STATE WATER RESOURCES CONTROL BOARD
CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

SECOND REVISED DRAFT INITIAL BIOLOGICAL GOALS FOR THE LOWER SAN JOAQUIN RIVER

April 2023

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Appendix A Microsoft Excel file containing data and calculations

Appendix B Technical Stock Recruitment analysis for Lower San Joaquin River Tributaries (Please see the June 2022 report)

Chapter 1

Introduction

1.1 Bay-Delta Watershed Background

The Bay-Delta watershed includes the Sacramento and San Joaquin River systems, the Delta, Suisun Marsh, and San Francisco Bay. The Sacramento and San Joaquin River systems, including their tributaries, drain water from about 40% of California's land area, supporting a variety of beneficial uses of water. The Bay-Delta is one of the most important ecosystems in California as well as the hub of California's water supply system. As the largest tidal estuary on the west coast of the Americas, it provides habitat to a vast array of aquatic, terrestrial, and avian wildlife in the Delta, San Francisco Bay, and near-shore ocean, as well as a diverse assemblage of species upstream of the Delta. The Sacramento and San Joaquin rivers and the Delta also provide a portion of the water supply for two-thirds of Californians, a variety of industrial purposes, and millions of acres of farmland, in addition to supporting commercial and recreational fishing and boating businesses on the rivers, the Delta, the Bay, and into the ocean.

It is widely recognized that the Bay-Delta ecosystem is in a state of prolonged decline. Changes in land use due to agricultural practices, urbanization, and flood control combined with substantial and widespread water development, including the construction and operation of the Central Valley Project (CVP) and State Water Project (SWP) and other water infrastructure projects, have been accompanied by significant declines in nearly all species of native fish, as well as other native and nonnative species dependent on the aquatic ecosystem. Fish species have continued to experience precipitous declines in recent years. In the early 2000s, scientists noted a steep and lasting decline in population abundance of several native estuarine fish species that has continued and worsened during the sustained drought during 2012-2016 and 2020-2022. Simultaneously, natural production of all runs of Central Valley salmon and steelhead remains near all-time low levels.

In response to declining native fish populations, the State Water Resources Control Board (State Water Board) initiated two processes to update and implement flow-dependent water quality objectives in the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta watershed (Bay-Delta Plan) for the reasonable protection of fish and wildlife. In December of 2018, the State Water Board adopted revisions to the Bay-Delta Plan including updating the flow objectives for the reasonable protection of fish and wildlife in the lower San Joaquin River and its three eastside tributaries, the Stanislaus, Tuolumne, and Merced Rivers and the program of implementation to achieve the objectives (LSJR flow update).[1] The State Water Board is also currently in the process of updating other portions of the Bay-Delta Plan for the reasonable protection of fish and wildlife in the Sacramento River and Delta and associated tributaries (Sacramento/Delta update).

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[1] The Office of Administrative Law (OAL) approved the regulatory action on February 25, 2019.

1.2 Bay-Delta Plan and Biological Goals

The recently approved LSJR flow and planned Sacramento/Delta updates to the Bay-Delta Plan are intended to provide for the reasonable protection of fish and wildlife beneficial uses by supporting and maintaining flow-and related aquatic habitat conditions necessary for the natural production of viable native fish and aquatic species populations rearing in, or migrating through, the Bay-Delta Estuary. The Bay-Delta Plan requires development of biological goals for LSJR salmonids because they are among the fish species most sensitive to LSJR flow modifications. Biological goals are quantitative metrics that the State Water Board will use to assess if the actions it is taking under the Bay-Delta Plan, and in coordination with state agencies and other entities to implement the plan, are making sufficient progress towards the Plan's objectives of achieving and maintaining the natural production of viable native fish and aquatic species populations. The Bay-Delta Plan requires biological goals to be developed for the following population metrics: abundance, productivity, genetic and life history diversity, and spatial extent. These metrics are referred to as viable salmon population (VSP) parameters. The salmonid biological goals for the LSJR flows program of implementation are required to be specific to the LSJR and its tributaries and to contribute to meeting the salmon protection (doubling) objective established in state and federal law.

The LSJR flow update requires the development of biological goals for the LSJR within six months of OAL approval of the amendments. Although initial draft goals were developed and released to the public in September 2019, the State Water Board has not yet completed consideration and taken an action regarding approval of the goals. This draft report identifies proposed initial biological goals for the LSJR that are focused on fall-run Chinook salmon in conformance with the 2018 Bay-Delta Plan. Fall-run chinook salmon were selected due to their relative abundance compared to other sensitive indicator species and the availability of information and monitoring data for this species.

In a separate process, parties are working to develop possible voluntary agreements (VAs) to implement the Bay-Delta Plan that included metrics and outcomes (previously referred to as biological and environmental targets) to evaluate the effectiveness of proposed VA specific assets. Biological goals have a broader scope and apply to all of the actions needed to reasonably protect fish and wildlife, including actions applied to tributaries that do not participate in a VA, and recommended non-flow measures that can be achieved by other organizations outside the Water Boards' authorities (e.g., ocean harvest, hatchery management). The biological goals identified in earlier versions of this report were developed in coordination with prior VA efforts, and coordination will continue to occur with VA processes as appropriate.

1.3 Purpose and Use of Approved Biological Goals

Progress toward achieving biological goals will inform adaptive implementation actions and help determine whether future changes to the Bay-Delta Plan and its implementation are needed, including actions by the State Water Board (water right and water quality actions) and actions by other entities (e.g., fishing regulations, hatchery management, habitat restoration, etc.).

The biological goals serve multiple purposes, including informing adaptive implementation of the LSJR flow requirements, along with other scientific information; evaluating the effectiveness of the program of implementation; guiding the development and assessment of the monitoring and evaluation program; and informing future changes to the Bay-Delta Plan. The best available scientific information on achievement of, or furtherance of, biological goals will support these purposes and related actions by the State Water Board and actions by other entities. Individual biological goals will be used in different ways.

The LSJR flow objective applies during the February through June time period, as well as October, because increased flows during these months will have the most direct and immediate effect on improving juvenile salmonid habitat and survival which are primary limiting factors to increasing adult abundance and achieving a viable population (Michel 2019, State Water Board 2018, Appendix C). Thus, the biological goals that will primarily be relied upon to inform approval of adaptive implementation adjustments[2] are the goals that most immediately reflect the condition of these functions, i.e., juvenile survival, production, and life history diversity goals (timing and percent size classes). The best available science on achievement of, or furtherance of, these juvenile goals will be used to inform whether adaptive implementation actions, including flow shaping, flow shifting, and adjustments within the percent of unimpaired flow range, should be approved. Best available scientific information may include information such as juvenile survival estimates produced by flow-abundance relationships, stock-recruitment relationships, monitoring and forecast information about habitat conditions such as temperature, floodplain activation, estimates of quality and quantity of spawning, rearing, and migration habitat, fry production, and juvenile outmigrant survival.

Progress toward achieving the remaining biological goals will also inform adaptive implementation actions, but to a lesser degree and only to the degree that those goals are influenced by tributary flows. For example, through-Delta survival is affected by in-Delta diversions (e.g., SWP and CVP exports), tidal dynamics, and habitat conditions, as well as LSJR tributary and mainstem LSJR flows and other factors. Similarly, the cohort replacement rate is affected by ocean conditions and the fitness of juvenile fish arriving in marine habitats (fitness is influenced in part by tributary and mainstem flows, for example, through size selective mortality) and other factors.

Mainstem San Joaquin River, Delta, and ocean conditions and other limiting factors will be considered in determining how to use biological goals to inform whether to approve adaptive implementation actions and whether additional actions beyond tributary flow actions are needed to achieve those goals.

Information developed through evaluation of all of the biological goals is intended to inform evaluations of the effectiveness of the LSJR flow objectives and program of implementation and future reviews and potential updates to the Bay-Delta Plan, including whether the Board should consider modifications to the flow objectives, whether the Board should be taking actions beyond the tributary flow actions to achieve those goals, as well as whether other agencies or entities should be taking actions.

Table 1.1 provides a summary of the biological goals and their role in informing: approval of adaptive implementation of the LSJR flows, the effectiveness of the program of implementation, the San Joaquin River Monitoring and Evaluation Program (SJRMEP), and future changes to the Bay-Delta Plan.

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[2] Bay-Delta Plan (2018), page 26, "The State Water Board may approve adaptive adjustments to the flow requirements … if information produced through the monitoring and review processes described in this program of implementation, or other best available scientific information, indicates that the change for the period at issue will satisfy the following criteria for adaptive adjustments: (1) it will be sufficient to support and maintain the natural production of viable native San Joaquin River watershed fish populations migrating through the Delta; and (2) it will meet any existing biological goals approved by the State Water Board."

method, which captures the larger juvenile fish but does not represent smaller life-stages of fry and parr well. While there is only one within tributary survival goal at the confluence, this does not preclude using additional rotary screw traps or other information. Additional key information should be collected from juvenile monitoring locations upstream of the confluence, e.g., to measure egg to fry survival. Tracking juvenile metric information from multiple locations in the river is needed to understand variable conditions that may be causing differential survival during different life-stages, locations, or timing.

While tributary juvenile survival will be a primary metric for measuring tributary- specific performance, the conditions that juveniles experience in the tributaries will still greatly influence fitness and survival during migration in the LSJR, the Delta, and as they enter the ocean, e.g., through size-selective mortality. Juvenile survival between the tributary confluences and Mossdale will need to be tracked and evaluated to understand the fate of the juveniles more thoroughly in the LSJR, and to evaluate any disproportionate mortality that may occur in the tributaries or the LSJR. Scientific studies are needed to develop monitoring designs and tools to evaluate juvenile success from the tributaries down to Mossdale and the Delta exit, e.g., tagging RST captured fish, microchemistry studies of captured fish at Mossdale or Chipps Island trawls.

The intermediate progress assessment timelines to meet the juvenile productivity goals were removed, and the timeline to achieve the juvenile survival goals has changed to 5 years. Juvenile productivity is the metric that is most directly influenced by the conditions in the tributaries, so changes to juvenile survival should be observed readily with the implementation of the Bay-Delta Plan.

The juvenile productivity goal includes a new metric that is complementary to the initial percent juvenile survival metric, which is anticipated to be necessary when the juvenile production reaches levels that are predicted to attain the salmon protection objective. The narrative lower San Joaquin River flow objective requires that the tributaries provide sufficient inflow conditions to support viable native fish populations, and the Salmon Protection objective requires that water quality conditions together with other measures in the watershed be sufficient to achieve the doubling of natural production of Chinook salmon. Accordingly, tributary carrying capacity should be sufficient to support viable populations and salmon doubling. Juvenile production will be limited by the carrying capacity of a tributary and density-dependent influences. As the spawner abundance approaches and exceeds the amount that the carrying capacity supports, then it is expected that the juvenile survival rates will decrease. This decrease in juvenile survival proportion should not be an indication of poor habitat conditions if the carrying capacity is at a level that supports viable populations and the salmon doubling objective.

