediate planning and implementation in representative streams (representative streams are described in Section 4.5). Initial research and monitoring will provide information on the ability to reduce key sources of uncertainty for different model components, and the associated cost of reducing that uncertainty. The conceptual models will be used as a framework to construct and parameterize quantitative JPE models using currently available information from existing sampling programs and historical information, as described in Section 3.1.2, and update the models with newly generated information from monitoring and targeted studies as it becomes available. These quantitative models will be used to evaluate key sources of uncertainty in each model and the required level of monitoring and targeted studies necessary to reduce that uncertainty to a level determined to be acceptable by the structured decision-making process. Throughout the JPE development process, cost, benefit, and other critical information associated with each JPE approach, such as take, will be fed back into the structured decision-making process to support the final decision regarding which JPE approach to implement on an ongoing basis.

3.2.1 Adult JPE

Figure 19 JPE Based on Monitoring of Adult Passage or Holding

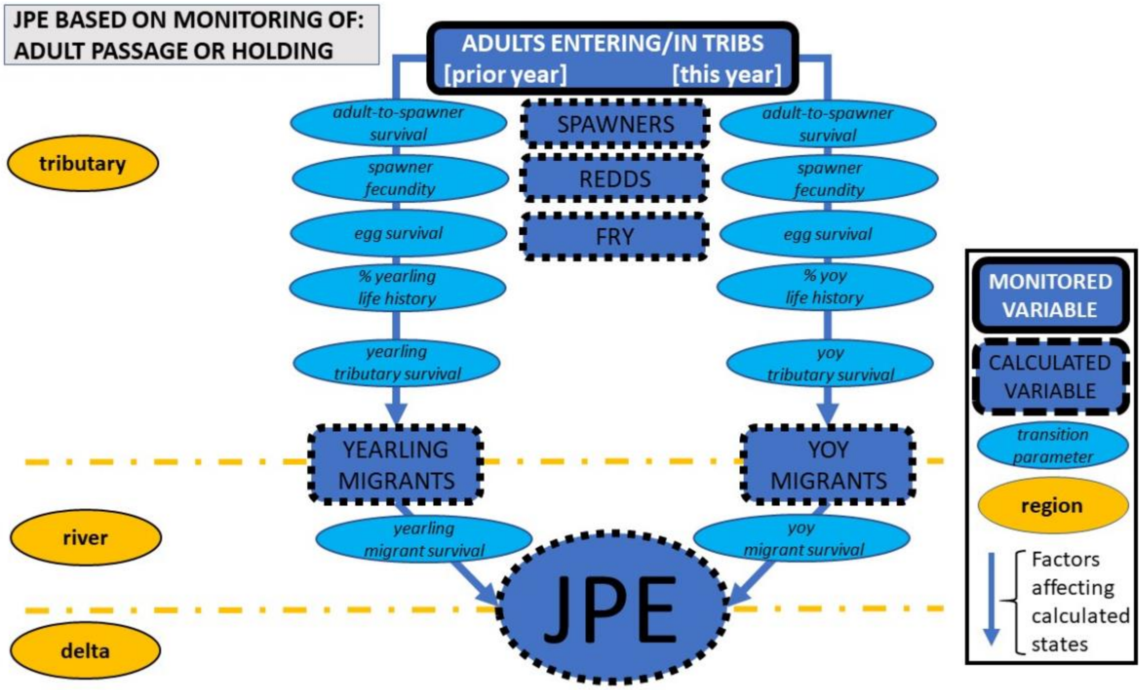


Figure 19 notes: JPE = juvenile production estimate, YOY = young-of-the-year

Monitoring of adult abundance, either during passage into tributaries or while holding in tributaries, presents the first opportunity to gather annual predictive information for calculating a spring-run JPE. The adult passage and holding life stages are the most spatially and temporally distant from juveniles entering the Delta. As a result, the adult based JPE has the greatest potential for predictive error, because of compounded uncertainty across the largest number of life stage transitions of any JPE approach under consideration. Another issue is that passage and holding abundance surveys do not determine sex ratios. But adult abundance during passage or holding is also, arguably, the least challenging life stage to monitor and has the greatest potential to provide consistent and reasonably accurate abundance estimates over a range of environmental conditions. Carcass surveys could provide a reliable estimate of sex ratios where population numbers are large enough for an adequate sample size to be collected. Historical adult abundance data are likely to have the longest contiguous historical datasets, with the least variability in monitoring approach across tributaries, making the adult JPE a preferred candidate for initial modeling. For these reasons, an adult-abundance-based JPE providing an early-season "rough" estimate would be highly valuable for initial planning and decision-making each year, particularly if coupled with a more certain JPE based on later life-stage monitoring, which could be applied to calculate updated loss thresholds for water management. Such a hybrid approach, Delta entry JPE conceptual model, is discussed in more detail in Section 3.2.4.

3.2.2 Fry JPE

Figure 20 JPE Based on Monitoring of Juveniles Rearing in Tributaries

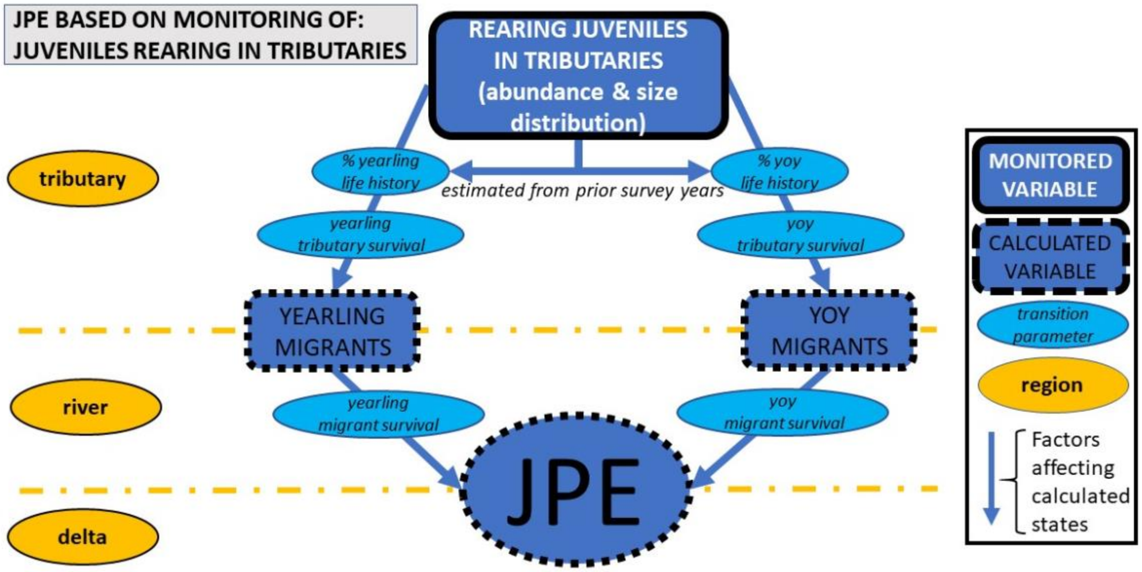


Figure 20 notes: JPE = juvenile production estimate, YOY = young-of-the-year

The abundance of juveniles produced from redds in tributary streams would be the primary input for a fry JPE. This strategy would provide an estimate of juvenile production for each tributary, which could be used to calculate a JPE earlier than monitoring older outmigrants that are already moving toward the Delta. For tributaries with no feasible monitoring location between spawning and rearing reaches, abundance estimates would require surveys across potentially large habitat areas, rather than monitoring at a fixed location. In these tributaries, obtaining reasonably accurate abundance estimates of juveniles after fry emergence, but prior to outmigration, may prove so challenging, because of potentially overlapping emergence and outmigration periods, that there is no obvious “good time” to conduct surveys for rearing juveniles across tributaries. A fry JPE would require estimating survival during rearing to outmigration in each spring-run tributary because estimates for each tributary may vary substantially. Regardless of whether a fry JPE proves feasible, monitoring the abundance of fry or tributary rearing juveniles during the JPE research and development period may provide information on the yearling life-history strategy and on yearling and YOY tributary survival.

3.2.3 Tributary Outmigrant JPE

Figure 21 **JPE Based on Monitoring of Tributary Juvenile Outmigrants**

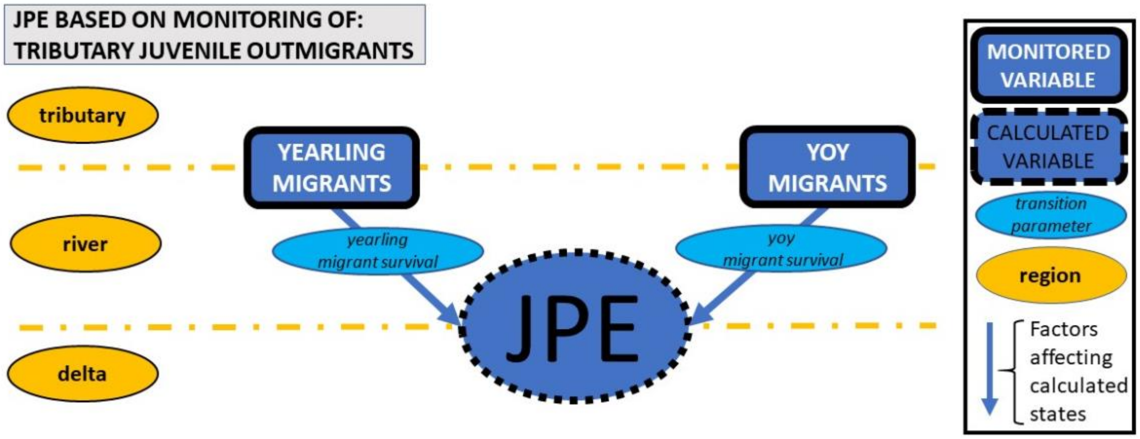


Figure 21 notes: JPE = juvenile production estimate, YOY = young-of-the-year

A tributary outmigrant JPE would be based on abundance sampling for the duration of juvenile outmigration at a fixed location on each tributary near the confluence with the Sacramento River. This approach is similar to the JPE approach for winter-run Chinook, in that the JPE calculation would require the same general input variable (outmigrant abundance), but only require survival to be estimated for the reach downstream of RSTs prior to Delta entry (i.e., river survival). But, as for winter-run, separate river survival estimates would be needed for YOY and yearling spring-run migrants. In addition, separate river survival estimates may be needed for each spring-run tributary, at least initially, to establish how widely estimates vary among tributaries; this is because the migration path between RSTs in each tributary and the point of Delta entry expose outmigrants to unique tributary reaches between RSTs and the mainstem, and, for upstream tributaries relative to downstream tributaries, to unique reaches of the mainstem Sacramento River. Another complication of applying this JPE approach is that, for many tributaries, outmigrants may enter the Delta a short distance and time after outmigrating from natal tributaries, providing little lead time for a JPE relative to monitoring at Delta entry. As suggested previously, these complicating circumstances for spring-run may require a progressive, iterative series of JPE estimates throughout the outmigration season, with less precise estimates occurring early in the season, leading to a final JPE near the end of the outmigration season.

