Draft Voluntary Agreement Science Program

Contents

Preface

Document Purpose

This document is a preliminary draft of the Science Plan which, in final form, will be content for Exhibit E to the Global Voluntary Agreement. The Systemwide Governance Committee provides this draft to the State Water Resources Control Board for information, as the Board prepares its Staff Report to update the Bay-Delta Plan. The purpose of the Draft Science Plan is to provide the framework and specific approach for evaluating the outcomes of the Flow and Non-flow Measures and ultimately to inform the State Water Board's assessment in Year 8 of the VA Program as described in the March 29, 2022, MOU and Term Sheet. The VA Parties will update this document as necessary following the public review process, including to address comments received.

Voluntary Agreement Draft Science Program

1 Introduction and Background

The Voluntary Agreements (VA or VAs) Program, described in the March 29, 2022, Term Sheet, is an alternative Program of Implementation for the Sacramento River, Delta, and Tributary update to the San Francisco Bay/Sacramento-San Joaquin Delta Water Quality Control Plan. The scientific rationale for the VA approach of providing both environmental flows and habitat improvements for native fishes is described in the 2023 Draft Scientific Basis Report Supplement in Support of Proposed Voluntary Agreements for the Sacramento River, Delta, and Tributaries Update to the San Francisco Bay/Sacramento-San Joaquin Delta Water Quality Control Plan (2023 Draft Scientific Basis Report Supplement), and the forthcoming Draft Scientific Basis Report for the Tuolumne River.

1.1 Voluntary Agreement Science Program and Governance

The VAs include formation of a VA Science Program, guided by the VA Science Committee. The VA Science Program is a coordinated collective of tributary- and Delta-focused monitoring and research programs relevant to understanding the outcomes of VA implementation that has several high-level functions:

- To inform decision-making by the Systemwide Governance Committee, Tributary/Delta Governance Entities, and VA Parties;
- To track and report progress relative to the metrics described in Section 2 of this document;
- To reduce management-relevant uncertainty; and
- To provide recommendations on adjusting management actions to the Systemwide Governance Committee, Tributary/Delta Governance Entities and VA Parties.

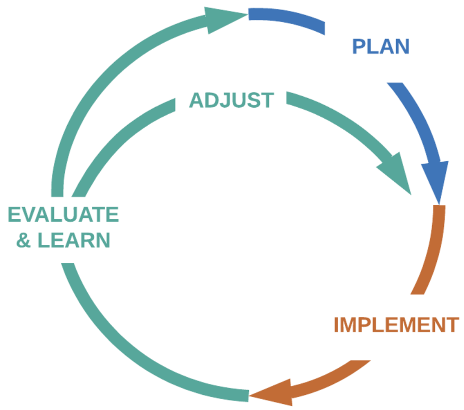
Individual tributary and Delta science programs will play a key role in generating the base of information necessary to support these functions. Tributary and Delta-specific science plans will provide the detailed guidance for monitoring VA actions by leveraging existing tributary monitoring networks. The primary role of the VA Science Program will be to work toward increasing consistency over time in how these tributary- and Delta-focused programs track progress relative to metrics described in this Plan, to enable a broad and synthetic understanding of the outcomes of VA actions. The VA Science Committee will play a key role in building this consistency by advising on project- and tributary-specific science and monitoring plans, and by directing VA funding (through recommendations to the Systemwide Governance Committee) into specific improvements in the monitoring network. For example, the VA Science Committee will review project-specific science and monitoring plans and will recommend changes to ensure that priority management-relevant uncertainties (i.e., those that are most relevant to informing implementation of VA Flow and Non-flow Measures) are appropriately evaluated, and that the data are collected in a way that facilitates a consistent dataset across watersheds. This consistency will in turn enable a system-wide evaluation of the ecosystem response to similar habitat enhancement or flow actions taken in different tributary systems. This broader geographic scale of evaluation will inform the triennial reports in Year 3 and Year 6 required in the VA Term Sheet. Additionally, consistent data collection practices across systems will provide robust empirical data needed to enhance predictive modeling tools, such as life cycle models, which are necessary for simulating the effect of future management actions and informing adaptive management of VA actions.

As described in the Term Sheet, the State Water Board will, in Year 8 of the Program, assess whether to continue or modify the VA Program in consideration of a range of factors related to progress on implementation of VA commitments, availability of required permitting and funding, and protection of flows. In addition, and most relevant to the Science Program, the State Water Board will also consider whether synthesis reports and analyses produced by the VA Science Program support the conclusion that continuation of the VA Program, together with other actions in the Bay-Delta Plan, will result in attainment of the Narrative Objectives. Information collected by the VA Science Program on the biological and ecological outcomes of the VA actions will be instrumental to supporting the State Water Board's assessment of the effects of the VA Program but will not solely determine success or failure of the VA program.

The purpose of this Science Plan is to provide the framework and specific approach for evaluating the outcomes of the flow and non-flow measures and for addressing several important and broad-scale ecosystem management questions, described in the next section. The hypotheses and associated monitoring described in this Science Plan are intended to be thorough to describe a full range of potential approaches to assessing the biological and environmental outcomes; however, it is not anticipated that every flow and non-flow action will address each relevant hypothesis. Instead, this document is intended to provide guidance to the VA Science Committee as it develops recommendations for priority areas of focus for additional monitoring, active experiments, decision support modeling, and data analyses needed to fill knowledge gaps, assess the outcomes of the suite of VA measures, and inform ongoing and future decision making.

1.2 Adaptive Management and Decision Support for VA Flow and Non-Flow Measures

Figure 1. Adaptive management cycle



The VA Parties are committed to learning and adaptation over time with the goal of developing better, innovative, and long-term solutions and outcomes for native fish and wildlife. As such, the VA Parties are committed to learning from the implementation of VA flow and non-flow measures over the 8-year term of the VA Program and using this knowledge to inform future decisions about VA actions. Prior to the end of the 8-year term, the knowledge gained through the implementation of the VAs is expected to inform either a renewal of the VA Program and/or a Bay-Delta Plan update.

Adaptive management in the VA Science Program describes an approach to testing priority hypotheses related to the effects of the suite of VA measures and applying the resulting information to improve future management and regulatory decisions. The foundation of the VAs approach to adaptive management is articulated in a set of spatially nested Big Questions, which include:

- **Big Question 1**: Will implementation of individual VA flow and non-flow measures have the intended physical and biological effects at the site scale – and if not, why not?
- **Big Question 2**: Will the combination of VA flow and non-flow measures within a tributary result in improved tributary-level outcomes for native fish (e.g., juvenile production)?
- **Big Question 3**: Will changes in fish outcomes at the tributary scale result in improved population-level outcomes in support of the State Water Board's Narrative Objectives?

Collectively, these Big Questions articulate a bottom-up approach to understanding the aggregated effects of site-specific actions that VA Parties have taken in support of the Narrative Objectives. Section 2 elaborates on these questions further in Sections 2.2 through 2.4 of this Science Plan, which articulate specific hypotheses about the expected changes in key metrics relative to relevant pre-action baselines or reference sites. Observed or modeled changes relative to these metrics (summarized in Table 1) will be the primary means through which the VA Science Committee assesses progress relative to the core objectives of the VA Program and informs decisions both within and at the end of the term of the VA about whether and how to modify implementation. A variety of methods including monitoring, modeling, and field experimentation (e.g., mesocosm experiments) will enable assessment of the effectiveness of the VA actions in achieving the anticipated ecological and biological effects.

It is anticipated that through testing hypotheses and assessing progress relative to metrics described in this plan and synthesizing learning across tributaries, the VA Science Committee will contribute to:

- Improved understanding of the ecological response to the suite of VA actions at multiple spatial scales, in recognition of (a) the longer time required for restoration actions to mature, and (b) the relatively long lifecycles of some native fish species (e.g., Chinook salmon and Central Valley white sturgeon) relative to the term of the VA;
- Recommendations to modify VA Flow and Non-flow Measures within the term of the VA, in light of observed effects, to improve outcomes; and
- Refinement of existing and/or development of new decision support models to enable predictions of the effects of continued or modified VA actions in support of the State Water Board's assessment process near the end of the VA term and/or related decision making by VA Parties.

1.3 General Description of Proposed VA Actions

In general terms, the VA Program includes new flow and non-flow measures (including habitat restoration), to support the Narrative Objectives and implement the Bay-Delta Plan. This section briefly describes the nature of the flow and non-flow actions. More detail on the flow measures, including the default flow schedule, is provided in the Flow Measures Description; similarly, further detail on the non-flow measures, including descriptions of the kinds of projects and the implementation schedule, is provided in the Non-Flow Measures Description. The general descriptions below are intended to provide context for the following sections and aid the reader's understanding of the connection between the VA measures and the predicted effects.

1.3.1 Flow Measures

New flows will be provided with two main categories of intended benefits:

- **Flow actions for improved salmonid outcomes in the tributaries:** These flows are intended to provide a range of improved habitat conditions for fish populations in the tributaries by activating constructed spawning and rearing habitats, improving upstream and/or downstream migration conditions, and reducing pressures from both physical (e.g., depth, velocity), and non-physical habitat conditions such as pathogen loads. Timing of these flow actions varies by tributary. Specific anticipated benefits vary by tributary and are related to the anticipated timing of flow.
- **Flow actions for managed species benefits in the Delta:** Flows from tributaries and reduced Delta exports are provided with the intent to increase Delta outflow January to June (dependent on water year type), and during April and May in particular, to benefit a range of species and ecosystem processes. Flow actions may also include targeted provision of enhanced Delta outflow for specific Delta regions with a goal of improving habitat conditions for species of interest, such as Delta and Longfin Smelt.

1.3.2 Non-Flow Measures

A wide variety of non-flow measures have been proposed by Tributary and Delta Entities to augment the provision of flows in line with the comprehensive approach taken by the VA Program.

- **Tributary Chinook salmon spawning habitat restoration:** Restoration actions for enhancing Chinook salmon spawning habitat involve provision of additional spawning gravel in areas accessible to adult salmon, as well as adjustments to river morphology to create riffles typical of spawning areas. Restoration efforts will include improvements to existing spawning areas, and/or maintenance of previously restored areas.
- **Tributary Chinook salmon in-channel rearing habitat restoration:** Restoration actions for enhancing Chinook salmon rearing habitat in the channel involve the creation and enhancement of perennially inundated side-channel and other low-velocity habitats to provide improved and diversified rearing conditions.
- **Tributary Chinook salmon floodplain rearing habitat restoration:** Restoration actions for enhancing Chinook salmon rearing habitat on floodplains involve providing access to improved and diversified rearing habitats on a seasonal basis.
- **Fish passage improvements:** Fish passage improvements can reduce migration delay or improve access to habitat for both juvenile and adult migratory fishes. Actions to improve fish passage can include improvements to high priority instream structures such as dams, weirs, or culverts, screening of surface water diversions, or channel morphology adjustments to improve critical riffle depth for adult passage.
- **Predator management:** Actions to reduce the impact of predators on target species include physical restrictions on predator access (e.g., weirs), eliminating predator refugia, and direct removal of predators through seining or other collection methods.
- **Delta/Bypass floodplain restoration and seasonal flooding of agricultural land**: Restoration actions for floodplain habitats in the Bypasses and in the Delta involve providing access to improved and diversified rearing habitat conditions on a seasonal basis for a wide variety of native fish species. In addition to providing a greater area with suitable physical conditions for target native fish species, these actions are also intended to support improved ecosystem processes (e.g., zooplankton production) that support a suite of native aquatic species.
- **Tidal wetlands restoration:** Restoration actions for tidal wetlands in the Delta include a suite of actions to improve shallow-water habitat for native fish spawning and rearing, and to restore ecosystem function including increased production of zooplankton and macroinvertebrate taxa that support growth of native fishes.

2 Hypotheses, Metrics, and Baselines for Evaluating Outcomes of Voluntary Agreement Actions

2.1 General Framework for Hypotheses

The VA Science Plan is based on hypotheses that state the expected outcome of VA actions. To set into motion an adaptive management cycle, the hypotheses must be accompanied by metrics, which can be evaluated to assess whether the intended benefits are being realized in the ecosystems and native species populations of the VA tributaries and Delta. Given that the flow and non-flow actions of the VAs occur at varying spatial scales, and that target species (e.g., Chinook salmon) have multi-year generation times, hypotheses must also reflect the various spatial and temporal scales of the intended benefits. To this end, hypotheses are developed at three basic spatial and temporal "tiers" (Figure 2):

- **Local Tier: Effects of Non-flow Habitat Improvement Actions**. These hypotheses will test: (1) implementation of proposed habitat enhancements (i.e., whether the habitat improvement was implemented according to design); (2) whether it is providing improved habitat conditions with respect to both biotic and abiotic conditions; and (3) whether the site is being utilized by native fishes (Chinook salmon, Delta Smelt, Longfin Smelt, as well as other native species) in a way that is consistent with predictions. These sets of hypotheses are organized by the specific type of habitat project undertaken (e.g., Chinook Salmon spawning habitat, fish passage improvements, tidal wetlands). These hypotheses are evaluated at a sub-annual or annual scale.

- **Full Tributary and Delta Tier**: These hypotheses are developed to test predictions of how flow actions in the tributaries and the Delta will benefit native species. Additional hypotheses at this tier address how flow and non-flow actions in aggregate will contribute to changes in productivity of juvenile Chinook salmon within tributaries. For salmon, hypotheses are limited to the juvenile life stages, because these life stages reflect biological responses within the "zone of influence" of VA actions on the tributaries; that is, the species responses evaluated at this tier do not yet involve out-of-basin influences. Flow-specific hypotheses are generally evaluated at an annual scale. However, trends in the productivity of tributaries for juvenile salmon must be evaluated over several years.
- **Population-level Tier:** These hypotheses prompt evaluation of general population trends at both the tributary and system-wide (Sacramento and San Joaquin Valleys, and full Central Valley) spatial scales. At this tier, the VA parties recognize that population-level responses may not be observed during the term of the VAs because the non-flow actions will be incrementally implemented over the proposed eight-year period, and that time frame may not be sufficient to observe population-level responses. Furthermore, the occurrence of stochastic events or inter-annual variability in abiotic conditions could obfuscate trends in biological responses over the relatively short time frame. Additionally, out-of-basin factors that include ocean conditions, climate-induced changes to air temperature and hydrology, non-native species, and hatchery and harvest practices, can all influence population-level responses and these factors are outside of the control of VA parties. For these reasons, metrics provided at population-level tier are intended for tracking purposes regarding the narrative objectives. Because these hypotheses and metrics involve the full life span of native species, trends in these metrics will be reviewed on a temporal scale of 3 or more years.

Throughout the hypotheses (at all tiers), essential covariates are noted that must be tracked (e.g., water temperature) to analyze their potential impact on biological responses. These covariates are generally outside the control of the VA parties but may influence the success of the VA actions. If VA actions are not achieving predicted outcomes, covariate data may help explain the reason. Trends in covariate data as well as statistical models utilizing covariate data along with the data required for evaluating the metrics for predicted responses to VA actions will be reported in VA Science Program products, including the Triennial reports planned for Years 3 and 6 of VA implementation. These analyses will be evaluated in adaptive management processes, including prioritization of further investment in flow and non-flow actions.

