STATE WATER RESOURCES CONTROL BOARD
CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

REVISED DRAFT INITIAL BIOLOGICAL GOALS FOR THE LOWER SAN JOAQUIN RIVER

~~SEPTEMBER 2019~~ JUNE 2022

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Introduction

1.1 Introduction

In December of 2018, the State Water Resources Control Board (State Water Board) adopted revisions to the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (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 a program of implementation to achieve the objectives (LSJR flow update). The Office of Administrative Law (OAL) approved the regulatory action on February 25, 2019. The State Water Board is also currently in the process of updating flow~~-~~<u>-</u>related objectives in the Bay-Delta Plan for the reasonable protection of fish and wildlife in the Sacramento River and Delta and associated tributaries as well as other Bay-Delta Plan objectives and associated portions of the program of implementation (Sacramento/Delta update).

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 conditions necessary for the natural production of viable native fish and aquatic species populations rearing in, or migrating through<u>,</u> the Bay-Delta Estuary. 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<u>,</u> are making sufficient progress towards the Plan's objectives of achieving and maintaining the natural production of viable native fish and aquatic species populations. Biological goals ~~can also~~<u>will</u> inform adaptive management actions during implementation 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~~.~~<u>.,</u> fishing regulations, hatchery management, habitat restoration, etc.). <u>The biological goals are not regulatory targets or thresholds which, if not met, will trigger a regulatory action alone, such as a change in required percentage of unimpaired flow. Any long-term change in the percentage of unimpaired flow would require an action by the State Water Board through a public process.</u>

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 ~~more abundant status than~~relative abundance compared to other sensitive indicator species and the availability of information and monitoring data for this species. After consideration of additional public comments ~~and any needed changes to~~ the ~~draft initial biological~~ goals ~~for the LSJR, the goals would~~will be brought to the State Water Board for ~~possible~~ consideration of approval as early as the ~~end~~summer of ~~2019~~2022.

The biological goals are intended to evolve as scientific understanding of the Bay-Delta watershed evolves. Even after approval, the biological goals would be subject to change by the State Water Board based on new information and changing circumstances. The ~~need for potential future modifications of the initial goals was identified in the~~ 2018 Bay-Delta Plan and ~~recommended by~~ the Independent Scientific Advisory Panel (ISAP~~), discussed below.~~) recognized the need to be able to modify the initial biological goals and; therefore, this draft includes a set of proposed principles for developing biological goals and making future changes. Possible changes could include the addition of other species or environmental goals for habitat conditions that contribute to the biological goals such as temperature, instream and off-stream habitat acreage, and other factors. ~~In addition to the goals, a set of proposed principles for developing biological goals is identified.~~ These principles were used in the development of the draft initial biological goals for the LSJR and will guide both the refinement of the initial goals and the development of additional 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 other efforts to develop biological goals ~~(or similar products) and~~along with input from California Department of Fish and Wildlife (CDFW) staff.

The 2018 Bay-Delta Plan states that the State Water Board will seek recommendations on biological goals from ~~experts~~the Stanislaus, Tuolumne, and Merced Working Group (STM Working Group). Members of the STM Working Group should have necessary expertise in LSJR and tributary flow management, hydrology, operations and assessment needs including CDFW, the National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), and water diverters and users on the tributaries as well as State Water Board staff and nongovernmental organizations. The 2018 Bay-Delta Plan envisions that the ~~Stanislaus, Tuolumne, and Merced (STM)~~STM Working Group, when fully formed, will be comprised of a subset of representatives from these types of entities and agencies. ~~The State Water Board is sensitive to the fact that many of these same entities and organizations are currently engaged in working groups discussing the~~

~~development of a potential VA and that the establishment of the STM Working Group may distract from those efforts. Therefore, the State Water Board is initiating the STM Working Group in a limited manner by assigning an STM Coordinator. Staff~~When the draft initial report was released in September 2019, staff from the entities and organizations that are identified in the 2018 Bay-Delta Plan for potential future STM Working Group participation ~~are~~were included on the distribution list for ~~this draft report~~public review and ~~are invited~~comment. See Response to ~~provide input to~~Comments Section on the ~~State Water Board's STM coordinator who is identified in the cover letter to this draft report.~~ Draft Initial Biological Goals, for details regarding comments and responses.

In a June 13, 2022 letter, the State Water Board formed the initial STM Working Group by inviting representatives from specific agencies and informing other persons and entities with appropriate expertise of the opportunity to participate. A fully formed STM Working Group is intended to function as a watershed group and forum for facilitating coordination among the State Water Board and interested water agencies and other stakeholders who have expertise in LSJR issues. The STM will evolve over time as the State Water Board proceeds through the implementation process, including preparing products pursuant to the Bay-Delta Plan such as this biological goals report.

In a separate process, ~~VA~~ parties ~~are developing a set of~~working to develop a possible voluntary agreement (VA) to implement the Bay-Delta Plan that included metrics (previously referred to as biological and environmental targets (BETs~~)~~ ~~designed~~)) to evaluate the effectiveness of proposed VA specific assets. ~~It is envisioned that the~~ This effort may resume if potential VA ~~BETs would nest under and contribute toward meeting overall Bay-Delta Plan biological goals.~~ parties in the San Joaquin River watershed move forward with a proposal for a VA. 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 Board's authority (e.g~~.~~., ocean harvest, hatchery management~~, etc~~). The biological goals identified in this report ~~have been~~were developed in coordination with prior VA efforts to develop ~~VA BETs and coordination between these efforts~~metrics. If VA proposals are developed in the future for San Joaquin River tributaries, staff will ~~continue as the biological goals and BETs are refined prior to finalization.~~coordinate with VA parties on refinement of VA metrics and Biological Goals. 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 (collectively, 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.

1.2 Response to Comments on the Draft Initial Biological Goals

The Draft Initial Biological Goals for the Lower San Joaquin River report was released for public review and comment in September 2019. The State Water Board received written comments from 16 agencies, entities, or individuals providing information to consider during the development of biological goals. The report has been modified to address issues identified by the commenters. Below is a summary of the primary topics raised by commenters and a brief description of how the report addresses these comments.

Many commenters asked to clarify the relationship between biological goals and VAs. At the time, there are no proposed San Joaquin River tributary VAs that have been submitted to the Board for consideration. If this occurs in the future, the biological goals may be modified as appropriate to address those VAs. Future VA proposals may not include all LSJR tributaries included in the Bay-Delta Plan. Approved LSJR biological goals are needed for assessment of the broader suite of actions that may contribute to reasonable protection of beneficial uses, to cover all LSJR tributaries and the mainstem LSJR if one or more single-tributary VAs are proposed in the future, and to provide continuity after a potential adopted VA expires.

Commenters made various comments on the abundance goals and their connection to natural production doubling goals. Some commenters interpreted the escapement goal as a replacement or modification of the natural production doubling goal. Commenters objected to the inclusion of hatchery spawner contributions to the escapement goals because this would artificially inflate abundance metrics with hatchery contributions and would be inconsistent with doubling goals that are based on natural production (exclusion of hatchery contribution). In addition, some commenters expressed disagreement with existing state and federal laws and policies which require the doubling of natural production of chinook salmon. The biological goals are designed to measure population attributes to inform progress toward viable populations and the salmon doubling objective. Inclusion of hatchery spawners in abundance Biological Goals informs whether river habitats are improving survival in early life stages for the purposes of informing adaptive management of flows and future updates to the Bay-Delta Plan. Additional analyses outside of biological goals can be done to evaluate attainment of state and federal statutes for doubling the natural production of Chinook salmon that do not include hatchery spawner contributions to abundance.

Escapement is a measure of population abundance, which is a key indicator of viability, as described in the Lower San Joaquin River Flows narrative water quality objective. Escapement is readily monitored in the Lower San Joaquin River tributaries as well as most of the salmonid bearing tributaries of the Central Valley. The Anadromous Fish Restoration Program (AFRP) ocean production estimates are based on escapement values, and annual escapement on the Stanislaus, Tuolumne, and Merced Rivers is highly statistically correlated with the previous years' production estimates, respectively (Spearman's rho > 0.96, $p < 0.001$, $n > 60$ years). This correlation suggests that observed trends in river escapement are a good indicator of trends in ocean production. Likewise, trends in escapement will be used to measure progress toward population viability, e.g., positive trends in abundance, as recommended by the Independent Science Advisory Panel (2019).

Independent of its relationship with past production estimates, escapement data are useful for real-time management of the species, e.g., timing and spatial distribution of migration and spawning, estimates of juvenile numbers, or estimates of habitat needs to support juvenile offspring. Offspring produced within the rivers, regardless if the spawners were derived from natural or hatchery production, will contribute to natural production abundance in subsequent years. These offspring will be subjected to the environmental conditions that will select for traits that allow for local adaptation of populations. For these reasons and those outlined in the Chapter 3, the initial escapement goals will include both natural and hatchery spawners. Furthermore, the proportion of hatchery spawners will not remain unmanaged. The genetic diversity goals work with the abundance goals and aim to reduce hatchery influence on the Chinook salmon populations and spawner escapement in the lower San Joaquin River tributaries.

Comments were received on the draft productivity goals identifying that the post-fishing cohort-replacement rate (CRR) would not provide information on tributary conditions or efforts to improve natural production, since hatchery fish would be included in the calculation. However, unlike the draft escapement goal, hatchery fish would not be included in the calculation of the post-fishing CRR, and this was clarified in the report. Some commenters indicated that the pre-fishing CRR should not be included, or it was different than what the ISAP recommended. The ISAP recommended that "adult recruits (returning salmon prior to fishing) per spawner (R/S)" be greater than 1, which is equivalent to the pre-fishing CRR ≥ 1 draft productivity goal. Additional clarifying text was included in Chapter 3.2.1 for the Full Life Cycle Productivity Goals.

Some commenters recommended that the juvenile survival goal be a single value for each water body section because a range is ambiguous. Text was added to the report to clarify that the overall freshwater juvenile survival goal is 1.1%, and that the survival needed in each water body section may fluctuate depending on the success or circumstances in any given period. Others suggested that the survival goals should be developed for more specific life stages - e.g., egg to fry survival or within tributary survival. The draft juvenile survival goal only includes two endpoints for the initial biological goals to limit the overall number of metrics to track. Two of the three tributaries operate rotary screw traps near the confluence with the LSJR, so adding a survival goal at this location could be a viable option if it is found that this metric would help to inform the status of the species.

Commenters stated that the survival goals are unrealistic or unlikely to occur through water project management alone and suggested that predator control is necessary.

Evidence indicates that the survival goals are realistic given that they have been achieved in relatively recent prior years, independent of potential predator control actions. Implementation of the LSJR flow objectives will increase the frequency and duration of aquatic habitat conditions that promote survival of native fish species and suppress presence of predator populations by providing unfavorable habitat conditions for predator species. Comments regarding flow and non-flow actions, such as predator control, are more focused on adoption of the plan amendments than the establishment of biological goals. These types of comments were addressed in the response to comments for the Substitute Environmental Document, see Master Response 3.1 (p. 69 – 72).

Commenters stated that tributary managers don't have control over hatchery strays and that hatchery influence should be addressed through improved hatchery management practices, for example, improving the identification of hatchery fish through tagging or reducing straying by reducing the trucking of juvenile hatchery releases. Achieving the proportion of hatchery origin spawners (pHOS) goal can be reinforced by engaging with agency partners to produce and implement hatchery management plans and management actions that help to reduce the influence of hatchery straying into the tributaries.