3.2.4 Delta Entry JPE

Figure 22 JPE Based on Monitoring of Juveniles at Delta Entry

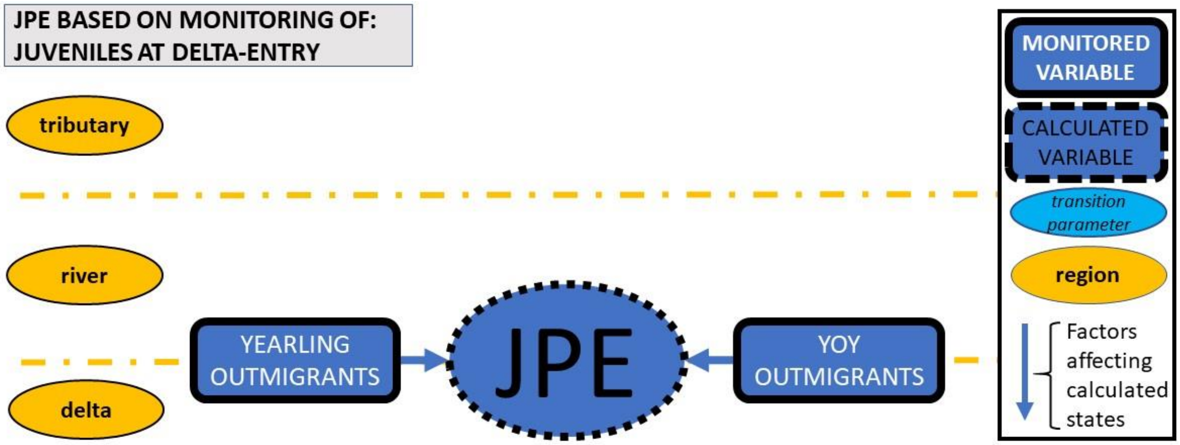


Figure 22 notes: JPE = juvenile production estimate, YOY = young-of-the-year

A Delta entry JPE would be based exclusively on monitoring at the point of Delta entry to assess juvenile spring-run abundance entering the Delta. An obvious drawback of a JPE based purely on Delta entry monitoring is that a full accounting of juvenile abundance for a migration season would not be complete until most juveniles had entered and possibly exited the Delta, which would be well after the annual JPE would be needed to guide water operations. But a Delta entry JPE approach could conceivably be coupled with monitoring of an earlier life stage, with the early life stage providing an initial, interim JPE and take estimate that could be updated throughout the migration season based on monitoring at the point of Delta entry. There are several potential benefits of such a combined approach. First, a final JPE based on Delta-entry monitoring could potentially provide the most accurate JPE of all the potential approaches because it integrates production across all Sacramento River tributaries and eliminates sources of uncertainty from abundance and transition parameters required by other JPE approaches. Second, there would be less concern over the relatively greater uncertainty of using an earlier life-stage JPE for planning. Finally, a Delta entry JPE would provide an annual source of empirical data that could be used over years to calibrate and refine the accuracy of an interim JPE calculated from an earlier life stage, which would in turn reduce uncertainties for resource planning earlier in the year.

Even if a Delta entry JPE is not integrated into a hybrid approach at the culmination of the JPE research and development process, a Delta entry JPE and associated abundance monitoring during the research and development phase will provide valuable information for parameter estimation and validation of the other JPE approaches.

3.3 JPE Model Component Information Sources

The following JPE model components are organized according to the life-stage sequences, from adult passage into spawning tributaries to eventual juvenile migration into the Delta. Stages representing abundances would be estimated from monitoring programs and serve as key input variables for a JPE calculation. Intervening transition parameters would be used to calculate one abundance stage from a previous stage. Each model component includes a brief description, followed by empirical information sources that could be used to estimate that model component. Information sources are subdivided as either existing, meaning the information was historically or is currently collected, or as information sources that could be developed through future research, data synthesis, or monitoring.

As discussed above, model components will first be estimated using existing information from the Central Valley region, wherever possible. If necessary, existing information from other systems could be used for initial parameter estimates. These initial JPE models will be used to assess major sources of uncertainty, and to help guide updates to the JPE Science Plan to reduce key sources of model uncertainty. Studies to develop new information, or to test and compare the efficacy of monitoring different life stages, will be conducted in a subset of representative streams, and this information will then be extrapolated to other streams. An important objective of the JPE research program will be to determine which kind of monitoring is most viable in each tributary, acknowledging that monitoring redundancy or year-to-year flexibility may be important in any given tributary, depending on environmental conditions that determine the relative viability among monitoring approaches.

3.3.1 Adult Passage Abundance

3.3.1.1 GENERAL DESCRIPTION

Adult passage refers to the number of adults entering tributaries during spawning migration. Sampling would presumably occur at fixed locations along a tributary downstream from all locations where adults would be expected to hold over the summer and would occur over the duration of the adult spring-run migration season. Passage monitoring has the potential to achieve highly accurate adult abundance estimates relative to field surveys of holding or spawning adults. Passage monitoring also provides information on adult sizes, which could be used for fecundity estimates; and on the distribution of run-timing among adults, which could be used to estimate the relative abundance of adults exhibiting run-timing consistent with homozygous versus heterozygous early and late migration genotypes. Although a passage-based JPE would include uncertainty caused by adult survival variability prior to spawning (i.e., over-summer survival, pre-spawn mortality) and an inability to distinguish sex ratios during passage estimation, these transition parameters may be possible to estimate in most tributaries, based on subsequent surveys of holding adults and carcasses. Passage-based adult abundance estimates may be the most viable approach for an adult-based JPE for tributaries in which rough terrain makes holding and spawning surveys difficult, or for tributaries lacking spatial separation among runs during the spawning season.

3.3.1.2 EXISTING INFORMATION

Video monitoring currently occurs on Clear, Cottonwood, Battle, Antelope, Mill, Deer, and Butte creeks, and the Yuba River; although the Yuba location is not downstream of all holding habitat, and as a result, does not currently count the entire adult population. In many of these locations, monitoring is well funded and has been ongoing for more than five years. Spring-run are genetically identified among winter-run adults collected at Keswick for hatchery spawning of winter-run; this information could be used in combination with historical adult passage video from the RBDD for estimating spring-run passage upstream of RBDD (adults are not currently videoed at RBDD). Adults entering the FRFH provide a metric of minimum adult passage into the system; although not all adults enter the hatchery, making the passage count incomplete.

3.3.1.3 POTENTIAL NEW INFORMATION

Video passage monitoring is the standard for passage estimation of migrant adults, but video monitoring is problematic during high-flow and high-turbidity conditions. If it is used as the primary input parameter for a JPE, studies should be conducted to estimate passage uncertainty. Some stations in the Central Valley currently produce a modeled confidence interval for passage counts, and these could be augmented by adult tagging studies that register adults at passage stations. Video equipment can fail, so a dependable video monitoring program would require adequate dedicated technical staff for maintenance of passage monitoring stations, and ideally would be coupled with instream sampling. Dedicated staff would also be necessary for video review; a passage monitoring program could invest in automated video analysis, but this would probably require updated video hardware at current passage stations. In the Yuba River, passage estimates could be improved by moving the passage monitoring station from Daguerre Point Dam to a location downstream of all adult-holding habitat. A monitoring station downstream from Daguerre Point Dam would also alleviate misrepresentation of migration timing caused by the pool at the base of the dam, which delays spring-run passage through the fish ladders. Daguerre Point Dam is one of the most accurate locations in the Central Valley for adult spring-run video monitoring because adults passing the dam must use the fish ladders, and conditions inside ladders are stable and favorable for video data capture. For this reason, it may be better to develop complimentary monitoring of fish downstream from the dam (e.g., snorkel surveys) rather than move the current video monitoring downstream, although regional staff have highlighted safety issues in the vicinity of the dam pool. A video monitoring station has been planned on the Feather River for several years to address uncertainty in adult escapement estimates caused by spatial overlap of spring-run and fall-run spawning habitat, but funding has not yet been approved. In general, pilot studies to improve passage monitoring should occur in spring-run tributaries where coordinated holding and spawning surveys can produce relatively robust abundance estimates, which would also allow for robust estimates of adult survival prior to spawning.

3.3.2 Adult Holding Abundance

3.3.2.1 GENERAL DESCRIPTION

Adult holding abundance refers to the number of adult spring-run holding over the summer in each tributary in cold-water pools. Surveys would presumably occur after flow and temperature conditions precluded both migration of additional adults into a tributary and substantial movement of adults within a tributary. During above normal and wetter water years, salmon can hold and survive in a much broader landscape than the over summer holding habitat typically included in snorkel surveys. Counts during these years would have a higher degree of uncertainty. Surveys of holding adults are complicated in some tributaries by spatial overlap of spring-run and fall-run adults, requiring some means of distinguishing race. Similar to a JPE based on adult passage, a JPE based on adult holding abundance would require estimation of the proportion of holding adults that survive to successfully spawn (over-summer survival) and estimation of sex ratios, although neither of these transition parameters are difficult to estimate with subsequent surveys of carcasses and holding adults.

3.3.2.2 EXISTING INFORMATION

Snorkel surveys are currently conducted in the Upper Sacramento River and Cottonwood, Clear, Antelope, Deer, Butte, and possibly Battle creeks. Historical snorkel survey data are available for Battle Creek and the Yuba River. Big Chico Creek surveys were halted in 2018 because rock and gravel obstructed the Iron Canyon fish ladder, preventing ascension upstream into the over summer holding pools; once access and funding are restored, snorkel surveys may resume. A weir is erected on Clear Creek every year to segregate spring-run and fall-run; in Butte Creek, the Parrott-Phelan diversion dam fish ladder is managed for the same purpose. Spring-run adults entering the FRFH and released back into the river are tagged to help distinguish them from fall-run adults. Tissue samples for genetic analysis are collected and archived from adults on many spring-run tributaries and could be used for estimating relative abundance among spatially overlapped spring-run and fall-run populations.

3.3.2.3 POTENTIAL NEW INFORMATION

Genetic analysis of archived and currently collected tissue samples could be used to estimate relative abundance among spatially overlapped spring-run and fall-run populations.

3.3.3 Escapement-to-Spawner Survival (Transition Parameter)

3.3.3.1 GENERAL DESCRIPTION

Escapement-to-spawner survival refers to an estimate of the fraction of adults passing into or holding in a tributary that survive to spawn. It can be estimated directly from the ratio of spawner abundance (described in Section 3.3.4) to adult passage or holding abundance (described in Sections 3.3.1 and 3.3.2). It is also estimated from surveys of pre-spawn mortality.

3.3.3.2 EXISTING INFORMATION

Pre-spawn mortality surveys are currently conducted on Butte Creek and the Feather River, and creel surveys on the Feather River may be useful for estimating the harvest component of pre-spawn mortality. Also, see information for adult passage (Section 3.3.1), adult holding (Section 3.3.2), and spawner abundance (Section 3.3.4).

3.3.3.3 POTENTIAL NEW INFORMATION

Additional information on escapement-to-spawner survival would be provided by expanding surveys of pre-spawn mortality, including error estimation; or by expanding monitoring and surveys of adult passage, holding, and spawner abundance as described in Sections 3.3.1, 3.3.2, and 3.3.4, respectively.

3.3.4 Spawner Abundance

3.3.4.1 GENERAL DESCRIPTION

Spawner abundance refers to the number of female spawners constructing redds in a tributary. Spawner abundance may be surveyed directly or inferred from redd surveys or surveys of post-spawn carcasses. Redd surveys provide a good "check" on spawner estimates. But in some places, like the Feather River, redd surveys may not provide good estimates of spawner abundance because high spawner density (fall-run and spring-run), and resulting superimposition of redds, makes individual redds difficult to distinguish. Redd superimposition also regularly occurs when the returning adult population is large in Butte Creek's upper spawning habitat because spawning gravel is limiting in this location; for this reason, carcass surveys are more reliable in Butte Creek, and egg estimation would be feasible if eggs were obtained from carcasses late in summer (late-August to early September). In addition, fecundity cannot be estimated from redd counts, which may make redd surveys less reliable for estimating subsequent fry production. Surveys would presumably occur throughout the spring-run spawning season. Surveys of spawning adults are complicated in some tributaries by spatial overlap of spring-run and fall-run spawning season and habitat, requiring some means of distinguishing race. The benefit of a JPE based on adult spawner abundance, in comparison to an adult passage or holding-based JPE, is that it would eliminate model uncertainty associated with escapement-to-spawner survival estimates and uncertain sex ratios. But, in some tributaries, the elimination of JPE error associated with escapement-to-spawner survival and sex ratios may be outweighed by potentially greater uncertainty caused by difficulty in estimating spawner abundance relative to estimating adults during passage or holding.