The hypotheses are not written for specific VA actions and shall not be the sole metric for determining VA success; instead, the VA Science Plan hypotheses provide a generalized framework for how each action should be assessed, including specific metrics to be used. Identified VA actions will have their own specific monitoring and science plans that are responsive to the VA Science Plan framework and VA participants may propose to add, modify, or exclude hypotheses for specific VA actions. For example, additional details on an appropriate range of gravel sizes for spawning Chinook salmon habitat restoration actions may be based on the tributary-specific historical data of gravel sizes associated with active spawning and/or hydrogeomorphic conditions in each tributary, and this range may differ across tributaries. Action-specific monitoring and science plans will be provided as appendices to the Science Plan as they become available. The VA Science Plan hypotheses and metrics are written from a western science perspective, but the VA Science Committee hopes to support ongoing dialogue on interweaving western science and traditional and tribal knowledges that can inform Tribal-non-Tribal partnerships in restoration and management activities.

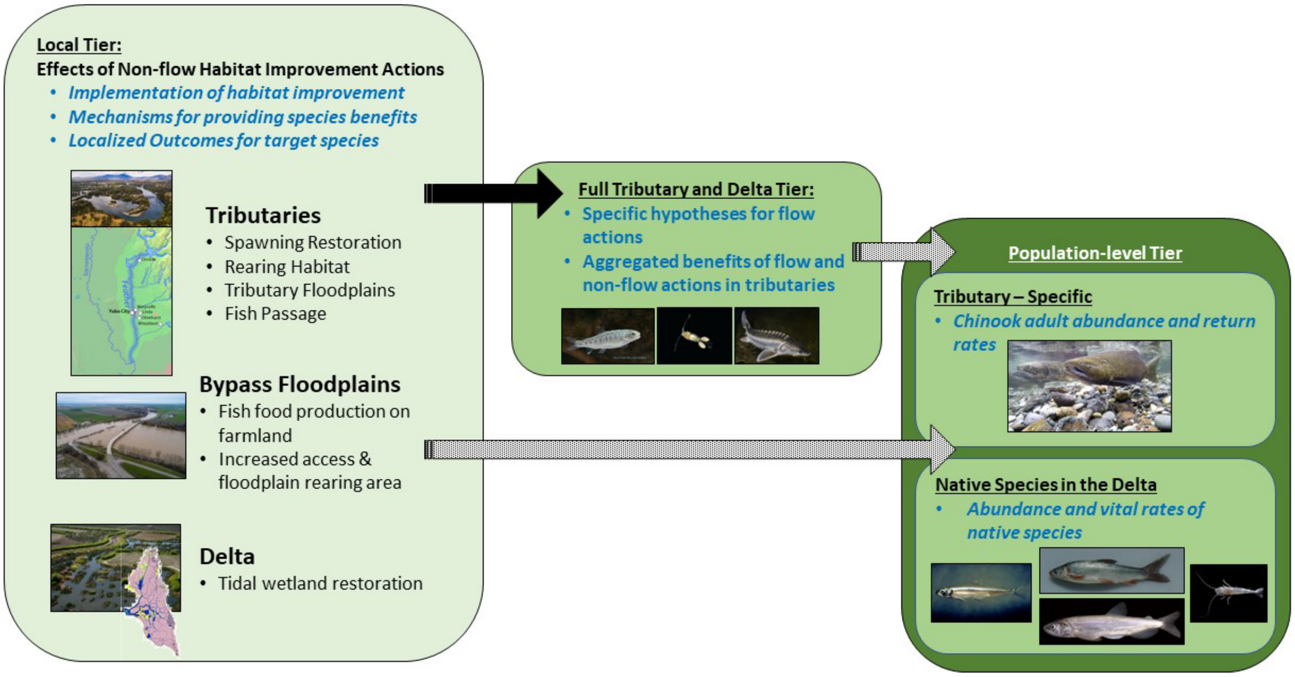


Figure 2 Tiered framework for hypothesis structure of the VA Science Plan. Local hypotheses will help inform the Full Tributary and Delta Tier hypotheses, as indicated by the black arrow. The gray arrows between the Local, Full Tributary and Delta, and Population-Level Tiers indicate increased uncertainty in population-level outcomes on the timeframe of the VAs.

Specific metrics are provided for each hypothesis and at all three tiers. To enable synthesis efforts to evaluate a suite of VA actions of a certain type (e.g., spawning habitat enhancements across multiple sites), where practicable it is important that the metrics, and the methods by which data are collected to produce the metrics, are consistent across monitoring efforts. Action-specific monitoring and science plans will identify how metrics (i.e., modeled or observational data) can be incorporated for testing hypotheses as part of decision support models evaluation of VA actions across local, tributary and Delta, and population-level tiers. Identification of metrics also facilitates the next portion of the VA Science Plan, which identifies where existing monitoring and science efforts provide the needed information, and where data gaps exist.

Finally, to guide analyses, it is necessary to set a baseline that will serve as a reference for understanding the impact of habitat improvements and/or flow deployments. Therefore, hypotheses and metrics are accompanied by a baseline that will guide analyses. Where appropriate, the 2023 Draft Scientific Basis Report Supplement is referenced for the baseline. In other cases, it is more appropriate to gather pre-project or reference site data for the needed metric.

Table 1. Summary of Voluntary Agreement Science Program Hypotheses, Metrics, Comparisons, and Covariates for Local, Full Tributary and Delta, and Population-Level Tiers. All hypotheses are explained in detail in Section 2 Hypotheses, Metrics, and Baselines for Evaluating Outcomes of Voluntary Agreement Actions**. Hypothesis ID subscripts indicate the Hypothesis Tier described in Figure 2 (**Subscripts of A, R, TribFP, Bypass FP, and TW **= Local Tier for Non-Flow Measures;** Subscripts of TribFlow, TribWide, and DeltaFlow **= Full Tributary and Delta Tier;** Subscripts of TribPop and SWPop **= Population-level Tier). *Indicates an Implementation Metric as described in Section 4.1.**

Action Type	Hyp. ID	Metric	Prediction	Basis for Comparison	Covariates
Spawning Habitat	H_{S1}	Spawning habitat acreage*	↑	Existing suitable habitat acreage, based on depth and velocity criteria from DEMs and hydraulic models	Flow, water temperature, and dissolved oxygen
Spawning Habitat	H_{S2}	Salmon redd density (#/unit area)	↑	Non-project, proximal reference sites measured concurrently	Flow, water temperature, and dissolved oxygen
Rearing Habitat	H_{R1}	Rearing habitat acreage*	↑	Existing suitable habitat acreage, based on depth and velocity criteria from DEMs and hydraulic models	Flow, water temperature and dissolved oxygen
Rearing Habitat	H_{R2}	Biomass density of secondary productivity (g/volume)	↑	Non-project, non-enhanced proximal reference sites measured concurrently	N/A
Rearing Habitat	H_{R3}, H_{R4}	Juvenile Chinook salmon densities (#/unit area)	↑	Proximal project and non-project reference sites measured concurrently	N/A
Tributary Floodplain	$H_{TribFP1}$	Tributary floodplain acreage subject to inundation*	↑	Existing floodplain acreage	Water temperature, dissolved oxygen, and flow
Tributary Floodplain	$H_{TribFP2}$	Biomass density of drift and benthic macroinvertebrates (g/volume)	↑	(1) Avg. densities for in-channel locations from historical record (2) In-channel locations measured concurrently with project areas	Water temperature, dissolved oxygen, water velocity, and indices of primary productivity
Tributary Floodplain	$H_{TribFP3}$	Juvenile salmon presence and densities (#/unit area or #/volume)	↑	Non-project, proximal reference sites measured concurrently	Water temperature and dissolved oxygen
Tributary Floodplain	$H_{TribFP4}$	Growth rate of juvenile salmon	↑	Derived through experimental work using caged fish	Water temperature, secondary productivity
Tributary Floodplain	$H_{TribFP5}$	Number of stranded juvenile salmon as a proportion of the tributary juvenile production estimate (JPE)	↔	(1) Historical estimates of stranding (2) Total population impact based on tributary JPE	N/A
Tributary Floodplain	$H_{TribFP6}$	Prevalence of native fish community (relative catch of	↑	Historical period of record for fish community sampling (seining, electrofishing, rotary screw traps)	N/A

Action Type	Hyp. ID	Metric	Prediction	Basis for Comparison	Covariates
		native fishes compared to non-native fishes)			
Fish Passage	**H_{Pass1}**	Water velocity at surface water diversions	↓	Pre-project water velocities Pre- and post-project velocities compared with NMFS 1997 criteria for fish passage	N/A
Fish Passage	**H_{Pass2}**	anadromous fish passage efficiency	↑	Pre-project passage efficiency data	N/A
Bypass Floodplain	**$H_{BypassFP1}$**	Acreage of shallow flooded ag land for invertebrate production and export (thru March 31)*	↑	Pre-project flooded acreage	N/A
Bypass Floodplain	**$H_{BypassFP2}$**	Zooplankton and macroinvertebrate densities (# and weight/unit volume)	↑	Adjacent riverine sites; upstream and downstream of field drainage locations	Dissolved oxygen in drained waters and the presence and concentrations of potential contaminants (i.e., pesticide residue, methylated mercury) in drainage water and in invertebrates
Bypass Floodplain	**$H_{BypassFP3}$**	Sulfur and carbon isotopic signature in diet, otoliths and/or eye lenses of juvenile Chinook salmon	↑	Experimental work using caged juvenile salmon exposed to varying levels of food items sourced from flooded ag land	N/A
Bypass Floodplain	**$H_{BypassFP4}$**	(1) Acreage of Bypass floodplain habitat* (2) Frequency of MFEs	↑	(1) Pre-project acreage (2) MFE frequency on historical record in SWRCB 2023 Sci Basis Draft Suppl Report	Water temperature, dissolved oxygen, and flow
Bypass Floodplain	**$H_{BypassFP5}$**	(1) Hydrologic connectivity with enhanced bypass floodplains (2) Juvenile salmon and native fish densities near bypass entry points	↑	(1) Estimated duration and frequency of hydrological connectivity before project implementation (2) Historical data on juvenile salmon densities during inundation	Water temperature, dissolved oxygen, turbidity, and predator (aquatic & avian) densities
Bypass Floodplain	**$H_{BypassFP6}$**	Number of stranded juvenile salmon as a proportion of the upstream JPEs	↔	(1) Historical estimates of stranding (2) Total population impact based on Sacramento Valley JPE (combined from tributary JPEs) – *pending modeling effort to produce this estimate.*	N/A

Action Type	Hyp. ID	Metric	Prediction	Basis for Comparison	Covariates
Bypass Floodplain	$H_{BypassFP7}$	(1) Number of adult anadromous fish observed to pass through major passage structures (2) Number of stranded adult anadromous fish observed at the base of major weir structures	↑	(1) Fish surveys for period of record for each major bypass (Yolo and Sutter). (2) Experimental, targeted studies examining behavior at weir modifications.	N/A
Tidal Wetlands	H_{TW1}	Tidal wetland habitat acreage*	↑	Modeled existing acreage of tidal wetland habitat, as described in the SWRCB 2023 Sci Basis Draft Suppl Report	Water temperature, turbidity, specific conductivity, pH, water residence time, and presence of CyanoHABs.
Tidal Wetlands	H_{TW2}	Densities of beneficial secondary production native fish diets zooplankton, epiphytic, and benthic invertebrates)	↑	Pre-project secondary production densities	Estimated quantity of water filtered by invasive clams
Tidal Wetlands	H_{TW3}	Community composition of native fish diets reflective of their sampled habitat	↔	Diet composition of native fish in proximate, non-project sites in pelagic and/or littoral habitat.	N/A
Tidal Wetlands	H_{TW4}	Condition factor and growth rate of native fishes	↑	Experimental studies using caged fish between tidal wetland and pelagic habitats	N/A
Tidal Wetlands	H_{TW5}	Presence of native fish	↑	Pre-project predator densities and/or non-project reference sites	Coverage of submerged and floating aquatic vegetation at entry/exit points of restored areas, density and movements of predators.
Tributary Flow Pulses	$H_{TribFlow1}$	Adult Chinook salmon fall upstream migration (spawner abundance/week)	↑	Weekly abundance estimates immediately before and after flow action	Water temperatures and dissolved oxygen
Tributary Flow Pulses	$H_{TribFlow2}$	Juvenile salmon outmigration rate	↑	Outmigration rates prior to flow action, same year	Fry density, fish size, turbidity, day length, PAR (sunlight), and temperature
Tributary Flow Pulses	$H_{TribFlow3}$	Juvenile salmon survival and travel time during outmigration	↑	Survival of acoustically tagged salmon during and outside of pulse flows	Water temperature, turbidity, and dissolved oxygen
Tributary Flow Pulses	$H_{TribFlow4}$	(1) *C. shasta* spore density (#/volume)	↓	Spore densities and infection rates two weeks prior to flow pulses, same year	Water temperature and dissolved oxygen

Action Type	Hyp. ID	Metric	Prediction	Basis for Comparison	Covariates
		(2) Clinical infection rate of *C. shasta* in juvenile salmon			
Tributary Juvenile Salmon Production	$H_{TribWide1}$	Trend # estimated outmigrating juveniles / female spawner (≥ 3 years)	↑	Annual values in historical data record prior to VA implementation	Flow, water temperatures and dissolved oxygen
Tributary Juvenile Salmon Production	$H_{TribWide2}$	Condition factor of emigrating Chinook salmon	↑	Available historical data for each tributary	N/A
Tributary Juvenile Salmon Production	$H_{TribWide3}$	Coefficient of variation in emigration timing and body size	↑	Available historical data for each tributary prior to VA implementation	N/A
Increased Spring Delta Outflow	$H_{DeltaFlow1}$	Acreage of suitable spawning and rearing habitat for Delta and Longfin Smelt	↑	Modeled habitat area without implementation of VA flow measures as described in the SWRCB 2023 Scientific Basis Draft Report Supplement	N/A
Increased Spring Delta Outflow	$H_{DeltaFlow2}$	(1) Larval and juvenile Longfin smelt distribution (2) Estimated larval and juvenile longfin smelt entrainment at South Delta facilities	1. ↑ 2. ↓	(1) Longfin smelt catch in Smelt Larval Survey and special studies (2) Modeled estimates of larval and juvenile longfin smelt entrainment across variable flow conditions in historical years	Water temperature, turbidity, and distribution/abundance of longfin smelt spawning stock
Increased Spring Delta Outflow	$H_{DeltaFlow3}$	Delta and longfin smelt entrainment; estimated proportional loss of juvenile Chinook salmon to entrainment	↓	Estimates of entrainment risk in historical years with conditions similar to VA flow measures but with lower outflows.	Population abundance, distribution, regional hydrodynamics, water quality, and water temperature.
Increased Spring Delta Outflow	$H_{DeltaFlow4}$	(1) Travel time of outmigrating juvenile salmon in the Delta (2) Juvenile salmon Delta survival	1. ↓ 2. ↑	(1) Published studies on acoustically tagged juvenile salmon survival and travel times, associated with known outflow levels (2) Experimental comparison of acoustically tagged salmon with and without VA outflows	Water temperature, dissolved oxygen, turbidity, submerged aquatic vegetation coverage along migration routes, and predator densities at critical junctures