Commenters stated that tributary populations have developed different emigration timing strategies, and one timing schedule based on another tributary (i.e., timing was in part based on Stanislaus River salmon) would be detrimental to the populations. Some commenters argued that static calendar based criteria are uninformative when considering extreme variation, or that there is no evidence that more narrow emigration windows or that specific percentages of emigration from different life stages would be more appropriate for the population. Likewise, some commenters argued that attempting to widen migration into June would likely reduce survival by exposing juveniles to warmer temperatures and predators.

Salmon on the tributaries may exhibit different timing or narrower timing strategies because habitat conditions currently do not allow for full expression of migration timing strategies. Chronically depressed populations with narrow emigration windows suggest that the narrow windows do not support viable populations. Implementing LSJR flow objectives should produce emigration windows that allow for a more complete expression of genetic and phenotypic diversity. The biological goals assess whether flows produce habitat conditions that result in broader expression of phenotypical diversity, including June emigration in some years.

Commenters recommended that the timeline for the diversity goals be accelerated because the targets should be achievable quickly through flow improvements and other actions. Some recommended that biological goals for diversity should also include goals for spring-run Chinook and steelhead. Emigration timing is largely controlled by the presence or absence of adequate habitat conditions that are controlled in large part by flow management. Improvements in emigration timing and size distribution should be observed relatively quickly upon implementation of the LSJR flows. The initial biological goals are focusing on fall-run Chinook first, and additional goals for other species may be developed in the future.

Commenters identified issues with the use of available data, hatchery stray information, use of stock-recruitment models, and best-available science. The report has been revised to incorporate more reference to and use of recent data and analyses including, but not limited to, the CDFW GrandTab dataset and the proportion of hatchery strays to San Joaquin River tributary escapement using the constant fractional marking program analyses. A new section was added to the report describing new stock-recruitment analyses that examine the relationships between adult fall-run Chinook salmon spawners and juvenile recruits for the Stanislaus and Tuolumne Rivers. These analyses evaluated the influences of environmental covariates on recruits per spawner relationships. These analyses can be strengthened with additional data as actions to improve environmental conditions in the rivers are implemented.

Commenters identified procedural or legal concerns with the adoption and use of the biological goals. Some commenters believe that the State Water Board should not adopt the biological goals while there are legal challenges to the 2018 Bay-Delta Plan amendment. Additionally, commenters stated that the adoption of numeric biological goals would constitute the adoption of new water quality objectives, thus the adoption of goals would require an assessment of balancing resources or the State Water Board should prepare an environmental document. The 2018 Plan amendments, including the program of implementation requirement to develop biological goals, were approved by the Office of Administrative Law on February 25, 2019. Accordingly, the amendments and the program of implementation are in effect. The pending legal challenges do not obviate the State Water Board's responsibility to implement the objectives of the Plan amendments.

The State Water Board adopted new and revised Lower San Joaquin River flow objectives in the 2018 Plan amendments, which in part, require flow conditions that support and maintain viable fish populations. The water quality objectives identify indicators of viability which include population abundance, spatial extent, distribution, structure, genetic and life history diversity, and productivity. The water quality objective is in the form of flow rate, so flow rate will be used to measure compliance. Biological goals, as indicators of viability, will inform the State Water Board of the conditions that flow rates in combination with other actions are supporting. In addition, information derived from monitoring and assessment will inform the actions the State Water Board may take including, but not limited to, adjusting the required flow rates within the range of the adopted water quality objectives. The new and revised water quality objectives were developed considering the reasonable protection of all beneficial uses, and the water quality objectives and program of implementation were assessed for potential environmental impacts.

Chapter 2

Approach and Principles for Developing 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. 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 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. The BDCP included new water diversion intakes in the north Delta, water conveyance tunnels through the Delta, and large-scale, long-term habitat restoration program within the greater Delta area. BDCP included a proposal for juvenile salmonid survival objectives in the Delta for the purpose of guiding conservation actions, adaptive management, and assessing BDCP performance relative to ecological outcomes.

The proposed BDCP was substantially modified in 2015. The HCP and NCCP components were removed, and the water supply and habitat restoration components were bifurcated. Although the proposed BDCP 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.

2.1.3 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 is intended to provide 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 ~~viable salmonid population (~~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. ~~The SEP participants plan to develop similar information for the Merced, Tuolumne, and lower San Joaquin rivers in the future.~~

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 ISAP Report on Bay-Delta Plan Biological Goals

As previously noted, 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 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 of background materials 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 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 many decades of 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.

2.2 Principles for Developing 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 Initial Biological Goals for Native Bay-Delta Fish Species

- 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 ~~becomes~~become available.

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 characterized by an individual population attribute, for example, abundance. Rather, all VSP parameters should be used to evaluate the sustainability of a given population. 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 abundance as "the number of adult fish returning to spawn, measured over a ~~times~~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 ~~with~~, including counts entering hatcheries and migrating past dams, carcass surveys~~ being the dominant method (CDFW 2019). ~~, live fish counts, and ground and aerial redd counts. Initial fall-run Chinook salmon escapement goals for LSJR tributaries are proposed in Table 1. The escapement goals in Table 1 represent a doubling of the average escapement for each tributary from 1967 to 1991. The 1967-1991 baseline escapement estimates were derived from Mills and Fisher (1994; see Appendix A).

The proposed escapement goals are ~~consistent with~~an indicator to measure progress toward the salmon doubling goals identified in existing state and federal requirements discussed above~~ with provisions for real world~~. 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 incorporate considerations ~~related to~~for our ability to distinguish between hatchery fish and naturally spawned fish in real-time and the time it takes to detect trends in abundance given natural variation in salmon populations due to hydrologic and other conditions. 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 1. LSJR Fall-Run Chinook Salmon Escapement Goals

River	Escapement Goal as a ~~6~~5-Year Running Average	Progress Assessment[1]
All	Positive generational trend in escapement, measured as a 5-year geometric mean	Until numeric abundance goals are met
Stanislaus River	9,600	Year 6, measurable progress Year 9, substantial progress Year ~~TBD*,~~15, achieve the goal
Tuolumne River	17,800	Year 6, measurable progress Year 9, substantial progress Year ~~TBD*,~~15, achieve the goal
Merced River	~~9~~8,000	Year 6, measurable progress Year 9, substantial progress Year ~~TBD*,~~15, achieve the goal

~~*To be determined based on public comment and other relevant information.~~

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 that thereafter abundance levels are maintained at that level. Progress toward meeting the escapement goal is proposed to be measured and reported

[1] Year number after implementation begins.

annually but fully detecting whether the goal has been met will take time.[2] Salmon populations characteristically experience wide variations in abundance even under pre-development conditions due to variable hydrology~~ and~~, 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 ~~confidence will take several generations. The State Water Board is specifically seeking comments on the time interval that should be identified for achievement of these goals. The State Water Board is considering a 15-year time interval, which encompasses a large enough sample size (5 generations of salmon) to detect an overall abundance trend given natural fluctuations and statistical confidence.~~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.

Progress toward meeting the escapement goal is proposed to be assessed for intermediate progress starting at year 6 after the beginning of implementation providing time for two generations of salmon to return to the spawning grounds. By year 6 it is expected that measurable progress toward meeting the escapement goal ~~would~~will be made. For the purposes of these biological goals measurable progress means a reversal of declines and statistically significant detectable levels of improvement in escapement from the start of implementation period (95% confidence level). Regular progress assessments are proposed to continue annually thereafter. By year 9 when information is available for 3 generations of salmon, substantial progress toward achieving the goals would be expected. For the purposes of these biological goals substantial progress means improvements on a trajectory that the goal could be reasonably met.

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. ~~However, as discussed above, currently data~~GrandTab does not characterize whether fish are ~~not available to distinguish~~wild or hatchery ~~from~~ origin, only whether the adults are spawning in-river (natural~~ origin fish. ~~) or in-hatchery. Since 2007, the constant fractional marking program (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. The estimated average proportion of Hatchery Origin Spawners on the Stanislaus, Tuolumne, and Merced Rivers using CDFW 2010-2014 CWT recoveries is 69%, 50%, and 73%, respectively (Kormos et al. 2012; Palmer-Zwahlen and Kormos 2013 and 2015; Palmer-Zwahlen et al. 2018a and 2018b).

[2] 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.

For that reason and also due to the issues with the salmon doubling estimates that the ISAP raised, for the purposes of the initial LSJR biological goals, it is proposed that initially, natural and hatchery origin fish be counted toward meeting the escapement goal until hatchery marking increases enough to credibly characterize the proportion of hatchery origin fish in the population. In the interim, increasing total escapement (natural and hatchery origin fish) demonstrates an improvement in habitat conditions for in-river rearing and spawning.

~~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 recruits they produce. This document will refer to adult fish that return to spawn as "spawners" and juvenile fish that survive to the ocean environment as "recruits."~~

~~Established SR models can be used to identify the effects of local management actions (e.g., flow, water temperature, habitat restoration) and long-term trends in productivity and abundance. However, it will take time to build SR models given that available watershed specific data need to be compiled by State Water Board staff and some data may not be available for each LSJR tributary. To create an effective SR model, age composition in spawning adults is needed to correctly allocate 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. To do this, brood tables that include information about a group of spawners that were hatched in the same year need to be prepared identifying the brood year, the number of adult spawners, and the total number of progeny (returning adults) produced by those spawners. This information is not yet available and/or compiled and will take time 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 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 routinely collected on all the 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, hatchery marking increases enough to reliably count natural origin fish, and/or when other relevant information becomes available.~~ Furthermore, knowledge of the total escapement number will inform the amount of habitat needed to support the year's spawning cohort and their offspring (e.g., spawning and rearing habitat acres).

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 ~~proposed~~identified in Table 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. 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[3] 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.

[3] Pre-fishing CRR are derived using harvest and spawner escapement data for ~~a given year~~associated years.

Table 2. LSJR Fall-Run Chinook Salmon Full Life Cycle Productivity Goals for Each Tributary

Productivity Metric	Goal	Progress Assessment[4]
CRR Trend[5]	Positive generational trend until a CRR > 1 is met, measured as a 5-year geometric mean	Until numeric productivity goals are met (year 15)
Pre-Fishing CRR [6]	Pre-Fishing CRR > 1 and > post-fishing CRR until abundance goals met and then sustained, measured as a 5-year geometric mean	Year 6, measurable progress Year 9, substantial progress Year 15, achieve the goal
Post-Fishing CRR[7]	Post-Fishing CRR > 1 until abundance goals met and then sustained CRR > 1, measured as a 5-year geometric mean ~~as a 5-year running average~~	Year 6, measurable progress Year 9, substantial progress Year 15, achieve the goal

Progress toward meeting the productivity goals will be assessed annually~~.~~ for each tributary. The proposed 15-year time interval for achieving the goal provides time for the goals to be met. By year 6 when information is available for 2 full generations of salmon, it is expected that measurable progress toward meeting the CRR productivity goal would be made by demonstrating a reversal of declines and statistically significant level of improvement in CRR. By year 9 when information is available for roughly 3 full generations of salmon, substantial progress toward achieving the goals would be expected and demonstrated by improvements in productivity on a trajectory that the productivity goals should be reasonably met after 5 generations or 15 years after the implementation.

3.2.2 Juvenile Productivity Goals

~~To~~In order to help ~~to~~ 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.[8] Early life-stage productivity can be expressed as the number of ~~juvenile fish~~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

[4] Year number after implementation begins.

[5] 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.