3.3.4.2 EXISTING INFORMATION

Redd surveys, using aerial methods or walking the streams, are currently conducted on the Upper Sacramento River; on Battle, Clear, and Mill creeks; and on the Feather River. Limited redd surveys are also conducted on the Yuba River in the reach below Englebright Dam where the U.S. Army Corps of Engineers conducts spawning gravel augmentation. But Feather River surveys are intended for mapping redd distribution and are not designed to estimate abundance. Post-spawn carcass surveys for spring-run are currently conducted on Butte Creek, on the Feather River, and downstream from Daguerre Point Dam on the Yuba River. Carcass surveys on the Yuba River are conducted for both fall- and spring-run combined. On the Feather River, spring-run adults tagged and released from hatchery returns are used to differentiate spring-run and fall-run in carcass surveys.

3.3.4.3 POTENTIAL NEW INFORMATION

Spawner surveys could be expanded. Spawner and redd abundance can also be estimated from post-spawn carcass surveys, which could be expanded. Carcass surveys have the added benefit of providing estimates of sex ratios and measurements of fish length to estimate egg production (fecundity). Similarly, adult passage coupled with pre-spawn carcass mortality surveys can provide estimates of spawner abundance. But carcass surveys are difficult in small, remote tributaries such as Mill and Deer creeks, and redd surveys may be a more viable option. Alternatively, spawner abundance could be estimated from earlier life stage abundances, coupled with transition parameter estimation from Butte Creek, where dependable carcass surveys with sex ratios are conducted annually. Adding redd surveys in Butte Creek could provide verification of the assumed 1:1 relationship between post-spawn carcass and redd counts, but see comment about Butte Creek in Section 3.3.4.1. Accurate redd counts have proven difficult to obtain in the Feather River because crowded spawning in limited available habitat makes individual sites difficult to distinguish because of the high degree of red superimposition (i.e., overlap). Redd counts on the Yuba River could be expanded to include additional areas where spawning is known to occur. Similar difficulties may occur in tributaries with similar conditions.

3.3.5 Spawner Fecundity (Transition Parameter)

3.3.5.1 GENERAL DESCRIPTION

Spawner fecundity refers to an estimate of the number of eggs that each spawning female is predicted to deposit, typically based on spawner length.

3.3.5.2 EXISTING INFORMATION

Distributions of spawner fecundity, which varies from year to year, is currently estimated for Feather River spring-run at the FRFH and could be extrapolated to other tributaries. Additionally, fecundity information could be estimated from pre-spawn mortality carcass data for tributaries where such data exist.

3.3.5.3 POTENTIAL NEW INFORMATION

The most reasonable, accurate, and cost-effective approach for estimating spawner fecundity would be from pre-spawn or post-spawn mortality carcass surveys. But, because of immaturity of gametes when spring-run females arrive in holding habitat, it has previously proven difficult to obtain an accurate count of eggs in the tributaries. Late-season pre-spawn mortalities, obtained after the eggs have developed and loosened in the skein, may provide better estimates. But pre-spawn mortality and post-spawn retention of eggs will vary considerably between watersheds. Applications to acquire egg estimates will have to vary between watersheds. Initial attempts on Butte Creek have shown fewer eggs per female when compared to FRFH females, but sample size and technique have presented difficulties. Egg counts would be possible with enough carcasses and development of a proven technique to separate eggs from skein and each other (eggs are fragile when handling). Fry emergence trapping can also be used to estimate spawner fecundity, but is comparatively difficult to conduct, and it is comparatively difficult to achieve reliable emergence counts by this means.

3.3.6 Egg-to-Fry Survival (Transition Parameter)

3.3.6.1 GENERAL DESCRIPTION

Egg-to-fry survival refers to an estimate of the proportion of eggs produced by female spawners that survive to emergence as fry.

3.3.6.2 EXISTING INFORMATION

An egg-to-outmigrant parameter is estimated for the Feather River, based on fry abundance surveys in the vicinity of the spawning grounds.

3.3.6.3 POTENTIAL NEW INFORMATION

Egg incubation boxes can be used to estimate egg-to-fry survival. An egg-to-fry survival study is planned for the Feather River as part of a Federal Energy Regulatory Commission settlement agreement. Either female spawner or redd abundance estimates could be used in determining egg-to-fry survival. Alternatively, a spawner-to-fry production parameter could be estimated based on fry emergence trapping; but, as noted above, emergence trapping is difficult to implement, and it is difficult to achieve accurate emergence counts by this means.

3.3.7 Proportion of Fry Adopting a YOY vs. Yearling Migrant Life History (Transition Parameter)

3.3.7.1 GENERAL DESCRIPTION

This is an estimate of the proportion of juveniles in each tributary expected to outmigrate during the winter and spring directly following emergence (as YOY), or the following fall, winter, and spring (as yearlings). This parameter would be necessary to determine YOY and yearling outmigrant abundance from monitoring of earlier life stages, and to apply different survival rates prior to outmigration and during river migration. Researchers also identify an intermediate, sub-yearling outmigrant, which may require a more nuanced accounting than simply YOY versus yearling (Cordoleani et al., in press).

3.3.7.2 EXISTING INFORMATION

Catch ratios in existing monitoring programs, primarily RST data, could provide an initial indication of relative YOY versus yearling juveniles. But trap efficiencies vary between these year classes, particularly during low flow and turbidity conditions when yearlings are better able to avoid the traps, and over-summering yearlings would have lower survival rates prior to outmigration, which would complicate estimates. Beach seining and snorkel surveys on the Feather River and post-restoration monitoring (seine and snorkel) on the Yuba River could be used to estimate YOY versus yearling relative abundance. But the small scale at which this sampling occurred, and the limitations of these sampling methods, do not provide for estimating abundances and transition parameters.

3.3.7.3 POTENTIAL NEW INFORMATION

This life-stage information is difficult to obtain because tributaries are open systems; because fish are always on the move, with relatively continuous outmigration when conditions are suitable; and because of differences in catchability and survival. But surveys for juvenile abundance (described in Section 3.3.8) or tributary survival or monitoring of outmigrants (described in Section 3.3.9) could also provide information on juvenile life-history diversity. During the summer months on Cottonwood, Antelope, Deer, and Mill creeks, thermal barriers effectively segregate and stop passage of yearlings until fall, providing an opportunity to survey the yearling population. Butte Creek snorkel surveys have observed schools of yearlings and have noted annual variation in prevalence. Otolith microchemistry of ocean caught or returning adults could also provide an indication of successful strategies each year. This does not necessarily reflect the ratio of emergent juvenile following each strategy because juveniles following YOY versus yearling life histories likely experience different life-time survival rates between emergence and adulthood.

3.3.8 YOY and Yearling abundance in Tributaries

3.3.8.1 GENERAL DESCRIPTION

Juvenile abundance refers to the number of juveniles, both YOY and yearlings, rearing in a natal tributary stream. Those not expected to follow a YOY migrant life history (and which survive) will become the next year's yearling population. Surveys for these abundance estimates would presumably occur on representative reaches of a tributary stream after all expected fry emergence had occurred. Distinctions between YOY and yearlings would be by size and timing of capture. Survey abundance would then be extrapolated to estimate entire tributary abundance based on surveys of available habitat.

3.3.8.2 EXISTING INFORMATION

Beach seining and snorkel surveys have been conducted on the Feather River and post-restoration monitoring (seine and snorkel) on the Yuba River. The small scale at which this sampling occurred and the limitations of these sampling methods, do not provide for estimating abundances and transition parameters.

3.3.8.3 POTENTIAL NEW INFORMATION

Similar to monitoring for abundance estimates of holding or spawning adults, abundance estimates of this life stage would likely require surveys across potentially large habitat areas, rather than monitoring at a fixed location. Obtaining reasonably accurate abundance estimates of juveniles after fry emergence, but prior to outmigration from tributaries, may prove to be the most challenging among all the possible life stages. One reason for this difficulty is that, because of potentially overlapping emergence and outmigration periods, there is no obvious good time to conduct surveys for rearing juveniles across tributaries. Other issues are the potentially dispersed distribution of rearing juveniles along tributaries and the need to conduct habitat surveys to scale subsampling up to tributary scale population estimates. For the purpose of initial modeling, the heterogeneity of monitoring methods and data availability for juveniles in the tributaries is also a challenge. On the other hand, monitoring of tributary-rearing juveniles during the JPE research and development period may provide much-needed information on the yearling life-history strategy, and on yearling and YOY tributary survival. Snorkel, seine, or electrofishing surveys could be used to provide estimates of juvenile abundance and age class distribution. For tributaries in which there is a fairly clear separation between spawning and rearing areas, the most feasible sampling strategy would be to estimate fry passing a discrete location on each tributary that is downstream of the spawning area and upstream of most juvenile rearing habitat (e.g., using an RST). With the exception of Clear Creek, this would not be practical for the Upper Sacramento basin spring-run tributaries or for other watersheds that are too remote and difficult to access. In these tributaries, sampling would have to occur on valley floors where potentially overlapping distribution with fall-run and late-fall-run would require genetic testing to estimate the proportion of spring-run. Although this fixed-point sampling would not provide information on YOY versus yearling abundance, snorkel surveys during the summer months could provide information on the abundance of yearling juveniles. Reclamation is planning mark-recapture surveys for steelhead in tributary streams, which is a potential opportunity for simultaneous estimation of spring-run juvenile abundance.

3.3.9 YOY and Yearling Tributary Survival to Outmigration (Transition Parameter)

3.3.9.1 GENERAL DESCRIPTION

Survival to outmigration refers to the survival rate from the time of emergence to the point of outmigration from natal tributaries for juveniles following either a YOY or yearling life history. The survival rate may also cover a shorter time period if juvenile sampling occurs at some point after emergence and prior to outmigration. Survival rates could be estimated from fry production estimates, coupled with RST monitoring of outmigrant abundance. Similarly, juveniles marked during surveys of tributary streams could be monitored at outmigrant sampling locations to estimate survival prior to outmigration. Note that both approaches would require RST monitoring of outmigrants at strategic locations.

3.3.9.2 EXISTING INFORMATION

Information on outmigrant sampling, as described below in Section 3.3.10, could be used in combination with fry production and monitoring of tributary-rearing juveniles. Survival of YOY was estimated during a recently completed five-year study on the Feather River using CWTs. Ongoing tagging studies to estimate survival of outmigrants from Clear and Battle creeks also appear in the RBDD RST data. Channel-spanning PIT antennas are currently in operation downstream of rearing habitat on lower Mill Creek (river mile 1.5), lower Battle Creek (approximately river mile 3), and Clear Creek (approximately river mile 3), all of which could contribute to survival estimation. Otolith data from adults, as described in Section 2.2.2, may also be applied to the development of survival estimates for this transitional period. Although it is unclear how tributary survival would be disentangled from survival occurring over the entire life cycle, otolith data are available from Clear, Battle, Deer, Mill, Chico, and Butte creeks and from the Feather and Yuba rivers.

3.3.9.3 POTENTIAL NEW INFORMATION

CWTs, PIT tagging, or some other method of marking juveniles in tributaries could be coupled with outmigrant monitoring to provide estimates of survival. Materials for PIT antennas are on hand and could be installed on lower Deer and Antelope creeks. These survival estimates could be modeled with respect to environmental variable data to further refine model estimates of survival. Repeated mark-recapture surveys during the same season could be used to determine survival rates during different periods of tributary rearing. Juvenile marking and recapture could be accomplished during tributary abundance surveys if a program is implemented. Tributary rearing survival could be estimated from a comparison of juvenile abundance from trapping immediately downstream from spawning grounds (see Section 3.3.8), and again at outmigration (see Section 3.3.10). Reclamation is planning mark-recapture surveys for steelhead in tributary streams, which is a potential opportunity for simultaneous tagging and tracking of spring-run juveniles for survival estimates.

3.3.10 YOY and Yearling Outmigrant Abundance

3.3.10.1 GENERAL DESCRIPTION

Juvenile outmigrant abundance, including both YOY and yearling fish, refers to the number and timing of juvenile migrants leaving natal tributary streams. Sampling would presumably occur at fixed locations in the lowermost reaches of each tributary downstream from most rearing habitat.