Action Type	Hyp. ID	Metric	Prediction	Basis for Comparison	Covariates
Increased Spring Delta Outflow	$H_{DeltaFlow5}$	Annual proportion of juveniles with isotopic signature of floodplain rearing and growth	↑	Period of record for available samples (otoliths and/or eye lenses) that can be associated with known levels of Bypass inundation	Water temperature, turbidity and the timing, magnitude, and frequency of floodplain inundation
Increased Spring Delta Outflow	$H_{DeltaFlow6}$	White sturgeon age-0 and age-1 year class indices	↑	Period of record for age-0 and age-1 year class indices	N/A
Increased Spring Delta Outflow	$H_{DeltaFlow7}$	Freshwater-associated zooplankton densities in Western Delta and Suisun Marsh regions	↑	Regional sampled densities and community assemblage across datasets collecting zooplankton samples	Phytoplankton biomass density and composition, salinity, water temperature, and turbidity
Increased Spring Delta Outflow	$H_{DeltaFlow8}$	(1) Frequency, magnitude, severity of Harmful Algal Blooms (2) Cyanotoxin concentrations	↔	Period of record of cyanoHAB visual observations during routine monitoring surveys, and cyanotoxin data collected in special studies	Water temperature, turbidity, salinity, and nutrient concentrations/ratios, and Delta outflow
Tributary Adult Chinook Population	$H_{TribPop1}$	Isotopic signature of floodplain rearing in adult population, evident in otoliths and/or eye lenses	↑	Period of record of archived samples across a variety of flow conditions, including years with known Bypass inundation	N/A
Tributary Adult Chinook Population	$H_{TribPop2}$	Natural origin adult Chinook salmon population estimates by tributary, and trend in abundance (harvest plus escapement)	↑	(1) Tributary adult abundance estimates from AFRP Doubling Goal years (1967 – 1991) (2) Tributary adult abundance since 2010	N/A
Tributary Adult Chinook Population	$H_{TribPop3}$	Trend in the tributary Cohort Replacement Rate (CRR) for natural origin fish	↑	(1) Trend in the natural origin CRR in the period of record for each tributary (2) CRR since 2010	N/A
Systemwide Chinook Population	H_{SWPop1}	Annual Chinook salmon escapement and harvest for Sacramento and San Joaquin Valleys	↑	(1) Escapement + Harvest for AFRP Doubling Goal years (1967 – 1991) (2) Escapement + Harvest since 2010	N/A
Systemwide Chinook Population	H_{SWPop2}	Trend in CRR for natural origin fish for Sacramento and San Joaquin Valleys	↑	(1) CRR for AFRP Doubling Goal years (1967 – 1991) 2) CRR for Central Valley since 2010	N/A

Action Type	Hyp. ID	Metric	Prediction	Basis for Comparison	Covariates
Native Delta Species Populations	$\mathbf{H_{SWPop3}}$	Distribution and population estimates for native species (California Bay shrimp, Sacramento splittail, longfin smelt, Delta smelt)	↑	Species abundance indices from 2023 Draft Scientific Basis Report Supplement.	N/A
Native Delta Species Populations	$\mathbf{H_{SWPop4}}$	Estimated number of Longfin smelt larvae per number of spawning adults	↑	Period of record in historical data in years with consistently sample habitat area, associated with Delta outflow	N/A

2.2 Local Tier Hypotheses: Effects of Non-flow Habitat Improvement Actions in Tributaries and the Delta

2.2.1 Chinook Salmon Spawning Habitat Enhancement on Tributaries

Augmentation of spawning habitat on several tributary systems is expected to result in an increased number of redds in restored areas. The following hypotheses pertain to suitability of improved spawning habitat and the Chinook salmon response to increased habitat area.

H_{S1}: The area of suitable spawning habitat, conforming to specified depth and velocity criteria, will increase in habitat enhancement areas, at design flows.

The **metric** for this hypothesis will be the acreage of spawning habitat with suitable water depths and velocities, and sizes of spawning gravel. Spawning habitat criteria, including depth, velocity, and target spawning substrate size will be defined in the specific VA action science and monitoring plan and associated design documents. The suitable gravel size for spawning habitat will be a range and distribution of spawning substrate sizes specific to the spawning population and hydrogeomorphic conditions in each tributary.

Covariates to measure for a comprehensive assessment of the effective suitability of restored spawning habitat will include flow, water temperatures and dissolved oxygen to ascertain whether they are in an appropriate range for spawning and egg incubation throughout the applicable time periods for each tributary. Water temperature and dissolved oxygen will be measured concurrently at the project locations and in nearby reference sites used by Chinook salmon for spawning.

The **baseline** for this hypothesis evaluation will be the quantification of the existing spawning habitat area within the project area boundary (polygon). This quantification will be accomplished by using available (or newly developed) topographic mapping (digital elevation model, or DEM), and applying available hydraulic (preferably 2D) models to calculate water depths and velocities within each computational pixel within the project area boundary. Spawning habitat area according to water depth, velocity, and substrate criteria at design flows test the implementation of the VA actions for increasing spawning habitat, and the methodology for evaluating the total area of this habitat is detailed further in Section 3.1.4 of the Strategic Plan for the Proposed Agreements to Support Healthy Rivers and Landscapes on “Methods for Assessing VA Non-flow Measure Completion.”

H_{S2}: The density of Chinook salmon redds will increase in habitat enhancement areas compared to proximate, non-enhanced areas.

The **metric** for this hypothesis will be the number of Chinook salmon redds per unit area in habitat enhancement project areas, while also accounting for the potential for redd superimposition.

The **baseline** for this hypothesis will be the redd density and superimposition rate at habitat enhancement locations compared to adjacent areas within the same reach, measured concurrently along with water quality criteria. In systems where redd mapping has been conducted consistently at both project locations and adjacent, non-enhanced locations, historical data can also be leveraged to examine trends and changes in redd density after the enhancement action.

2.2.2 Habitat enhancements for in-channel and floodplain habitat on tributaries

Enhancement of in-channel rearing habitat for juvenile salmon in tributaries is expected to result in increased secondary productivity and increased utilization of rearing habitats. Hypotheses include the mechanisms through which this outcome for juvenile salmon are expected. Additional habitat enhancement actions in the tributaries include increased availability of floodplain areas and improvement of habitat access by resolving known barriers to anadromous fish passage. These latter actions are expected to benefit juvenile salmon as well as other native species.

2.2.2.1 Chinook Salmon In-channel Rearing Habitat

H_{R1}: **The area of juvenile rearing habitat within channels and in side-channels that conforms to specified water depth and velocity criteria will increase in habitat enhancement areas, at design flows.**

The **metric** for this hypothesis will be the acreage of in-channel and side channel rearing habitat conforming to water depth and velocity criteria. Rearing habitat criteria, including depth and velocity will be defined in the specific VA action science and monitoring plan and associated design documents.

Covariates to measure for a comprehensive assessment of the effective suitability of enhanced rearing habitat will include water temperature, dissolved oxygen, and flow to ascertain whether they are in an appropriate range for juvenile Chinook salmon rearing through the applicable time periods for each tributary and its relevant Chinook salmon runs. Water temperature and dissolved oxygen will be measured concurrently at the project locations and in nearby reference sites used by juvenile Chinook salmon for rearing.

The **baseline** for this hypothesis evaluation will be the quantification of the existing rearing habitat area within the project area boundary (polygon). This would be accomplished by using available (or newly developed) topographic mapping (DEM) and applying available hydraulic (preferably 2D) models to calculate water depths and velocities within each computational pixel within the project area boundary. Rearing habitat area according to water depth and velocity criteria test the implementation of the VA actions for increasing rearing habitat, and the methodology for evaluating the total area of this habitat is detailed further in Section 3.1.4 titled “Methods for Assessing VA Non-flow Measure Completion” of the Strategic Plan for the Proposed Agreements to Support Healthy Rivers and Landscapes.

To represent the existing (pre-project) suitable habitat, quantification will be based on the hydraulic (depth, velocity) suitability criteria. However, recognizing that the addition of cover elements within or near hydraulically suitable habitat results in higher quality rearing habitat, the combination of hydraulic and cover suitability will be addressed by a separate hypothesis (see H_{R3}).

H_{R2}: **Enhanced rearing habitat will have higher biomass density of secondary productivity (e.g., drift and benthic macroinvertebrates) compared to adjacent sites.**

The **metric** for this hypothesis will be biomass density (weight of invertebrates per unit volume sampled) of secondary productivity per unit of habitat in restored sites, both in-channel and in newly constructed side channels for rearing, compared to adjacent, non-enhanced sites.

The **baseline** for this hypothesis will be biomass density of secondary productivity per unit of habitat in adjacent, non-enhanced sites.

The two following hypotheses are devoted to the expected outcome of increased juvenile Chinook salmon densities at restored areas. H_{R3} addresses the change in density resulting specifically from the addition of cover elements (e.g., large woody debris) to enhanced in-channel habitat. Understanding this response will help guide design of future rearing habitat enhancements. H_{R4} addresses the expected change in juvenile Chinook salmon densities more generally. **Covariates** to measure for a comprehensive assessment of the utilization (e.g., juvenile densities) of enhanced rearing habitat identified in H_{R1} are applicable to these two hypotheses.

H_{R3}: Adding cover elements to hydraulically suitable habitat (based on water depth and velocity) will result in increased densities of juvenile Chinook salmon utilizing habitat enhancement project areas.

The **metric** for this hypothesis will be juvenile Chinook salmon densities (expressed as the number of individuals per unit area) where cover elements are incorporated within the project boundary compared to locations where cover is limited or absent.

The **baseline** for this hypothesis will be juvenile salmonid density measured concurrently at: (1) specific locations within the project boundary where cover elements are not incorporated into constructed habitat; and/or (2) nearby reference sites where cover is limited or absent.

H_{R4}: Enhanced rearing habitat areas will have increased juvenile salmon densities compared to channel areas outside of project location.

The **metric** for this hypothesis will be juvenile Chinook salmon density (expressed as number of individuals per unit area) in habitat enhancement project locations.

The **baseline** for this hypothesis will be juvenile salmonid density at nearby tributary locations where enhancement measures have not been conducted, measured concurrently with juvenile salmonid densities at project locations.

2.2.2.2 Tributary floodplain restoration

The anticipated outcomes of tributary floodplain restoration are increased rearing habitat availability and suitability for juvenile salmon, and increased secondary productivity, which will be beneficial for salmon and other native fishes. These outcomes are hypothesized to occur through the following mechanisms.

$H_{TribFP1}$: The area of tributary floodplain habitat appropriate for native fish rearing will increase through floodplain enhancement actions.

The **metrics** for this hypothesis will be the acreage of floodplain habitat subject to inundation during periods of Chinook salmon rearing. Tributary floodplain habitat criteria, including water depth, velocity, and values for cover (e.g., as described in SJRRP 2012) will be defined in the specific VA science and monitoring plan and associated design documents for individual actions.

Covariates to measure for a comprehensive assessment of the effective suitability of inundated floodplain habitat include water temperature, dissolved oxygen, and flow in order to evaluate how tributary floodplain habitats restoration responds to different climate and hydrology scenarios. Inundation of tributary floodplain habitats may be dependent in some years on deployment of VA flow measures in tributaries. To inform best practices for flow deployments to achieve adequate inundation of tributary floodplain habitat, the area of inundated habitat will be tracked along with flow.

The **baseline** for this hypothesis will be the existing acreage of floodplain habitat.

$H_{TribFP2}$: Biomass densities and/or bioassessment indices of secondary productivity will be higher on tributary floodplains compared to adjacent riverine habitats.

The **metric** for this hypothesis will be the biomass density (measured in weight per unit water volume sampled) of drift and benthic macroinvertebrates sampled on tributary floodplains compared to the densities measured in adjacent riverine habitats. This hypothesis is best measured by targeted sampling occurring during the period of inundation of tributary floodplains.

Covariates for this hypothesis include water temperature, dissolved oxygen, and water velocity, indices of primary productivity (e.g., chl-*a)* as all these factors influence local densities of secondary productivity.

The **baseline** for this hypothesis will be the average sampled densities during the period of record for in-channel locations, where a tributary system maintains a sampling program for drift and benthic macroinvertebrates. An additional basis for comparison will be sampled densities of secondary productivity in in-channel locations, measured concurrently with densities in enhanced tributary floodplain locations. These in-channel locations may be upstream, adjacent to, and downstream of enhanced floodplain areas. If floodplain project areas are contributing food resources for in-channel rearing, biomass densities of secondary productivity will be higher in adjacent and downstream locations compared to locations upstream of project areas.

$H_{TribFP3}$: Juvenile salmon will utilize enhanced tributary floodplains, as measured by presence/absence, fish density, and relative densities between tributary floodplains and in-channel rearing locations.

The **metrics** for this hypothesis will be the sampled presence of juvenile salmon in restored areas and the density of fish per unit of area or water volume sampled. To account for annual variation in overall densities of juvenile salmon, the metric can be standardized as the ratio of juvenile salmon densities between floodplain habitats and in-channel rearing habitats.

Covariates to measure for a comprehensive understanding of the use of inundated floodplain habitat include water temperature and dissolved oxygen.

The **baseline** for this hypothesis will be the densities of juvenile salmon in non-restored, in-channel locations. The ratio of densities in floodplains to in-channel locations greater than 1 indicates rates of utilization than in-channel rearing locations. While it is difficult to compare fish densities across years because there are many confounding factors (hydrologic conditions, fish numbers, etc.), data from prior years may provide valuable context.

$H_{TribFP4}$: Growth of juvenile salmon in tributary floodplain restoration sites will be faster than growth of juvenile salmon rearing in in-channel locations.

The **metric** for this hypothesis will be the growth rate of juvenile salmon on restored tributary floodplains compared with the growth rate in in-channel locations, measured concurrently.

Covariates to measure to evaluate this hypothesis include water temperature and density of invertebrates serving as a food resource for juvenile salmon (e.g., drift invertebrates), as these are important controlling factors for juvenile salmon growth.