[6] Ibid

[7] Ibid

[8] Eggs ~~are~~ in nests referred to as redds; alevin are larval fish with an egg sac for food; fry are small juvenile fish less than ~~45~~ 55 mm (1.7 inches) that have recently emerged from nests; parr are juvenile fish larger than ~~60~~55 mm (2.4~~2~~ inches) but less than ~~90~~75 mm (3.~~5~~0 inches); smolts are larger than ~~90~~75 mm (3.~~5~~0 inches) and have started to transform physiologically to adapt to marine environments.

environment throughout the fry, parr, and smolt life stages. Freshwater exit survival includes survival from all three of these juvenile life stages to the estuary.

Table 3 shows the initial fall-run Chinook salmon productivity goals for juvenile survival. The productivity metric for juvenile survival has two different components: one for the riverine portion (eggs to the Delta entry) and one for through-Delta survival to the ocean. ~~The goals are presented as numeric ranges which~~The overall freshwater juvenile survival goal is 1.1% survival, and the numeric ranges are the initial apportioning to each of the components. The goals are presented as ranges because it is anticipated that survival needs may fluctuate across the components depending on variable environmental conditions, restoration activity timing, localized conditions, etc. The numeric ranges are based on the Conservation Planning Foundation Report and peer-reviewed literature referenced below. ~~The~~ Meeting the juvenile survival ranges ~~are~~is also expected to ~~contribute to meeting~~meet the ~~CRR~~CRR's for the ~~juvenile component of the~~ full lifecycle productivity goals based on current knowledge of the survival of subsequent life stages.

Table 3. LSJR Fall-Run Chinook Salmon Juvenile Survival Goals for each tributary

Productivity Metric	Goal	Progress Assessment[9]
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)
LSJR tributary (egg) to Mossdale survival (SJRS)	SJRS ~~≥~~ 5.5–20%[10] as a 5-year geometric mean	Year 6, measurable progress Year 9, substantial progress Year 15, achieve the goal
LSJR at Mossdale to Chipps Island (Through-Delta) Survival (SJDS)	SJDS ~~≥~~ 20–50%[11] as a 5-year geometric mean	Year 6, measurable progress Year 9, substantial progress Year 15, 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)[12] (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

[9] Year number after implementation begins.

[10] 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.

[11] Ibid.

[12] 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.

percent in 1999; 34 percent in 2001; SJRGA 2009, 2013)[13], 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 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.

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. The proposed goals are articulated as a range based on these considerations.

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 ~~river.~~ 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 (~~RSTs~~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 ranges could be re-evaluated and refined based on the availability of new information and routine monitoring.

~~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 the Vernalis Adaptive Management Plan's[14] 2011 annual technical report show that higher survival occurred between 1994 and 2001 (i.e., 80 percent in 1995; 40 percent from 1997-1998; 20 percent from 2001-2006; SJRGA 2011), which suggests that the proposed LSJR through-Delta juvenile survival goal is achievable. Annual assessments of juvenile 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.~~

[13] 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).

[14] ~~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.~~

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 (Wooton,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

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

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

where R_t represents estimates of total annual recruits for year t, and S_t are annual estimates of adult spawners. F_t represents any covariates evaluated, and γ_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.

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 4). 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 model runs 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 4). 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 4. 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
	γ 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
	β density-dependence	2.061 (10^{-5})	8.44 (10^{-5})	0.24	0.811	
	γ 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
	γ 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
	β density-dependence	2.75 (10^{-5})	8.15 (10^{-5})	0.03	0.97	
	γ 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
	γ 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
	β density-dependence	1.85 (10^{-5})	8.9 (10^{-5})	-0.21	0.84	
	γ 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
	β 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
	β density-dependence	1.87 (10^{-5})	1.36 (10^{-4})	4.51	0.89	

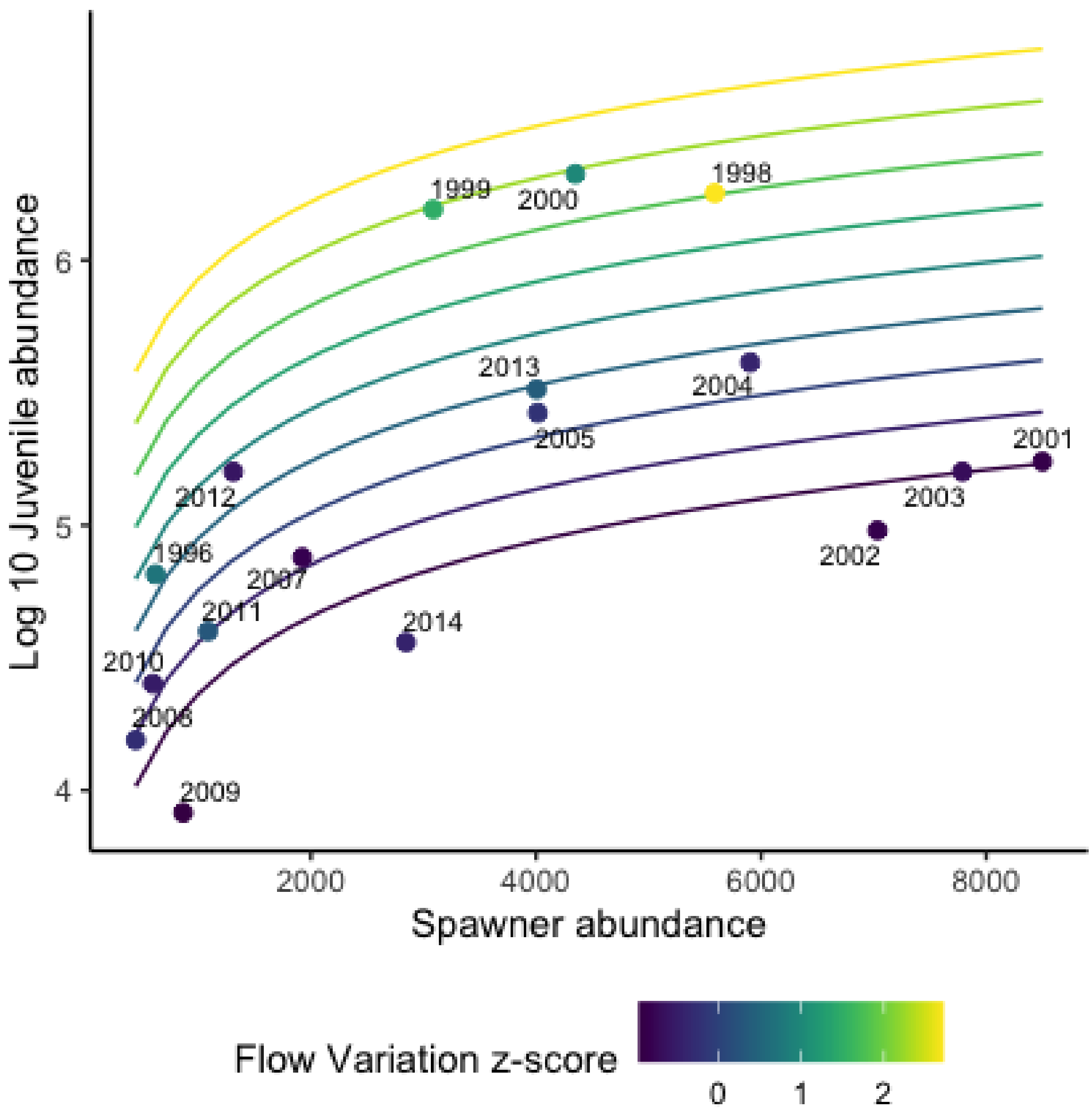

Figure 1. Beverton-Holt flow variation covariate model predictions for juvenile Chinook salmon recruitment on the Stanislaus River from 1996-2014 (data points). Y-axis represents log 10 transformed juvenile abundance and the x-axis represents spawner abundance. Colored lines represent the effect of flow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

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 5). 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 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 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 6. 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 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 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 6. 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	

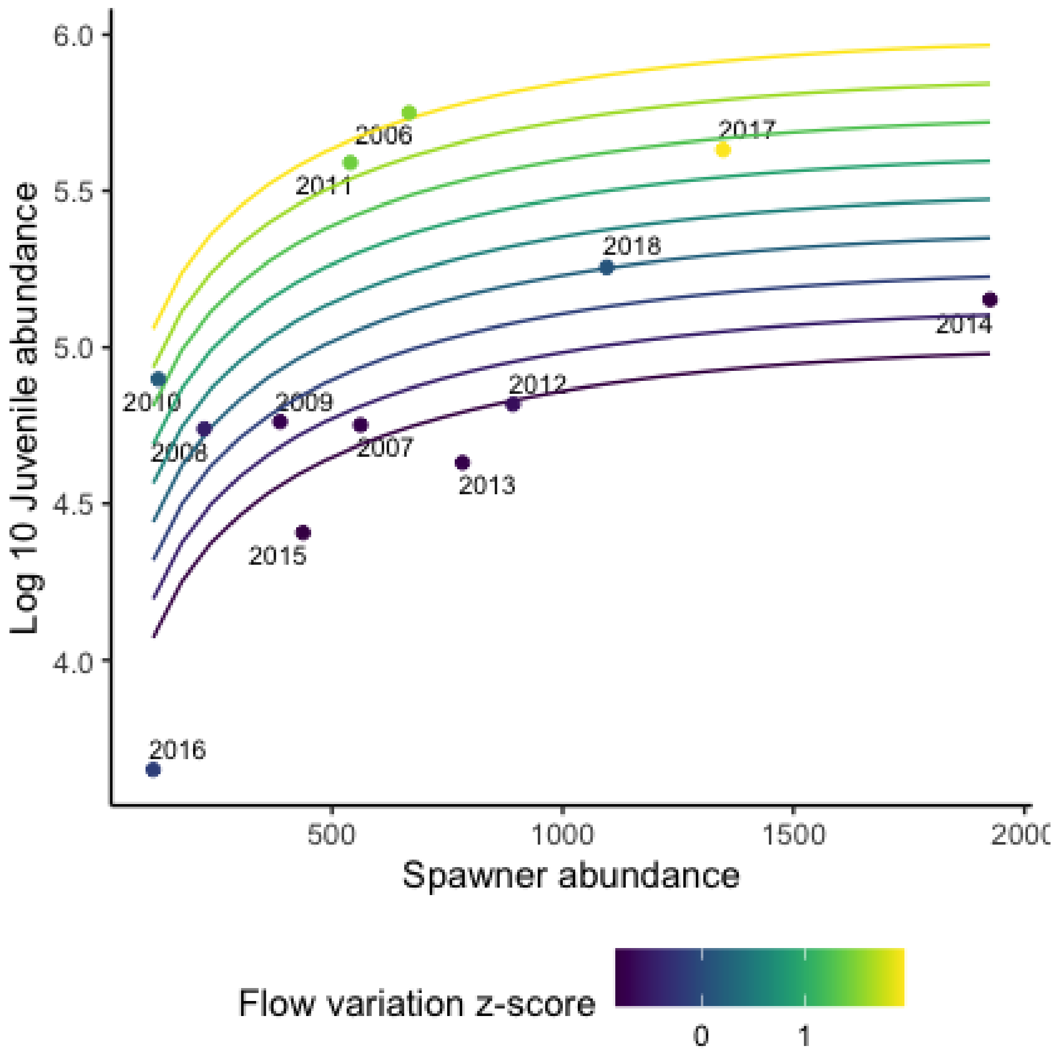

Figure 2. Ricker flow variation covariate model predictions for juvenile Chinook salmon recruitment on the Tuolumne River from 2006-2018 (data points). Y-axis represents log 10 transformed juvenile abundance and the x-axis represents spawner abundance. Colored lines represent the effect of flow variation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

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 17,000 adult female salmon based on peak fry densities (FERC, 2019). 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.