3.3.10.2 EXISTING INFORMATION

RST monitoring is ongoing in the Feather River, Butte Creek, Clear Creek, and Battle Creek, although some of these traps may be upstream of substantial areas of rearing habitat. Outmigration from the Upper Sacramento River, Clear Creek, and Battle Creek is also monitored at the RBDD RST. Tisdale and Knights Landing RST monitoring may provide additional outmigrant abundance estimates for nearby tributaries. Historical RST data are available from Mill and Deer creeks, and for the Yuba River.

3.3.10.3 POTENTIAL NEW INFORMATION

Studies are needed to define catch efficiencies for both YOY and yearlings on existing RSTs to improve abundance estimates of historical and future data. The Butte Creek program, in particular, is challenging because nearly all outmigrant juveniles are funneled into the traps in numbers that require volumetric sampling during periods of abundant outmigration. All RST-based abundance estimates would have to account for suspended sampling during high-flow events. The Butte Creek RST could be moved downstream, such as to the lower part of the Sutter Bypass, or an additional RST could be installed to account for rearing and potential mortality occurring between its current location at Parrot Phelan Dam and the end of the Sutter Bypass, although this would introduce Butte Creek fall-run or even other Sacramento River populations of all races into the sampling mix. Another option on Butte

Creek is mark-recapture-based estimates of outmigrant abundance generated by PIT tagging at outmigrant RSTs and assessing recapture at downstream monitoring locations. On the Feather River, regional experts indicate that a second RST sampling location at Beer Can Beach would greatly improve estimation of outmigrant abundance and transition parameters that depend on outmigrant sampling. On the Yuba River, two or three RSTs at the historic sampling location near Hallwood Boulevard would capture emigrating fish, but genetic sampling may be needed to differentiate between spring- and fall-run.

3.3.11 YOY and Yearling River-Migration Survival (Transition Parameter)

3.3.11.1 GENERAL DESCRIPTION

YOY and yearling river-migration survival accounts for survival during migration and rearing in the mainstem Sacramento River prior to Delta entry. For practical purposes, river-migration survival may also encompass survival in tributary streams downstream of tributary outmigrant sampling locations. Because of differences in the size, swimming ability, habitat selection, behavior, and other factors, survival rates are expected to differ between YOY and yearlings.

3.3.11.2 EXISTING INFORMATION

Ongoing and historical studies using acoustically tagged juveniles from Mill, Deer, and Butte creeks offer some measure of in-river survival. The accuracy of these survival estimates is limited by small sample sizes and by marking of salmon late in the migration season when mortality is highest because of warmer water temperatures and associated higher predator activity. Survival studies of AT juveniles captured by RSTs at RBDD and in Butte Creek may also be useful. NOAA Southwest Fisheries Science Center (SWFSC) is leading joint AT and CWT releases across a range of juvenile sizes to estimate river survival of winter-run and FRFH spring-run, which could be applied to natural-origin spring-run. Other AT data, including potentially much larger sample sizes, are available through the CalFishTrack collaborative program, or the California Fish Tracking Consortium website. These data include survival estimations from multiple runs, under a variety of environmental conditions and over multiple years.

3.3.11.3 POTENTIAL NEW INFORMATION

Enough data may be available from existing AT studies to obtain survival estimates for the mainstem. But there is relatively little information on survival in tributary streams between outmigrant sampling locations and the mainstem. Release of AT juvenile salmon at outmigrant sampling locations could provide this information and would augment existing information on mainstem Sacramento River survival. Although AT tagging is suitable for yearling juveniles, YOY caught in outmigrant sampling are typically too small for ATs. But the Feather River program is planning AT releases of both hatchery and natural-origin spring-run over the next two years, using juveniles as small as 60 millimeters. For outmigrant YOY, an alternative is PIT tag or CWTs with subsequent recapture at Delta entry, with PIT tags being the preferred alternative because they allow sampling that does not require handling fish. Surrogate fall-run could also be used for tagging studies to estimate survival, assuming that survival variation among juveniles is primarily caused by differences in juvenile size and life stage, and by environmental factors, rather than by genetic identification; but hatchery surrogate use would likely be limited to each hatcheries watersheds to protect the genetic integrity of non-hatchery watersheds. Tagging studies would require a robust Delta entry monitoring program, including an adequate understanding of sampling efficiency. Adequate efficiency estimates could be obtained from existing AT tagging and CWT mark-recapture data, especially during initial model development and parameterization.

3.3.12 YOY and Yearling Abundance at Delta Entry (JPE)

3.3.12.1 GENERAL DESCRIPTION

Juvenile abundance at Delta entry is, essentially, the purpose of the JPE, acknowledging that the JPE would need to account for sampling efficiency and resulting uncertainty of the JPE at this location. A Delta entry monitoring program would sample juvenile salmon downstream of the confluence of the Feather River and Sacramento River or combine sampling information from locations on these rivers just upstream of this confluence, if sampling proves more tractable at these upstream locations.

3.3.12.2 EXISTING INFORMATION

Downstream of the confluence, the ongoing USFWS Delta Juvenile Fish Monitoring Program (DJFMP) conducts regular beach seine and trawl surveys in the vicinity of the Delta entry. The beach seines target pre-smolt YOY migrants, which tend to migrate closer to the margins of the river channel. The trawl targets older juveniles and yearlings (i.e., smolts) migrating closer to the center of the channel. Time series of these data may also suggest an important environmental correlation of Delta-entry abundance and timing (Brandes and McLain 2001; del Rosario et al. 2013; Munsch et al. 2019). Historical genetics information for the DJFMP Sacramento Trawl could also be used to assess the spring-run component of trawl catch, and the required scale of a race identification program for this location. NOAA SWFSC is leading joint AT and CWT releases across a range of juvenile sizes to estimate trawl efficiency for winter-run juveniles caught at Chipps Island.

Upstream of the confluence, ongoing RST monitoring occurs near Knights Landing and Tisdale Weir on the Sacramento River; on the Feather River and Butte Creek, the two spring-run tributaries of the lower Sacramento River; and on the toe drain in the Yolo Bypass, a tidal slough accessed by salmon during lower river flow by distributary channels that depart the Sacramento River just downstream of Delta entry, and which becomes part of a floodplain accessed by juveniles during flooding just upstream of Delta entry via the Fremont Weir. Juvenile fyke trapping also occurs on Butte Creek, and beach seining occurs in the lower Yolo Bypass Toe Drain during non-flood conditions, and on both banks of the Yolo Bypass during flooding. Ongoing efficiency studies for the Knights Landing RST could be used to assess the efficacy and required scale of screw trap sampling at upstream locations to determine a JPE, although mainstem RST efficiencies are likely different than smaller stream RST efficiencies such that direct efficiency sampling on smaller tributaries would be preferable. RST monitoring on the Feather River is conducted relatively high in the river, thus this sampling does not account for juvenile mortality prior to entering the Sacramento River. Historical RST monitoring data is available for the Yuba River for 1999–2009.

3.3.12.3 POTENTIAL NEW INFORMATION

One potential location for a new Delta-entry RST monitoring station and trawl survey would be in the Sacramento River downstream from the confluence with the Feather River, including tests to quantify environmental effects on trap and trawl efficiency and abundance estimate uncertainty, and to account for juvenile migrants diverted through the Yolo Bypass during overtopping of the Fremont Weir. This location would not account for the specific contribution of Yuba River fish or fish loss in the Feather River prior to convergence with the Sacramento River as described above. Thus, another potential location for new Delta-entry monitoring would be in the lower Feather River near State Route 99 upstream of the confluence with the Sacramento River. This location along with Knights Landing and Tisdale RSTs on the Sacramento River could provide juvenile data for fish entering the Delta from both sides of the valley. Additionally, information on trawl efficiency could be obtained from existing and ongoing evaluation of the Chipps Island Trawl efficiency. Efficiency studies could be expanded to account for YOY versus yearling catch efficiency, and for diel differences in migration behavior, because trawls are typically conducted only during daytime; but the scientific literature and existing RST data from Knights Landing may provide adequate information on both of these topics. Similarly, a Knights Landing RST efficiency study, perhaps in conjunction with temporary augmentation from additional screw traps, could help determine whether a screw trap downstream of the confluence or a screw trap on the lower Feather River would be viable option for estimating outmigrant abundance, noting that flows at Knights Landing may not be a good model for efficiency at flows higher than approximately 30,000 cubic feet per second because additional flows are channeled down bypasses.

3.4 Environmental Conditions

Environmental conditions affect spring-run Chinook salmon across all life stages and have the potential to influence many of the JPE model components described above. Flow, temperature, and turbidity are known or expected to affect multiple transition parameters (e.g., survival), and the “catchability” of both YOY and yearlings, which affects the estimates of transition parameters. These effects are both direct, such as mortality caused by lethal temperatures, and indirect, such as temperature effects on predator activity, juvenile ability to avoid predators, and lethal and non-lethal outcomes of elevated pathogen activity. As a result, these environmental variables, and likely others, will be considered for inclusion in both abundance and parameter estimation, and in JPE model equations. Additional flow and water quality sampling may be helpful in reaches that are not covered by existing sampling programs.

4.0 Study Plan Items Identified for Immediate Implementation

As described in Sections 3.1.2 and 3.2, monitoring and targeted studies in representative streams will be planned and implemented as soon as possible to provide information on cost, labor, capability, and uncertainty for alternative JPE approaches. This information will help with model validation and JPE evaluation using structured decision-making. It will also provide valuable data on patterns of fish abundance and movements across different parts of the landscape to help build spring-run life-cycle models.

4.1 JPE Science Plan Timeline

A timeline for this effort is shown on Figure 23. All JPE Science Plan elements slated for immediate implementation will be initiated by the end of January or early February 2021. The first priority for the JPE Team is the selection of representative streams so that subteams can form to identify, plan, and execute required new monitoring in each stream, targeting surveys of holding adults in midsummer 2021 as the earliest possible new monitoring that can be established. Subteams will also be formed in January 2021 to plan and initiate Delta-entry monitoring stations, and to initiate building the spring-run JPE database and initial quantitative models. DWR began the Race Identification Program planning and contract development in November 2020 and will continue planning and rollout of this program in coordination other JPE Science Plan efforts to allow spring-run to be accurately identified in monitoring programs supporting JPE model development. In December 2020, DWR began searching for a decision analyst to help facilitate JPE Team meetings and structure decision-making processes, with the objective of having a decision analyst attending meetings by the end of February 2021. All of these immediate implementation efforts will proceed in parallel and will be coordinated through the JPE Team. Additional monitoring and targeted studies to support development of a spring-run JPE will be determined by the JPE Team in subsequent years based on quantitative uncertainty modeling and analysis of other information from the ongoing effort. A JPE approach will be selected and submitted to CDFW for approval in October 2024, and implemented in

January 2025 on a trial basis, with annual evaluation and updating of the approach by the JPE Team thereafter.