The new component of the juvenile productivity goal will allow the juvenile productivity goal to be met through meeting a juvenile production goal (Table 3.4). The juvenile production goal is the estimated number of juveniles at Delta exit or number of juveniles exiting the tributaries needed to meet the Salmon Protection objective doubling of the natural production of salmon. The juvenile productivity goal can be met through either attaining the juvenile production goal or through the freshwater juvenile survival goal during population rebuilding.

The juvenile survival goal, abundance goal, and genetic diversity goals as well as the salmon protection objective are now quantitatively linked, so the goal values and attainment of the goals must take into consideration the relative performance of the other goals. For example, maintaining a long-term tributary juvenile survival at 10% may not be adequate if this survival is only maintained with low spawner abundances, e.g., <1,000 spawners. The intent of the Bay-Delta Plan amendments is for the inflow conditions in coordination with the other actions in the Program of Implementation to improve conditions and the carrying capacity in the LSJR tributaries and contribute to population viability and meeting the salmon protection objective. Additional actions may be necessary to improve juvenile survival (e.g., increase the juvenile survival goal higher up to the species' typical survival rates, if the scientific information warrants it). However, if the tributary exhibits ≥10% tributary survival throughout the range of escapement values up to the escapement goal and mean escapement remains low, then this may suggest that conditions outside of the tributary are inadequate to support the population. In this case, actions elsewhere in the mainstem LSJR or Delta or downstream may be warranted.

1.5.4 Progress Assessment Timeline for Other Biological Goals

The progress assessment timeline for the full life cycle productivity goals has been modified to be consistent with the juvenile productivity goal timeline, with the achievement of the goal expected by Year 10 (Table 3.2). The full life cycle productivity metrics rely on adequate survival in the previous life stages to provide enough cohorts; however, attaining a pre-fishing CRR and post-fishing CRR > 1 will not require that the juvenile productivity goal be met first because the juvenile productivity goal represents a post-fishing CRR > 1.5. Progress toward attaining the full life cycle productivity goals is expected as juvenile outmigration survival increases, but with an expected time lag associated with the time needed for juveniles to recruit to the adult life stage and return to tributaries as spawning adults.

The progress assessment timelines for the life history diversity goals have been modified to reflect the focus on tributary specific performance and the intermediate assessment endpoints have been removed (Tables 3.9 and 3.10). The juvenile emigration timing goal identifies achievement by Year 10, and the proportion of size class migration by Year 12 (Cain et al. 2019). The life history diversity metrics are planned to be evaluated as part of the monitoring and evaluation program as indicators of habitat availability and quality as well as drivers of juvenile and adult success. Sturrock et. al. (2019) found differential success of juvenile life stages to adulthood on the Stanislaus River. Importantly, the researchers found that in some years, the juveniles that migrated out of the river as parr had the highest return rate as adults, even though most of the juveniles emigrated as fry and smolts. This finding suggests that individual life stages of juveniles can be drivers of adult survival and success, and further highlights the need to support all 3 life stages of juveniles for viable salmon populations. In addition, this finding reiterates the importance of using the multiple lines of evidence approach of the VSP concept and using multiple key attributes for measuring salmon population performance.

Chapter 2
Approach and Principles for Developing and Revising Biological Goals

2.1 Approach to Developing Biological Goals

The approach to developing the biological goals principles, and the initial biological goals identified in this report, was based on current bodies of work for this and similar purposes, including existing state and federal requirements, other major efforts completed by state and federal agency staff and stakeholders to identify quantitative biological goals for salmon and other species, and recommendations from the ISAP. Each of the sources of information that informed the development of the biological goals in this report is described further below.

2.1.1 Salmon Doubling

The Central Valley Project Improvement Act (CVPIA), a federal law enacted in 1992, mandated changes in the management of the CVP, particularly for the protection, restoration, and enhancement of fish and wildlife. The CVPIA added fish and wildlife as project purposes and, among other actions, established the Anadromous Fish Restoration Program (AFRP) to "implement a program which makes all reasonable efforts to ensure that, by the year 2002, natural production of anadromous fish in Central Valley Rivers and streams will be sustainable, on a long-term basis, at levels not less than twice the average levels attained during the period of 1967-1991." The State Fish and Game Code includes analogous provisions for salmon doubling (Fish and Game Code § 6902). The Salmon Protection Objective in the Bay-Delta Plan similarly requires that "water quality conditions shall be maintained together with other measures in the watershed sufficient to achieve a doubling of natural production of Chinook salmon from the average production of 1967-1991, consistent with the provisions of State and Federal law." These state and federal provisions are generally referred to in this document as salmon doubling goals.

The salmon doubling goals are stated in terms of "natural production" to achieve a self-sustaining, resilient population (USFWS 1995). As defined in Title 34 of CVPIA, natural production is estimated as the number of "…fish produced to adulthood without direct human intervention in the spawning, rearing, or migration processes." (CVPIA, section 3403(h). This metric is calculated using the natural-origin adult salmon returning to spawn in river (escapement) along with the commercial and recreational harvests of adult salmon. Natural-origin fish (wild fish) are the offspring of parents that spawned in the wild (e.g., in a river) while hatchery-origin fish are offspring of parents that spawned in a hatchery and were at least partially reared in a fish hatchery prior to release in a river or estuary.

Fish populations that depend on hatchery supplementation are not considered self-sustaining. California salmon fisheries heavily depend on artificial propagation from fish hatcheries to supplement stocks because they are not self-sustaining. In particular, hatchery production has become increasingly important in supporting ocean commercial and recreational and in-river fisheries for fall- and spring-run Chinook salmon and Central Valley steelhead. Central Valley fall-run Chinook salmon has the largest combined hatchery program in the state heavily supporting ocean and in-river fisheries (California Hatchery Scientific Review Group 2012). The proportion of natural-origin to hatchery-origin adult salmon returning to spawn in the Central Valley has been estimated but is not documented with sufficient monitoring data for fall-run Chinook salmon and other salmon runs. For that reason, the ISAP questioned the use of the salmon doubling goals. They also questioned the accuracy of the natural production estimates the AFRP developed for the 1967-1991 period and whether those estimates included a high enough proportion of hatchery fish. These factors were taken into consideration in development of the proposed goals.

2.1.2 ISAP Report on Bay-Delta Plan Biological Goals

The State Water Board contracted with the Delta Stewardship Council's Delta Science Program to convene an ISAP to provide recommendations on the development of biological goals for the Bay-Delta Plan. The State Water Board received those recommendations in April 2019, and they informed this draft report as did input from the CDFW, STM members, and the public.

The Delta Science Program convened the ISAP, at the request of the State Water Board, to recommend scientifically defensible methods for formulating quantitative biological goals that can be used to assess progress toward achieving reasonable protection of fish and wildlife beneficial uses in the Bay-Delta and the associated narrative objectives included in the Bay-Delta Plan. The ISAP was composed of six scientists with expertise in aquatic ecology; population dynamics; Pacific salmon; and native fishes in the San Francisco Estuary, freshwater, estuarine, marine, and coastal ecosystems. The ISAP began their review in late 2018 and released a draft report, titled "Developing Biological Goals for the Bay-Delta Plan: Concepts and Ideas for an Independent Science Advisory Panel" (ISAP Report) in February 2019. The ISAP presented its draft recommendations describing methods for formulating biological goals to the State Water Board at a public meeting on March 4, 2019, and considered public and State Water Board staff input. The ISAP completed and released a final report on April 22, 2019.

The ISAP Report describes methods that may be used to determine ecological responses to management actions (e.g., flow or non-flow habitat restoration actions). The ISAP Report contains recommendations for metrics to track changes in ecological responses for salmonids, other Bay-Delta fish species, and ecosystem processes in the San Francisco Bay, Delta, and tributaries. For these metrics, the ISAP recommends tracking abundance and distribution and establishing a goal of increasing abundance, productivity, and distribution rather than establishing a specific quantitative value for a biological goal.

For salmonids, the ISAP supports methods to develop biological goals based on the VSP criteria of abundance, productivity, spatial structure and diversity, while emphasizing "abundance and productivity are the most important and intuitive metrics for setting biological goals." The ISAP recommended evaluating salmonid abundance and productivity by developing stock-recruitment (SR) relationships that incorporate density dependence in survival rates. The ISAP also recommended tracking trends in productivity and abundance in response to management actions rather than setting specific targets for abundance or productivity.

The ISAP reviewed the Conservation Planning Foundation Report's approach to developing quantitative biological goals for fall-run and spring-run Chinook salmon and Central Valley steelhead on the Stanislaus River. The panel observed that the draft report (released in 2016) was well written, thorough, and contained valuable information. The ISAP identified several constructive criticisms while noting that a comprehensive review of the draft report was beyond the scope of the charge to the panel and that it was easier to identify a few critical comments than to the discuss the multiple strengths of the approach. The Conservation Planning Foundation Report's approach was developed in collaboration among five state and federal agencies, a public utility, and four conservation organizations over the span of six years. The ISAP Report was completed in a shorter time period by established scientists with experience and expertise in aquatic ecology, population dynamics, and fish biology. Recommendations from the ISAP Report are incorporated into the initial biological goals to the extent they are consistent with requirements to establish quantitative biological goals and are possible to develop within the timeline for State Water Board consideration of biological goals.

2.1.3 Stanislaus River Scientific Evaluation Process

The Scientific Evaluation Process (SEP) was a multi-agency and stakeholder effort started in March 2013, to identify and synthesize the best available science on restoring ecological conditions in the lower San Joaquin River and its tributaries, including restoration of sustainable native populations of fall-run Chinook salmon, spring-run Chinook salmon, and steelhead. SEP participants included: CDFW, USFWS, U.S. Bureau of Reclamation, NMFS, American Rivers, The Bay Institute, Trout Unlimited, The Nature Conservancy, and others. In November 2016, the SEP participants released a draft report which was peer reviewed, and based on comments, revised and finalized in April 2019. The report is titled, *Conservation Planning Foundation for Restoring Chinook salmon and Steelhead in the Stanislaus River (Conservation Planning Foundation Report*) (Cain et al. 2019). The Conservation Planning Foundation Report provides a framework for ecological restoration efforts on the Stanislaus River. The report identifies watershed-specific criteria for restoration of the Stanislaus River that are based on the four key VSP criteria—abundance, life history and genetic diversity, productivity, and spatial structure (McElhany et al. 2000)—for Chinook salmon (spring- and fall-runs) and Central Valley Steelhead.