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 (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 are 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 ~~(phenotypic)~~ 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~~, or near 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 ~~have~~ locally ~~adapted gene complexes that~~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 ~~“pollutes”~~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). 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).

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.

~~The first~~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 and reduce pHOS and increase PNI.

Table 47 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 47. LSJR Fall-Run Chinook Salmon pHOS Genetic Diversity Goals

Genetic Diversity Metric	Goal	Progress Assessment
pHOS	Decreasing trend, as a 5-year running average[14]	Assessed on an ongoing basis
pHOS	≤ 50%, as a 3-year running average	Year 9 after beginning of implementation
pHOS	≤ 20%, as a 3-year running average[15]	Year 15 after beginning of implementation

3.3.2 Life History Diversity Goals

Life history diversity for salmonid species can be ~~defined~~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 ~~times~~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[16] of the Central Valley system leave their natal rivers and streams at ~~difference~~varying sizes, times of the year, and ages. It is thought that this life history variation contributes to ~~their population~~ 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. ~~Individuals with distinct~~However, current flow management actions tend to select for a single

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[14] 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.

[15] 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 13, page 69.

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

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 ~~may experience differential survival and thus~~(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 ~~a~~the population's overall 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; ~~and~~ 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 ~~5~~8 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).

Table ~~5~~8. LSJR Fall-Run Chinook Salmon Juvenile Emigration Timing Goals

Juvenile Size Class* (Phenotype)	~~Life History Diversity Goal~~ ~~Emigration~~ Positive Detection Each Week near Mouth of Each Tributary	Progress Assessment
Fry	Last week of January to second week of April[17]	Year 6, incremental progress Year 9, additional incremental progress Year 15, achieve the goal
Parr	First week of February to last week of May[18]	Year 6, incremental progress Year 9, additional incremental progress Year 15, achieve the goal
Smolt	Third week of February – first week of June[19]	Year 6, incremental progress Year 9, additional incremental progress Year 15, achieve the goal

* Size classes are defined as fry ~~≤ 45~~< 55 millimeters (mm); parr ~~46-90~~55 - 75 mm; smolt >~~90~~75 mm.

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 ~~fish.~~Chinook salmon. Recent advances in techniques analyzing chemical markers recorded in otoliths ~~enable~~have enabled reconstruction of the movement patterns of individual fish. In the Central Valley system, the otolith mineral ~~analysis~~analyses using various elements (strontium isotope ratio, $^{87}Sr/^{86}Sr$; Sr/Ca and Ba/Ca)[20] ~~and~~combined with radius measurements ~~combined could be~~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. ~~In the Stanislaus River, juveniles are sampled at the RST located in the river channel adjacent to Caswell Memorial State Park.~~

Table ~~6~~ 9 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).~~ 2015, 2020). The

[17]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.

[18] Ibid.

[19] Ibid.

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

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 ~~6~~9. 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 Size Class* Minimum Percentage as a 3-Year Running Average at the Mouth of the Tributary~~Wys	Below Normal, Dry, and Critical WYs ~~Size Class Minimum Percentage as a 3-Year Running Average at the Mouth of the Tributary~~	Progress Assessment
Fry ≥ 20%[21]	Fry ≥ 20%[22]	Year 6, incremental progress
Parr ≥ 20%[23]	Parr ≥ 30%[24]	Year 9, additional incremental progress
Smolt ≥ 10%[25]	Smolt ≥ 20%[26]	Year 15, achieve the goal

* Size classes are defined as fry ~~≤ 45~~<55 mm; parr ~~46-90~~55 - 75 mm; smolt >~~90~~75 mm.

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

[21] 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.

[22] Ibid.

[23] Ibid.

[24] Ibid.

[25] Ibid.

[26] Ibid.

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 approach for spatial structure biological goals 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

Estimates of naturally spawning fall-run salmon in the San Joaquin River drainage, 1967-1991 (N.E. = No Estimate) from Mills and Fisher (1994) and Escapement Goal calculations.

	Stanislaus River			Tuolumne River			Merced River		
Year	grilse	adults	total	grilse	adults	total	grilse	adults	total
1967	345	11,540	11,885	333	6,467	6,800	141	459	600
1968	3,620	2,765	6,385	6,510	2,090	8,600	310	240	550
1969	308	12,019	12,327	580	31,620	32,200	25	575	600
1970	2,585	6,712	9,297	3,146	15,254	18,400	1,584	3,116	4,700
1971	913	12,708	13,621	1,444	20,441	21,885	142	1,448	1,590
1972	443	3,855	4,298	857	4,243	5,100	399	2,129	2,528
1973	49	1,185	1,234	93	1,896	1,989	169	628	797
1974	246	504	750	99	1,051	1,150	71	929	1,000
1975	172	1,028	1,200	136	1,464	1,600	207	1,493	1,700
1976	134	466	600	165	1,535	1,700	79	1,121	1,200
1977	0	0	0	0	450	450	29	321	350
1978	17	33	50	94	1,206	1,300	89	436	525
1979	6	94	100	123	1,060	1,183	253	1,667	1,920
1980	17	83	100	53	506	559	80	2,771	2,851
1981	24	976	1,000	4,504	9,749	14,253	2,733	6,758	9,491
1982	N.E.	N.E.	N.E.	378	6,748	7,126	68	3,006	3,074
1983	250	250	500	12,195	2,641	14,836	12,603	3,850	16,453
1984	4,438	7,001	11,439	7,246	6,556	13,802	6,165	18,495	24,660
1985	1,252	12,070	13,322	1,452	38,870	40,322	1,083	13,758	14,841
1986	1,001	4,887	5,888	503	6,785	7,288	381	5,142	5,523
1987	2,265	4,027	6,292	13,748	1,003	14,751	1,390	1,505	2,895
1988	494	11,850	12,344	311	6,038	6,349	190	2,570	2,760
1989	57	1,911	1,968	45	1,229	1,274	25	104	129
1990	191	301	492	21	75	96	6	18	24
1991	106	166	272	8	45	53	30	89	119
Average	789	4018	4807	2162	6761	8923	1130	2905	4035
Doubling multiplier			x2			x2			x2
Escapment goal (pre-rounding)			9,614			17,845			8,070

Appendix B: Technical Stock Recruitment analysis for Lower San Joaquin River Tributaries

Methods

All statistical analyses were performed using R Studio Version 1.2.5033.

R packages used for this analysis:

Fisheries Stock Assessment (FSA): FSA provides R functions to conduct typical introductory fisheries analyses. For this analysis, the following FSA R function was used (Ogle et al. 2020):

> srStarts(): This function finds reasonable starting values for parameters in specific parameterizations of the "Beverton-Holt" and "Ricker" stock-recruitment models. The outputs of srStarts are used as starting estimates to determine the nonlinear (weighted) least-squares estimates of the parameters (i.e., α and β) of the stock-recruitment models.

Data Preparation

Data Sources

Chinook salmon spawner escapement data were acquired from the CDFW GrandTab database to represent the number of parental stock. GrandTab is a compilation of escapement estimates of late-fall, winter, spring, and fall-run Chinook salmon in California's Central Valley. Estimates are based on counts of fish entering hatcheries and migrating past dams, carcass surveys, live fish counts, and ground and aerial redd counts. Escapement estimates from 1996-2014 were acquired for the Stanislaus River and 2006-2018 for the Tuolumne River.

Juvenile outmigration data were acquired from rotary screw trap (RST) operations to represent the number of recruits for each river. Rotary screw traps are used to monitor and estimate abundance and migration characteristics of juvenile salmonids. On the Stanislaus River data were used from the RST operated near Caswell State Park from 1996-2014 (Sturrock et al. 2019). On the Tuolumne River, data were used from the RST operated near the town of Waterford, California from 2006-2018 (TMID 2018). This analysis focuses on better understanding the relationship between parental stock and juvenile outmigrants within the tributaries to the San Joaquin River. Ideally, the data used for the analysis would be from a RST located near the confluence with the San Joaquin River, as is the case with the Stanislaus River. However, on the Tuolumne River, data were used from the RST located near Waterford instead of the RST located downstream near Grayson, which abundance estimates were inconsistent due to low flows, inadequate water depth, and heavy debris loads of water hyacinth (TMID 2018).

Flow and temperature data were acquired from U.S. Geological Survey gauging stations 113030000 (Stanislaus River) and 1129000 (Tuolumne River) located near the confluence with the San Joaquin River (https://waterdata.usgs.gov/nwis) to represent environmental variables that may influence stock-recruitment relationships and increase model predictive ability. Daily mean flow between January 1 – June 30 were computed for each year as an indicator of general hydrological conditions during the bulk of the rearing and outmigration period for juvenile Chinook salmon. Flow variation (mean of the 7-day running mean of daily maximum minus daily minimum flow) for the January – June period was used as a metric that could account for both flow volume and flow variability (i.e., flow pulses) during the rearing and outmigration period (Sturrock et al. 2020). For use in the stock-recruitment models, the flow statistics were standardized by converting the flow metrics for each year to z-scores so that the average flow values were zero (Munsch et al. 2020b).

Water temperature statistics were computed by averaging the daily maximum temperatures for six different time periods to determine whether temperature conditions during certain periods exhibited possible influences on juvenile productivity (Jan-Jun, Feb-Jun, Jan-Mar, Jan-Apr, May-Jun, and Sept-Oct). The spring periods were selected because they encompass the rearing and outmigration period for juvenile Chinook salmon, and these periods also represent when juvenile fish are likely to encounter warmer water conditions during the spring (Fisher 1994). The September to October time period was included to examine the possible effects of fall temperatures on adult spawners and subsequent juvenile productivity.

Stock Recruitment Models

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

$R_t = \alpha * S_t$, Density-independent
$R_t = (\alpha * S_t / 1 + \beta * St) + y_F * F_t$, Beverton-Holt
$R_t = \alpha * S_t * \exp(-\beta * S_t) + y_F * F_t$, Ricker

where R_t represent estimates of total annual juvenile recruits for year t, and S_t are annual estimates of adult spawners. F_t 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.

Non-Linear Least Squares Regression

Non-linear least squares regression (NLS) was used to estimate final parameters for both the Beverton-Holt and Ricker Models. NLS is a useful tool because it can produce unbiased parameter estimates regardless of the distribution and variance of error values. The relationships between an ecological response (i.e., juvenile recruitment) and drivers (i.e., parental stock, water temperature, and flow) are often non-linear in nature, which makes the application of NLS particularly useful over traditional linear models (Munsch et al. 2020a). Indeed, non-linear relationships are well documented in salmonid ecology, including the non-linear effect that water temperature, flow, and predation have on juvenile salmonid mortality, habitat occupancy, and survival (Munsch et al. 2020a). NLS uses an iterative algorithm and initial starting values to estimate the parameters of the stock-recruitment models. Fitting NLS models with different error structures can lead to different parameter estimates. Quinn II and Deriso (1999) suggested that the multiplicative error model should be the default choice for the Beverton-Holt and Ricker models. Therefore, both the dependent and independent variables of the stock-recruitment models were log transformed to achieve a multiplicative error structure (i.e., log-normal errors).

Akaike Information Criterion

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 which gives the minimum AIC was considered the most parsimonious and best-fit model.