Figure 23 JPE Science Plan Timeline

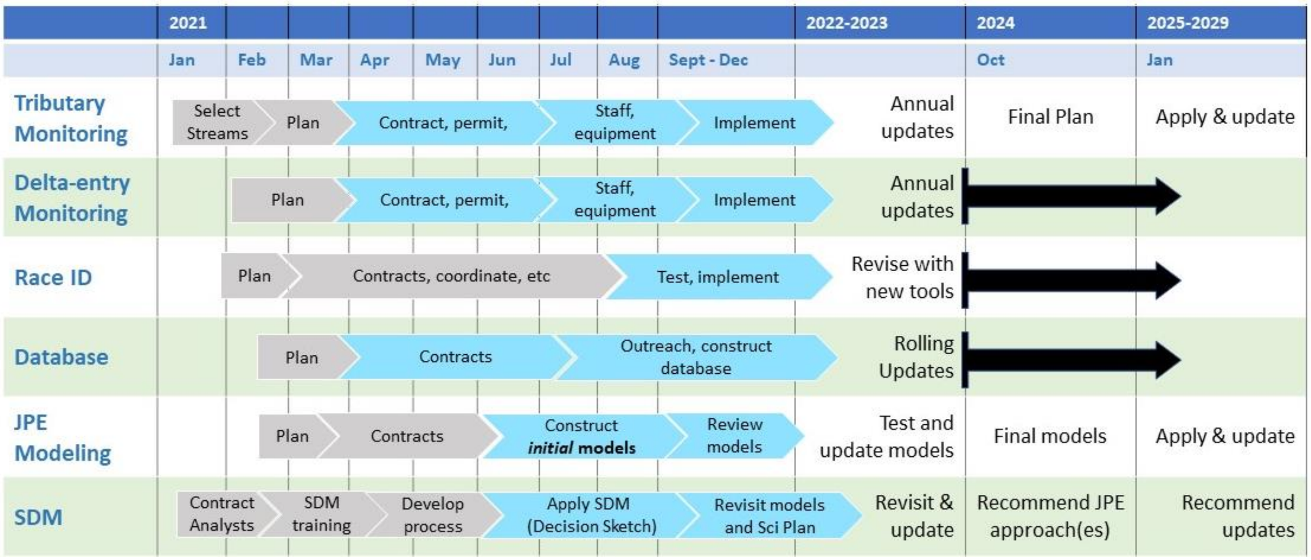


Figure 23 notes: JPE = juvenile production estimate, SDM = structured decision-making process

4.2 New Monitoring and Studies in Representative Streams

A primary purpose of initiating the planning and implementation of field studies beginning in January 2021 in representative streams will be to obtain initial data that can inform the different potential JPE approaches. For example, this sampling will provide real-world estimates of cost, feasibility, and measurement uncertainty. This information will be used in the structured decision-making process following the research and study phase to aid selection of a JPE approach, and to make informed decisions regarding which subsequent studies will provide the most cost-effective means to improve JPE model certainty.

As previously mentioned, augmented monitoring of life stages will initially occur in a subset of representative streams. Estimated transition parameters, parameter variability, and observation error can then be applied to populations in other streams. Because the physical and environmental characteristics of representative streams and the status of ongoing monitoring programs will strongly influence where and what kind of monitoring will be needed in each stream, selection of representative streams will be among the first tasks of the JPE Team in implementing the JPE Science Plan.

4.2.1 Representative Stream Selection

The JPE Team will use structured decision-making principles to guide the selection of representative streams to ensure the criteria used to compare potential streams are focused on clearly defined objectives and are transparently and objectively applied. To achieve this, the JPE Team will solicit information and advice from regional experts as appropriate. Among criteria that will be considered in the selection of representative streams are:

- **Contribution to spring-run juvenile population entering the Delta**. It is imperative that estimates of observational error and uncertainty be measured for the streams producing the largest abundances of spring-run YOY and yearling juveniles because this source of uncertainty will have the largest effect on overall JPE accuracy. By comparison, streams with very small average escapement, even with high variability in actual abundance or high observation uncertainty, will have relatively minor influence on overall JPE uncertainty. Populations in the streams with the greatest abundances of juveniles will also be less detrimentally affected by study activities than smaller, more sensitive populations. These dominant contributing streams will likely include, but not be limited to, Butte Creek and Feather River.
- **Applicability of information gain to other streams**. Spring-run tributaries are not alike, but some tributaries may serve as models for others. If streams have conditions similar to those found in other streams, this will allow the use of empirically derived transition rates from the representative stream for the similar streams. These criteria will likely be determined by grouping streams according to geography, geology, hydrology, and other characteristics. Similarly, if a decision must be made between a stream that can represent multiple other streams and a stream that shares few characteristics with other streams it would be more valuable for model development to select the more representative stream. This criterion would have to be balanced against the value in having information from a stream that is unique, and which may demonstrate environmental stochasticity or life-history diversity that are not currently characterized or completely understood.

- **Ongoing salmon monitoring**. Streams with well-developed and secure ongoing monitoring programs will allow more rapid implementation, and more refinement of research methods for a given cost. In addition, existing data sets from ongoing programs will allow back-application of newly derived uncertainty estimates for use during model parameterization.
- **Ongoing monitoring of environmental conditions**. As with ongoing monitoring of salmon, streams with existing environmental monitoring will require less additional effort and cost and will allow more rapid implementation.

4.2.2 Study Planning for Representative Streams

After representative streams have been selected, the JPE Team will create subteams for each stream which will use information gained through consultation with regional program leads to establish gaps in monitoring and necessary targeted studies to estimate life-stage abundances and transition parameters necessary for testing and evaluating the JPE approaches. In collaboration with the subteams and regional program leads, the JPE Team will develop detailed plans to address those gaps and will begin implementing those plans as soon as possible given the targeted life stages and the time necessary to obtain permits, contracts, equipment, and other requirements. The following sections describe some of the new program elements that may be implemented in any given representative stream.

4.2.3 Adult Passage Abundance Monitoring in Representative Streams

To the extent possible, video monitoring should be used to monitor adult passage abundance. Understanding the capability of this technology in small and large tributaries will inform the potential to use these tools more widely and aggressively (for example on the Yuba River below Daguerre Point Dam). Research and development should start by identifying any deficiencies in adult passage monitoring currently taking place in each tributary. Deficiencies could include use of old or manual technology, poor site selection, suboptimal fish routing (too wide of a viewing area), staffing shortages, and more.

Initial assessment could include interviews with each monitoring program lead to review current objectives and potential deficiencies. A review of monitoring options could help to identify whether there are opportunities to improve technology and perhaps better automate fish passage counts. Efficiency estimates would assess the proportion of the population captured on video and the rate of error in video analysis. Demonstrating the application of the best available technology on the representative streams could inform other monitoring efforts.

4.2.4 Spawner Abundance and Redd Surveys in Representative Streams

Because some form of spawner or redd survey occurs in most tributaries, this implementation plan will probably involve augmenting and testing the uncertainty of existing surveys. Monitoring program leads for each representative stream will be consulted to ascertain the existence and comprehensiveness of spawner and redd surveys. They will be asked to assess constraints and challenges that may be hindering the ability to provide dependable abundance estimates. It is expected that most programs may require only modest additional resources to achieve improved spawner abundance estimates. Tests to obtain uncertainty estimates would be designed to assess the tradeoff between survey effort and accuracy.

4.2.5 Pre-Spawner and Post-Spawn Carcass Surveys in Representative Streams

Pre-spawn carcass surveys can be accomplished during monitoring of holding adults over summer. Post-spawner carcass surveys can be conducted for either spawner abundance estimates, which requires substantial effort, or for estimating spawner sex ratio only, which requires much less effort.

4.2.6 Tributary Outmigrant Abundance Monitoring in Representative Streams

In addition to outmigrant abundance, monitoring of juveniles as they exit tributaries can be used to estimate condition-dependent and life-stage-specific tributary survival and subsequent migration survival. Sampling outmigrants also provides an opportunity to monitor juveniles as they exit natal streams, such as for acoustic tracking studies. Outmigrant monitoring will be accomplished with RSTs, either new or augmented to address inefficiencies. The JPE Team will engage with existing RST program leads to catalog the successes and limitations of existing programs and to determine which lessons from more successful RST programs can be applied to other streams with similar conditions. Consideration will include options to trap at different locations to better meet program objectives and minimize impacts to fish (e.g., to minimize mortality during capture).

Except for Clear Creek, spring-run spawning habitat in the Upper Sacramento River Basin is difficult to access for sampling. For this reason, RST sampling sites for Upper Sacramento spring-run populations are limited to valley floor reaches downstream of spawning areas used by multiple salmon runs. If any of these are selected as representative streams, accurate race identification will be needed, potentially requiring genetic testing for a large number of sampled juveniles to estimate spring-run abundance.

Because RSTs only capture fish from a small portion of the cross-section of a water body, it will be necessary to implement a method to project the RST catch numbers to parts of the water body outside of the RST capture zone. Mark-recapture trials of marked fish released upstream of the RST must be conducted to determine the efficiency of the RST when catching juvenile salmonids moving downstream during a given time period. When natural-origin fish are used, identifiable external marks like Bismarck brown dye, visible elastomers, or PIT tags would be used to tag natural-origin fish, rather than CWT, so that handling is not required for efficiency tests. These studies may be paired with AT releases to account for mortality between release sites and the RST. Separate mark-recapture trials need to be conducted over variable hydrologic conditions and for each life stage of juvenile spring-run to accurately estimate site-specific trap efficiencies over the course of a sampling season, or possibly year-round. A subset of Feather River Hatchery spring-run could be set aside and raised to the yearling life stage (not standard practice) and used in lieu of the more standard Coleman Hatchery late-fall. Many individual fish will need to be captured, and a subset of fish marked and recaptured.

4.2.7 Outmigrant Survival Study in Representative Streams

Outmigrant survival will likely be assessed with juveniles tagged with ATs and tracked using the existing acoustic receiver system put in place for winter-run. Additional receiver arrays would be placed at the confluence of representative streams and the Sacramento River to assess survival in the reaches below the RST location. To track survival of YOY, tags designed for smaller fish (down to 60 millimeters fork length) can be used. But 60 millimeters is still larger than most YOY spring-run outmigrants moving from January through March. An alternative may be to use PIT tags or CWT on natural-origin juveniles caught in outmigrant RSTs, and then recaptured at a second RST at the tributary confluence with the Sacramento River, or at

Delta entry. PIT tagging is preferable to eliminate the need for lethal take to identify tagged individuals. This would require good efficiency estimates at the recapture RST. CWTs were successfully used in this manner in the Feather River from 2008-2012 at sites approximately 12 miles apart. This type of testing could also be used for fall-run as a surrogate for spring-run if they are relatively similar in size to spring-run, and if the stream already has an existing fall-run population. But the lack of individual identification with CWT sampling would require all groups with the same tag code to be released simultaneously on tributaries and require a large and costly effort to recover enough individuals from each release group to obtain a reasonable sample size for survival estimation. In contrast, PIT tags allow releases to be spread out as necessary allowing more flexible use of resources and personnel.

4.2.8 Delta Entry Abundance Monitoring

The JPE Team expects that some form of Delta-entry monitoring will be necessary, at least during the JPE research and development phase. An abundance estimate at Delta entry will not be subject to the compounded process and observation error of other estimation methods because it provides a direct measurement of the JPE. This estimate will be useful for calibrating all the other JPE models and will provide an estimate of YOY versus yearling production for the JPE. Monitoring at Delta entry will also be useful for tracking tagged juveniles during tributary-specific survival studies.

The location for a Delta-entry monitoring station will most likely be either downstream of the confluence of the Sacramento and Feather rivers, or a new RST on the Feather River combined with existing RSTs at Tisdale and Knights Landing on the Sacramento River. A Delta entry monitoring program will likely consist of multiple RSTs and possibly also pilot trawl sampling. The pilot RST program will require efficiency tests and other studies to establish the appropriate sample sizes and scale needed to obtain reliable Delta-entry abundance estimates if a longer-term program is established. As much as possible, the pilot study will leverage information obtained from the RST program at Knights Landing to inform sampling design.

To be effective, an RST program will likely require at least four RSTs, paired on each side of the river. The major challenge of a Delta entry abundance-monitoring program is the low number of spring-run leaving the system, creating a combined problem of low catch and relatively low trap efficiency.

Monitoring on the tributaries could be used to inform expectations for catch in Delta-entry monitoring. This would provide information for a long-term operation. Another challenge is devising a method to account for juvenile salmon that migrate around the RSTs during flooding of the Yolo Bypass.