The **basis for comparison** for this hypothesis will involve experimental work potentially using caged fish, as it is difficult to assess individual, habitat-specific growth rates within tributaries on free-ranging juvenile salmon. Additionally, it is desirable to assess the minimum duration of time needed for rearing and habitat inundation to achieve growth differences between restored tributary floodplain and in-channel rearing, as this duration is a current area of uncertainty. Experimentation can provide empirical data on the differentiation of growth rate and the period of floodplain rearing needed to achieve a size benefit; this empirical data can subsequently be used to inform predictive modeling tools developed to simulate anticipated outcomes from further restoration actions across different climate and hydrology scenarios.

$H_{TribFP5}$: Enhanced tributary floodplain areas will not contribute to stranding of juvenile salmon at levels significant to the estimated annual production estimate for the

tributary after flows recede and floodplain areas are no longer connected to the mainstem.

The **metric** for this hypothesis will be the number of fish sampled in floodplain enhancement project areas in outstanding isolated pools after connectivity with the mainstem of the tributary system has ceased. In addition to field surveys, it may be possible to investigate the potential for stranding with a mapping exercise in ArcGIS using a high-resolution LiDAR layer to examine the density of potential entrapment areas and the distance to wetted areas connected to the mainstem. The combination of a mapping study and field surveys may serve to develop an estimate of the likely population of juveniles that are unable to emigrate due to isolation from the main migration corridor. It will be important to evaluate this metric in the context of the estimated annual juvenile production estimate for the tributary. Over multiple years of collecting data (and utilizing historical data on stranding where possible), it may be possible to model an estimate of the proportion of the juvenile population, across different hydrology conditions, that does not emigrate from tributaries because of isolation and determine whether this is a significant population impact.

The **baseline** for this hypothesis will be densities of apparently stranded Chinook salmon in historical studies that have aimed to estimate the number of fish remaining in isolated pools. The comparison will not be whether the estimate of total stranded fish has increased, but how much observed stranding contributes to significant population impact based on annual juvenile production estimates. The ability to make these comparisons is dependent on the availability of relevant sampling in floodplain enhancement areas, particularly the availability of sampling data after elevated flows have receded. If juvenile salmon sampling efforts have not typically occurred in the vicinity of the project area, it is possible that no baseline information will be available for this hypothesis. In these cases, the estimate of total stranding can still be compared to the annual juvenile production estimate for the tributary.

$H_{TribFP6}$: Increased inundation of tributary floodplain habitat will be associated with increased prevalence of juvenile native fishes (e.g., native minnows, juvenile salmon) during early spring months.

The **metric** for this hypothesis will be the catch frequencies of native fish species (e.g., Sacramento splittail, hitch, Sacramento blackfish, Sacramento pikeminnow, Chinook salmon, Sacramento sucker) in routine surveys (community composition in beach seine, snorkel surveys, backpack electrofishing, and/or RST catch). Previous studies and the natural history of native Central Valley fishes indicate that the above listed species utilize tributary floodplain habitats as young-of-the-year for rearing habitat, typically during the early spring months (Moyle et al. 2007). Introduced species (e.g., black bass, common carp, mosquitofish) also utilize tributary floodplain habitats but are more prevalent in later spring months (e.g., May and June).

The **baseline** for this hypothesis will be native fish species catch during the period of record for each tributary system, compared to the period of VA implementation when tributary floodplains are inundated. While it is difficult to compare catch rates across years because there are many confounding factors (hydrologic conditions, fish numbers, etc.), data from prior years may provide valuable context.

2.2.2.3 Fish passage improvements

Addressing barriers to fish passage on tributaries is expected to result in improved access and accessibility of both spawning habitat and rearing habitat such that there is increased connectivity between quality habitats. Passage rates and efficiency at target locations should increase. For juvenile salmon moving downstream during outmigration, survival at specific locations where diversions were previously unscreened, is expected to increase. The hypotheses below describe the mechanisms for these outcomes.

H_{Pass1}: Screening surface water diversions in accordance with National Marine Fisheries Service passage criteria will reduce entrainment potential for juvenile salmonids.

The **metric** for evaluating screening actions will be the observed water velocity at the diversion point. To determine velocity suitability, the observed water velocity should be in conformance with NMFS screening criteria (NMFS 1997), and to relevant literature on juvenile salmon physiology to assess whether screens are effectively reducing risk of entrainment and impingement.

The **basis for comparison** for this hypothesis will be the NMFS criteria for water velocities at diversion points. Pre-project velocities, if measured, can also be a baseline to determine the change in velocity post-project.

H_{Pass2}: Improvements to dams, weirs, and culverts will improve adult fish passage past the areas of improvement and reduce anadromous fish migration delays.

The **metric** for this hypothesis will be the passage efficiency past fish passage improvement projects (proportion of fish approaching that successfully pass the project area (Bunt et al. 2012)) over the range of expected flows during migration periods for Chinook salmon, white and green sturgeon, and Pacific lamprey. Improvement projects should follow NMFS guidelines for fish passage facilities (NMFS 2023).

If **baseline** data on adult anadromous fish passage rates are available for specific project areas, then fish passage rates before the improvement action will provide the baseline. While it is difficult to compare passage rates across years because there are many confounding factors (hydrologic conditions, fish numbers, etc.), data from prior years may provide valuable context. In some cases, there may not be baseline data available as adult fish passage data requires active counting and/or video capture of adult fish movements at target locations.

2.2.3 Delta/Bypass floodplain restoration and seasonal flooding of agricultural land

Floodplain enhancement in the Delta region (Yolo Bypass) and in the Sacramento River system at Sutter Bypass has two general approaches. The first approach involves managed flooding of agricultural fields to provide shallow-water habitat for increased productivity of invertebrates, which can then be re-directed into riverine habitats to support fish growth. The first set of hypotheses in this section addresses uncertainties on the ability of food-rich water from flooded agricultural fields to provide a growth benefit to juvenile salmon rearing in the mainstem of the Sacramento River.

The second floodplain enhancement approach involves weir modifications and other improvements to increase the frequency and magnitude of floodplain activation and increase accessibility of floodplain habitats to native fishes. Previous research on floodplain ecology, particularly in Yolo Bypass, has provided ample evidence that beneficial invertebrate taxa for juvenile salmon and other native fishes are present in higher densities on flooded Bypasses than adjacent, riverine channels and that juvenile salmon growth is faster in floodplains than in the river mainstem (Sommer et al. 2001; Takata et al. 2017; Cordoleani et al. 2022). Because food web and growth benefits are well established, hypotheses on these factors are not included in this second section of hypotheses. Instead, hypotheses are focused on uncertainties regarding the efficacy of weir improvement efforts to increase accessibility for juveniles and provide safe passage for adult Chinook salmon and sturgeon that navigate flooded bypasses in the course of their upstream migrations.

Implementation of other actions to create salmon rearing habitat by actively managing water in or across multiple agricultural fields through the use of water control structures, berms or levees, may also be included in some floodplain enhancement projects and these will be evaluated by the VA science committee/program based on data from previous, ongoing, and future research (Katz et al. 2017; Corline et al. 2017; Sommer et al. 2020; Holmes et al. 2021).

2.2.3.1 Seasonal flooding of agricultural land to support production of zooplankton and drift/benthic macroinvertebrates for export to riverine rearing habitats to provide increased food resources for fish

$H_{BypassFP1}$: The amount of shallow-water area in acres in seasonally flooded agricultural land that is suitable for production of zooplankton and macroinvertebrates appropriate for juvenile salmon consumption will increase.

The **metric** for this hypothesis will be acreage of shallow water areas that are inundated and meet duration and water temperature suitability criteria for zooplankton and macroinvertebrate production (Corline et al. 2017).

The **baseline** for this metric will be the amount of inundated area available and suitable for secondary production before managed flooding action occurs.

$H_{BypassFP2}$: Densities of beneficial zooplankton and macroinvertebrates for juvenile salmon will increase in seasonally flooded agricultural land compared to riverine habitats and will also increase in proximate, suitable riverine habitats after flooded agricultural fields are drained.

The **metric** for this hypothesis will be the sampled densities (# or weight per unit volume) of food taxa (e.g., cladocerans, copepods, insects, amphipods) in proximate suitable habitat, with suitability defined by water depth, velocity, and temperature zooplankton and macroinvertebrates in targeted inundation areas as well as adjacent riverine habitats after flooded fields are drained. Sampled densities will be compared between flooded agricultural fields and adjacent riverine sites. In addition to sampled densities, evaluation of this hypothesis can explore the potential for modeling drift densities using particle tracking models to estimate the full footprint of subsidizing food densities through this action of draining highly productive waters from flooded agricultural fields.

Covariates to measure to assess whether there may be unintended impacts of agricultural field drainage include dissolved oxygen in drained waters and the presence and concentrations of potential contaminants in drainage water and in invertebrates. Contaminants to track include pesticide residue and methylated mercury.

The **baseline** for this hypothesis will be the comparisons between flooded agricultural fields and adjacent riverine sites, as well as riverine locations that are upstream of field drainage sites.

$H_{BypassFP3}$: Juvenile salmon consuming zooplankton and macroinvertebrates derived from seasonally flooded agricultural land will bear an isotopic signal of these items in their diet and in their eye lenses and otoliths.

The **metric** for this hypothesis will be the isotopic signature in juvenile salmon diet, eye lenses and/or otoliths that were exposed to food items derived from seasonally flooded agricultural land. Recent studies already demonstrate that floodplain rearing is evident through sulfur ($\delta^{34}S$) and carbon ($\delta^{13}C$) isotopes measured in otoliths (Bell-Tilcock et al. 2021), and the mechanism for this signature occurs through floodplain-sourced food. A current uncertainty is whether fish consuming food from seasonally flooded agricultural land but that are not rearing directly on floodplains, also bear this isotopic signature. Confirming that isotopic tools can be used to detect a floodplain-sourced diet is useful for potential future analyses seeking to quantify the extent to which food subsidy benefits from seasonally flooded agricultural lands contribute to the Chinook salmon population. A second uncertainty is whether, if the food subsidy is detected in Chinook salmon, if it is distinguishable from the isotopic signature present in juveniles rearing on Bypass floodplain habitat.

The **basis for comparison** for this hypothesis will be experimental work in which juvenile Chinook salmon are raised in cages with varying degrees of exposure to food sourced from seasonally flooded agricultural land. The isotopic signatures in these caged fish can also be compared with those of juvenile salmon rearing directly on Bypass floodplain habitat, in years where both food subsidy actions and floodplain inundation are occurring.

2.2.3.2 Floodplain enhancement actions that target increased rearing habitat to be used directly by native Central Valley fishes

$H_{BypassFP4}$: The acreage of floodplain habitat appropriate for native fish rearing and the frequency of meaningful floodplain events (MFEs) will increase through Bypass floodplain enhancement actions.

The **metrics** for this hypothesis will be the acreage of floodplain habitat subject to inundation during periods of Chinook salmon rearing, and the frequency of flood events that meet suitability criteria for MFEs. The suitability criteria for MFEs will regard the magnitude, inter-annual and intra-annual frequency, and duration of inundation deemed to provide biologically meaningful benefits for native fishes rearing in floodplain habitat. These criteria will be consistent with those provided in the 2023 Scientific Basis Draft Supplement Report (SWRCB 2023).

Covariates to measure for a comprehensive assessment of the effective suitability of inundated floodplain habitat include water temperature, dissolved oxygen, and flow.

The **baseline** for this hypothesis will be the average acreage and duration of flooded bypass lands before the flow action (either targeted flooding of agricultural lands or delay of draining after a natural flood event) for the 1922 – 2015 time series (as described in the 2023 Scientific Basis Draft Supplement Report, SWRCB 2023).

$H_{BypassFP5}$: Weir modifications in Bypass locations will increase the duration of hydrologic connectivity and utilization of floodplain habitat by juvenile salmon.

The **metric** for this hypothesis will include the duration of hydrologic connectivity (e.g., # days with flows passing through weir notches) of enhanced bypass floodplains with migration corridors for Chinook salmon during periods of active migration. Additional metrics will include the presence of juvenile salmon or other native fishes on inundated bypass floodplains, including sampled fish densities in the local vicinity of entry points to enhanced bypass floodplains, particularly where weirs or other structures have been modified to support access.

Covariates for this metric include water quality (water temperature, dissolved oxygen, turbidity) on floodplain habitats, as well as predator densities (both predatory fishes and avian species) near weir structures.

The potential **baselines** for this hypothesis will be the estimated duration and frequency of hydrologic connectivity during outmigration periods in the historical timeseries, dates and frequency of observed Chinook salmon presence in project locations during inundation events in the historical timeseries, where data are available. If juvenile salmon sampling has not typically occurred in the vicinity of the project area, it is possible that no baseline information will be available for presence or density metrics.

$H_{BypassFP6}$: Increased access to Bypass floodplains will not result in detrimental impacts to juvenile Chinook salmon populations, including the potential for stranding and predation while on the floodplain.

The **metrics** for evaluating this hypothesis will be the number of juvenile salmonids remaining in flooded areas after drainage is complete and there is no more connectivity with the Sacramento mainstem. This metric will be evaluated in the context of the estimated risk to significant population impact based on the annual juvenile production estimates of upstream tributaries. Over multiple years of collecting data (and utilizing historical data on stranding where possible), it may be possible to model an estimate of the proportion of the juvenile population of the Sacramento Valley, across different hydrology conditions, that does not emigrate from Bypass because of isolation and determine whether this is a significant population impact.

The **baseline** for this hypothesis will be densities of apparently stranded Chinook salmon in historical studies (e.g. Sommer et al. 2005) that have aimed to estimate the number of fish remaining in isolated pools. The comparison will not be whether the estimate of total stranded fish has increased, but how much observed stranding contributes to significant population impact based on annual juvenile production estimates. However, there is no long-running historical record of stranding events on bypass floodplains and stranding numbers are likely to vary across years due to variation in total population sizes and hydrologic conditions. Therefore, this hypothesis may be best evaluated through targeted sampling of floodplain areas at the end of the drainage period.

$H_{BypassFP7}$: Weir modifications and/or removal of existing passage barriers will result in improvements in passage for adult anadromous fish (Chinook salmon, white sturgeon, lamprey).

The **metric** for this hypothesis will be the number of adult anadromous fish observed to pass through major passage structures (e.g., at Fremont Weir). A second metric will be the number of adult anadromous fish observed at the base of major weir structures after connectivity with the main riverine channel has ceased. The number of stranded fish should be contextualized by the estimated annual adult abundance for each species.

Covariates for this hypothesis include water depth, velocity, and water temperature during periods of anadromous fish presence and passage or attempted passage at weir structures.

The **baseline** for this hypothesis will be the period of record of stranded adult fish surveys for each major Bypass (Yolo and Sutter). Data on adult fish stranding (both Chinook salmon and green and white sturgeon) are typically collected as part of fish rescue operations (e.g., CDFW 2019). In addition, as weir modifications are implemented, special, targeted studies may also be useful to assess their impacts on adult fish passage. These studies could include acoustic tagging of adult fishes in Yolo or Sutter Bypasses to determine response to weir modifications (e.g., Johnston et al. 2020).