Results

Stanislaus River

Table 1. 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
	γ 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
	β density-dependence	$2.061\ (10^{-5})$	$8.44(10^{-5})$	0.24	0.811	
	γ 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
	γ 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
	β density-dependence	$2.75\ (10^{-5)}$	$8.15\ (10^{-5})$	0.03	0.97	
	γ 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
	γ 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
	β density-dependence	$1.85\ (10^{-5})$	$8.9\ (10^{-5})$	-0.21	0.84	
	γ 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
	β 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
	β density-dependence	$1.87\ (10^{-5})$	$1.36\ (10^{-4})$	4.51	0.89	

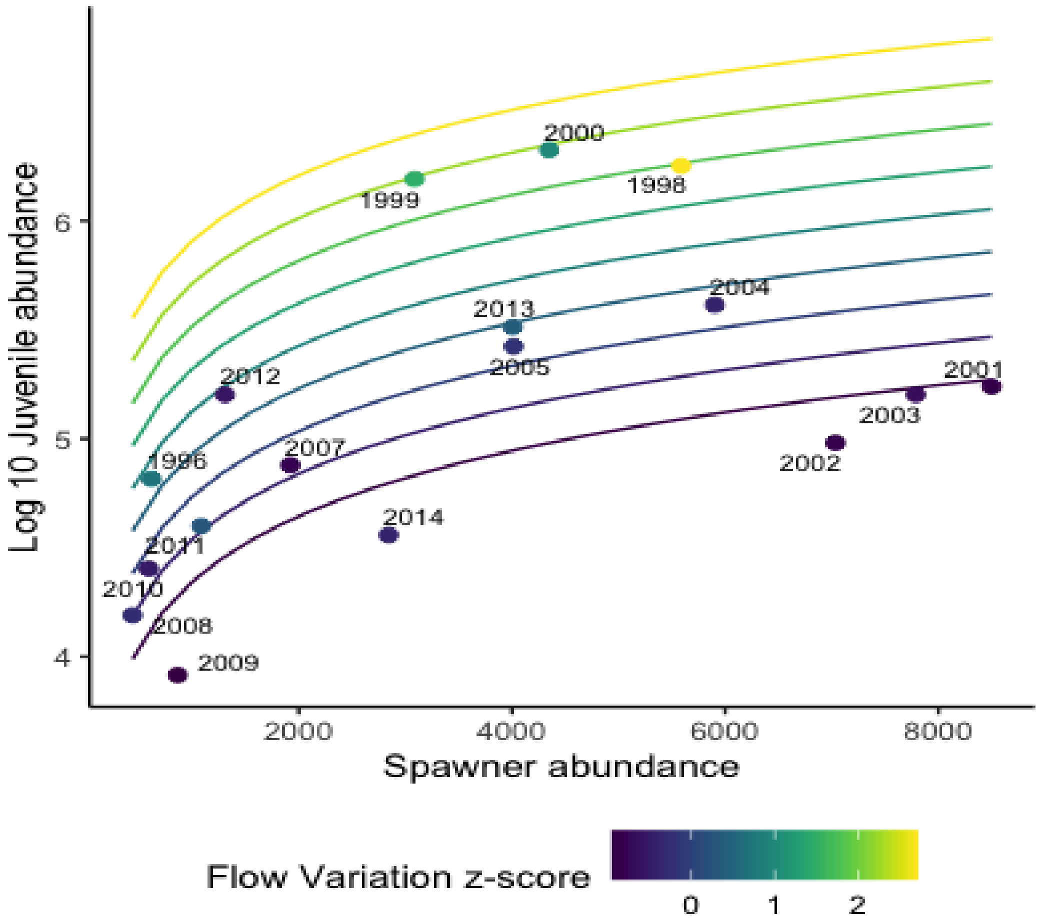

Figure 1. Density-independent flow variation covariate model predictions for juvenile Chinook salmon recruitment on the Stanislaus River from 1996-2014 (data points). Y-axis represents log 10 transformed juvenile abundance and the x-axis represents spawner abundance. Colored lines represent the effect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

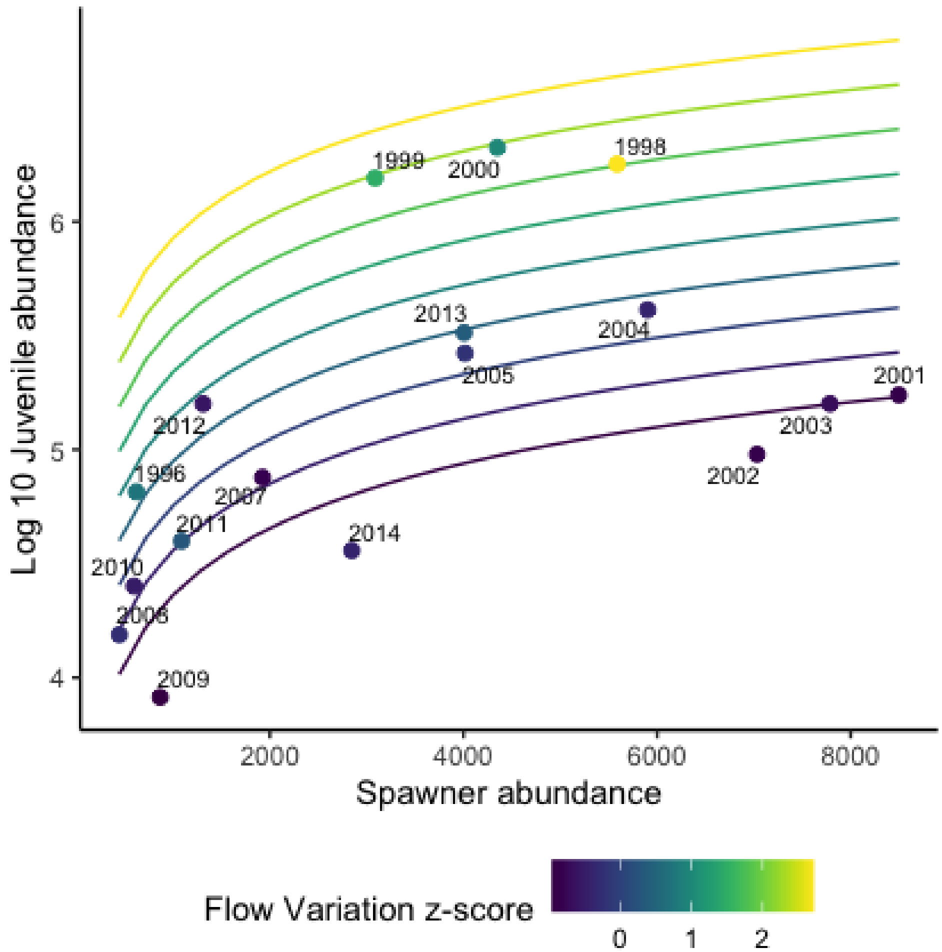

Figure 2. Beverton-Holt flow variation covariate model predictions for juvenile Chinook salmon recruitment on the Stanislaus River from 1996-2014 (data points). Y-axis represents log 10 transformed juvenile abundance and the x-axis represents spawner abundance. Colored lines represent the effect of flow variation on the SR relationship with darker colors (purple) indicating lower flow variability and lighter colors (yellow) representing higher flow variability.

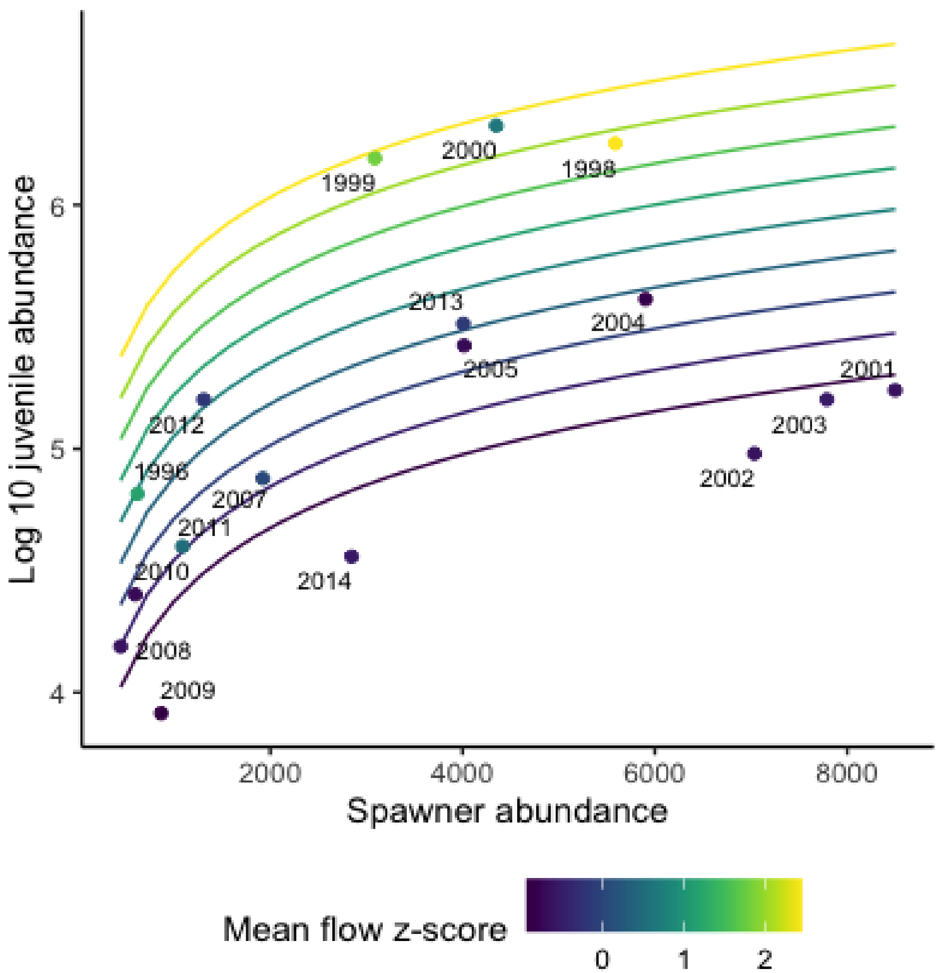

Figure 3. Density-independent mean flow covariate model predictions for juvenile Chinook salmon recruitment on the Stanislaus River from 1996-2014 (data points). Y-axis represents log 10 transformed juvenile abundance and the x-axis represents spawner abundance. Colored lines represent the effect of flow on the SR relationship with darker colors (purple) indicating lower mean flow and lighter colors (yellow) representing higher mean flow.

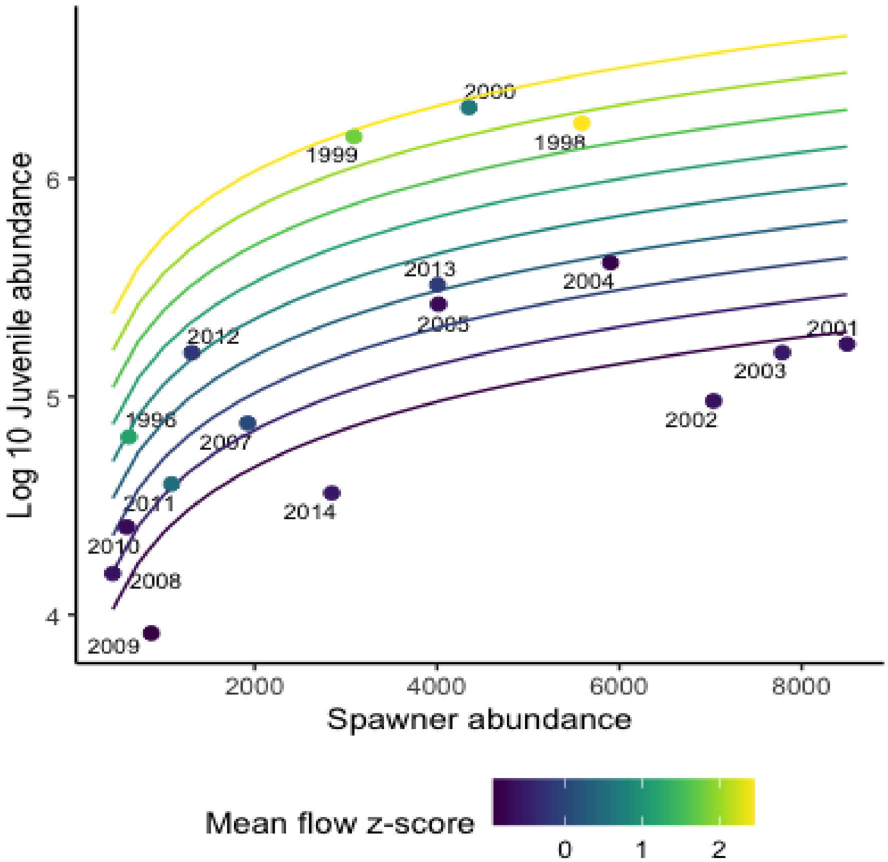

Figure 4. Beverton-Holt mean flow covariate model predictions for juvenile Chinook salmon recruitment on the Stanislaus River from 1996-2014 (data points). Y-axis represents log 10 transformed juvenile abundance and the x-axis represents spawner abundance. Colored lines represent the effect of flow on the SR relationship with darker colors (purple) indicating lower mean flow and lighter colors (yellow) representing higher mean flow.