The Conservation Planning Foundation Report identified quantitative criteria for demonstrating restoration on the Stanislaus River for the attributes that could be controlled by in-river conditions. The report did not specifically develop criteria for abundance at a river-specific scale because abundance is not completely controlled by conditions in the river (e.g., ocean survival). Additionally, no specific criteria were established for increasing spatial structure as the report only described the salmonid population of a single river system, the Stanislaus River. The Conservation Planning Foundation Report includes quantitative benchmarks for the remaining attributes such as productivity (stage-to-stage survival rates in freshwater), juvenile life history diversity (size at and timing of migration), and genetic interactions with other runs and hatchery fish in the Stanislaus River.

Although the Conservation Planning Foundation Report was developed specifically for the Stanislaus River, the criteria and scientific knowledge compiled and summarized in that report are valuable to inform this State Water Board process. As discussed in the introduction of this report, the biological goals are intended to evolve as scientific understanding evolves. Even after approval, the biological goals would be subject to change by the State Water Board based on new information and changing circumstances.

2.1.4 Bay Delta Conservation Plan

The Bay Delta Conservation Plan (BDCP) was a proposal for a large-scale habitat conservation plan (HCP) pursuant to the federal Endangered Species Act and a natural community conservation plan (NCCP) pursuant to state law. BDCP included new water diversion intakes in the north Delta, water conveyance tunnels through the Delta, and a large-scale, long-term habitat restoration program within the greater Delta area. BDCP also included a proposal for juvenile salmonid survival objectives (ICF International 2013) in the Delta for the purpose of guiding conservation actions, adaptive management, and assessing BDCP performance relative to ecological outcomes.

The BDCP proposal was substantially modified in 2015. The HCP and NCCP components were removed, and the water supply and habitat restoration components were bifurcated. Although the BDCP proposal did not advance as an HCP/NCCP, the proposed biological goals and objectives for salmonid survival through the Delta and summaries of scientific knowledge regarding survival in the upper portions of the watershed are valuable to inform this process and as starting points for salmonid biological goals for the Bay-Delta Plan.

2.2 Principles for Developing and Revising Biological Goals

This section identifies the principles that were used to develop the proposed biological goals. These principles are also proposed for making refinements to these goals and additional goals. The proposed principles are intended to guide and provide consistency during development of biological goals in the watershed's different locations and for various types of habitat and fish species.

2.2.1 Principles for Developing and Revising Initial Biological Goals for Native Bay-Delta Fish Species

- Biological goals must meet the requirements of the Bay-Delta Plan and Program of Implementation.
- Use available scientific information to establish a numeric value or range of values for biological goals.
- Express goals in terms that are specific, measurable, achievable, relevant (quantitative and focused on results), and time bound.
- Goals for salmonids should be developed for each of the four VSP parameters: 1) abundance, 2) productivity, 3) diversity, and 4) spatial structure.
- Goals for other (non-salmonid) fish species in the watershed should:
  - Use the VSP parameters, in principle, when data are available.
  - Consider indicator species and species assemblages as metrics to track populations or communities and habitat changes and to represent responses of multiple fish species.

- Environmental metrics may be proposed as environmental goals to track the quality and/or quantity of aquatic habitat in response to management actions. Examples of environmental metrics include temperature, dissolved oxygen, or other metrics that document the quality and quantity (spatial and temporal extent) of available habitat.
- Use an adaptive management approach to review and potentially refine goals if and/or when new information developed through monitoring and evaluation activities or other relevant sources of scientific information become available.
- At least every five years, review approved biological goals and revise, if needed, to reflect updated scientific knowledge and to be consistent with best available scientific information including information developed from assessing approved biological goals, information regarding viable salmonid populations, recovery plans for listed salmonids, or other appropriate and relevant information sources.

Chapter 3

Initial Biological Goals for LSJR Fall-Run Chinook Salmon

This section describes proposed LSJR biological goals for fall-run Chinook salmon for the Stanislaus, Tuolumne, and Merced Rivers as required by the 2018 Bay-Delta Plan. As discussed above, the Bay-Delta Plan states that biological goals for LSJR salmonids will be developed for the VSP criteria of abundance, productivity as measured by population growth rate, genetic and life history diversity, and population spatial structure. Using the VSP criteria as a foundation for salmonid biological goals acknowledges that self-sustaining populations cannot be adequately characterized by an individual population attribute, for example, abundance. Rather, all VSP parameters should be used to evaluate the sustainability of a given population through the use of a multiple lines of evidence approach. The proposed biological goals for each of these parameters is described below.

3.1 Abundance Goals

Population abundance is a key measure of population viability for any species. Abundance refers to the number of organisms in a population. High abundance populations (larger populations) are less likely to become extinct than low abundance (smaller) populations because they are more resilient to environmental stressors and catastrophic events. NMFS defines salmon escapement as “the number of adult fish returning to spawn, measured over a time series” (National Oceanic and Atmospheric Administration [NOAA] 2006).

Abundance is an important population metric because it integrates all phases of the fish life cycle and, as such, is the cumulative result of survival across multiple life stages and habitats over a wide spatial range. Achieving abundance goals, however, relies partially on habitat conditions and management actions outside the influence of the LSJR flow objectives and other elements of the Bay-Delta Plan. Accordingly, the use of the abundance goals must be interpreted in context with other VSP goals to determine whether progress meeting the abundance goal is being influenced by factors outside of the direct control of the Bay-Delta plan, such as by ocean conditions.

For the purpose of developing biological goals for abundance, an escapement metric is proposed. Escapement refers to the number of adult fish returning to the spawning ground. Escapement was chosen as the goal because it eliminates the need to include estimates and uncertainty of ocean and recreational harvests that occur prior to spawning and because escapement is reliably monitored every year. Furthermore, escapement is a reliable analog for production as both estimates tend to increase and decrease together.

In California, annual escapement estimates are produced for salmonid bearing tributaries from multiple field surveys, including counts entering hatcheries and migrating past dams, carcass surveys, live fish counts, and ground and aerial redd counts. Initial fall-run Chinook salmon escapement goals for LSJR tributaries are proposed in Table 3.1. The escapement goals in Table 3.1 were quantitatively derived using tributary specific female spawner proportions and fecundity, the juvenile survival and productivity goals, ocean survival estimates and the salmon doubling objective. Because the escapement goal is quantitatively linked, any new information on ocean survival estimates, fecundity, or adjustments to the doubling goal can be used to refine and update the escapement goal.

The proposed escapement goals are an indicator to measure progress toward the salmon doubling goals identified in existing state and federal requirements discussed above. The proposed escapement goals do not replace, modify, or substitute for the existing state and federal requirements to double the natural production of salmon. The proposed escapement goals apply to the contributions of natural origin spawners only and exclude hatchery origin spawner contributions. The information needed to distinguish between natural and hatchery spawner contributions may include data from the constant fractional marking program or other studies (e.g., microchemistry, which will be evaluated in the SJRMEP). Positive trends in escapement, as well as similar trend goals, will be based on recent years of available data that are indicative of current population status. Once salmon escapement numbers in the tributaries are near the abundance goals, ocean natural production can be assessed to determine the attainment of the salmon protection objective and state and federal requirements for the doubling the natural production of salmon.

Table 3.1. LSJR Fall-Run Chinook Salmon Escapement Goals

River	Escapement Goal, measured as a 5-Year Running Average	Progress Assessment/Attainment Target[4]
All	Positive generational trend in escapement, measured as a 5-year geometric mean	Assessed annually/when numeric abundance goals are met
Stanislaus River	7,800	Assessed annually/Year 15 achieve the goal
Tuolumne River	15,500	Assessed annually/Year 25 achieve the goal
Merced River	7,300	Assessed annually/Year 15 achieve the goal

The first and most basic abundance goal identified above is a positive generational trend in escapement over time until the identified numeric abundance doubling goals are met and thereafter abundance levels are maintained at that level. Progress toward meeting the escapement goal is proposed to be measured and reported annually but fully detecting whether the goal has been met will take time.[5] Salmon populations characteristically experience wide variations in abundance even under pre-development conditions due to variable hydrology, ocean food supplies, catastrophic events, and other factors. As such, to detect a trend following management actions (e.g., habitat improvement through flow increases or channel improvement) with statistical confidence will likely take a minimum of 5 generations or 15 years, assuming Central Valley Chinook salmon typically return to spawn at 3 years old.[6]

Escapement data are currently compiled by CDFW's Anadromous Assessment Unit (GrandTab) on an annual basis and can be used to assess progress toward meeting the escapement goals. GrandTab does not characterize whether fish are wild or hatchery origin, only whether the adults are spawning in-river (natural) or in-hatchery. Since 2007, the constant fractional marking program

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[4] Year number after implementation begins.

[5] ISAP (2019) "Bradford et al. (2005) found that monitoring had to be conducted over a period of 4-6 generations (20-30 years for a Chinook population with a maximum age-at-return of 5 years) given a substantial increase in productivity from the flow or habitat treatment (e.g., 50% increase) and reasonably precise estimates of abundance (CV=20%)." Page 107.

[6] Based on the constant fractional marking program data, the vast majority of Central Valley spawner escapement recoveries are 2- and 3-year old fish. Accordingly, reasonably precise estimates in abundance could be obtained within 12-18 years (4-6 generations).

(CFM) has ensured that at least 25% of all fall-run Chinook hatchery fish are tagged with coded-wire tags (CWT) and are adipose fin clipped for visual identification. However, marking only one quarter of the hatchery fish prevents monitoring programs from effectively distinguishing between hatchery and natural origin fish on the spawning grounds in real-time, so robust information on the contributions of natural and hatchery origin spawners is delayed a couple of years until the CFM program analyses the data. The geometric mean of the proportion of Hatchery Origin Spawners on the Stanislaus, Tuolumne, and Merced Rivers using CDFW 2010-2019 CWT recoveries is 71%, 51%, and 61%, respectively (Kormos et al. 2012; Palmer-Zwahlen and Kormos 2013, 2015, 2020; Palmer-Zwahlen et al. 2018, 2019a, 2019b; Letvin et al. 2020, 2021a, 2021b).

Progress toward meeting all the biological goals, including the escapement goal, will be assessed annually, and the assessment will be evaluated through the SJRMEP with consideration of the other biological goals, environmental conditions, and other applicable information. As described previously, the timeline for the attainment of the abundance goals is quantitatively linked to the population growth rates consistent with attaining the juvenile productivity goals (See Appendix A for calculations).