2.2.4 Tidal wetlands

The expected outcomes of tidal wetland restoration for native fishes are twofold: 1) tidal wetland restoration will provide an increase in the density and abundance of food for native fishes; and 2) tidal wetlands will provide viable and suitable juvenile rearing habitat for native estuarine and migratory fish species, including Longfin smelt, Delta smelt, Chinook salmon, tule perch, Sacramento sucker, hitch, among others. Hypotheses below describe the mechanisms through which these outcomes will occur.

2.2.4.1 Tidal wetland support for beneficial food web processes

H_{TW1}: Tidal wetland habitat acreage will increase in proposed locations with tidal inundation depths and frequency of inundation according to project objectives, with assessment to include water quality suitability criteria.

The **metric** for this hypothesis will be the area (in acres) of tidal wetland habitat according to project design criteria for water depth and inundation at specific tidal stages.

Covariates to measure for a comprehensive assessment of the suitability of water quality conditions in tidal wetlands for native species benefit will include monitoring for water temperature, turbidity, specific conductivity, and pH, and comparing observed values to suitability criteria for Delta smelt, Longfin smelt, Chinook salmon and other native species of interest. These criteria should be consistent with the 2023 Scientific Basis Draft Supplement Report (SWRCB 2023). Additional factors that are important to track to comprehensively assess suitability include the presence of phytoplankton taxa that may contain toxins and are associated with cyanobacterial harmful algal blooms (cyanoHABs), such as *Microcystis, Anabaena*, and *Dolichospermum,* and for presence of toxins. CyanoHABs are often associated with conditions of high water residence time, vertical stratification, and warmer temperatures (Kudela et al. 2023). An existing uncertainty is the extent to which construction of new tidal wetlands may or may not be associated with cyanoHABs, and when these events do occur, their toxicity levels.

The **baseline** for this hypothesis is the modeled acreage of tidal wetland habitat as described in the 2023 Scientific Basis Draft Supplement Report (SWRCB 2023).

H_{TW2}: Invertebrate food densities representing beneficial taxa for native fish species diets will increase at restored tidal wetland sites and within their tidal footprints.

The **metrics** for this hypothesis will include sampled densities of zooplankton (such as copepods and cladocera) as well as epiphytic and benthic invertebrates (insects, amphipods, and isopods) that present beneficial food items for native fishes. These metrics will include the geographic scope of the tidal footprint of the restored area and will not be restricted to boundaries of the restoration site. Monitoring will at a minimum occur during times of the year with the highest likelihood of native species presence.

Metrics for this hypothesis may also include production rates of zooplankton and macroinvertebrates in the tidal footprint of restored sites compared with reference (i.e., pelagic) areas. These metrics are labor-intensive to obtain and are not reflected in routine monitoring programs, therefore if chosen as the most appropriate metrics, they will be obtained through targeted, special studies.

Covariates to measure include an assessment of the impact of filter-feeding, invasive clams. *Potamocorbula amurensis* and *Corbicula fluminea* on the assemblage and abundance of zooplankton food resources in the Estuary at large which could detract from increased productivity in restored tidal wetlands. From observations of clam densities, their biomass and potential filter-feeding rate can be modeled. To fully evaluate this hypothesis for zooplankton, the impact of filter-feeding clams should be estimated and compared with estimates for productivity.

The **baseline** for this hypothesis will be the invertebrate and zooplankton densities measured at reference sites and during pre-project monitoring activities as part of the CDFW Fish Restoration Program (Hartman et al. 2018).

H_{TW3}: Beneficial taxa for native fish diets (zooplankton and benthic or epiphytic invertebrates) will be present in native fishes sampled in restored tidal wetland sites.

The **metric** for this hypothesis will be the community composition of the diets of native fishes sampled in restored tidal wetland sites. The diet composition can be compared with the community composition of zooplankton and invertebrate taxa sampled at the sites to assess whether the fish community is likely to be sourcing its diet from secondary productivity in restored areas. Assessing fish diets may include use of genetic techniques to sample the full suite of taxa found in sampled fish, as traditional, visual methods may not be able to sample the full assemblage of diet items (Schreier et al. 2016).

This **basis of comparison** for this hypothesis will be the diet composition of native fishes of the same species sampled outside of restored tidal wetland areas, in different habitat types (shoreline or pelagic). The analysis of diet samples will address whether the community composition of native fish diets reflect their habitat (tidal wetland or at comparison locations).

H_{TW4}: Growth rate and condition of target fish species will be higher in or adjacent to tidal wetland habitat compared to pelagic habitats.

The **metrics** for this hypothesis will include direct measurements of growth rates or estimated growth rates (such as via laboratory examination of otoliths) of target fish species (Delta smelt, Longfin smelt, Chinook salmon, or other native fishes), as well as other indicators of fish condition and growth such as condition factor or gut fullness. Condition metrics will be derived from fish sampled on or near restored areas. To determine growth rate and confidently relate it to specific habitats, experimental studies using hatchery-sourced Chinook salmon or cultured Delta smelt can be used to compare growth rates between restored tidal wetland habitats and reference locations.

While growth rates of many native fishes have been published in the scientific literature, they are generally not habitat-specific (except for juvenile salmon growth on floodplains compared to riverine channels, (e.g., Takata et al. 2017)), so there is no clear temporal baseline for this hypothesis. For this reason, the effect of restored habitat on growth rate will be best addressed through special studies that leverage a spatial comparison between measured growth rates across habitat types, such as via cage studies.

2.2.4.2 Restored tidal wetlands as rearing habitat for native fishes

H_{TW5}: Target fish species presence and density will increase in restored tidal wetland habitat sites and the area of their tidal footprint.

The **metric** for this hypothesis will be the presence of targeted fish species (Delta smelt, longfin smelt, Chinook salmon, and resident Delta natives such as tule perch, Sacramento blackfish, Sacramento suckers, and hitch) in restored tidal wetland habitat. Presence may be measured by sampling conducted through traditional methods such as beach seines, newly developed technologies to visualize species presence (e.g. Cramer Fish Science Sampling Platform), or by positive species identification through environmental DNA (e.g., as in Schreier et al. 2016; Nagarajan et al. 2022).

Covariates to measure for this hypothesis will be the coverage of submerged and floating invasive aquatic vegetation at entry/exit points of restored areas, and the density and movements of predators (Striped bass, Largemouth bass or other *Micropterus* species, or Sacramento pikeminnow) at these locations. Predators along migration routes and dense aquatic vegetation can all limit native fish access to restored areas and may elevate predation risk to native fishes. Tracking aquatic vegetation coverage, predator densities, and evaluating predation risk are especially relevant to juvenile Chinook salmon during their outmigration period because restored tidal wetlands may provide beneficial rearing habitat but late migrating fish are commonly subject to high predation rates as temperatures increase (Nobriga et al. 2021). Predator concentrations and flux in and out of a wetland can be using imaging sonar technology such as DIDSON (Boswell et al. 2019; Bennett et al. 2021). Predation risk can be assessed and compared across habitat types through tethering approaches using Predation Event Recorders, which are designed to record the exact time and location of a tethered, anchored fish being predated (Michel et al. 2020). Coverage of submerged and floating invasive aquatic vegetation can be expressed as the percent coverage in the vicinity of entry/exit points (e.g., using a 50m buffered area around the entry/exit location).

Notably, an uncertainty with this hypothesis is the thresholds of predator densities and invasive aquatic vegetation coverage above which survival of native fish species is impaired or at which they will avoid shallow water habitat. Piscivores and invasive aquatic vegetation are prevalent in the Delta and will be present to some extent near shallow-water habitat. It will be beneficial in evaluation of this hypothesis to assess whether increases in predator densities or vegetation coverage result in reduced utilization of the restored habitat or a notable decrease in survival, and these questions will be best addressed through targeted experimental work rather than continuous monitoring efforts. Finally, comprehensive evaluation of increased predation risk near restored sites should include assessments of water quality, as relative risk of predation varies with turbidity (Ferrari et al. 2014) and water temperature (Nobriga et al. 2021). If thresholds of predators and invasive aquatic vegetation that cause avoidance of restored areas can be determined, this information could be used to inform the degree or control of these factors that is needed to maintain the potential for restored areas to be used by target species, and the feasibility of performing predator or vegetation control at the level required. Such threshold information may also be useful for prioritization and decision-making processes that must weigh the likelihood of realizing benefits to native fishes with the required resource investment.

In addition to measuring predator densities and coverage of invasive aquatic vegetation at and near restored areas, the ability of outmigrating juvenile salmon to access these sites can also be investigated using release of tagged fish (likely coded-wire-tag, or CWT, releases to achieve large release numbers) upstream of potential tidal wetland rearing locations, and then checking for the presence of these fish in restored areas.

The **baseline** for this hypothesis will be sampled fish densities measured at reference sites and during pre-project monitoring activities conducted by the CDFW Fish Restoration Program (Hartman et al. 2018). Historical data on fish assemblage and frequency of native species detection can also be obtained from the US Fish & Wildlife Service Delta Juvenile Fish Monitoring Program, which has collected data on juvenile fish communities in the Delta since 1976 (Speegle et al. 2022).

2.3 Full Tributary and Delta Tier Hypotheses: Effects of environmental flow in Tributaries and the Delta, and tributary responses to flow and non-flow measures

2.3.1 Tributary-wide Hypotheses, Metrics, and Outcomes

Hypotheses at the scale of full tributaries regard flow actions specifically and their benefits to target species and the tributary ecosystem, as well as predictions for how the aggregate of both flow and non-flow actions within tributaries will affect productivity, condition, and life history diversity of juvenile Chinook salmon. Specific hypotheses for benefits of flow actions are presented first, followed by hypotheses for how the population of juvenile salmon will change as a result of both flow and non-flow VA measures.

2.3.1.1 Tributary flow increases to enhance salmon survival and migration

Flow releases in tributaries can be used to improve migration and survival in multiple ways in addition to inundation of floodplain habitats and provision of suitable instream habitats for rearing and spawning. Fall pulse flows in selected tributaries (Mokelumne, Putah) have been observed to improve adult upstream migration by providing migration cues, reduce straying of adult Chinook salmon away from their natal streams, and thereby improve overall spawning stock escapement. Spring pulse flows can be beneficial in transporting juvenile Chinook salmon through the tributaries while conditions remain suitable and when conditions are most suitable for survival in downstream migratory pathways. Analysis of historical data and previously published studies that relate juvenile outmigration to elevated flow events may be helpful for designing the shape and necessary magnitude of pulse flow events to cue downstream migration. Additionally, spring pulse flows may contribute to reduced water temperatures and may improve conditions for juvenile fall-run Chinook salmon by reducing thermal physiological stress and reducing parasite and disease/pathogen load. Seasonal pulse flows on the Sacramento River may improve thermal conditions for multiple runs and life-stages of Chinook salmon.

$H_{TribFlow1}$: Fall pulse flows in selected tributaries (e.g., Mokelumne, Putah) will provide migratory cues for adult Chinook salmon upstream migration, resulting in an increased rate of adult migration to spawning habitats.

The **metrics** for this hypothesis will be rates of upstream migration (i.e., estimates of upstream migrant abundance over a specified time period – e.g., weekly) of adult fall-run Chinook salmon. The timeframe for calculation of the migration rate metrics would be the week encompassing the pulse flow release, as well as 1 week subsequent to the release to capture potential lag-phasing of response. Migration rates will be calculated using direct observation where available (e.g., spawner surveys, VAKI Riverwatcher photogrammetric systems, video documentation at counting weirs) and/or special studies using acoustic tags.

Covariates to be measured for a comprehensive evaluation of the effectiveness of pulse flows will include water temperatures and dissolved oxygen to ensure they are suitable for adult fall-run Chinook salmon upstream migration. These variables should be measured before and during flow pulses to enable an assessment of whether they contributed to reduced water temperatures, which may be possible unless there are confounding factors (e.g., storm events) that preclude a robust comparison of before vs. after conditions.

The **baseline** for this hypothesis will be the weekly rates of upstream migration of adult fall-run Chinook salmon, prior and subsequent to fall pulse flow releases, during the annual periodicity of upstream migration.

$H_{TribFlow2}$: Pulse flows provided during spring months will provide outmigration cues for downstream migration of juvenile Chinook salmon, as indicated by an increase in the rates of juvenile outmigration associated with pulse flow releases.

The **metrics** for this hypothesis include rates of juvenile outmigration (i.e., estimates of outmigrant abundance over a specified time period – e.g., weekly). The timeframe for calculation of the migration rate metrics will be the week encompassing the pulse flow release, as well as one week subsequent to the release to capture potential lag-phasing of response. It is anticipated that migration rates will be calculated using rotary screw trap (RST) capture data. Secondarily, a retrospective analysis to help evaluate this hypothesis after the outmigration period is over would involve examination of whether spikes in juvenile Chinook salmon catch at RSTs (relatively high percentages of total catch for the season) are associated with VA pulse flows. This hypothesis may also be tested using a paired release design, in which batches of hatchery-origin juvenile salmon tagged with coded-wire-tags are released concurrently with a flow pulse and outside of a flow pulse window. The rate of tagged fish detected at downstream RSTs can then be compared between flow conditions.

Covariates to be measured for a comprehensive evaluation of the effectiveness of pulse flows include fry density, fish size, turbidity, day length, PAR (sunlight), lunar phase, and temperature.

The **baseline** for this hypothesis will be the weekly rates of juvenile outmigration for up to 2 weeks prior to spring pulse flow releases and after elevated flows due to the flow release have subsided.

$H_{TribFlow3}$: Pulse flows provided during spring months will increase survival of downstream migrating juvenile Chinook salmon, as indicated by an increase in the survival rate of juvenile outmigration associated with pulse flow releases.

The **metrics** for this hypothesis will be travel times and survival rates of juvenile salmon outmigrating from tributaries, as measured by acoustically tagged juvenile salmonids of hatchery origin. The timeframe for calculation of the survival rate metrics will be the weeks during and subsequent (approximately 1-2 weeks) to the pulse flow release. It is anticipated that survival rates will be calculated using acoustic telemetry data. The study design for evaluating this hypothesis may include tagged fish releases with and without flow pulses to compare both travel time and survival under different flow conditions within the same season. If pulse flows are designed to vary with respect to both magnitude and duration, it may be possible and desirable to develop an experimental design in which the survival of tagged fish is compared across different pulse flow strategies (e.g., sustained flow release of lesser magnitude vs. brief flow release of larger magnitude), with a goal of identifying thresholds for producing a survival benefit. Some experiments along these lines are already being conducted to guide operations of the State Water Project and the Central Valley Project (described and analyzed in real-time CalFishTrack (noaa.gov)).

Covariates to measure to assess the suitability of conditions for downstream migration include water temperature, turbidity, and dissolved oxygen. As water temperatures decrease, Chinook salmon survival is likely to increase during outmigration (Smith et al. 2003; Nobriga et al. 2021). To assess the relationships between flow, water temperatures, turbidity and dissolved oxygen and migration travel times and survival rates, these parameters will be tracked before, during, and after flow pulses.