4.3 Race Identification

A vital component of producing an accurate annual spring-run JPE is having a precise way to distinguish spring-run from the other three Central Valley salmon races (i.e., winter, fall, and late fall). Given the anticipated need for large-scale race identification for juvenile and adult Chinook salmon in the Sacramento River, its tributaries, and at salvage facilities, it is worthwhile to optimize identification methods. Widely used current methods are either error-prone (e.g., traditional LAD approaches) or could benefit from efficiency improvements (e.g., genetic approaches). The ideal race identification process will be accurate, simple, fast, and inexpensive. The goal is to develop a process that embodies as many of these characteristics as possible. The following sections outline the steps being planned to achieve that goal. More general information on probabilistic length at date (PLAD) and genetics approaches are discussed in Section 2.4.

4.3.1 Development of Probabilistic Length-at-Date Spatial Models

Site- and environment-specific PLAD models will be created, with an emphasis on locations being considered as potential sampling sites for JPE-related monitoring. While the focus of PLAD model development will be spring-run identification, PLAD models will also produce assignment probabilities for the other Central Valley salmon races. Existing genetic data and associated metadata will be relied on heavily for development of these models. Several laboratories have databases with genetic race identifications and corresponding metadata that can be used to build initial PLAD curves. Data will be requested relating to species, date, collection location, tributary, life stage, length, adipose fin clip status, tissue type, and the genetic race-assignment probabilities. Additional field and genetic data will be collected, as needed, to better parameterize models. It is anticipated that sampling locations closer to spawning sites will produce more reliable PLAD race assignments (Hendrix, personal communication), but the accuracy of all models, and conditions when they may be more or less reliable, will be determined during the research and development phase. In all cases, determination of model accuracy will rely on obtaining accurate genetic race assignment.

Once the accuracy of PLAD models is determined across a range of different conditions for a given location, the method will be used in field tests using an interactive web-based application to easily input the date, location, and fork length and receive back the PLAD assignment for each race. It is expected there will be high-probability PLAD assignments for spring-run juveniles at some locations and times. Similarly, some PLAD assignments will have very low assignment probability for spring-run. These two sets of juveniles will be readily identifiable by field crews based on fork length and can be released without further handling. Juveniles with fork length in mid-probability ranges for spring run, or other populations of concern (e.g., winter-run) will be briefly retained so that field crews can non-lethally sample tissue from a representative subsample for genetic race assignment. Tissue will also be collected on occasion from a subsample of high- and low-probability PLAD assigned spring-run for verification.

The use of PLAD models will allow rapid data input of race assignment and assignment probabilities to the JPE database for interim JPE calculations, including calculation of JPE uncertainty, which will be updated with more accurate race assignments from genetic race assignments. In addition, PLAD models will allow tissue sampling and genetic testing to be targeted to a limited number of fish to reduce the physical impact on fish and provide the most efficient use of the genetics program resources.

4.3.2 Use of Current Genetic Methods to Inform JPE Approaches

Current, commonly employed genetic methods (e.g., SNP genotyping using microfluidics or next-generation sequencing platforms) will initially be used to assist in the research and development of other aspects of the JPE. There are several established baselines used by different labs to assign Central Valley Chinook salmon race; each typically consists of genotyping panel loci developed by many contributors (e.g., Brunelli et al. 2008, Clemento et al. 2014, Meek et al. 2016, Narum et al. 2018, Thompson et al. 2019; Thompson et al. 2020). All the established baselines have high accuracy race assignment, can genotype sex, and typically use one or more of the GREB1L/ROCK1 associated loci (Prince et al. 2017, Narum et al. 2018, Thompson et al. 2019; Thompson et al. 2020) to distinguish early (winter/spring) and late (fall/late fall) migrating individuals (see Section 4.3.5.1).

SNP panels can be assessed using several different genotyping tools, including Fluidigm's SNP Type assays and Genotyping-in-Thousands by sequencing (GT-seq; Campbell et al. 2014). These established genetic techniques, or others as appropriate (e.g., RAPTURE [Ali et al. 2016] or RAD-seq), will be used to identify race of sampled juveniles to inform initial JPE approaches, improve PLAD curves, estimate relative abundance in spatially overlapping spring-run and fall-run populations, and assess potential monitoring and sampling locations.

4.3.3 Development of New Genetic Tools

Though current genetic tools are extremely accurate for race identification, they are typically not considered simple or very fast. Currently, samples are sent to a molecular laboratory because the laboratory techniques and data analyses require considerable training, expertise, and equipment. After the work begins in the laboratory, it typically takes several days to complete, depending on the genotyping method. This can be reduced to as little as approximately 24 hours by working around the clock, with a corresponding premium in cost. As mentioned at the start of this race identification section, the ideal race identification process will be simple, fast, accurate, and inexpensive. Using PLAD in conjunction with genetics is one way to build these characteristics into the race identification process. A second way is to develop new genetic tools that embody these characteristics as well.

Specific High-sensitivity Enzymatic Reporter unLOCKing (SHERLOCK) is a recently developed CRISPR-based genetic identification tool (Gootenberg et al. 2017) that detects a specific genetic sequence (e.g., a sequence that distinguishes spring-run from other Chinook salmon races). Detection of the target sequence triggers a fluorescent reaction. Many of the tool's attributes are advantageous in both laboratory and field settings. Specifically, the tool is:

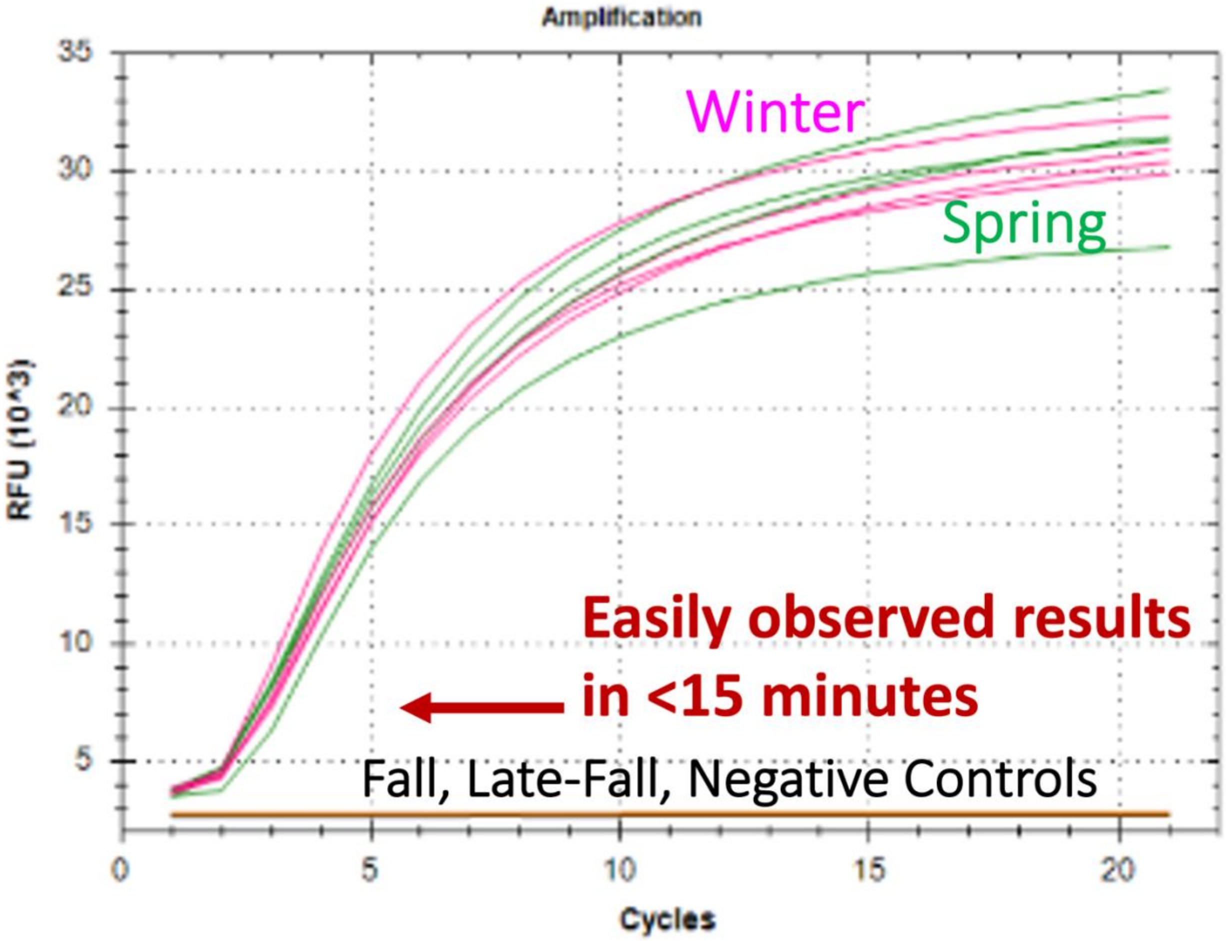
- Sensitive: can detect very small quantities of DNA.
- Specific: capable of distinguishing single base pair differences.
- Fast: results routinely achieved in less than 30 minutes and for some assays in less than 15 minutes.

- Inexpensive: a single reaction for human diagnostic disease testing costs less than one dollar.
- Simple: “one-pot” reactions can be prepared ahead of time, and very minimal equipment (a fluorescent plate reader) is needed for easy-to-understand results.

The tool also performs equally well whether using minimally invasive mucus swabs or fin clip samples (Baerwald et al. 2020). An alternative visualization result is possible using lateral flow strips, which are akin to using a pregnancy test strip. This type of visualization might be particularly useful in the field when testing a limited number of samples. The tool also eliminates the need for time-intensive molecular laboratory training and can be performed and analyzed by non-geneticists with minimal training. This would allow field crews to determine genetic race assignment of small subsets of sampled salmon having low PLAD assignment accuracy in the field, and real-time genetic identification could be processed at SWP facilities for immediate incorporation into take estimates, threshold exceedances, and JPE calculations. The ability to conduct genetic race identification in the field or at salvage facilities would be highly advantageous for informing real-time management of water operations. Although SHERLOCK’s ease and speed make it useful for field race identification, in most cases it will lack the specificity to identify specific tributary origin as is possible with genetic methods that use considerably more genetic markers. This is because the SHERLOCK assay essentially examines a single genetic marker (typically a SNP But, with more time to study SNPs throughout the genome, it may be possible that a small subset of tributary-specific SNPs will be discovered, which could be used to develop additional SHERLOCK tests in the future.

Assays for race identification on the SHERLOCK platform are already in development and some are nearing completion, which achieve discernible fluorescence (~9 relative fluorescence units) in less than 15 minutes (Figure 24). It is anticipated that SHERLOCK assays will be developed to accurately discriminate between all four Central Valley salmon races. SHERLOCK assays will also be optimized to further reduce cost while increasing field deployability, speed, sample throughput, ease of use, and visualization options. The accuracy of SHERLOCK assays for race identification will be carefully assessed by comparing it to adult phenotypic run timing and other genetic methods. If accuracy is verified, the value of using SHERLOCK genetic identification in tandem with PLAD will be compared to using existing genetic tools with PLAD, to identify the most streamlined and accurate process for race identification.