3.2 Productivity Goals

Productivity describes the population growth rate of a species, and productivity can be expressed in full life cycle terms or juvenile terms. Positive population growth is necessary to increase abundance over time. In full life cycle terms, positive population growth occurs when the number of spawners that were hatched in the same year (cohort) is greater than the number of spawners that produced them. The Cohort Replacement Rate (CRR) is a simple way to describe full life cycle productivity (number of cohort spawners produced per spawner). If a cohort's returning spawners outnumber their parental spawners, the CRR is greater than one and abundance will increase. In juvenile terms, productivity is expressed as juvenile survival (e.g., tributary survival) or as the number of juvenile fish per spawner from the same cohort (recruits (R) per spawner (S) or R/S).

3.2.1 Full Life Cycle Productivity Goals

Initial productivity goals for LSJR adult fall-run Chinook salmon are expressed as CRR, or the number of returning spawners per brood year spawner and are identified in Table 3.2. The first and most basic productivity goal is a positive increasing trend in CRR until a CRR of greater than 1 is attained. Goals are also proposed for both pre- and post-fishing to account for the commercial and recreational ocean and inland salmon fishery or other mortality that may remove adult salmon from the population of potential spawners (ISAP 2019). The post-fishing CRR goal of greater than 1 is a foundational goal because it represents the basic concept that the population must at least replace itself to persist over time, and the population must more than replace itself to grow and meet the abundance goals identified in Section 3.1, Abundance Goals. Post-fishing CRR will be derived from within river natural spawner escapement to incorporate all losses that may prevent a fish from returning to spawn in its natal river or stream. An accurate post-fishing CRR estimate will require age structure information so that all of a cohort's spawners returning to their natal tributaries can be attributed to their brood year parental spawners.

The pre-fishing CRR[7] goal of greater than 1 and greater than the post-fishing CRR is meant to provide for fishing practices in the productivity goals. The pre-fishing CRR must be greater than 1 and greater than the post-fishing CRR for the population to persist, grow, and sustain commercial and recreational fishing. It is difficult to be certain about how much greater than one the pre-fishing CRR must be at this time to accommodate commercial and recreational fisheries and have a growing population so this portion of the goal is narrative at this time but can be modified in the future. Progress toward meeting the productivity goals will be assessed annually for each tributary. Progress toward attaining the full life cycle productivity goals is expected as juvenile outmigration survival increases, but with an expected time lag associated with the time needed for juveniles to recruit to the adult life stage and return to tributaries as spawning adults. The timeline for achievement of the full life cycle goals is by Year 10.

Table 3.2. LSJR Fall-Run Chinook Salmon Full Life Cycle Productivity Goals

Productivity Metric	Goal, measured as a 5-year geometric mean	Progress Assessment/Attainment Target[8]
CRR Trend[9]	Positive generational trend until a CRR > 1 is met	Assessed annually/when numeric productivity goals are met
Pre-Fishing CRR[10]	Pre-Fishing CRR > 1 and > post-fishing CRR until abundance goals met and then sustained	Assessed annually/Year 10, achieve the goal
Post-Fishing CRR[11]	Post-Fishing CRR > 1 until abundance goals met and then sustained CRR > 1	Assessed annually/Year 10, achieve the goal

3.2.2 Juvenile Productivity Goals

3.2.2.1 Juvenile Survival

In order to help inform management actions, evaluating productivity of Chinook salmon at juvenile life stages in the river and Delta is important. Productivity during these life stages is critical to producing adult spawners and meeting the overall CRR and abundance goals. Early life stages include egg, alevin, fry, parr, and smolt.[12] Early life-stage productivity can be expressed as the number of outmigrant recruits per spawner (R/S) or as a percent survival such as percent egg-to-smolt survival or percent egg-to-freshwater exit survival (i.e., outmigrant survival) because juvenile Chinook salmon migrate out of the freshwater environment throughout the fry, parr, and smolt life

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[7] Pre-fishing CRR are derived using harvest and spawner escapement data for associated or other applicable method to estimate ocean production.

[8] Year number after implementation begins.

[9] ISAP (2019). Developing Biological Goals for the Bay-Delta Plan: Concepts and Ideas from an Independent Scientific Advisory Panel. April 2019, section 4.6, pages 109-110.

[10] Ibid

[11] Ibid

[12] Eggs in nests referred to as redds; alevin are larval fish with an egg sac for food; fry are small juvenile fish less than 55 mm (1.7 inches) that have recently emerged from nests; parr are juvenile fish larger than 55 mm (2.2 inches) but less than 75 mm (3.0 inches); smolts are larger than 75 mm (3.0 inches) and have started to transform physiologically to adapt to marine environments.

stages. Freshwater exit survival includes survival from all three of these juvenile life stages to the estuary.

Table 3.3 shows the initial fall-run Chinook salmon productivity goals for juvenile survival. The productivity metric for juvenile survival has three different components: one for the within tributary portion (eggs to the tributary confluence with the LSJR), one for through-Delta survival, and one for overall freshwater juvenile survival (egg to Chipps Island). The overall freshwater juvenile survival goal is 1.5%, which represents a long-term minimum juvenile survival level to sustain the natural populations, with an expected low risk of extirpation. The through-Delta survival will primarily be used as an indicator of the conditions juvenile migrants are experiencing through the Delta, and actions that may need to be taken by the State Water Board or others to improve juvenile survival. The egg to tributary confluence with the LSJR juvenile survival goal and the juvenile production goal are primary indicators of tributary conditions, and these are expected to be the goals that are most influenced by the implementation of the LSJR flow objectives. Meeting the juvenile survival goals is also expected to meet the CRR's for the full lifecycle productivity goals based on current knowledge of the survival of subsequent life stages.

Table 3.3. LSJR Fall-Run Chinook Salmon Juvenile Survival Goals

Productivity Metric	Goal, measured as a 5-year geometric year	Progress Assessment/ Attainment Target[13]
Juvenile Productivity Trend	Positive trend in juvenile survival until abundance goal is met, measured as a 5-year geometric mean	Until numeric abundance goals are met (year 15)
Freshwater juvenile Survival (egg to Chipps Island)	≥ 1.5%	Assessed annually/Year 5, achieve the goal
LSJR at Mossdale to Chipps Island (Through-Delta) Survival (SJDS)	≥ 20%[14]	Assessed annually/Year 5, achieve the goal
Egg to tributary confluence with LSJR	≥ 10%[15]	Assessed annually/Year 5, achieve the goal

The rate of juvenile survival through the LSJR and the Delta is not fully understood or documented. Nonetheless, multiple studies have estimated through-Delta juvenile survival for LSJR Chinook salmon. Available information indicates that current juvenile survival in the LSJR and Delta is low with some reports of through-Delta survival at less than 5% (Buchanan et al. 2018, Cain et al. 2019). However, through-Delta survival estimates reported in pre-Vernalis Adaptive Management Plan (VAMP)[16] (1994-1999) and VAMP (2000-2006) Coded Wire Tag studies show that higher survival has occurred in recent history (i.e., 79 percent in 1995; 60 percent in 1999; 34 percent in 2001; SJRGA 2009, 2013)[17], and the overall geometric mean for 1994-2006 was 15% which suggests that the proposed LSJR through-Delta juvenile survival goal is achievable. Annual assessments of juvenile

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[13] Year number after implementation begins.

[14] Cain et al. (2019). Conservation Planning Foundation for Restoring Chinook Salmon (*Oncorhynchus tshawytscha*) and O. mykiss in the Stanislaus River. Seattle, WA. April 2019. Pages 50-55.

[15] Ibid.

[16] The Vernalis Adaptive Management Plan was an experimental management program proposed by parties to the San Joaquin River Agreement in lieu of meeting the pulse flow objective included in the 1995 Bay-Delta Water Quality Control Plan.

[17] Data from 1994-1995 is guesstimated from the 2011 Annual Technical Report, Figure 5-1 (SJRGA 2013). Data from 1996-2006 is from the 2008 Annual Technical Report, Table 5-6 (SJRGA 2009).

survival through the Delta should be measured to further inform the achievability of the goals and to identify successful migration routes with higher survival as well as locations and time periods that show low survival.

The implementation of LSJR flows will have less direct effect on through-Delta survival of juveniles than on within-tributary survival. Additional actions in the Delta will likely be necessary to improve juvenile through Delta survival. Some non-flow actions have already been implemented. For example, the California Ecorestore[18] multi-agency effort, launched in 2015 to advance the restoration of critical habitat in the Delta and estuary, has completed about 7000 acres of the 38,000 acre restoration target. Some of the completed projects include the San Joaquin River corridor in the Delta, which should improve the habitat and survival of migrating salmon.

Survival estimates in other watersheds (i.e., Columbia and Thompson Fraser rivers) have also been documented (Buchanan et al. 2018; Dietrich et al. 2016; Welch et al. 2008). Based on these studies, there is significant evidence indicating that juvenile survival is considerably higher in other west coast rivers occurring in the northern portion of the range of salmon. The survival studies also indicate that outmigration survival varies between years and populations, and that survival correlates with environmental conditions such as flow, temperature, and turbidity.

Additional information on juvenile survival is needed to further refine the proposed juvenile survival goals. Critical information is lacking for understanding tributary survival rates from the egg stage to the juvenile stage to the confluence with the mainstem LSJR. The current goals are focused on the migratory life stages, but future goals may be considered as egg survival models are developed or adapted for LSJR tributaries. Furthermore, information on the survival rate in the mainstem San Joaquin to the Delta is also not well documented. Estimating survival rates in the tributaries and the mainstem river requires either enumerating juvenile fish that are captured in rotary screw traps (RST), trawl nets and beach seines, by passive detection with acoustic tags, or other new methodologies that may be developed. Further studies are needed on the tributaries and the mainstem river to better understand juvenile survival and the environmental variables that influence the rate. The proposed survival goals will be re-evaluated and may be refined based on the availability of new information and routine monitoring.

3.2.2.2 Juvenile Production

Juvenile productivity metrics are essentially an indicator of the amount and quality of habitat that juveniles are provided. The intent of the LSJR flow objectives is to improve the habitat and increase the carrying capacity in the tributaries so that survivability of juvenile native fishes can improve and abundances can be increased. However, juvenile survival rates may not appear to perform as well when the population reaches the carrying capacity of the rivers. For example, a large number of spawners may produce the same number of juvenile outmigrants as a lower number of spawners, but at a lower juvenile survival rate. This is an example of compensatory density dependence, which is essential for the resilience of populations and a sign of a viable population (McElhany et al. 2000). If the carrying capacity of the tributaries is consistent with attaining narrative water quality objectives, then the populations should represent viable populations over the long-term. However, as spawner abundances fluctuate with variable environmental conditions, juvenile survival rates could be lower than the juvenile survival goals when spawner abundances are higher than the long-term mean of the population.