The **baselines** for this hypothesis are the travel times and survival rates of acoustically tagged juvenile outmigration during the periods before and after the spring pulse flow releases. In addition, analysis of historical data, migration survival models and previously published studies that relate juvenile outmigration to elevated flow events (Steel et al. 2020; Hassrick et al. 2022), may be helpful for assessing the effectiveness of these actions.

$H_{TribFlow4}$: Flow increases during spring months will result in reduced pathogen density in the water column and reduced rates of clinical infection (i.e., disease) in Chinook salmon juveniles in tributaries.

The **metrics** for this hypothesis will be: (1) the number of spores per liter of *Ceratomyxa shasta:* and (2) the rate of clinical infection (disease) in Chinook salmon juveniles, based on USFWS methodologies for assessing disease compared to infection (Foott et al. 2021).

Covariates that may affect the impact of flow increases on *C. shasta* include water temperature and dissolved oxygen.

The **baseline** for this hypothesis will be existing spores per liter of *C. shasta* and rate of clinically infected Chinook salmon juveniles in tributaries up to 2 weeks before flow pulses occur. Where historical data are available, both *C. shasta* densities and clinical infection rates can be assessed for flow rates.

2.3.1.2 In-river juvenile salmon productivity, condition, and diversity

Generally, the suite of habitat enhancement measures for a tributary is expected to collectively result in biological responses for the population of juvenile salmon that outmigrate to the Delta. Tributary-specific in-river anadromous salmonid productivity is addressed through evaluation of trends in the annual ratio of the number of out-migrating fry and juveniles (collectively "juveniles") produced by a given number of spawners. Production of juveniles (expressed as number of outmigrants per spawning female) has been demonstrated to be a useful measure for evaluating in-river habitat conditions on salmon populations, and has been shown to be relatively immune to variations in year-to-year adult population abundances (Botkin et al. 2000). Tributary-specific juvenile anadromous salmonid life history diversity, which relates to population resiliency and is supported by increased habitat complexity and diversity (Herbold et al. 2018, Carlson and Satterthwaite 2011), is addressed through evaluation of trends in achieving variable distributions in the size and emigration timing of juvenile anadromous salmonid annual outmigrant populations.

$H_{TribWide1}$: The suite of VA measures implemented within a tributary will result in an increase in the rate of juvenile Chinook salmon productivity per spawning female adult.

The **metric** for this hypothesis is the trend in the annual ratio of the number of juvenile outmigrants per female spawner. The metric will be calculated from juvenile outmigrant data (# fish captured at RSTs) and adult biometric and spawning stock escapement data (e.g., carcass surveys, redd surveys, and/or direct observation such as video/VAKI Riverwatcher™/counting weirs). This metric will be evaluated as a trend over multiple years (e.g., >3).

Covariates to measure for a complete assessment of juvenile productivity will include flow, water temperatures and dissolved oxygen to ascertain whether they are in an appropriate range for spawning, egg incubation, and juvenile rearing prior to outmigration throughout the applicable time periods for each tributary. Water temperature and dissolved oxygen will be measured at locations used for spawning and juvenile rearing longitudinally distributed in each tributary. Overall escapement and redd superimposition are also important covariates to measure as they may affect estimates of the total number of eggs and fry.

The **baseline** for this hypothesis will be the trend in the annual values of the metric during the period of data availability prior to implementation of VA measures.

$H_{TribWide2}$: Increased habitat quality and associated primary and secondary production to support the base food web will result in improved condition of Chinook salmon emigrating from the tributaries.

The **metric** for this hypothesis will be the range and mean of the condition factor (Fulton's condition factor (Nash et al. 2006)) of the population of Chinook salmon emigrating from tributaries into the Delta system.

The **baseline** for this hypothesis will be the condition factor of Chinook salmon of the emigrating population for the period of record for each tributary.

$H_{TribWide3}$: The suite of VA measures implemented within a tributary will result in an increase in life history diversity of outmigrating juvenile salmonids.

The **metrics** for this hypothesis will be the coefficients of variation in the timing and body size of the juvenile Chinook salmon emigrant population over the annual period of emigration. Increased life history diversity may be reflected in larger numbers of yearling-sized juvenile salmon exiting tributaries and increased temporal diversity of outmigration for any given body size emigrating from the systems. Life history diversity may also be reflected in increased spatial diversity of outmigrating juveniles of any size (e.g., number of systems with evidence for both fry and yearling outmigrants).

The **baseline** for this hypothesis will be coefficients of variation in the timing and body size of the juvenile Chinook salmon emigrant population over the annual period of emigration for those years when data is available prior to implementation of VA measures.

2.3.2 Flow actions for managed species and ecosystem health in the Delta

$H_{DeltaFlow1}$: Increased spring Delta outflow results in increased availability of suitable adult spawning and larval rearing habitat for Delta smelt and longfin smelt.

The **metric** for this hypothesis will be modeled acreage of suitable habitat in the North, Western, and Central Delta regions as well as Suisun Marsh with appropriate ranges of water temperature, turbidity, and salinity for Delta and Longfin smelt, following the suitability criteria and modeling approach described in the 2023 Draft Scientific Basis Report Supplement (SWRCB 2023). The basis for this hypothesis is that as spring flow increases, the low salinity zone moves seaward and salinity-based habitat indices increase (Kimmerer et al. 2013).

The **baseline** for this hypothesis will be the modeled habitat area without implementation of VA flow measures, 2023 Draft Scientific Basis Report Supplement (tiered approach to integrate CalSim and the RMA Bay-Delta Model, described in Figure 5-4).

$H_{\text{DeltaFlow2}}$: Increased Delta outflows in the spring will facilitate transport of larval and juvenile longfin smelt larvae to downstream rearing areas, thereby reducing entrainment risk.

The **metrics** for this hypothesis will be the distribution of sampled Longfin smelt larvae and juveniles (Eakin 2021), modeled estimates of larval Longfin smelt entrainment at the South Delta pumping facilities (Gross et al. 2022), and estimated entrainment of juvenile longfin smelt (>20mm in size) from the numbers collected at the South Delta fish collection facilities.

Covariates for this hypothesis will be water temperatures and turbidity during the larval and juvenile rearing season, and the distribution and abundance of spawning stock of longfin smelt in the preceding spawning period.

The **baseline** for this hypothesis will be the period of record of larval Longfin smelt catch in the Smelt Larval Survey as well as special studies conducted to investigate the life history and distribution of Longfin smelt (e.g., Lewis et al. 2020). To assess the relationship between entrainment risk and VA flows, the baseline will be the modeled estimate of larval longfin smelt entrainment across variable flow conditions (Gross et al. 2022) and the historical dataset for estimated juvenile longfin smelt entrainment at the South Delta pumping facilities (expanded from salvage numbers). These entrainment estimates will be compared between VA spring flow measure implementation and historical years for the same months but with lower outflow conditions.

$H_{\text{DeltaFlow3}}$: Increased Delta outflows during spring months will reduce risk of entrainment in the South Delta pumping facilities for Delta smelt and juvenile Chinook salmon.

The **metrics** for this hypothesis will be the estimated entrainment of Delta smelt adults in early spring months, and for Delta smelt larvae and juveniles, and the proportional loss of juvenile salmonids in all spring months. Entrainment for adult Delta smelt is estimated from the numbers of salvaged Delta smelt at South Delta fish collection facilities and through modeling that accounts for sampling efficiency at salvage operations and other factors (Kimmerer 2008; Kimmerer 2011; Smith 2019), or through behavior-driven movement models that are a combination of behavior and particle tracking models (Korman et al. 2021). Entrainment of Delta smelt larvae is estimated through particle tracking modeling in which the transport of larvae as passive particles is simulated (Kimmerer and Rose 2018). Entrainment of juvenile Chinook salmon is estimated through an expansion of the number of juveniles salvaged at fish collection facilities (Kimmerer 2008). Estimated entrainment of juvenile salmonids will be considered within a population context given that previous studies have demonstrated that the highest entrainment rates are likely to occur at elevated diversion levels, but that the overall contribution of entrainment to mortality during outmigration may be low (Zeug and Cavallo 2014).

Covariates to measure for robust assessment of entrainment risk for Delta smelt include the population abundance estimate and its distribution during winter months prior to the spring outflow period, regional hydrodynamics (i.e., calculated flows in DAYFLOW for the San Joaquin River, exports, Sacramento River), and water quality (e.g., turbidity) (Grimaldo et al. 2021).

Covariates to measure for robust assessment of juvenile salmon entrainment risk also include local South Delta hydrodynamics, the overall abundance estimate of juvenile salmonids for each run entering the Delta, Delta Cross Channel gate operations, and water quality parameters such as water temperature.

The **baseline** for this hypothesis will be modeled estimates of entrainment risk for Delta smelt and juvenile salmonids in prior years over a range of hydrologic conditions, including outflow levels comparable to those achieved through implementation of VA flow measures, and outflow levels lower than those levels. Previously published studies can also serve as a basis for comparison (Kimmerer 2008; Smith 2019; Grimaldo et al. 2021; Korman et al. 2021).

$H_{DeltaFlow4}$: Increased Delta outflow during spring months reduces travel time and increases survival through the tidal region of the Delta for outmigrating juvenile salmonids.

The **metric** for this hypothesis will be the travel time and survival rate of juvenile anadromous salmonids within the tidal Delta, from Delta entry points from both the Sacramento and San Joaquin Valleys, as measured by acoustically tagged juvenile salmonids of hatchery origin (Perry et al. 2018; Hance et al. 2022).

Covariates to measure to assess possible factors contributing to travel time and survival through the Delta include water temperature, dissolved oxygen, turbidity, submerged aquatic vegetation coverage along migration routes, and (where possible) predator densities at critical junctures ("hotspots," Michel et al. 2020).

The **baseline** for this hypothesis will be the available published information on acoustically tagged juvenile salmon travel time and survival through the Delta (e.g., as described in Perry et al. 2018) during outflow conditions similar to those achieved through VA flow implementation and compared to lower outflow conditions. An experimental approach to evaluating this hypothesis is comparison of travel time and survival of acoustically tagged juvenile salmon with and without increased spring outflows, in the same year.

$H_{DeltaFlow5}$: In years where the magnitude, duration, and intra-annual frequency of a Meaningful Floodplain Event are achieved on Yolo and Sutter Bypasses, the population of juvenile salmon leaving the Delta will have a higher proportion of individuals with evidence of bypass floodplain rearing.

The **metric** for this hypothesis will be the annual proportion of juvenile Chinook salmon leaving the Delta bearing the signature of floodplain rearing and growth through isotopic analyses of otoliths and/or eye lenses (Bell-Tilcock et al. 2021). It is anticipated that samples for this analysis will be sourced through the USFWS Delta Juvenile Fish Monitoring Program (DJFMP), which trawls for juvenile salmon and other species at the confluence of the Sacramento and San Joaquin Rivers (Chipps Island Trawl, Speegle et al. 2022). As needed, other special studies can be used to increase sample size when floodplain conditions allow.

Covariates to measure to consider the various environmental factors that may influence the proportion of juvenile salmon utilizing floodplain rearing habitats include water quality variables in floodplain habitats and the riverine Delta migration routes (water temperature, turbidity), metrics of secondary productivity, as well as the timing, magnitude, and frequency of floodplain inundation for each year of samples.

The **baseline** for this hypothesis will be a comparison of the proportion of juvenile salmon utilizing floodplain habitats prior to exiting the Delta across years with different degrees of Bypass inundation (e.g., little to no inundation, to high levels of inundation through the juvenile salmon rearing period). The period of record for this comparison will be the time series for which salmon eye lenses are available (including in archived samples).

$H_{DeltaFlow6}$: Provision of spring flow pulses and increased spring Delta outflow will be associated with increased year class indices for age-0 and age-1 white sturgeon.

The **metric** for this hypothesis will be white sturgeon year class index strength measured through the San Francisco Bay Study conducted by the California Department of Fish and Wildlife. The number of larvae and juvenile sturgeon is positively correlated with Delta outflow during winter and early spring months (Fish 2010).

The **baseline** for this hypothesis will be the period of record for the San Francisco Bay Study. Analyses will leverage white sturgeon year class indices for Delta spring outflow levels similar to those achieved through implementation of VA flow measures and compared with years with lower outflows.

$H_{DeltaFlow7}$: Increased Delta outflow in the spring will result in transport of freshwater-associated zooplankton taxa (e.g., *Daphnia* spp. and *Pseudodiaptomus forbesi*) into the Western Delta and Suisun Marsh regions.

The **metric** for this hypothesis will be the average regional sampled densities of freshwater-associated zooplankton (using datasets described and integrated in Bashevkin et al. 2022a) in the Delta in the spring months during and after implementation of VA flow measures. Community composition of zooplankton is another useful metric for assessing whether assemblage changes across flow conditions. Increased Delta outflow is hypothesized to transport freshwater-associated zooplankton into the low salinity zone (Kimmerer et al. 2019) and increase their regional densities.

The composition of zooplankton taxa in turn affects habitat suitability for native fishes because zooplankton vary in their nutritional quality for fishes; for example, *Daphnia* spp and *Pseudodiaptomous forbesi* are taxa that are important food sources for Delta smelt (Slater and Baxter 2014). Other important taxa to examine for a relationship with Delta outflow include *Eurytemora affinis*, and mysid shrimp.

Covariates to measure to assess conditions influencing zooplankton community composition include phytoplankton biomass density and composition, salinity, water temperature, and turbidity.

The **baseline** for this hypothesis will be the regional sampled densities (regions as described in Bashevkin et al. 2022b) and assemblages of zooplankton in the historical dataset for similar outflow conditions as achieved through VA flow measure implementation and compared with the same months and regions for lower outflow conditions.

$H_{DeltaFlow8}$: Provision of increased spring outflows in the Delta will not be related to the prevalence of cyanoHABs or their toxicity during summer and fall months of the same year.

The **metric** for this hypothesis will be the frequency, magnitude, and severity of cyanoHABs in the Delta and Suisun Marsh region, as measured by consistent visual observations of *Microcystis* presence during routine Delta monitoring surveys, such as the Environmental Monitoring Program, Summer Townet Survey, and the Fall Midwater Trawl (Hartman et al. 2022b). CyanoHAB events in the Delta typically occur in summer and fall months (approximately July – November). While decreased retention time and lower water temperatures during the cyanoHAB season have been correlated with lower *Microcystis* abundance and reduced toxicity (Lehman et al. 2022), there is no evidence that increased outflows during the spring season as proposed by the VAs will affect the abundance of *Microcystis* or other cyanobacteria taxa and associated toxicity levels later in the same year.

Covariates to measure to evaluate this hypothesis include Delta outflow through the spring season when VA flows are implemented, as well as during the cyanoHAB season. Water temperature, turbidity, salinity, and nutrient concentrations and ratios (nitrate, ammonium) are also relevant to assessing the key factors contributing to the abundance of cyanoHAB taxa.