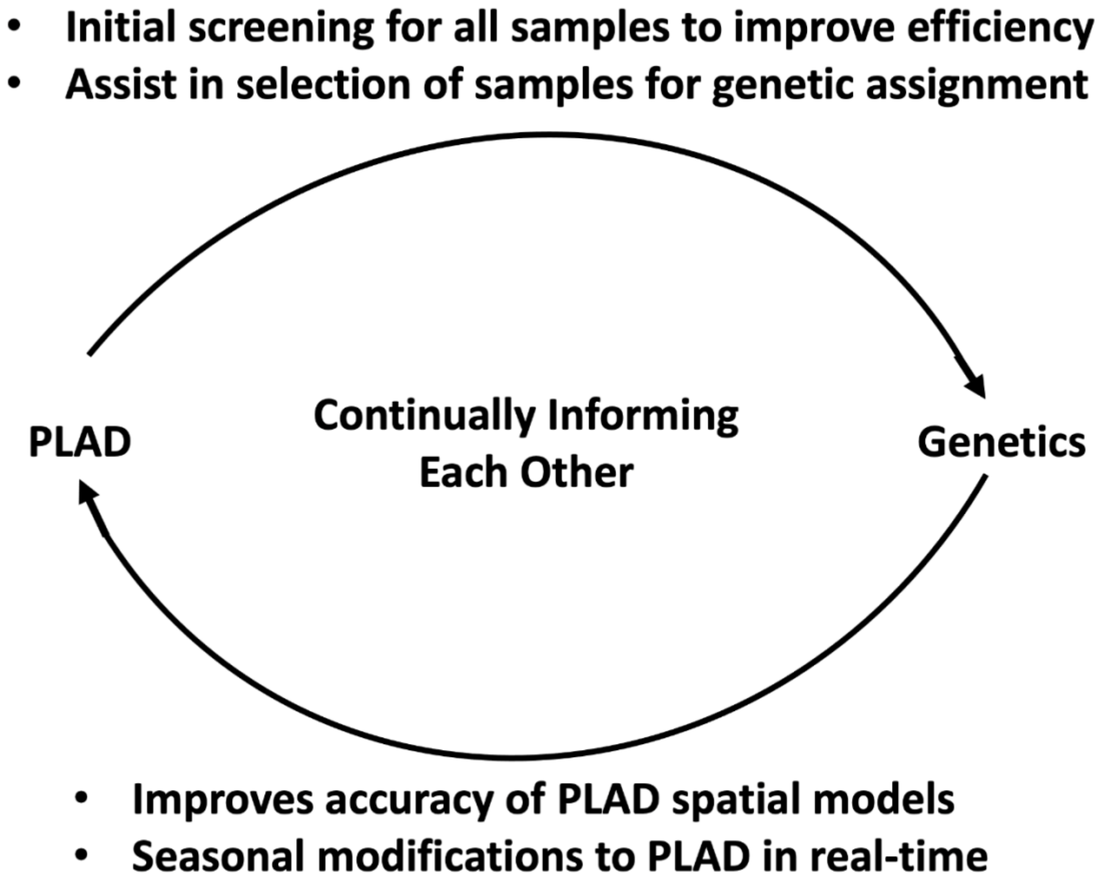
Figure 24 **SHERLOCK Early Migration Assay Results, Showing Rapid Detection of Winter- and Spring-Run Individuals**



4.3.4 Approach for Combining PLAD and Genetics

Combining PLAD and genetic methods is likely the most powerful and efficient approach for race identification because these methods are complementary tools that work to inform each other. Figure 25 provides schematics showing the synergistic relationship of these methods, while Figure 26 shows how they can work together in a single race identification process.

Figure 25 Synergy between PLAD and Genetics for Race ID Program

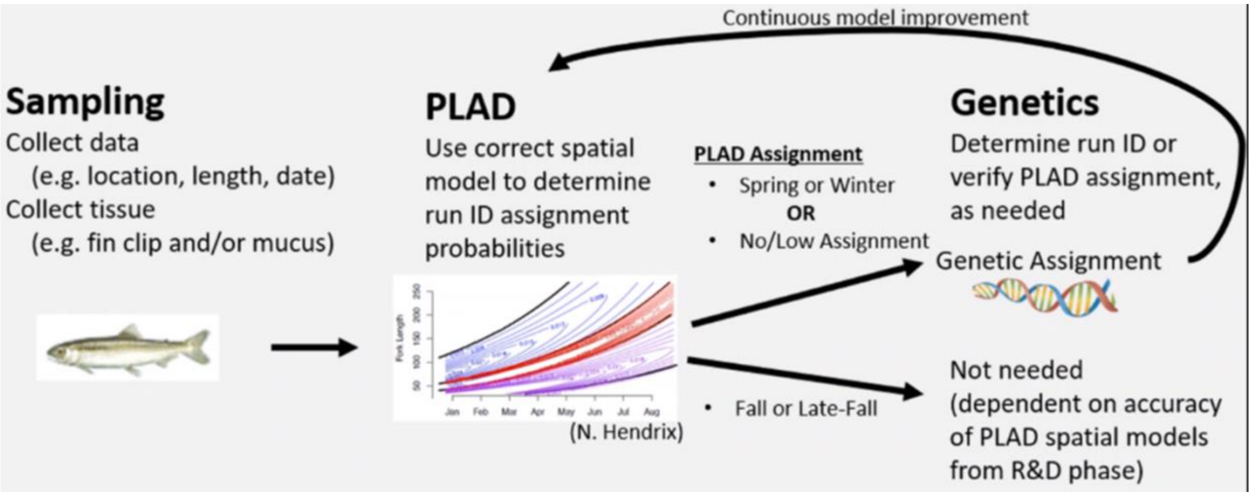


- Initial screening for all samples to improve efficiency
- Assist in selection of samples for genetic assignment

- Improves accuracy of PLAD spatial models
- Seasonal modifications to PLAD in real-time

Figure 25 note: PLAD = probabilistic length and date

Figure 26 Schematic of Anticipated General Steps in the Race Identification Process



Sampling
Collect data
(e.g. location, length, date)
Collect tissue
(e.g. fin clip and/or mucus)

PLAD
Use correct spatial model to determine run ID assignment probabilities

PLAD Assignment
- Spring or Winter
OR
- No/Low Assignment
- Fall or Late-Fall

Genetics
Determine run ID or verify PLAD assignment, as needed

Genetic Assignment

Not needed (dependent on accuracy of PLAD spatial models from R&D phase)

Figure 26 note: PLAD = probabilistic length and date

4.3.5 Potential Challenges for Race Identification

4.3.5.1 HYBRIDIZATION BETWEEN SPRING-RUN AND FALL-RUN

Interbreeding between spawning run types (e.g., spring-run and fall-run) leads to increased intermixing of early- and late-migration alleles in the GREB1L/ROCK1 region found on Chinook salmon chromosome 28. Each salmon has two alleles, one inherited from each parent. Salmon that inherit either two early or two late alleles for run-migration timing (i.e., a homozygous genotype) appear to produce reliable corresponding early or late phenotypes across different river systems and salmonid species. On the other hand, salmon that inherit an early allele from one parent and a late allele from the other (i.e., a heterozygous genotype) typically produce phenotypes that are intermediate in run-migration timing and the distribution of run-timing for the heterozygous population can overlap on both ends with the early and late homozygous genotypes (Thompson et al. 2020). It is critical to obtain a characterization of GREB1L/ROCK1 genotypes with known migratory phenotypes throughout the Central Valley so that juveniles collected with heterozygous genotypes can be accurately assigned or subjected to more thorough genetic testing, enabling either a final accurate race assignment or a definition of hybrid without assignment to a single race.

4.3.5.2 SAN JOAQUIN RIVER RESTORATION PROGRAM SPRING-RUN STOCK COME FROM FEATHER RIVER HATCHERY

Genetically distinguishing the spring-run San Joaquin River Restoration Program’s (SJRRP’s) experimental population from that of the Feather River Hatchery may be problematic because the hatchery is the source for the SJRRP’s spring-run stock. While all hatchery-produced juveniles are currently tagged, naturally spawned juveniles have no identifying marks. This is a potential issue only for those fish collected at salvage because other sampling will occur in the Sacramento River or its tributaries and not in the San Joaquin system. Staff of the SJRRP will be consulted to develop identification strategies, both genetic and nongenetic. Potential tools for determining origin of salvaged SJRRP salmon include otoliths, CWT, PIT tagging, AT, photonic tagging (which has been done previously by SJRRP; Hutcherson et al. 2020), and parentage-based tagging. These or an alternative method of marking SJRRP salmon could be used to better characterize the contribution of the San Joaquin experimental population to salvage, to determine if further action is needed, and to help identify the best approach.

4.3.5.3 LOGISTICS AND PLANNING FOR SCALE-UP IN RACE IDENTIFICATION PROCESS

Incorporating increased use of genetics into monitoring approaches for spring-run will require extensive coordination between existing monitoring programs. Sampling kits will need to be distributed across agencies conducting monitoring. Personnel will need training on different sampling techniques (mucus swab versus fin clip), depending on genetic analysis. New standard operating procedures will need to be created to describe genetic sampling procedures and field-based deployment of SHERLOCK, if applicable. A laboratory with the necessary equipment and reagents will be required for running large batches of genetic samples. Dedicated staff will be needed for laboratory processing of samples and for coordinating across partnering groups. Depending on the genetic tools used, these staff will require different levels and areas of expertise (e.g., molecular biology, genetics, or bioinformatics) to set up reactions, process samples, and interpret results. The amount of interagency coordination and genetic identification that will be conducted on an annual basis may be extensive, and DWR may find it most cost-effective to create in-house capabilities for a SHERLOCK genetic identification program, while simultaneously relying on collaborations with other fish genetic laboratories to augment research and development as well as large-scale race assignment (e.g., CDFW, UC Davis Genomics Variation Laboratory, Genidaqs, NOAA Southwest Fisheries Science Center, or Michigan State University).

4.4 Data Management

In early 2021, the JPE Team will form a subteam to guide DWR in the establishment and coordination of a database to serve as a central repository for existing and newly generated data on spring-run. The database will provide format and location for regional programs to upload data from ongoing monitoring programs, and a link for initial development and continuous updating of JPE and life cycle models.

The JPE Data Management subteam will include experts in data management and quality assurance, and representatives of regional monitoring programs to ensure a data management process that facilitates rather than complicates data management across monitoring programs. Participants may be drawn from collaborating agencies on the JPE Team or outside these institutions (i.e., as consultants). Initial steps are expected to include:

- Identification of additional intellectual resource needs.
- Identification of existing data sources.
- Sources likely to be used in the program.
- Formation of a timeline for completing the Spring-run JPE Data Management Plan.
- Determination of a short-term local storage solution.
- Development of file naming conventions.

Other key attributes of the data management plan are likely to include:

- Data Collection Program Manager: individual(s) responsible for the project, including their contact information.
- Point of Contact: individuals data users should contact for data access or with questions about the data (include contact information).
- Data Descriptions: brief description of the information (to be) gathered, including the nature and scale of the data, and the approximate size (in MB) of the resulting dataset(s).
- Related Data: existing or ancillary datasets relevant to the program or data that are collected simultaneously.
- Metadata: including a description of metadata standards, file name(s), and information on how users can access the metadata.
- Coding and Data Processing: a plan for how programming codes are developed, shared, and annotated, including a location where they can be stored, accessed, and published.
- Storage and Backup: a description of the short-term storage methods and back-up procedures for the data, including the physical and electronic resources to be used for the short-term storage of the data.
- Archiving and Preservation: the procedures for long-term archiving and preservation of the data, including succession plans for the data should the expected archiving entity cease to exist.

- Access and Sharing: a description of how data will be shared, including (1) access procedures, (2) embargo periods, (3) technical mechanisms for dissemination (e.g., website addresses or listserv information), (4) whether access will be open or granted only to specific user groups, and (5) a timeframe for data sharing and publication.
- Format: formats in which the data will be generated, maintained, and made available, including both data type (e.g., spreadsheet, relational database) and file format (extension).
- Quality Assurance: brief description of procedures for ensuring data quality, including links to Quality Assurance Project Plan and/or Quality Assurance/Quality Control Standard Operating Procedures.
- Rights and Requirements: a link to, or instructions for, locating the agency's rights and requirements for data use.

The IEP Data Utilization Work Group (DUWG) has developed a data life cycle model (adapted from Faundeen et al. 2013) that could provide the basis for developing the Spring-Run JPE Data Management Plan. The major steps from the DUWG model are design, collect, process, analyze, maintain, and share. DUWG observes that these steps "may be sequential or iterative, but every step in the process should include metadata, quality assurance, and backups."

Additional information that will be considered during data management plan development will be the U.S. Geological Survey Data Management website: https://www.usgs.gov/products/data-and-tools/data-management, and the DataOne data management best practices website: https://www.dataone.org/best-practices.