Table 2. Results of AIC for density-independent water temperature covariate ranges on the Stanislaus River

Water temperature period	AIC	Change in AIC
February-June	25.58	0
January-June	26.25	0.67
May-June	26.74	.94
January-March	28.45	2.87
September-October	28.88	3.3
January-April	29.58	4.0

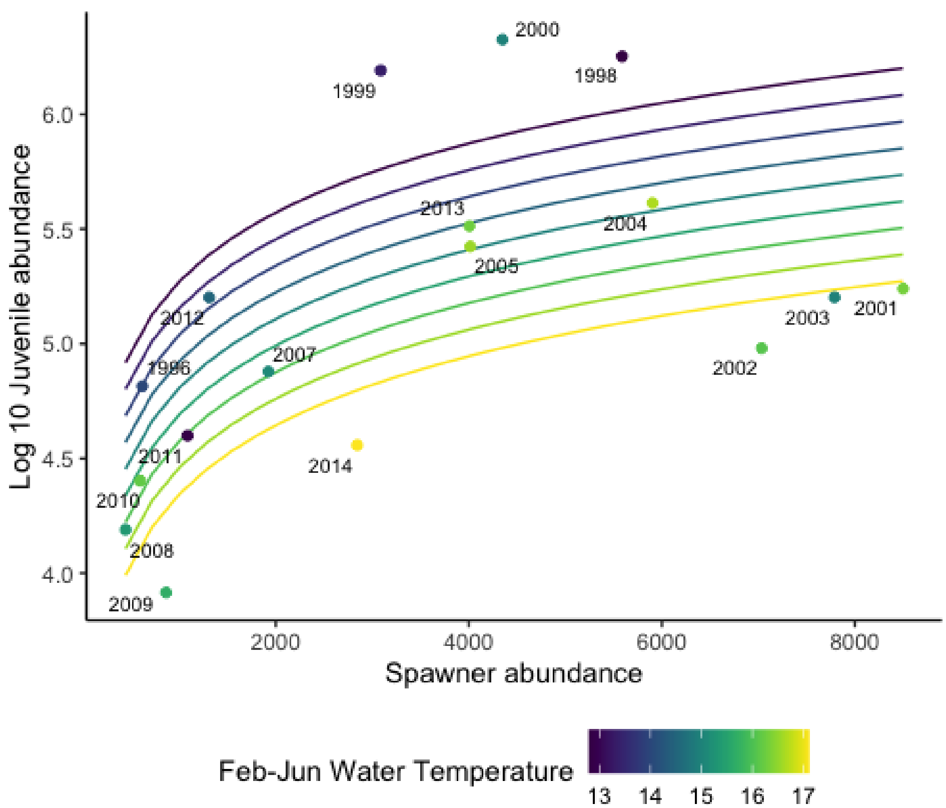

Figure 5. Density-independent water temperature covariate model predictions for juvenile Chinook salmon recruitment on the Stanislaus River from 1996-2014 (data points). Y-axis represents log 10 transformed juvenile abundance and the x-axis represents spawner abundance. Colored lines represent the effect of February to June water temperature on the SR relationship with darker colors (purple) indicating cooler water temperatures variability and lighter colors (yellow) representing warmer water temperatures.

Table 3. Results of AIC for Beverton-Holt water temperature covariate ranges on the Stanislaus River

Water temperature period	AIC	Change in AIC
February-June	27.51	0
January-June	28.16	0.65
May-June	28.72	1.21
January-March	30.38	2.87
September-October	30.86	3.35
January-April	31.57	4.06

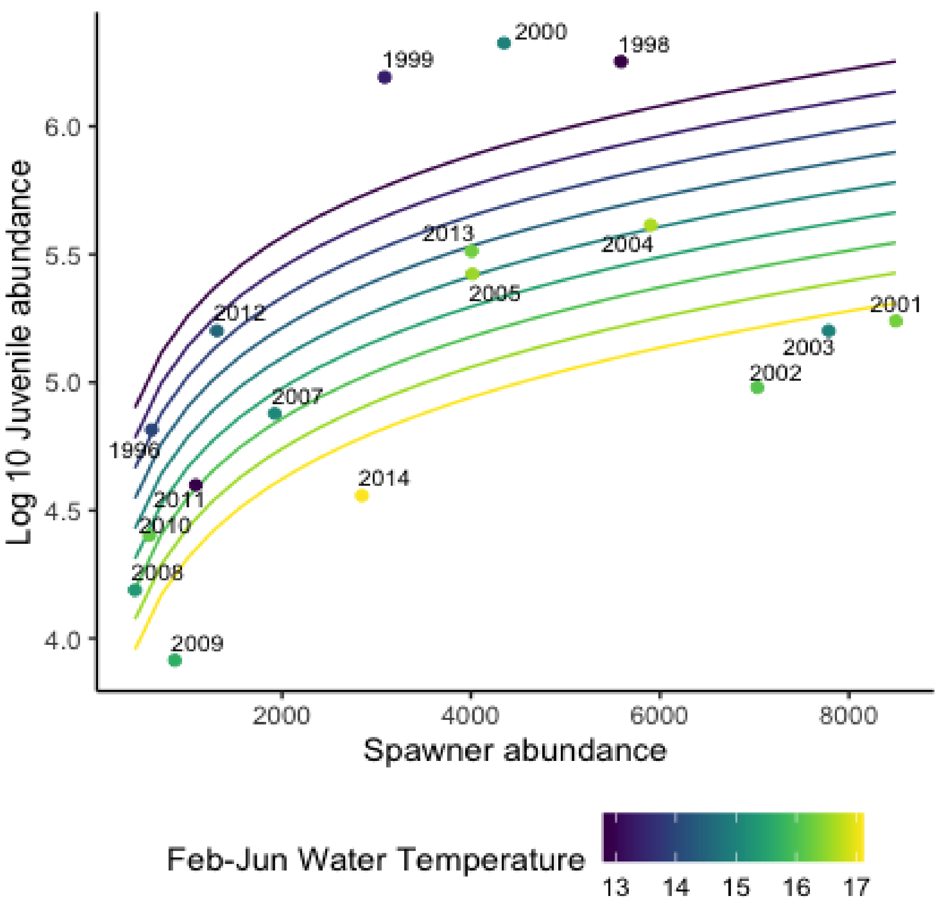

Figure 6. Beverton-Holt water temperature covariate model predictions for juvenile Chinook salmon recruitment on the Stanislaus River from 1996-2014 (data points). Y-axis represents log 10 transformed juvenile abundance and the x-axis represents spawner abundance. Colored lines represent the effect of February to June water temperature on the SR relationship with darker colors (purple) indicating cooler water temperatures variability and lighter colors (yellow) representing warmer water temperatures.

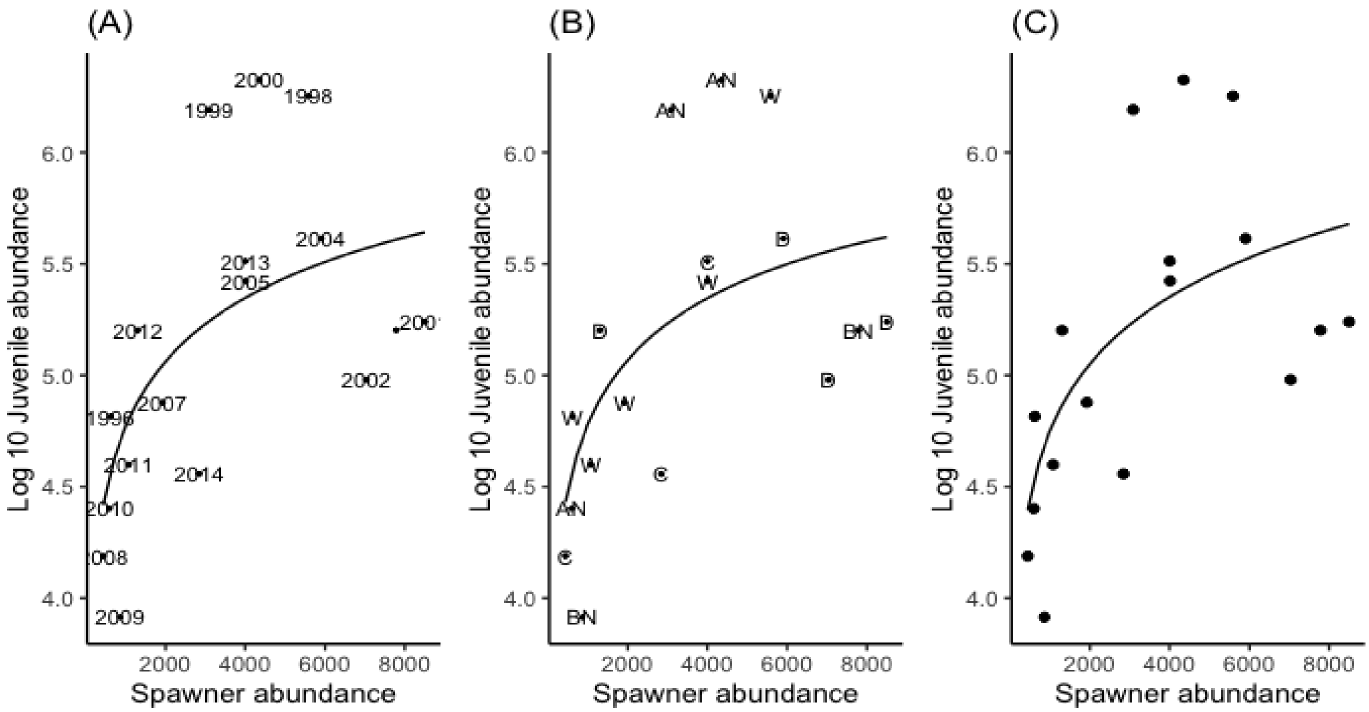

Figure 7. Stock-recruit models (no covariate) predictions for juvenile Chinook salmon recruitment on the Stanislaus River from 1996-2014. Y-axis represents log 10 transformed juvenile abundance and the x-axis represents spawner abundance. (A) is the Beverton-Holt model with data points labeled with the outmigration year, (B) is the Ricker model, and (C) is the density-independent model. (B) data point labels show observed water year type such that W is wet, AN is above normal, BN is below normal, D is dry, and C is a critical water year type.