The **baseline** for this metric will be the period of record of cyanoHAB visual observations in routine surveys with corresponding Delta outflow calculations and similar temperatures. The evaluation of this hypothesis will involve an investigation of the relationship between spring outflow levels similar to those achieved through implementation of VA flow measures and the cyanoHAB observations later in the same year. This evaluation will need to be done for a range of spring outflow levels and temperatures to understand whether a relationship exists.

2.4 Population-level Tier Hypotheses: Trends in native species populations in tributaries, the Delta, and at the system-wide scale

Population-level considerations include tracking the status and trends in abundance and productivity of target fish species at the tributary-specific scale, within the Delta, and at the scale of the full Sacramento and San Joaquin Valleys. Temporal trends and annual variability in abundance and productivity provide measures of population status and viability. Population-level trends in abundance and productivity are important considerations regarding the narrative objectives of the SWRCB Bay-Delta Water Quality Control Plan.

At the full system-wide and population-level scale, a goal of the VA Program is that the aggregate of flow and habitat measures contribute to a trend of increased abundance. To this end, metrics of population abundance (listed below) will be tracked, and the VA Science Program will work to fill any gaps in the monitoring and science network to allow a comprehensive ability to track these metrics. As discussed above, it is important to acknowledge that many of the population-level outcomes are influenced by factors outside the control of VA Parties (e.g., climate-induced changes to hydrology and temperatures, ocean conditions, hatchery and harvest practices, among others). In addition, the multi-year life span of some target species mean that it will not be realistic to expect significant changes in trends to population-level metrics within the 8-year term of the VAs. For these reasons, metrics provided at population-level tier are intended for tracking purposes regarding the narrative objectives.

2.4.1 Tributary-Specific Chinook Salmon Population-level Response

The VA Program endeavors to provide population-level benefits for natural-origin Chinook salmon. However, there are five major hatcheries in the Central Valley for fall run Chinook salmon, releasing an average total of approximately 30 million juvenile salmon annually (Huber and Carlson 2015). While the hatchery production sustains the commercial and recreational fishery for Central Valley salmon, hatcheries and their release practices influence life history diversity and cause increased straying of adults to tributaries other than their natal system (Sturrock et al. 2019). Since 2007, Central Valley hatcheries have implemented the Central Valley Constant Fractional Marking (CFM) Program maintained a practice of a consistent marking rate, using coded-wire-tags of 25% of released fall-run Chinook salmon (California Hatchery Scientific Review Group 2012). The purpose of this program is to allow estimation of the contribution rates of hatchery fish to Central Valley Chinook populations and their harvest. While this program has allowed for separate abundance estimates of natural and hatchery-origin adult salmon since 2010 (the first year that all adult returns would have been included in the CFM program), the majority of hatchery fish released cannot reliably be distinguished from natural origin fish or identified to their natal tributary. Given this, and for the purpose of the VA hypotheses and metrics for population-level Chinook salmon abundance and life history metrics, initially both natural- and hatchery-origin adults will be included in evaluating metrics until hatchery practices allow a more accurate characterization of the proportion of hatchery-origin fish on the spawning grounds.

Following the March 2022 VA Term Sheet and the narrative objective for the update for the Bay-Delta Water Quality Control Plan, the primary baseline for hypotheses regarding population increases will be the estimated abundances during the 1967-1991 period that is used as a baseline for the Anadromous Fish Restoration Program (AFRP) doubling goal. A secondary baseline for these hypotheses, to reflect recent conditions and contemporary adult salmon counting methods, will be the annual abundance of adults (harvest plus escapement) by tributary since 2010 because consistent marking practices were in place for returning hatchery origin adults starting in that year.

$H_{TribPop1}$: Increased availability of floodplain rearing habitat and invertebrate food sources produced on seasonally flooded agricultural land will result in increased usage of these habitats and food sources, reflected in retrospective analyses in the returning adult populations of natural-origin Chinook salmon.

The **metric** for this hypothesis will be the isotopic signature associated with floodplain rearing (Bell-Tilcock et al., 2021) and floodplain-sourced food resources in the otoliths and/or eye lenses**.** The adults sampled to test this hypothesis should be potential beneficiaries of VA restoration actions to increase availability of bypass rearing habitat and production of invertebrate food sources through managed seasonal flooding of agricultural land. Addressing this hypothesis will require an investigation of whether the isotopic signature of floodplain rearing can be detected from otolith or eye lenses obtained from adults, as this capability of the tool has not yet been published and represents an area of uncertainty.

The **baseline** for this hypothesis will be archived samples of otoliths and/or eye lenses of adults returning to the Sacramento Valley before implementation of VA actions to enhance Bypass floodplains. Testing this hypothesis may require an assessment of whether Sutter Bypass rearing and consumption of invertebrates from seasonally flooded agricultural land results in a unique signature in Chinook eye lenses and/or otoliths, as has been shown for Yolo Bypass (see also $H_{BypassFP3}$).

$H_{TribPop2}$: Implementation of the suite of VA measures within a tributary will result in an increase in the average estimated annual natural origin Chinook salmon adult abundance, and the trend in annual abundance values.

The **metrics** for this hypothesis will be the average of annual natural origin Chinook salmon spawning stock production estimates (harvest plus escapement) calculated over the period of implementation of VA measures, and the trend in annual Chinook salmon spawning stock escapement estimates calculated over the period of implementation of VA measures. The annual reports made available through Pacific States Marine Fisheries Commission (PSMFC) and CDFW on the estimated proportion of the adult population comprised of hatchery fish, based on the Constant Fractional Marking Program (Letvin et al. 2021) will be the basis for estimated natural origin fish. Notably, to accurately evaluate this hypothesis, it will be necessary to estimate the tributary-specific origin of harvested fish, including ocean harvest using otolith microchemistry (Barnett-Johnson et al. 2008).

The **baseline** for this hypothesis will be values of the metrics calculated over the period of 1967-1991 per the Anadromous Fish Restoration Program (AFRP) doubling goal. A secondary baseline, to reflect recent conditions and contemporary adult salmon counting methods, will be the annual abundance of adults (harvest plus escapement) by tributary, since 2010.

$H_{TribPop3}$: Implementation of the suite of VA measures within a tributary will result in a positive trend in adult Chinook salmon Cohort Replacement Rate (CRR) for natural origin fish over the period of implementation of VA measures.

The **metric** for this hypothesis will be the trend in annual Chinook salmon spawning stock CRR for natural origin fish, calculated over the period of implementation of VA measures. Notably, evaluation of this hypothesis will require accurate identification of hatchery and natural origin returning adults and their age to assign returns to cohorts. The annual reports made available through Pacific States Marine Fisheries Commission (PSMFC) and CDFW on the estimated proportion of the adult population comprised of hatchery fish, based on the Constant Fractional Marking Program (Letvin et al. 2021) will be the basis for estimated natural origin fish. Because the 8-year term of the VA Program is limited for assessing a change in the trend, the CRR value will also be tracked on an annual basis.

The **baseline** for this hypothesis will be the trend in annual Chinook salmon spawning stock CRR calculated over the period of record prior to the implementation of VA measures. A secondary baseline, to reflect recent conditions and contemporary adult salmon counting methods, will be the annual abundance of adults (harvest plus escapement) by tributary, since 2010.

2.4.2 System-wide Anadromous Chinook Salmon Population-level Response

H_{SWPop1}: Implementation of the full suite of VA measures will contribute toward increased annual natural origin Chinook salmon abundance across the Sacramento and San Joaquin Basins.

The **metric** for this hypothesis will be estimates of the average annual natural origin adult escapement and harvest of fall-run Chinook salmon for the Sacramento and San Joaquin Basins over the period of VA implementation.

The **baseline** for this hypothesis will be the average of natural-origin escapement values associated with the Anadromous Fish Restoration Program Doubling Goal (years 1967-1991). A secondary baseline, to reflect recent conditions and population numbers, will be estimates of natural-origin escapement for fall run Chinook salmon since 2010.

H_{SWPop2}: Implementation of the full set of VA measures will contribute to a trend of population growth for natural origin Chinook salmon over time.

The **metric** for this hypothesis will be annual natural-origin adult Chinook salmon cohort replacement rates and trends over multiple years (e.g., > 3 years) over the period of VA implementation.

The **baseline** for this hypothesis will be the annual natural-origin adult Chinook salmon cohort replacement rate trends during the period associated with the Anadromous Fish Restoration Program Doubling Goal (years 1967-1991). A secondary baseline, to reflect recent conditions and population numbers, will be annual adult Chinook salmon cohort replacement rates and trends for natural-origin fall run Chinook salmon since 2010.

2.4.3 Population-level responses for Native Species Communities in the Delta

H_{SWPop3}: Population estimates for native species, including California Bay shrimp, Sacramento splittail, longfin smelt, and Delta smelt will increase as a result of increased Delta outflow and increased area of suitable habitat during spring months.

The **metric** for this hypothesis will be increased distribution and population estimates of spawning adults and rearing juveniles for native species in the Delta using a statistically appropriate sample design for detecting differences in distribution and abundance. Notably, population estimates of the listed native species are not all currently available, except for Delta smelt through the enhanced Delta smelt monitoring program (EDSM, operated by the USFWS). For Delta smelt, some change in abundance is expected regardless of VA flow and habitat actions because of supplementation with cultured Delta smelt occurring since 2021. The number of supplemented Delta smelt should be tracked as an important covariate, and as much as possible, quantitatively tracked as a contributing factor to population changes. For other species, abundance is tracked through seasonal abundance indices, which do not have an uncertainty estimate with respect to population size. Seasonal abundance indices can serve as a surrogate where population estimates are lacking; however, sampling designs that are statistically appropriate for developing population estimates with uncertainty estimates are necessary for adequate evaluation of this hypothesis.

The **baseline** for this hypothesis will be the seasonal abundance indices for California Bay shrimp, longfin Smelt, Delta smelt, and other selected native species using the baseline in the 2017 Draft Scientific Basis Report Supplement and the 2023 Draft Scientific Basis Report Supplement. Delta smelt population estimates for the period of record for the survey can serve as an additional baseline for Delta smelt.

H_{SWPop4}: Increased availability of spawning habitat through implementation of VA flow for longfin smelt will result in improved spawning success.

The **metric** for this hypothesis will be the estimate of the number of larval Longfin smelt per estimated number of spawning adults.

The **baseline** for this hypothesis will be the estimated ratio of larval longfin smelt to adult spawning adults in available historical data in years with habitat area availability consistent with that achieved during VA flow and habitat implementation and years with lower outflow. For longfin smelt, this baseline must be derived from historical datasets that sampled the full geographic coverage of the spawning habitat for the species.

3 Monitoring Networks to Support VA Metrics

The VA Science Program has a geographic scope spanning the upper watersheds of VA Bay-Delta tributaries (below rim dams) to Suisun and San Pablo Bay. The VA Science Program is intended to cover multiple scales (local to population-level responses), multiple trophic levels and native species communities, as well as covariate data on stressors that may impede realization of VA measure benefits. Given the goal of examining ecosystem responses at multiple scales and across the full watershed, it is necessary to examine, build, and tune the monitoring networks such that they produce data that can be integrated across tributaries, can track species populations across multiple life stages, and actively inform adaptive management of both flow and non-flow VA measures.

Throughout the watershed, an extensive suite of monitoring programs already exist and has been producing data for decades (Heublein et al. 2017; Johnson et al. 2017; Delta Independent Science Board 2022). Existing monitoring programs have been established in response to a plethora of regulatory mandates and management questions and have continued for varying lengths of time. In some cases, despite having similar information needs, monitoring approaches may use different methodologies, making comparisons and data integration difficult. To achieve the consistency and targeted monitoring needed to support evaluation of VA metrics, it is necessary to evaluate existing monitoring efforts through the lens of what is needed for VA metrics. As appropriate, existing monitoring activities will be leveraged to provide data to populate the metrics for evaluating the hypotheses at the Local, Full Tributary and Delta, and Population-level Tiers. A summary of the relevant existing monitoring activities to collect data on these metrics is described here; however, in some cases the existing monitoring activities will not be sufficient for addressing relevant hypotheses. To this end, this section also summarizes the major gaps in current monitoring networks, particularly for addressing metrics required for evaluating hypotheses at the Full Tributary and Delta and Population-level Tiers.

3.1 Monitoring Needed for Local Tier Hypotheses

3.1.1 Monitoring Needed to Assess Tributary Habitat enhancements

Assessing the localized responses to efforts to enhance habitat for Chinook salmon and other native fishes in tributaries involves 4 general types of data collection: (1) mapping habitat in order to calculate area of suitable habitat; (2) assessing lower trophic responses to habitat changes by measuring benthic macroinvertebrate community composition and biomass; (3) juvenile salmon utilization of enhanced rearing habitat, along with the native fish community assemblage; and (4) adult salmon use of enhanced spawning habitat. The necessary approaches for each of these types of data collection are described in this section and compared with existing monitoring efforts to identify where data collection needs are covered and where there are gaps.

3.1.1.1 Tributary Habitat Mapping (H_{R1}, H_{S1}).

To achieve a consistent estimate of available spawning and rearing habitat and to assess changes in the available area after habitat enhancements have occurred, habitat maps need to be produced through a combination of remotely sensed elevation and topography, and hydraulic modeling to assess the water depth and velocity as critical measures for quantifying habitat area. The topography and elevation should be remotely sensed (e.g., via LiDAR) and augmented by multi-beam echosounder bathymetry as necessary to ensure that the habitat map is based on a consistent, synoptic measurement. Four elements are needed for the VA tributaries to have consistently produced maps and to measure change in habitat area in a consistent way: (1) a Digital Elevation Model (DEM), (2) a 2-dimensional hydraulic model, (3) a cover map that illustrates habitat features such as cover and woody vegetation, and a substrate map characterizing substrate composition, and (4) a hydrology model simulating operations and hydrology scenarios in order to determine the habitat area under different conditions. The general methodology for assessing spawning and rearing habitat area is described in Section 4.1 on Accounting Protocols for Non-Flow Habitat Measures.

Most, but not all, tributary systems have a DEM based on remotely-captured imagery, a 2-D hydraulic model, at least partial cover and substrate maps, and a hydrologic model for simulations. However, there are some systems using ground survey data and bathymetry for the DEM, cover maps are lacking from some systems, and there is not consistency in the hydraulic model used (Table 2).

Table 2. Summary of habitat mapping efforts by tributary. SRH-2D = Sedimentation and River Hydraulics – Two Dimensional Model (USBR 2008); TUFLOW = proprietary hydraulic model (www.tuflow.com); HecRAS = US Army Corps of Engineers Hydrologic Engineering Center River Analysis System (https://www.hec.usace.army.mil/).