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[18] https://water.ca.gov/Programs/All-Programs/EcoRestore

The juvenile production goal is the estimated number of juveniles at Delta exit or number of juveniles exiting the tributaries needed to meet the Salmon Protection objective doubling of the natural production of salmon (Table 3.4). The juvenile productivity goal can be met through either attaining the juvenile production goal or the freshwater juvenile survival goal. It is expected that during the initial population rebuilding period, the juvenile survival goal will be attained first, but in the long-term the juvenile production goal will be the most important goal for assessing tributary conditions.

Table 3.4. LSJR Fall-Run Chinook Salmon Juvenile Production Goals

Productivity Metric	Goal Per cohort year	Progress Assessment/ Attainment Target
Stanislaus River		
Confluence Juvenile Production	2,700,000	Assessed annually on an ongoing basis
Delta exit (Chipps Island) Juvenile Production	400,000	Assessed annually on an ongoing basis
Tuolumne River		
Confluence Juvenile Production	4,700,000	Assessed annually on an ongoing basis
Delta exit (Chipps Island) Juvenile Production	700,000	Assessed annually on an ongoing basis
Merced River		
Confluence Juvenile Production	2,200,000	Assessed annually on an ongoing basis
Delta exit (Chipps Island) Juvenile Production	300,000	Assessed annually on an ongoing basis

3.2.3 Preliminary Stock Recruitment Analysis

The ISAP recommended the use of SR models for tracking adult or juvenile abundance and productivity in addition to, or instead of, establishing quantitative biological goals for abundance and productivity. An SR model describes the relationship between the number of spawners (the stock) and the total number of adult or juvenile recruits they produce.SR models can be used to evaluate the effects of environmental factors and local management actions (e.g., flow, water temperature, or habitat restoration) on long-term trends in productivity and abundance, as well as incorporate density-dependent evaluations, as recommended by the ISAP.

State Water Board staff conducted SR analyses to examine the relationship between adult fall-run Chinook salmon spawners and juvenile recruits for the Stanislaus and Tuolumne Rivers. Data were not available to evaluate SR models for the Merced River. Flow and water temperature were evaluated as environmental covariates in the SR models.

The simplest of the SR models is the density-independent SR model. This model predicts that recruits increase at a constant rate with increasing spawners or, alternatively, that the number of recruits per spawners is continuous for all spawner levels. The density-independent model does not typically reflect the population dynamics of most natural populations because the model does not consider the effects of density-dependence on growth, mortality, fecundity, and recruitment. Density-dependent effects refers to intrinsic processes that are either positively or negatively impacted by population density.

The more complex Beverton-Holt and Ricker stock-recruitment models build upon the simple density-independent model by incorporating density-dependence. The models predict that at low spawner abundances, density-independent factors (e.g., environmental stressors and birth and death rate) exert a higher influence on population dynamics. However, as the number of spawners increase, density-dependent factors (e.g., competition for habitat space and food and predation rates) become more influential on population structure (Subbey et al. 2014). The Beverton-Holt and Ricker models can produce different results and line curvature due to differences in underlying assumptions. The Beverton-Holt model assumes a high mortality rate of recruits due to juvenile competition and predation. The Beverton-Holt model is usually selected when it is hypothesized that recruitment is limited by food availability or habitat space, and that predators can adjust their feeding rates based on changes in prey abundance. The Ricker model assumes egg and juvenile mortality is proportional to the initial cohort size. This model is generally selected if it is hypothesized that cannibalism of juveniles by adults is high, redd superimposition is significant, and the effects of predators are not immediate and display a time-lag response (Wootton 1990). Nonetheless, both models lead to less per capita recruitment as spawning stock increases in abundance.

The following stock-recruitment models were applied to the data for the Stanislaus and Tuolumne Rivers,

$R_t = \alpha * S_t$, Density-independent

$R_t = (\alpha * S_t / 1 + \beta * S_t) + y_F * F_t$, Beverton-Holt

$R_t = \alpha * S_t * \exp(-\beta * S_t) + y_F * F_t$, Ricker

where Rt represents estimates of total annual recruits for year t, and St are annual estimates of adult spawners. Ft represents any covariates evaluated, and y F represents the coefficient for the covariate effect. Parameter α represents intrinsic productivity (i.e., slope near the origin) and parameter β represents density-dependence (i.e., how to incorporate diminishing returns in juveniles recruits per adults as the number of adults increases). The density-independent model, which does not include the density-dependence term (β), is the simplest of the three models because it assumes that birth and death rates of the population are not influenced by population size or adult spawner abundance.

Model parameters (Greek letters in equations) for the stock-recruitment models were estimated using non-linear least square regression in R statistical computing environment (R). Non-linear regression methods use an iterative algorithm that requires starting values for the model parameters. Starting values were estimated from linearized models for the Ricker and Beverton-Holt models using the Fisheries Stock Assessment package in R.

Juvenile recruit values were derived from abundance estimates based on RST data collected near Caswell State Park (1996 to 2014) on the Stanislaus River and RST data collected near Waterford, CA on the Tuolumne River (2006-2018). CDFW GrandTab escapement estimates were used for adult spawner values for the corresponding years.

Flow covariate statistics were based on discharge data from USGS Gauge 113030000 near Ripon, CA for the Stanislaus River and USGS 1129000 near Modesto, CA for the Tuolumne River. Mean flow between January 1-June 30 were computed for each year to encompass the entirety of the rearing and outmigration period for juvenile Chinook salmon. Flow variation was the 7-day maximum difference in mean daily flow from January to June. Water temperature statistics were computed by averaging the daily maximum temperatures for six different time periods to determine the most influential period for juvenile production (Jan-Jun, Feb-Jun, Jan-Mar, Jan-Apr, May-Jun, and Sept-Oct).

Model selection was based on Akaike Information Criteria (AIC). AIC is a maximum likelihood estimator that identifies the model that strikes the best balance between model fit and complexity. The model that has the lowest AIC value is considered a better-fit model than a model with a higher AIC value. Additional information for the methods and development of the SR models can be found in Appendix B for the Technical Stock Recruitment Models.

3.2.4 Results for the Stanislaus River

The Ricker and Beverton-Holt covariate models resulted in similar AIC values, which indicates neither model had substantially more support as the most parsimonious when considering both model complexity and fit (Table 3.5). For the purposes of brevity and the intuition that the underlying assumptions of the Beverton-Holt more closely align with the ecological conditions on the Stanislaus River than the Ricker (i.e., rearing habitat and predation are more limiting than spawning habitat), only the Beverton-Holt model results are presented further.

The SR models suggest that density-dependent effects do not have a strong influence on the Stanislaus River juvenile abundance for this dataset. This is made evident by the intrinsic productivity parameter (α) being significantly larger than the density-dependence parameter (β). Spawner abundance mediated density-dependence does not appear to have a major influence on juvenile production at current population levels, and density-independent factors may be more of a driver than density-dependent factors. Furthermore, AIC scored the density-independent model as the top model of the three non-covariate models, which further supports the finding that density-dependence may not have a significant influence on juvenile production when considering all juvenile size classes and water year types.

The addition of environmental covariates to the SR models improved model predictive ability compared to the models with no covariates. Covariate models including flow variation resulted in the lowest AIC scores followed by the mean flow and Feb-June water temperature covariates (Table 3.5). Flow variation and mean flow coefficient values were positive, which indicates that higher or more variable flow conditions during the outmigration window is beneficial to juvenile production (Figure 1). The covariate effect for water temperature was negative, suggesting that as water temperature increases, juvenile production decreases. The Feb-June water temperature period was selected as the best fit model among the six temperature periods (see Appendix A for AIC selection of temperature periods).

Table 3.5. Summary statistics for stock-recruitment model variables with values for estimated parameters, standard error, t-value, significance (p-value), and differences in AIC test results for juvenile Chinook salmon SR data on Stanislaus River.

Model	Variables	Estimate	Standard Error	t-value	p-value	Δ AIC
Density-Independent + Flow Variation	α_{spawners}	56.16	10.15	5.54	$p<0.001$	0
	$\gamma_{\text{flow variation}}$	0.43	0.81	5.30	$p<0.001$	
Beverton-Holt + Flow Variation	α_{spawners}	60.17	19.65	3.06	$p<0.01$	1.91
	$\beta_{\text{density-dependence}}$	2.061 (10^{-5})	8.44 (10^{-5})	0.24	0.811	
	$\gamma_{\text{flow variation}}$	0.43	0.08	5.11	$p<0.001$	
Density-Independent +Flow Mean	α_{spawners}	56.16	11.18	5.03	$p<0.001$	3.29
	$\gamma_{\text{flow mean}}$	0.40	0.09	4.51	$p<0.001$	
Beverton-Holt + Mean Flow	α_{spawners}	56.71	19.70	2.86	$p<0.01$	5.29
	$\beta_{\text{density-dependence}}$	2.75 (10$^{-5)}$	8.15 (10^{-5})	0.03	0.97	
	$\gamma_{\text{flow mean}}$	0.40	0.09	4.34	$p<0.001$	
Density-Independent + Feb-June Temperature	α_{spawners}	1.04 (10^{5})	3.13 (10^{5})	0.33	0.74	11.84
	$\gamma_{\text{water temperature}}$	-0.02	0.08	-2.50	$p<0.01$	
Beverton-Holt + Feb-June Temperature	α_{spawners}	1.11 (10^{5})	3.48 (10^{5})	0.32	0.75	13.77
	$\beta_{\text{density-dependence}}$	1.85 (10^{-5})	8.9 (10^{-5})	-0.21	0.84	
	$\gamma_{\text{water temperature}}$	-0.22	0.09	-2.42	$p<0.01$	
Density-Independent	α_{spawners}	56.15	16.60	3.38	$p<0.01$	15.84
Ricker	α_{spawners}	61.67	31.76	1.94	0.07	17.78
	$\beta_{\text{density-dependence}}$	2.65 (10^{-5})	1.12 (10^{-4})	0.23	0.82	
Beverton-Holt	α_{spawners}	59.81	31.84	5.03	0.08	17.78
	$\beta_{\text{density-dependence}}$	1.87 (10^{-5})	1.36 (10^{-4})	4.51	0.89	