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, so only the Ricker analysis is presented.

Table 4. 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 5. 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
	γ 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
	β density-dependence	9.54 (10^{-5})	2.60 (10^{-4})	0.37	0.72	
	γ water temperature	-0.07	0.01	-6.1	p<0.001	

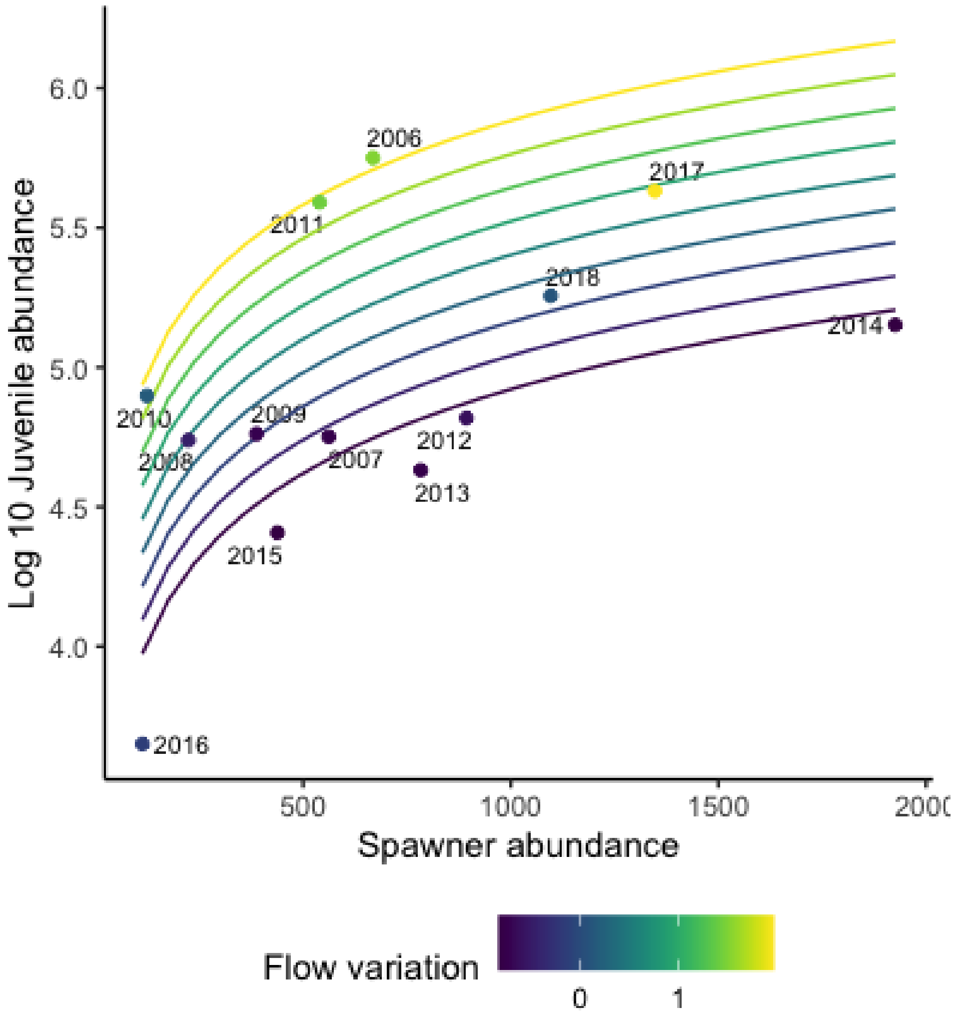

Figure 8. Density-Independent flow variation covariate model predictions for juvenile Chinook salmon recruitment on the Tuolumne River from 2006-2018 (data points). Y-axis represents log 10 transformed juvenile abundance and the x-axis represents spawner abundance. Colored lines represent the effect of flow variation on the SR relationship with darker colors (purple) indicating lower flow variability and lighter colors (yellow) representing higher flow variability.

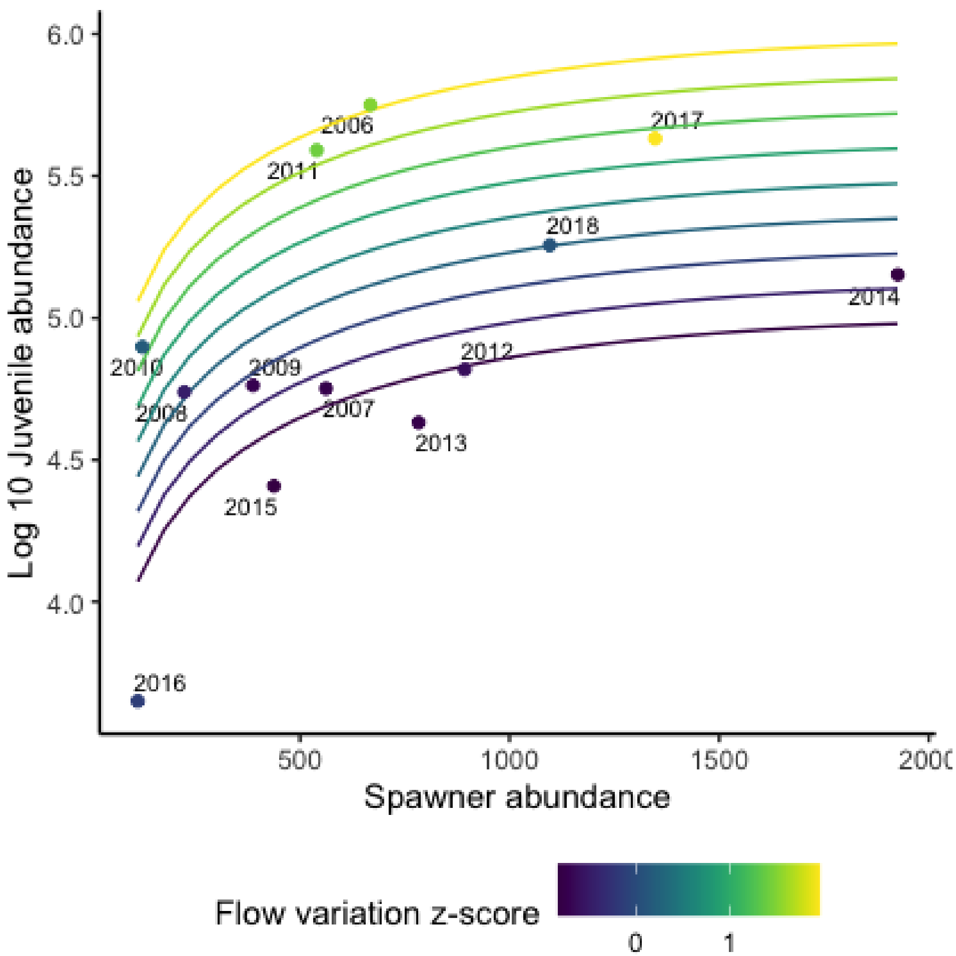

Figure 9. Ricker flow variation covariate model predictions for juvenile Chinook salmon recruitment on the Tuolumne River from 2006-2018 (data points). Y-axis represents log 10 transformed juvenile abundance and the x-axis represents spawner abundance. Colored lines represent the effect of flow variation on the SR relationship with darker colors (purple) indicating lower flow variability and lighter colors (yellow) representing higher flow variability.

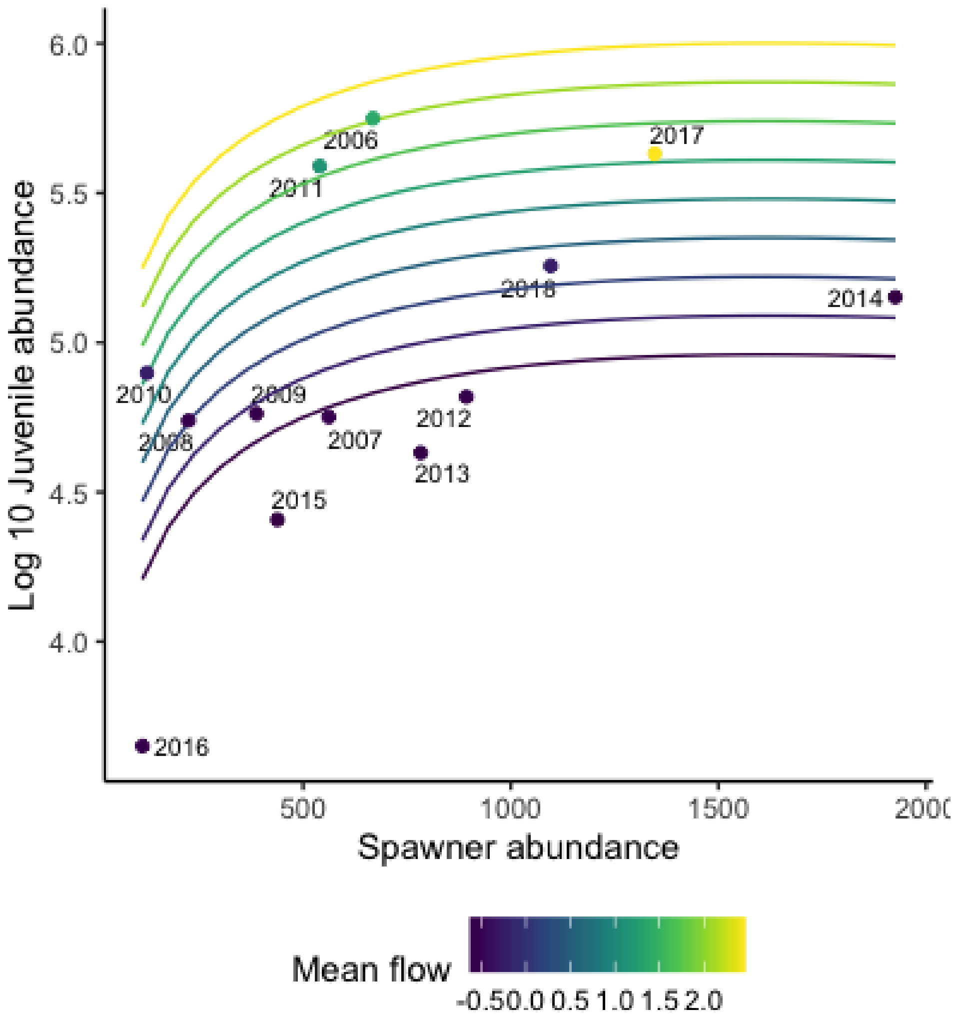

Figure 10. Ricker mean flow covariate model predictions for juvenile Chinook salmon recruitment on the Tuolumne River from 2006-2018 (data points). Y-axis represents log 10 transformed juvenile abundance and the x-axis represents spawner abundance. Colored lines represent the effect of flow on the SR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