4.5 Initial JPE Quantitative Models Development

In early 2021, the JPE Team will form a JPE Modeling subteam to plan and implement building of initial JPE quantitative models. The subteam will oversee the following:

- Use of data in the spring-run database (Section 4.2) to build and parameterize initial quantitative JPE models.
- Subsequent updating of these models with new information.
- Use of models to identify and quantify sources of uncertainty.

Initial model development is a high-priority task because it will be integral to the ongoing process of identifying monitoring and studies needed to reduce key sources of uncertainty, and to help define the criteria to be used for selecting a final JPE modeling and monitoring approach at the end of the four-year research and development phase.

4.6 Structured Decision-Making Process

To assist in decisions regarding the best use of limited funds for JPE research and development, and ultimately in the final selection of a JPE approach, the JPE Team will use structured decision-making tools and processes whenever possible given constraints of time and ITP conditions. Structured decision-making is a transparent process for breaking down complex resource management problems into their science-based and value-based elements, the former focused on predicting the outcomes of actions, the latter on what outcomes are targeted for achievement. In this way, each can be addressed by the appropriate tools and people. This is exactly the kind of complex problem faced in the development of a JPE. The broad geographic distribution of spring-run spawning and rearing habitat, combined with the species' diverse life history, may require that multiple life stages and types of monitoring be used to develop a JPE. Because the best life stages and methods for calculating a JPE are unknown and may vary among streams, different approaches will be compared (Section 3.2) according to accuracy, uncertainty, and take; these are some of the science-based elements involved in selecting a JPE approach. Determining how to balance accuracy, uncertainty, take, and cost to achieve agreed upon fundamental objectives is the value-based aspect of the problem.

Structured decision-making will include identification and consideration of the following:

- Fundamental objectives.
- The decision-makers (those legally empowered to make the final decisions).
- Stakeholders and technical experts.
- The legal and regulatory context of those decisions.
- Decision timelines, scope, and scale.

- Constraints such as take resulting from science and monitoring activities.
- Key uncertainties.
- Potential added benefits of research and development for developing a spring-run life-cycle model (development of a spring-run life-cycle model is a requirement of ITP Condition of Approval 7.5.3).

These considerations will be used as much as possible to help guide planning and implementation of studies and analyses needed for testing and comparing different JPE approaches, beginning with selection of representative streams for augmented monitoring and targeted studies, and will ultimately be used to help with final JPE approach selection. In structured decision-making, the initial evaluation of the problem elements is the most critical step toward a successful, widely acceptable decision outcome. For this reason, a professional decision analyst will be recruited to assist with initial problem evaluation, and then be consulted at various phases of JPE Science Plan implementation.

4.7 Next Steps

Beginning in winter 2021 the JPE Team will lead the effort to develop a JPE approach through January 2025 according to the high-level timeline shown in Figure 23 and the milestones noted below:

1. December 1, 2020: JPE Team submits a draft spring-run JPE Science Plan to CDFW.
2. Winter 2021: Draft JPE Science Plan is reviewed and approved by CDFW.
3. January 2021 to May 2024: JPE Team and subteams plan and implement research and monitoring activities as outlined in the JPE Science Plan.
4. January 2024: Results of JPE research and monitoring, culminating in a recommended JPE approach and initial calculation, are included as part of activities reviewed by an external panel for the ITP four-year review.

5. October 2024: A final JPE approach is selected based on multiple factors (e.g., feasibility, accuracy, timeliness, management value, scientific value, and cost) and subject to CDFW approval.
6. January 2025: Approved JPE approach is implemented each year with ongoing evaluation by the JPE Team.
7. 2028: Four years of implemented JPE calculations are included as part of activities reviewed by an external panel for the second ITP four-year review.

As of winter 2021, subteams have been formed to begin planning and implementing new monitoring, race identification, data collection, and model building. As a part of this planning process, the JPE Team will also establish a process for review and incorporation of ongoing JPE Science Plan results into “next steps” decisions regarding additional monitoring and targeted studies, or revision of existing monitoring, to meet JPE research and development objectives and deadlines. The JPE Team will use structured decision-making to establish a process for selecting a final JPE approach and monitoring plan based on fundamental objectives for the JPE science program identified in the ITP and further refined by the JPE Team.

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5.1 Personal Communications

California Department of Fish and Wildlife (written comment on draft plan, January 14, 2021).

Noble Hendrix, Queda Consulting (multiple phone conversations and emails, October–November 2020)

Rachel Johnson, National Oceanic and Atmospheric Administration (telephone conversation, January 7, 2021).

Appendix A

Full text of Condition 7.5.2 from Department of Fish and Wildlife 2020 Incidental Take Permit for Long-term Operation of the State Water Project in the Sacramento-San Joaquin Delta (2081-2019-066-00)

7.5.2 New and Ongoing Monitoring Required to Develop and Establish a JPE. Within 30 days of the effective date of this lTP, Permittee as part of the Collaborative Science and Adaptive Management Program shall convene a Spring-run JPE Team including experts from CDFW, DWR, NMFS, USFWS, and Reclamation. To further advance collaboration, upon convening, the Spring-run JPE Team may invite other experts in fish biology, hydrology, or operations of the SWP and CVP to meetings of the Spring-run JPE Team to assist with discussion and analyses. Permittee shall prepare a draft Spring-run JPE Monitoring Plan in collaboration with the Spring-run JPE Team that describes monitoring required to inform the development of the JPE prior to December 1, 2020. The plan shall include, but not be limited to:

- *Feather River adult passage monitoring and escapement surveys*: Monitoring needed to develop adult spawner abundance estimates from which to derive production estimates. Monitoring includes continuing redd surveys and carcass surveys for CHNSR and collecting genetic samples from all carcasses.
- *Lower Yuba River adult passage monitoring and escapement surveys*: Monitoring needed to develop adult spawner abundance estimates from which to derive production estimates. Monitoring includes continuing adult salmonid passage surveys, via the Vaki Riverwatcher at Daguerre Point Dam, redd surveys for CHNSR, upstream of Daguerre Point Dam, and carcass surveys for CHNSR upstream of Daguerre Point Dam. Collect genetic samples from all carcasses.
- *Deer, Mill, and Butte Creek adult passage monitoring and escapement surveys*: Monitoring needed to develop adult spawner abundance estimates from which to derive production estimates. Monitoring includes passage surveys via video monitoring stations on Deer, Mill and Butte creeks, carcass surveys, and redd surveys.
- *Feather River RST monitoring at RM 61 and 45. 8*: Monitoring to provide estimates of the number of CHNSR emigrating through the

upper limits of the Feather River via two existing RSTs at RM 45.8 (High Flow Channel RST) and RM 61 (Low Flow Channel RST).

- *Feather River RST monitoring near Beer Can Beach*: New monitoring near Beer Can Beach (river mile 7) to provide estimates of the number of CHNSR entering the Delta from the Feather River Basin. Data obtained would be used to integrate all Feather River Basin-origin fish into the JPE. The data obtained can also be used as a point of comparison for reach-specific loss estimates from upstream sites when used in conjunction with acoustic telemetry data.
- *Lower Yuba River RST monitoring*: Monitoring to provide estimates of the number of CHNSR emigrating through the lower Yuba River via two RSTs near Hallwood Boulevard. Collect genetic samples on all length-at-date CHNSR. These data can also provide an upstream measurement to assess reach-specific loss estimates in coordination with acoustic telemetry data.
- *Deer, Mill, and Butte Creek RST monitoring*: Monitoring needed to develop in-season production estimates and provide data on the egg-to-fry survival and emigration timing of yearling and young-of-the year (YOY) CHNSR. Collect genetic samples on all length-at-date CHNSR. These data can also provide an upstream measurement to assess reach-specific loss estimates in coordination with acoustic telemetry data.
- *Tisdale Weir and Knights Landing RST monitoring*: Monitoring is needed to provide estimates of the number of CHNSR entering the Delta from the Sacramento River Basin. Collect genetic samples on all length-at-date CHNSR. The data obtained can be used as a point of comparison for reach-specific loss estimates from upstream sites. Weir overtopping and Sutter Bypass activation can influence the detectability of Chinook salmon at the Knights Landing monitoring station. Water entering the Sutter Bypass provides an alternative route in which juvenile salmon are routed around the Knights Landing monitoring station. Monitoring upstream of Tisdale Weir will provide an additional measure of· abundance prior to weir influence.
- *RST AT monitoring*: Monitoring using ATs on fish to provide estimates of loss and timing of yearling CHNSR emigrants in the fall and emigrating YOY CHNSR in the spring at all new and ongoing RSTs.

- *Genetic identification of CHNSR to support ongoing and new monitoring and development of a CHNSR JPE*: Genetic samples shall be collected from all fish (or a subsample of fish where appropriate) and analyzed to race to improve identification of CHNSR-sized fish observed during monitoring and better inform migration and production estimates. Permittee shall coordinate with the CDFW Genetics Lab and NMFS Southwest Fisheries Science Center regarding the methodology for collecting and analyzing all genetic samples.
- *Trap capture efficiency studies*: Research to guide annual CHNSR JPE calculations using current methods of visibly marking trap captured and hatchery sourced fish including late fall-run and fall-run Chinook salmon. Studies should also include developing trap efficiency models using the paired AT-coded-wire tagged (CWT) releases from Livingston Stone National Fish Hatchery (NFH), Coleman NFH, and Feather River Fish Hatchery.
- A list of the entities that shall receive funding from Permittee to implement required monitoring programs.

This list of required monitoring may be modified in the final monitoring plan if approved by CDFW. Permittee shall work collaboratively with the Spring-run JPE Team members to incorporate edits and comments on the draft Spring-run JPE Monitoring Plan while preparing the final plan. After the final Spring-run JPE Monitoring Plan is approved in writing by CDFW, Permittee shall fund and implement required monitoring beginning the calendar year after the effective date of this ITP, according to the timelines specified in the CDFW-approved plan. At a minimum, Permittee shall convene the Spring-run JPE Team quarterly every year following initiation of the final monitoring plan to:

- Review data obtained from new and ongoing monitoring programs,
- Review methods used to implement monitoring and recommend adjustments as they deem appropriate,
- Formulate an approach to calculating a CHNSR JPE, including the following elements:
    - Total in-river escapement,
    - Adult female estimate,
    - Adult female estimate minus pre-spawn mortality,

  - Average fecundity,
  - Total viable eggs,
  - Estimated egg-to-fry survival based on Juvenile Production Index (JPI) at ongoing and new monitoring stations/total viable eggs,
  - Fry equivalents of juvenile production,
  - Fry-to-smolt survival estimates,
  - Number of smolts, and
  - Upper river to Delta survival.
- Request additional monitoring if it is deemed necessary to complete a CHNSR JPE within five years of the effective date of this ITP,
- Recommend approaches to using the CHNSR JPE and monitoring results as operational criteria to minimize take of CHNSR as a result of Project operations, including operations at the south Delta export facilities, and
- Evaluate the need to revise and update the plan to incorporate genetic testing of CHNSR when it becomes available.

Permittee shall make all raw data acquired as a part of the monitoring program available to members of the Spring-run JPE Team within ten days of a request.

Within four years of the effective date of this ITP, and in collaboration with the Spring-run JPE Team, Permittee shall review data collected over the past four years and prepare a draft plan that describes the approach to calculating a CHNSR JPE and long-term monitoring needed to collect the data to calculate a CHNSR JPE annually. Permittee shall submit the draft plan to the Spring- run JPE Team for review and work collaboratively with team members to incorporate their comments into the final draft. Permittee shall submit the final plan to CDFW for approval no more than four years and six months after the effective date of this ITP to ensure that annual calculation of a CHNSR JPE is initiated within five years of the effective date of this ITP. After the final draft Spring-run JPE Plan is approved by CDFW, Permittee shall convene the Spring-run JPE Team annually to provide an annual JPE estimate for CDFW, Reclamation, USFWS, and NMFS and share all data obtained through long-term monitoring programs.

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