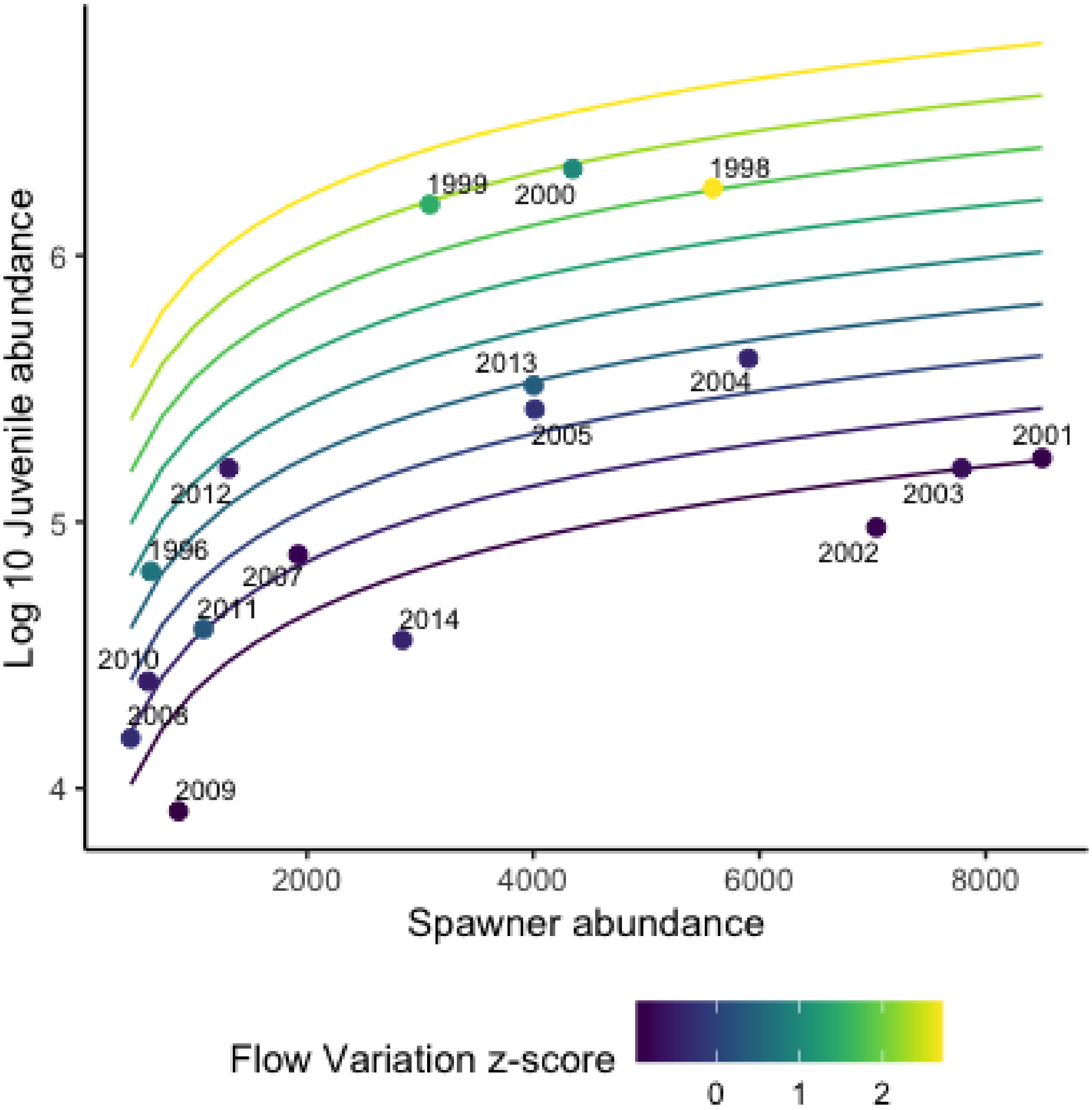

Figure 1. Beverton-Holt flow variation covariate model predictions for juvenile Chinook salmon recruitment on the Stanislaus River from 1996-2014 (data points). Y-axis represents log 10 transformed juvenile abundance and the x-axis represents spawner abundance. Colored lines represent the effect of flow variation on the SR relationship with darker colors (purple) indicating lower flow variability and lighter colors (yellow) representing higher flow variability.

3.2.5 Results for the Tuolumne River

For the Tuolumne River, the non-linear least square regression function did not converge for the Beverton-Holt model when applied to the dataset. Ricker model results for the Tuolumne River hold similar conclusions to that of the Beverton-Holt model on the Stanislaus River, and density-dependence did not appear to have a strong effect on the Tuolumne River juvenile abundance (Table 3.6). This is made evident by the intrinsic productivity parameter (α) being significantly larger than the density-dependence parameter (β) for the Ricker model, which suggests that juvenile outmigration is positively associated with fall spawner abundances. Among the three non-covariate SR models, the density-independent model again resulted in the lowest AIC value; however, the Ricker model resulted in minimal deviation in AIC value.

The addition of environmental covariates improved model predictive ability compared to the model with no covariates. Similar to the Stanislaus River SR analysis, the flow variation covariate model resulted in lower AIC values than the flow mean covariate models for both the density-independent and Ricker models (Table 3.5). However, differences between AIC values for the top models were small, which suggests some support and validity for both the Ricker model and the flow mean covariate. Similar to the flow covariate models, the density-independent model was a better fit for the Tuolumne River dataset (Table 3.5). Missing temperature data precluded the direct comparisons of temperature and flow covariate models; however, density-dependent and density-independent temperature covariate model results can be seen in Table 3.7. In general, higher and more variable flow on the Tuolumne River generally leads to increased juvenile production (Figure 2), while warmer spring time water temperature is associated with lower juvenile production.

Table 3.6. Summary statistics for stock-recruitment model variables with values for estimated parameters, standard error, t-value, significance (p-value), and differences in AIC test results for juvenile Chinook salmon SR data on Tuolumne River.

Model	Variables	Estimate	Standard Error	t-value	p-value	Δ AIC
Density-Independent + Flow Variation	α_{spawners}	161.50	32.11	5.03	$p<0.001$	0
	$\gamma_{\text{flow variation}}$	0.34	0.09	3.81	$p<0.01$	
Ricker + Flow Variation	α_{spawners}	215.60	73.82	2.92	$p<0.05$	0.68
	$\beta_{\text{density-dependence}}$	$4.12\ (10^{-4})$	$4.00\ (10^{-4})$	1.03	0.33	
	$\gamma_{\text{flow variation}}$	0.35	0.09	3.91	$p<0.01$	
Ricker + Mean Flow	α_{spawners}	249.10	94.68	2.63	$p<0.05$	2.98
	$\beta_{\text{density-dependence}}$	$6.18\ (10^{-4})$	$4.46\ (10^{-4})$	1.39	0.2	
	$\gamma_{\text{flow mean}}$	33.69	0.10	3.35	$p<0.01$	
Density-Independent + Flow Mean	α_{spawners}	161.60	36.39	4.44	$p<0.001$	3.26
	$\gamma_{\text{flow mean}}$	0.30	0.10	2.98	$p<0.05$	
Density-Independent	α_{spawners}	161.60	46.87	3.45	$p<0.01$	8.97
Ricker	α_{spawners}	194.40	100.60	1.93	0.08	10.73
	$\beta_{\text{density-dependence}}$	$2.65\ (10^{-4})$	$6.02\ (10^{-4})$	0.44	0.67	

Table 3.7. Summary statistics for stock-recruitment water temperature covariate variables with values for estimated parameters, standard error, t-value, significance (p-value), and differences in AIC test results for juvenile Chinook salmon SR data on Tuolumne River.

Model	Variables	Estimate	Standard Error	t-value	p- value	Δ AIC
Density-Independent + May-June Temperature	α_{spawners}	6081	3637	1.67	0.13	0
	$\gamma_{\text{water temperature}}$	-0.07	0.01	-6.45	p<0.001	
Ricker + May-June Temperature	α_{spawners}	6,364	4,060	1.57	0.15	1.83
	$\beta_{\text{density-dependence}}$	9.54 (10^{-5})	2.60 (10^{-4})	0.37	0.72	
	$\gamma_{\text{water temperature}}$	-0.07	0.01	-6.1	p<0.001	

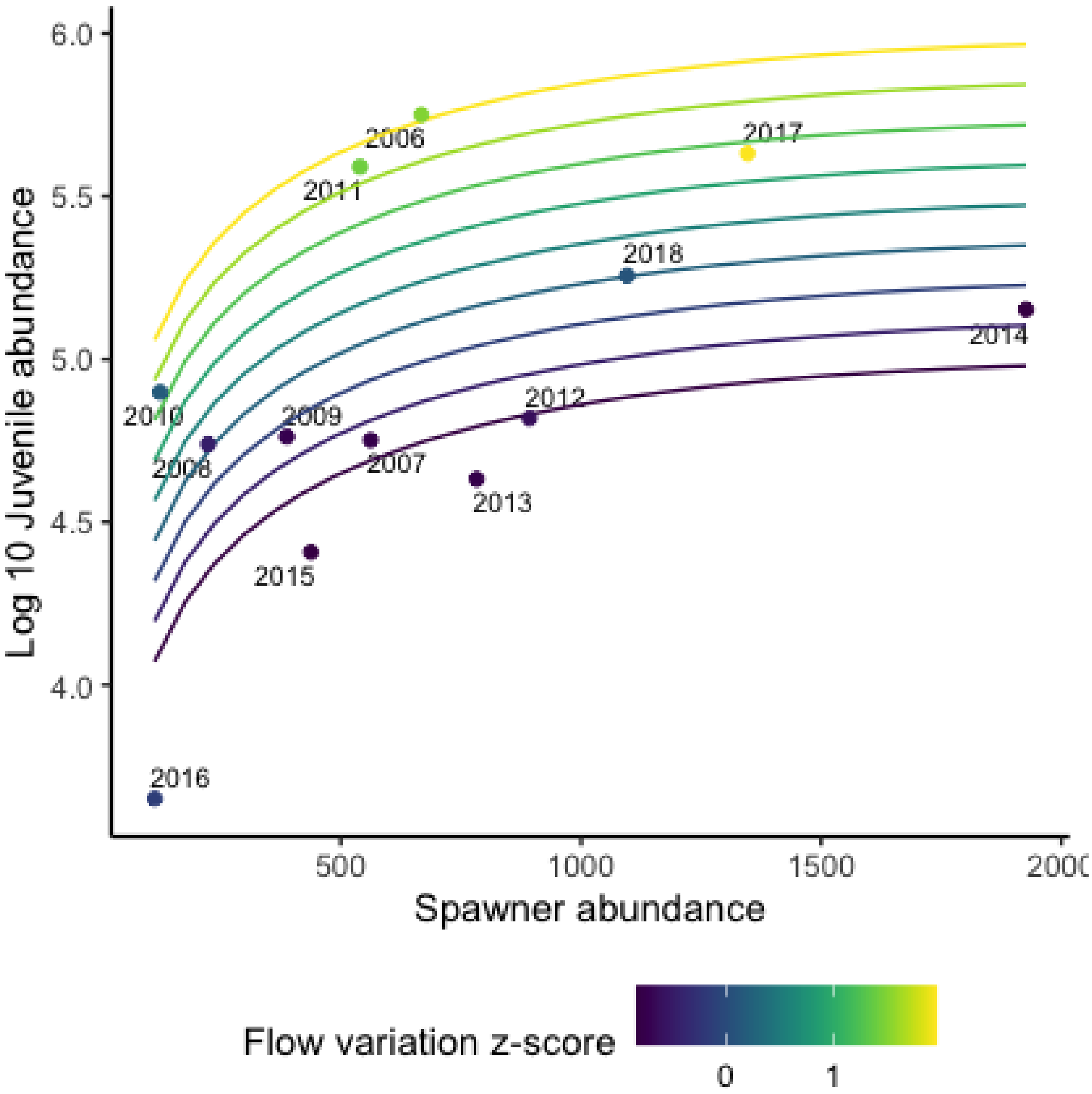

Figure 2. Ricker flow variation covariate model predictions for juvenile Chinook salmon recruitment on the Tuolumne River from 2006-2018 (data points). Y-axis represents log 10 transformed juvenile abundance and the x-axis represents spawner abundance. Colored lines represent the effect of flow variation on the SR relationship with darker colors (purple) indicating lower flow variability and lighter colors (yellow) representing higher flow variability.