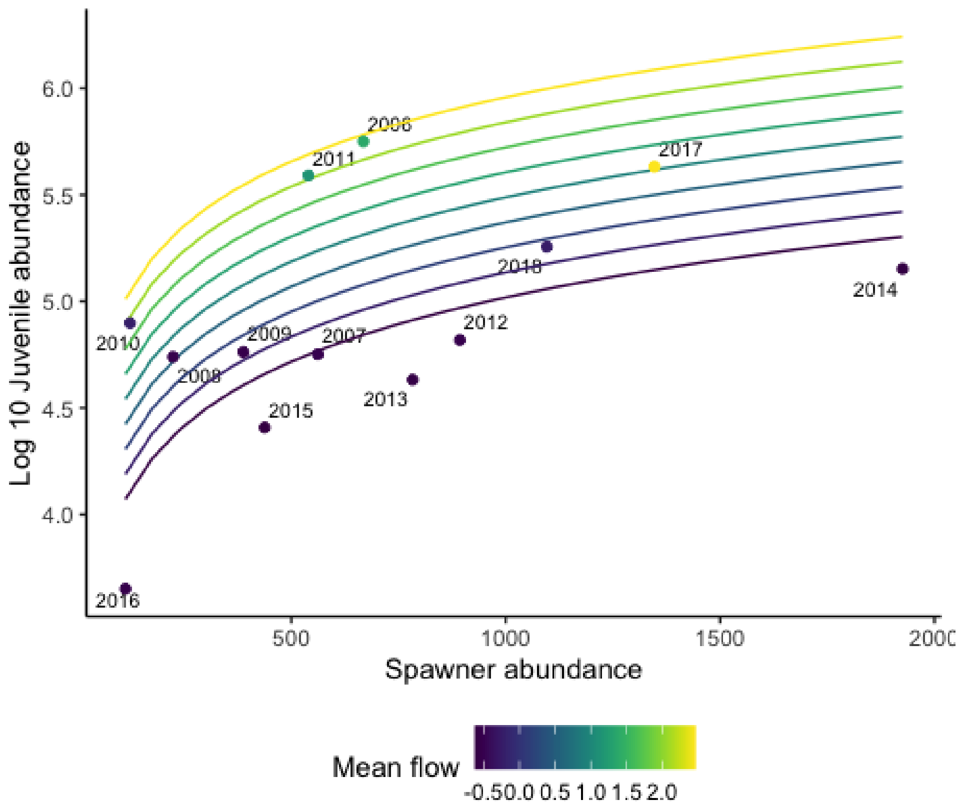

Figure 11. Density-independent mean flow covariate model predictions for juvenile Chinook salmon recruitment on the Tuolumne River from 2006-2018 (data points). Y-axis represents log 10 transformed juvenile abundance and the x-axis represents spawner abundance. Colored lines represent the effect of flow on the SR relationship with darker colors (purple) indicating lower mean flow and lighter colors (yellow) representing higher mean flow.

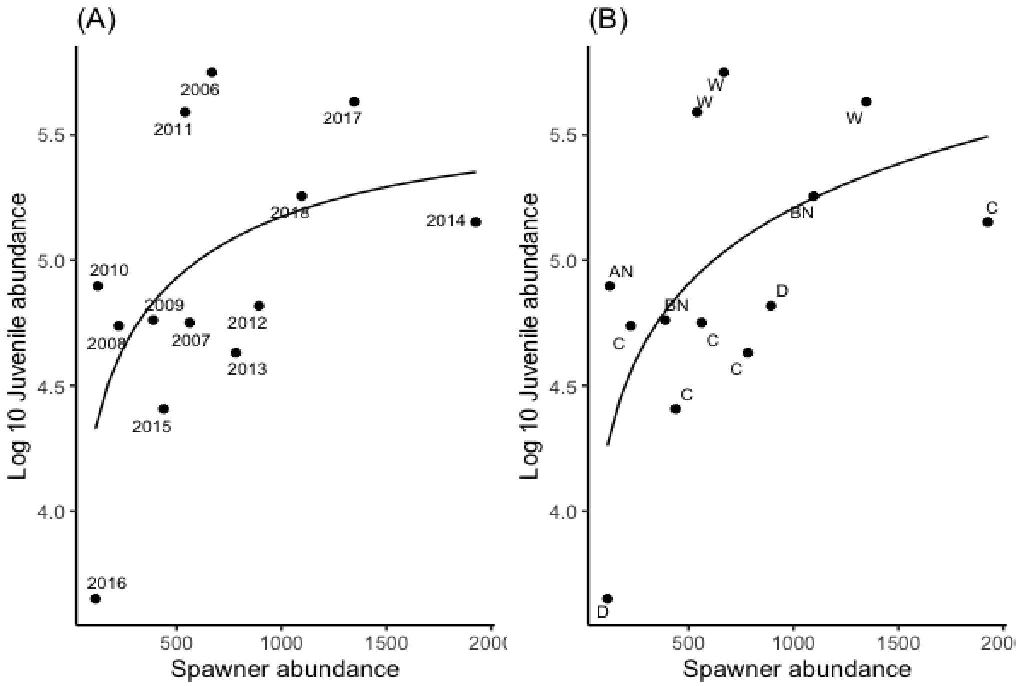

Figure 12. Stock-recruit models (no covariate) predictions for juvenile Chinook salmon recruitment on the Tuolumne River from 2006-2018. Y-axis represents log 10 transformed juvenile abundance and the x-axis represents spawner abundance. (A) is the Ricker model with data points labeled with the outmigration year, (B) is the density-independent model with labeled with observed water year type such that W is wet, AN is above normal, BN is below normal, D is dry, and C is a critical water year type.

Table 6. Results of AIC for density-independent water temperature covariate ranges on the Tuolumne River

Water temperature period	AIC	Change in AIC
May-June	-1.62	0
February-June	2.20	3.82
January-June	2.63	4.25
January-April	7.89	9.51
January-March	11.02	12.64
September-October	12.16	13.78

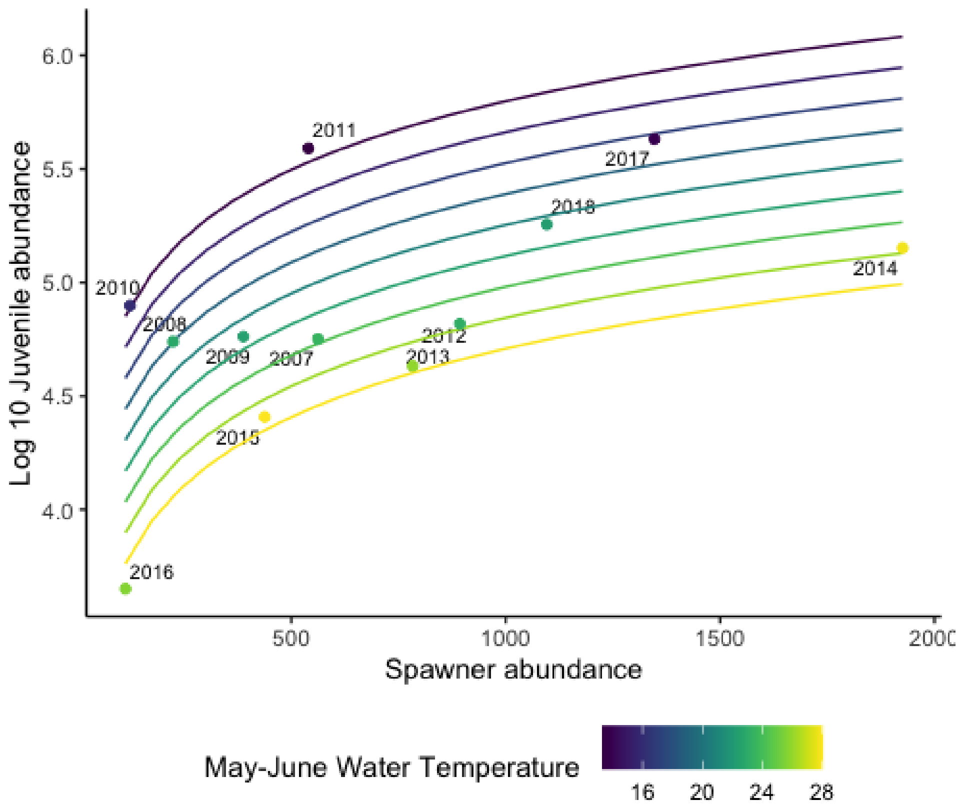

Figure 13. Density-independent water temperature covariate model predictions for juvenile Chinook salmon recruitment on the Tuolumne River from 2006-2018 (data points). Y-axis represents log 10 transformed juvenile abundance and the x-axis represents spawner abundance. Colored lines represent the effect of water temperature on the SR relationship with darker colors (purple) indicating cooler water temperatures and lighter colors (yellow) representing warmer water temperatures.

Table 7. Results of AIC for Ricker water temperature covariate ranges on the Tuolumne River

Water temperature period	AIC	Change in AIC
May-June	0.21	0
February-June	3.25	3.04
January-June	3.66	3.45
January-April	7.87	7.66
January-March	11.29	11.08
September-October	18.6	18.39

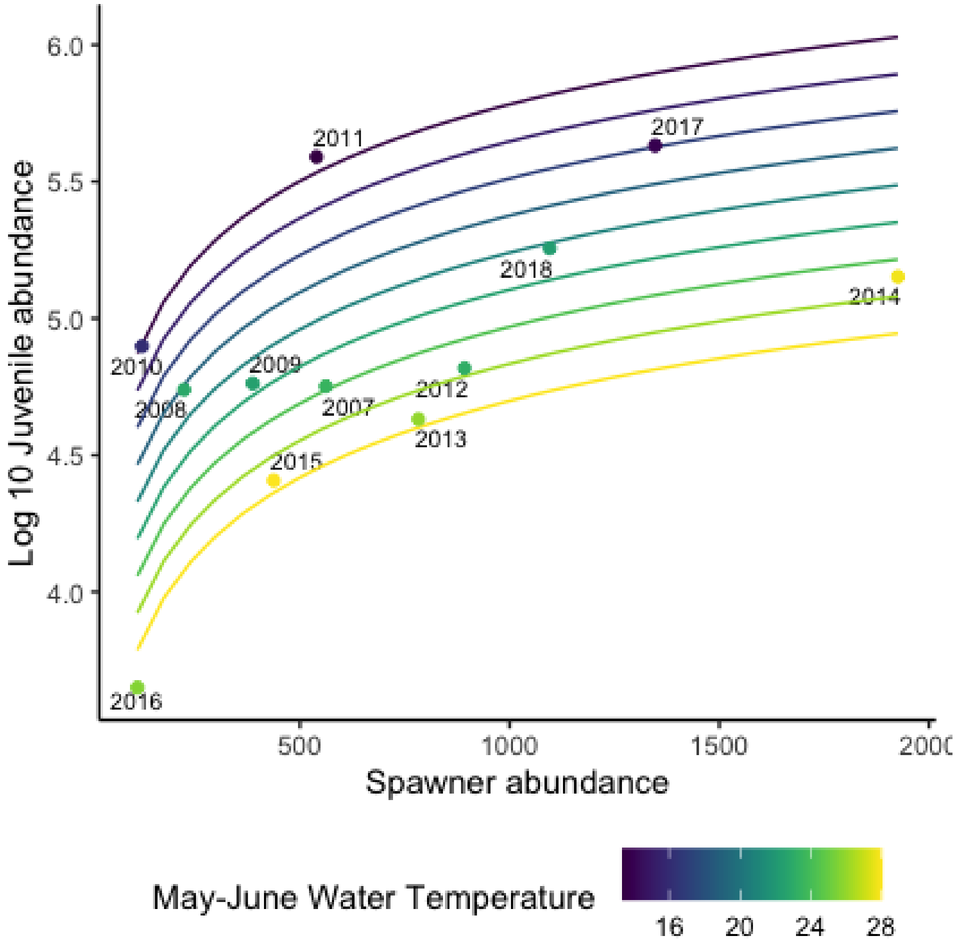

Figure 14. Ricker water temperature covariate model predictions for juvenile Chinook salmon recruitment on the Tuolumne River from 2006-2018 (data points). Y-axis represents log 10 transformed juvenile abundance and the x-axis represents spawner abundance. Colored lines represent the effect of water temperature on the SR relationship with darker colors (purple) indicating cooler water temperatures and lighter colors (yellow) representing warmer water temperatures.

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