3.2.6 Discussion

The SR model results found that juvenile production is a function of spawner abundance, flow, and temperature on the Stanislaus and Tuolumne Rivers. Density-dependence showed little influence on juvenile outmigration suggesting that intrinsic productivity may be the current primary driver of stock recruitment. This finding indicates that juvenile production will initially increase proportionally with increasing spawner abundance given adequate environmental conditions. This general conclusion aligns with one of the findings of Pilger et al. (2019) that adult escapement is a significant predictor of juvenile abundance on the Stanislaus River. Additionally, the results of a similar stock recruitment analysis on the Tuolumne River found that peak recruitment would be reached at a spawner abundance of approximately 12,000 to 17,000 adult female salmon based on peak fry densities from seine catches (FERC, 2019, 2020, 2021, and 2022). This finding not only supports the conclusion that increased spawner abundance will increase juvenile production on the Tuolumne River, but also supports the applicability of the proposed abundance goal described above (Section 3.1, Abundance Goals). The density-independent models were also a better fit for both datasets, which further supports the conclusion that juvenile production is not currently limited by adult abundances because escapement levels are likely below the population's carrying capacity in the rivers.

Despite the findings of these analyses, it is likely that density-dependent processes still influence Chinook salmon juvenile production. For example, Sturrock et al. (2020) found that Stanislaus River juvenile migration phenotype expression was mediated by density-dependence as well as flow. In recent decades, both river systems have exhibited relatively low escapement relative to historic escapement numbers; therefore, it is reasonable to conclude that density-dependent effects may become more apparent as escapement increases and approaches the population's carrying capacity in the rivers. In addition, there is evidence that density-dependent processes may occur in upstream reaches of the Stanislaus River (Fishbio 2022), which influence on variability may have been obscured in the analyses for the downstream reach by additional factors that the juveniles experience as they migrate downstream. The evaluation of spawner-juvenile relationships, juvenile-environmental relationships, etc., may benefit from multiple stock recruitment analyses in each tributary.

The importance of flow and water temperature has been well documented for Chinook salmon populations across the species' range. The results of the SR covariate models found that years with higher and more variable stream flow improved within tributary juvenile outmigration. This suggests that benefits to juvenile salmon may be maximized through the implementation of the LSJR flow objectives using variable stream flow. This result is consistent with other studies that have also revealed the interdependent relationship between juvenile production, spawner abundance, and flow (Michel 2019; Munsch et al. 2020; Sturrock et al. 2020). Generally, warmer water temperatures during the spring recession flow period correspond to less juvenile production on both tributaries. Although this analysis did not examine interactions between water temperature and flow, it is possible that interaction effects could influence juvenile outmigration, e.g., warm water temperatures could limit outmigration success despite sufficient flow conditions.

State Water Board staff plan to conduct SR covariate analyses for the Chinook salmon population on the Merced River as data becomes available. State Water Board staff are also considering conducting full life cycle SR models for adult returns. However, it will take time to build full life cycle SR models given that available watershed specific data need to be compiled and some data may not be available for each LSJR tributary. To create an effective full life cycle SR model, age composition in natural spawning adults is needed to correctly assign returning adults back to their corresponding brood year (hatch year), as Chinook salmon mature and return to natal streams for spawning as 2- to 5-year old fish. The GrandTab database, while an excellent source for population data, does not include age structure brood tables necessary for SR models. CWTs, otoliths, and scales are routinely sampled during spawning surveys on the LSJR Tributaries, but a thorough analysis of these samples has not yet occurred. This information will take time and funding to develop for each of the tributaries.

The ISAP identified three key metrics of sampling that are required to effectively develop SR models for the LSJR tributaries. First, routine monitoring is required to quantify the escapement of adult Chinook salmon to conduct an age structure analysis. Second, a consistent and comprehensive measure of hatchery influence in spawning populations of Chinook salmon is needed. Third, effective monitoring of juvenile survival and tributary covariates to relate management actions to changes in recruitment rates are needed. Monitoring of important physical, chemical, and biological covariates is not consistently and reliably conducted on an annual basis for many Central Valley tributaries. Temperature, flow, and floodplain activation will need to be regularly monitored to build SR relationships that reliably assess management actions. State Water Board staff are compiling available fish and environmental data needed to produce brood tables and build simple SR models for LSJR tributaries. Initial escapement and juvenile survival goals can be revised when SR models become available, uncertainty in hatchery contributions is reduced, and when other relevant information becomes available.

3.3 Diversity Goals

Population diversity is an important VSP parameter that contributes to population stability, resilience, and persistence. Diversity is generally represented by genetic and life history variation. A more diverse population spreads and reduces the risk of extinction associated with habitat and climate changes across genetic differences and life history strategies to ensure survival across a broad range of resource availability and habitat conditions. Providing habitat conditions that allow for the full expression of genetic and life history diversity is important for maintaining these population characteristics and the long-term sustainability of salmon populations in the Central Valley.

3.3.1 Genetic Diversity Goals

Genetically inherited traits give Chinook salmon the ability to navigate freshwater and ocean habitats and return to spawn in natal rivers. Genetic differences among Chinook salmon persist because many of the life history traits such as the season of adult migration, are genetically inherited. At a finer scale, individual populations of fish may locally adapt to tributary-specific environmental conditions, which improve survival of their offspring in local habitats. The ability to maintain these adaptations is important to the continued survival of fish in highly variable habitat conditions.

Artificial propagation of Chinook salmon in hatcheries can change the genetic composition of hatchery fish away from the genetic characteristics that enabled fish of natural populations to better survive and reproduce. The presence of significant numbers of hatchery fish degrades the genetic pool for natural salmonid populations when the two interbreed. Many hatchery programs have disrupted the natural selection of population characteristics that are tailored to local conditions. Local adaptation is important because it maximizes the viability and productivity of the population, maintains biological diversity within and between populations, and enables the population to adjust to changing conditions that are often present with California's highly variable hydrologic conditions. Hatchery operations can also cause unintended negative ecological interactions whereby hatchery fish compete for food and space, prey upon natural-origin fish, and transfer disease. The ISAP (2019) contains a summary of hatchery impacts on natural-origin fish (See box 4.2, page 99).

Identifying the contribution of hatchery-origin fish to a population is essential for assessing the status, fitness, and resilience of salmon populations. Hatchery-origin spawners often make up a large proportion of the total Chinook salmon escapement in Central Valley tributaries, especially for fall-run Chinook salmon, (e.g., Willmes et al. 2018 and the CFM program). There is a considerable amount of evidence showing that productivity of hatchery-origin salmonids is considerably lower than that of wild-origin fish (Araki et al. 2008; Ford et al. 2016). Tributaries with high proportions of hatchery origin spawners may exhibit a slow recovery of natural populations, even if beneficial habitat conditions are provided.

The effects of a hatchery on a naturally spawning population depend on hatchery practices and differences in selective pressures in wild and hatchery environments. Salmon produced in hatcheries frequently spawn in streams and interbreed with natural-origin fish which can cause a reduction in the productivity of the overall population (Chilcote et al. 2011). The hatchery practice of releasing juveniles downstream of their natal watershed (e.g., within the Delta or San Francisco Bay) greatly increases the straying rates of hatchery adults into non-natal watersheds (Martson et al. 2012), which increases the influence of hatchery spawners on natural populations. The proportion Hatchery Origin Spawners or pHOS in a population is a key metric for tracking the genetic composition of the natural spawning population because artificial propagation tends to decrease the genetic variability of the natural population from which it is derived. Proportionate Natural Influence (PNI) represents the reproductive success of the population and is another important metric for tracking hatchery practices and adverse effects of hatchery salmonids on natural populations.

The ISAP (2019) recommends reducing the pHOS on the in-river spawning habitats and increasing the PNI which will contribute to an increase in the natural production of fall-run Chinook salmon. This will occur by increasing the productivity of natural spawners, allowing the species to adapt to local conditions, and reducing genetic homogeneity associated with domesticated hatchery salmon.

One step toward reducing pHOS is for individual hatcheries in the Central Valley to produce and implement Hatchery and Genetic Management Plans (HGMPs) for fall-run Chinook and for those hatcheries to increase marking of hatchery fish so that pHOS can be accurately measured in real-time. The following rivers in the Central Valley have hatcheries that produce fall-run Chinook: Battle Creek, Feather River, American River, Mokelumne River, and Merced River. The hatcheries that operate on these rivers would need to develop HGMPs and implement them to accurately estimate, e.g., 100% marking, and reduce pHOS and increase PNI, e.g., actions to reduce hatchery straying.

Table 3.8 contains initial genetic diversity goals for LSJR fall-run Chinook. These include incremental steps in reducing pHOS. Monitoring for other genetic diversity goals for increasing the PNI may be developed later after progress is shown toward achieving genetic diversity goals for pHOS.

Table 3.8. LSJR Fall-Run Chinook Salmon pHOS Genetic Diversity Goals for the LSJR Basin

Genetic Diversity Metric	Goal, measured as a 5-year running average	Progress Assessment/Attainment Target
pHOS	Decreasing trend, as a 5-year running average[19]	Assessed annually/when the genetic diversity goal is met
pHOS	≤ 15%	Assessed annually/Year 12 after beginning of implementation
pHOS	≤ 10%[20]	Assessed annually/Year 21 after beginning of implementation

3.3.2 Life History Diversity Goals

Life history diversity for salmonid species can be described as the variation in phenological traits (e.g., run timing and developmental rate) that allow a species to exhibit multiple life history strategies. These multiple strategies enable use of a wider array of environments (McElhany et al. 2000). Life history diversity is a crucial component of population resilience, which describes the ability of a population to persist and recover following disturbances across variable environmental conditions. Variation in life history traits such as variable migration, spawning, and rearing timing in local subpopulations (i.e., fish population in a tributary) reduces extinction risk at larger scales so that an environmental disturbance does not affect an entire population. In the Central Valley, the existence of four runs of Chinook salmon (winter-, spring-, fall-, and late fall-runs) with asynchronous spatial and temporal distributions allow them to occupy and use a range of ecological niches. Maintenance of multiple and diverse salmon stocks that fluctuate independently of each other would render a stabilizing portfolio effect to the existence of the overall salmon population in the region (Sturrock et al. 2015). Preserving and restoring life history diversity of salmonids is an integral goal of species conservation and attaining the narrative objective for LSJR native salmon.

Fall-run Chinook salmon juveniles migrating out[21] of the Central Valley system leave their natal rivers and streams at varying sizes, times of the year, and ages. It is thought that this life history variation contributes to the sustainability and overall stability of the system-wide Chinook salmon population (Sturrock et al. 2015, 2020), and thus is central to many recovery efforts. However, current flow management actions tend to select for a single migratory phenotype, which has reduced the production in the rivers (Sturrock et al. 2015, 2020). For example, in the Stanislaus River, despite the fact that the majority of juveniles that emigrated from the system in 1996-2014 were composed of smaller fry or larger smolt, the salmon that survived and returned as adults were dominated by those that emigrated as parr (Sturrock et al. 2015, 2020). The study suggests that the current flow management frequently selects against the survival of these other life history phenotypes (e.g., suppression of winter flows reduces the survival of fry). The authors predicted that supporting the survival of a broader range of migratory phenotypes can greatly improve adult production (e.g., >7-fold increases in some years) and contribute to the population's overall

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[19] ISAP (2019). Developing Biological Goals for the Bay-Delta Plan: Concepts and Ideas from an Independent Scientific Advisory Panel. April 2019. Section 4.6, page 111.

[20] Lindley et al. (2007). Framework for Assessing Viability of Threatened and Endangered Chinooks Salmon and Steelhead in the Sacramento-San Joaquin Basin. San Francisco Estuary and Watershed Science. Volume 5, Issue 1. February.

[21] Emigration is a term commonly used to describe juvenile "outmigration" from freshwater tributary and mainstem river systems. Emigration can be used interchangeably with "outmigration."

resiliency and stability. The timing and percentage of size class goals can be evaluated in the future based on information on the success of the return of natural spawners to the tributaries.

3.3.2.1 Timing of Migration for Size Classes Goals

The migration of juvenile Chinook salmon with different life history strategies across a broad migration window is a good indicator that the river environment is supporting the various juvenile life history strategies that are characteristic of resilient salmon populations. The Conservation Planning Foundation Report used the presence of juvenile outmigrants measured on a weekly basis for each size class of juveniles to develop migration windows for each size class in the Stanislaus River. The migration time windows were based on historical timing of migration data collected at the Caswell RST on the Stanislaus River from 1996 to 2014 (see Zeug et al. 2014; Sturrock et al. 2015). The parr and smolt migration windows were set to one to two weeks earlier than what was typically detected to reflect the desire to produce faster growth rates in-river which would result in the earlier appearance of larger size classes among outmigrants. Migrating juveniles with different life history strategies can be detected by installing and maintaining RSTs at (or close to) the mouth of each tributary river or stream during the migration time window.

Table 3.9 contains the initial emigration timing goals for each of the juvenile size classes for LSJR fall-run Chinook salmon. This is a presence/absence goal which is met by positive detection (presence) of migrating fish each week during the time period identified for each size class (fry, parr, smolt). The assessment and evaluation of this goal should take into consideration environmental conditions, such as climatic variability and downstream water temperatures. While the initial timing goals were developed using monitoring that occurred on the Stanislaus River, the initial timing goals are appropriate for the Tuolumne and Merced Rivers because all of the LSJR tributaries are dominated by straying hatchery origin spawners. No information has been provided that would suggest that the currently observed emigration timing on the tributaries is supporting viable populations of Chinook salmon. The intent of the goal is for the tributaries to allow the development of locally adapted emigration timing that supports a broad range of diversity that represents viability.

Table 3.9. LSJR Fall-Run Chinook Salmon Juvenile Emigration Timing Goals

Juvenile Size Class* (Phenotype)	Positive Detection Each Week near Mouth of Each Tributary	Progress Assessment/ Attainment Target
Fry	Last week of January to second week of April[22]	Assessed annually/Year 10, achieve the goal
Parr	First week of February to last week of May[23]	Assessed annually/Year 10, achieve the goal
Smolt	Third week of February – first week of June[24]	Assessed annually/Year 10, achieve the goal

* Size classes are defined as fry < 55 millimeters (mm); parr 55 - 75 mm; smolt >75 mm.

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[22] Cain et al. (2019). Conservation Planning Foundation for Restoring Chinook Salmon (*Oncorhynchus tshawytscha*) and O. mykiss in the Stanislaus River. Seattle, WA. April 2019. Table 9, page 62.

[23] Ibid.

[24] Ibid.

3.3.2.2 Minimum Percentage for Size Classes at Migration Goals

Quantifying the relative contribution of fry (FL <55 mm), parr (FL 55 to 75 mm), and smolt (FL >75 mm) outmigrants to adult populations has been largely limited due to technical difficulties associated with reconstructing the movements of early stages of returning adult Chinook salmon. Recent advances in techniques analyzing chemical markers recorded in otoliths have enabled reconstruction of the movement patterns of individual fish. In the Central Valley system, the otolith mineral analyses using various elements (strontium isotope ratio, 87Sr/86Sr; Sr/Ca and Ba/Ca)[25] combined with radius measurements have been used to reconstruct the size at which returning adults from the same cohort outmigrated the natal streams and rivers as juveniles (Miller et al. 2010; Sturrock et al. 2015; Sturrock et al. 2020). Outmigrating juveniles can also be sampled at (or close to) the mouth of each tributary river or stream (e.g., using RSTs) to estimate outmigrant timing, abundance, and size.

Table 3.10 shows the proposed LSJR life history diversity goals based on the cohort-specific proportions of the size classes (phenotypes) of outmigrating juvenile fish. These values are proposed in the Conservation Planning Foundation Report for the Stanislaus River and are derived from the returning adult otolith analyses for Central Valley rivers and streams (Miller et al. 2010; Sturrock et al. 2015, 2020). Similar to the emigration timing, these initial size proportions are applicable to the Tuolumne and Merced Rivers due to the large influence of hatchery origin spawners on all of the LSJR tributaries. The purpose of this juvenile size at emigration goal is to enhance the portfolio effects of diverse life histories that would eventually increase the adaptability and stability of Chinook salmon populations.

Table 3.10. LSJR Fall-Run Chinook Salmon Minimum Percentage for Different Size Classes* at Migration Goals for different water-year types. These are measured as 3-year running averages at the mouth of each tributary.

Wet and Above Normal WYs	Below Normal, Dry, and Critical WYs	Progress Assessment/Attainment Target
Fry ≥ 20%[26]	Fry ≥ 20%[27]	Assessed annually/Year 12, achieve the goal
Parr ≥ 20%[28]	Parr ≥ 30%[29]	Assessed annually/Year 12, achieve the goal
Smolt ≥ 10%[30]	Smolt ≥ 20%[31]	Assessed annually/Year 12, achieve the goal

* Size classes are defined as fry <55 mm; parr 55 - 75 mm; smolt >75 mm.

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[25] Sr = Strontium; Ca = Calcium; Ba = Barium

[26] Cain et al. (2019). Conservation Planning Foundation for Restoring Chinook Salmon (Oncorhynchus tshawytscha) and O. mykiss in the Stanislaus River. Seattle, WA. April 2019. Table 11, page 66.

[27] Ibid.

[28] Ibid.

[29] Ibid.

[30] Ibid.

[31] Ibid.

3.4 Spatial Structure Goals

Spatial structure refers to the geographic distribution of populations or individuals in a population. The spatial structure helps contribute to the persistence of a population through: (1) reducing the chance of catastrophic loss because groups of individuals are widely distributed spatially; (2) increasing the chance that locally extirpated or dwindling groups will be rescued by recolonization; and (3) providing more opportunity for long-term demographic processes to buffer a population from future environmental changes. In addition, broader geographic extent may decrease the extinction risk. Restoring areas that support source populations can increase the overall stability of metapopulations by increasing the number of individuals available to support nearby populations.

The spatial structure of a population is made up of the geographic distribution of individuals in the population and the processes that generate that distribution (McElhany et al. 2000). Spatial structure of a population depends on the amount of habitat available, the organization and connectivity of that habitat (i.e., habitat patches), and the relatedness and exchange rates of adjacent populations. Spatial structure influences the viability of salmonids because populations with restricted distributions and few spawning areas are at a higher risk of extinction from catastrophic environmental events than are populations with more widespread and complex spatial structures. A population with a complex spatial structure, including multiple spawning areas, experiences more natural exchange of gene flow and life history characteristics.

Restoring and sustaining Chinook salmon populations in the tributary streams and rivers within the Delta watershed would contribute to the overall spatial structure of the Chinook salmon population (Evolutionarily Significant Unit or Distinct Population Segment) in the Central Valley watershed. McElhany et al. (2000) offers spatial structure guidelines to be considered for viable salmonid populations. Spatial structure guidelines are met when the number of habitat patches is stable or increasing, stray rates are stable, marginally suitable habitat patches are preserved, refuge source populations are preserved, and uncertainty is incorporated (McElhany et al. 2000; see box A9, Spatial Structure Guidelines on page 100).

The initial spatial structure biological goal in the LSJR is to achieve the abundance, productivity, and diversity goals on all three LSJR tributaries, the Stanislaus, Tuolumne, and Merced rivers.

Chapter 4
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Appendix A
Microsoft Excel file containing data and calculations

Tabs included:

- Tuolumne River Constant Fractional Marking (CFM) Program data, ChinookProd data, Cohort Replacement Rate calculator, other summary calculations
- Stanislaus River CFM Program data, ChinookProd data, Cohort Replacement Rate calculator, other summary calculations
- Merced River CFM Program data, ChinookProd data, Cohort Replacement Rate calculator, other summary calculations
- Doubling Calculations
  - Abundance Goal Escapement Calculator
  - Juvenile Production Goal Calculator
  - LSJR Proportion of Hatchery Origin Spawner (pHOS) Estimator
  - Predicted Generational Escapement and pHOS Calculator
- Stanislaus River sex ratio and fecundity data
- Tuolumne River sex ratio and fecundity data
- Merced River sex ratio and fecundity data