Tributary	DEM availability/source	Hydraulic Model Platform	Cover Map Available	Hydrologic Model, Period of Simulation
Upper Sacramento	Yes/ 2017 Lidar, 2018 Sonar	Yes, 2D, SRH-2D	No	CALSIM2, 1922 – 2003
Upper Sacramento – Clear Creek	Yes/2017 LiDAR and Sonar	Yes, 2D, SRH-2D	Yes	CALSIM2, 1922 – 2003
Feather				
Yuba	Yes/ 2017 LiDAR and multibeam echo sounder	Yes, 2D, TUFLOW GPU	Yes	Yuba Daily Operations Model, 1922-2021
American	Yes/ 2017 LiDAR	Yes, 2D, HecRAS	Yes	CALSIM2
Mokelumne	Yes/ 2015 LiDAR and ground survey	Yes, 2D, HecRAS	Partial	HEC-HMS, calibrated to events of Feb 1986, Jan 1997, Feb 2017
Putah	Yes/2005 LiDAR	Yes, 2D, HecRAS	Partial	CalSIM2 (*verifying*)
Tuolumne	Yes/ 2012 and 2013 LiDAR	Yes, 1D, 2D, TUFLOW and HecRAS	Partial	Tuolumne River Operations Model, daily, range of years with variation in hydrology

3.1.1.2 Lower trophic responses in tributaries (H_{R2}, $H_{TribFP2}$).

Assessing the response of secondary producers in tributaries to habitat enhancements in-channel and floodplains involves collection and identification of benthic macroinvertebrates (BMI). There are multiple approaches for BMI sampling and laboratory identification (Carter and Resh 2001). However, standard operating procedures exist for California rivers and streams under the Surface Water Ambient Monitoring Program of the State Water Resources Control Board (SWAMP – Data and Interpretive Tools | California State Water Resources Control Board) and increasingly BMI data is being collected and shared through the California Environmental Data Exchange Network (CEDEN, CEDEN AdvancedQueryTool (ca.gov)). In the last decade, the California Stream Condition Index (CSCI) was developed to create a standardized index that could be compared across systems and used as a metric of ecosystem health (Mazor et al. 2016).

Despite statewide efforts to obtain consistency, an overview of BMI sampling efforts in VA tributaries reveals that data are not consistently collected and when data are collected, methodologies vary (Table 3). The upper Sacramento River and the Tuolumne River are the only systems reporting routine BMI monitoring. Most other systems collect BMI data on an as needed basis for special studies or restoration effectiveness monitoring. Most of the data are not readily available in a publicly accessible data repository. Therefore, more data requests are required to thoroughly determine whether existing efforts can be leveraged for evaluation of VA habitat enhancements. Existing efforts need to be spatially relevant to VA habitat enhancement sites.

For site-specific evaluations of the response of the BMI community to habitat enhancements, it may not be necessary to have entirely consistent methodologies across tributaries if the study design for individual efforts allows a comparison between project sites and comparison (non-enhanced sites) as described in the desired baselines for hypotheses H_{R2} and $H_{TribFP2}$. However, for synthetic report elements (Years 3 and 6 of the VA Program), it will be desirable to have consistent methodologies to communicate the range of responses observed across sites.

Table 3. Overview of Benthic Macroinvertebrate Sampling Efforts by Tributary.

Tributary	BMI Collected?	Equipment Type (Mesh Size if applicable)	Taxa ID Level	Data Availability
Upper Sacramento	Yes – as needed for special studies or restoration effectiveness monitoring and routine monitoring	Net (500 µm)	Lowest practicable level	Upon Request; anticipated posting of some data to SWAMP Data Dashboard and CEDEN database
Upper Sacramento – Clear Creek	Yes – as needed for special studies or restoration effectiveness, following BACI design	Quadrat	Lowest practicable level	Upon Request
Feather	Yes – as needed for restoration effectiveness monitoring	Net	Lowest practicable level, mostly to family	Mainly in technical reports, not necessarily online; some previous data published (Esteban and Marchetti 2004)
Yuba	Yes – as needed for special studies and restoration effectiveness monitoring	Net (500 µm)	Genus	Publicly available technical report posted online (Yuba County Water Agency 2013)
American	Yes – as needed for special studies and restoration effectiveness monitoring	Both Net (368 µm) and Quadrat	Family	Contained in technical reports, not necessarily online
Mokelumne	No	N/A	N/A	N/A
Putah	Yes – as needed for special studies and restoration effectiveness monitoring	N/A	N/A	Reports at https://www.scwa2.com/lower-putah-creek-coordinating-committee/lpccc-reports/
Tuolumne	Yes – as part of routine monitoring	Annual Hess (quadrat) or Kick-net (net-type sampling) at selected, consistent locations	Lowest practicable level (mostly to Family)	Upon Request

3.1.1.3 Juvenile salmon habitat use and densities on tributaries (H_{R3}, H_{R4}, $H_{TribFP3}$, $H_{TribFP5}$)

Juvenile salmon habitat use and density can be assessed through snorkeling surveys, seining, electrofishing, and special studies using individualized tagging approaches such as hydroacoustic tags. For assessment of VA hypotheses juvenile salmon response to in-channel and floodplain habitat enhancement projects, it will be necessary to pair sampling between project sites and comparison sites (non-enhanced sites), such as nearby tributary locations without restored habitat but that exhibit similar covariate (e.g., water temperature) suitability values.

Juvenile salmon habitat use is assessed in all VA tributaries, primarily through snorkeling efforts (Table 4) that cover all in-channel habitats. In most systems, tributary floodplain habitat is not covered in routine monitoring efforts, representing a gap in monitoring needs for understanding how juvenile salmon utilize enhanced floodplain habitat ($H_{TribFP3}$). Existing monitoring efforts, depending on their locations relative to in-channel habitat enhancement sites, may be appropriate for evaluating in-channel habitat enhancement projects. However, a closer investigation of the datasets is needed to conclusively determine whether these existing survey efforts can be leveraged or if new monitoring needs to be established. Ideally, and if appropriate, new efforts will use methodologies that are comparable to existing ones so that data can be assessed across all surveyed sites for additional context. While different methods (snorkeling, seining) may be used across tributaries and locations, the resulting density units (e.g., # fish/unit length of river or stream) should be comparable across efforts such that datasets from different systems can be used in an integrated analysis and responses to habitat enhancement efforts can be compared across systems.

Notably, it may be possible to address other Local Tier hypotheses on the tributaries through snorkel surveys, electrofishing, and/or seining conducted for juvenile salmon habitat use assessments. If non-salmonid species are recorded, the presence/absence and densities of these species can be assessed and related to utilization of enhanced floodplain habitat ($H_{TribFP6}$). In fact, these surveys may be the most likely opportunity for obtaining information on non-salmonid habitat use and distribution. Otherwise, non-salmonids are only tracked at rotary screw traps installed for assessing the timing and abundance of outmigrating juvenile salmonids (described in Section 3.2.1).

The potential for entrapment and/or stranding on tributary floodplain habitat ($H_{TribFP5}$) after hydraulic connectivity with the mainstem has ceased also requires some empirical observation of juvenile salmon in these areas, and this can be done with snorkel or seining surveys.

Table 4. Overview of approaches for assessing juvenile salmon habitat use and densities across tributaries.

Tributary	Survey Type	Metric	Habitat Types Sampled	Data Availability
Upper Sacramento	Snorkel	Juvenile salmon density (#/reach)	All in-channel habitats (pool, riffle, side channels). Floodplains not sampled.	*Information is Pending*
Upper Sacramento – Battle Creek	Snorkel	Juvenile salmon density (#/reach)	All in-channel habitats (pool, riffle, side channels). Floodplains not sampled.	*Information is Pending*
Upper Sacramento – Clear Creek	Snorkel	Juvenile salmon density (#/reach)	All in-channel habitats (pool, riffle, side channels). Floodplains not sampled.	*Information is Pending*
Feather	*Information is Pending*	*Information is Pending*	*Information is Pending*	*Information is Pending*
Yuba	Snorkel	Presence/absence, habitat use, density (#/reach)	All in-channel habitats (pool, riffle, side channels). Floodplains not sampled.	Upon request
American	Snorkel, seine, video	Juvenile salmon density (#/reach), behavior (from video)	All in-channel habitats, (pool, riffle, side channels). Floodplains at selected locations.	Upon request as well as some published data (Sellheim et al. 2016; Merz et al. 2019; Sellheim et al. 2020)
Mokelumne	Seine, backpack electrofishing	Presence/absence, fish condition	All in-channel habitats and floodplains when inundated	Upon request
Putah	Snorkel, seine, hydroacoustic tags	Juvenile salmon density (snorkel), species diversity (seine), mortality by reach and fish passage (hydroacoustic tags)	All in-channel habitats (pool, riffle, side channels). Floodplains not sampled but covered in fish movements from hydroacoustic tracking	Publicly available technical reports posted online (LPCCC Important Documents – scwa2.com)
Tuolumne	Snorkel	Presence/absence, relative abundance	All in-channel habitats, (pool, riffle, side channels). Floodplains at selected locations.	Publicly available technical reports posted online.

3.1.1.4 Adult salmon use of spawning habitat (H_{S2}).

Redd surveys, in which spawning areas are visually observed for the presence of redds, are the preferred way of collecting information on redd densities. Redd surveys are conducted on the American River, Upper Sacramento River systems (both Clear Creek and Battle Creek), Mokelumne and Yuba rivers. However, redd surveys are not currently conducted in the Feather River or in Putah Creek. Where spawning habitat enhancements are planned as part of the VA commitments (Sacramento River, American, Feather, Tuolumne, and Putah), redd surveys should be included as part of the project-specific science and monitoring plan.

If appropriate, redd surveys or other visual observations of adult anadromous fishes should be considered above fish passage improvement projects to assess species utilization and increased access to habitat that is upstream of locations that previously proved problematic for fish passage (H_{Pass2}).

3.1.2 Monitoring Needed for Bypass enhancements for floodplain habitat

3.1.2.1 Modeling bypass floodplain acreage and frequency of inundation ($H_{BypassFP4}$)

Evaluating changes in the acreage of floodplain habitat provided on Bypasses on the Sacramento River system requires hydraulic and hydrologic modeling that estimates the timing, frequency, extent, and duration of inundation over varying hydrological conditions and infrastructure scenarios (e.g., across alternatives for fish passage structures). For example, the Yolo Bypass Salmonid Habitat Restoration and Fish Passage Project, underway by DWR and USBR for the 2009 NMFS Biological Opinion for the Central Valley Project and DWR used hydraulic modeling for the Environmental Impact Statement and Report (USBR and DWR 2019), and can be used as a baseline for evaluating changes in floodplain acreage and frequency of inundation. A similar baseline model is currently under development for the Sutter Bypass and Butte Sink as part of the Floodplains Reimagined Program (https://floodplainsreimagined.org).

3.1.2.2 Measuring ecological connectivity between floodplain bypasses and river mainstem ($H_{BypassFP5-7}$)

In addition to evaluating the inundation footprint, frequency, and duration in the bypasses it is also necessary to monitor whether the increased area of inundation translates into ecological connectivity, which includes the ability of fish to volitionally access the floodplain habitat and emigrate from it to re-join the mainstem for outmigration, as well as transport of secondary production from bypass floodplains to the mainstem (Flosi et al. 2009). Important indicators of ecological connectivity are whether floodplain enhancement actions increase utilization of the bypass system by juvenile fishes and allow upstream passage of adult anadromous fishes. Monitoring of juvenile access to the floodplain requires a combination of acoustic tagging to track entrainment of juveniles through weir notches, as well as simulating entrainment through modeling approaches, such as the Critical Streakline Analysis and Eulerian–Lagrangian–agent method (ELAM, Goodwin et al. 2006). To assess juvenile salmon utilization of and egress from the bypasses, monitoring the population exiting the bypass is needed (e.g., using a rotary screw trap) as well as beach seine surveys to estimate numbers of stranded fish. Stranding surveys may be particularly necessary near artificial structures because evidence shows that juvenile salmon generally increase emigration rates from the Yolo Bypass during natural drainage periods (Takata et al. 2017), but are vulnerable to entrapment in stilling basins or artificial pools created by weirs or other structures (Sommer et al. 2005).

Tracking passage of adult anadromous fishes should include sonar imagery (e.g., using acoustic cameras such as the Dual Frequency Identification Sonar (DIDSON) camera, or the Adaptive Resolution Imaging Sonar (ARIS) technology) at fish passage structures. Concurrent with imagery, water depth, velocity, and temperature should be monitored at weir structures to assess conditions and compliance with passage criteria for anadromous fishes (NMFS 2023).

During periods of inundation, utilization of bypass floodplains by native fishes needs to be assessed through regular monitoring in a balanced design across the inundated area. Given that increased productivity and elevated densities of invertebrate taxa in floodplains relative to mainstem reaches are well-established in the scientific literature, the outcome of floodplain enhancement projects for food webs is not included in VA hypotheses. However, both fish species composition and invertebrate densities has been regularly monitored by the DWR Yolo Bypass Fish Monitoring Program since 1998 (https://iep.ca.gov/Science-Synthesis-Service/Monitoring-Programs/Yolo-Bypass). As floodplain enhancement projects proceed in the Sutter Bypass, the Yolo Bypass Monitoring Program can serve as a model for designing a comparable monitoring program.

3.1.3 Monitoring Needed for Tidal Wetland Restoration (H_{TW1-5})

Evaluating the Local Tier hypotheses for tidal wetland restoration actions requires three general types of assessment, monitoring, or experimental approaches to acquiring information: (1) ability to accurately model habitat area according to according to physical habitat criteria of water velocity and inundation level by tidal stage; (2) community composition and densities of zooplankton, benthic, and epiphytic invertebrate and fishes along with abiotic covariates (i.e. water quality parameters) in tidal wetland restoration areas and reference sites; and (3) biological covariates (cyanoHABs, invasive aquatic vegetation, predator densities and predation risk) in tidal wetland restoration sites and their vicinities.

3.1.3.1 Modeling Tidal Wetland Habitat Area (H_{TW1}).

Estimating the total area of tidal wetland habitat requires a multi-dimensional modeling approach that uses an updated bathymetry layer and can simulate flow conditions with consideration of water project operations, and that has geographic boundaries encompassing the Suisun Marsh, confluence area including Sherman Lake, and the Cache Slough Complex. Modeling of habitat acreage may use the same Resource Management Associates (RMA) Bay-Delta model, which has a 2-D depth-averaged approximation of salinity and was used in the 2023 Draft Scientific Basis Report Supplement (SWRCB 2023) to represent tidal wetlands (Figure 5-4 in SWRCB 2023). An alternate open source 3-dimensional model for estimating acreage is SCHISM (Semi-implicit Hydroscience Integrated System Model, Zhang and Baptista 2008; Zhang et al. 2016), which can be used for estimating the area of tidal wetlands with specific biological and physical characteristics across varying hydrological conditions. SCHISM has been validated for the San Francisco Bay-Delta (Chao et al. 2017). Both models use inputs on water operations from CALSIM or SACWAM.

This modeling approach can be used iteratively to assess change in modeled habitat area. Additional bathymetric data will need to be collected after tidal wetland to update the elevations for the RMA Bay-Delta model.

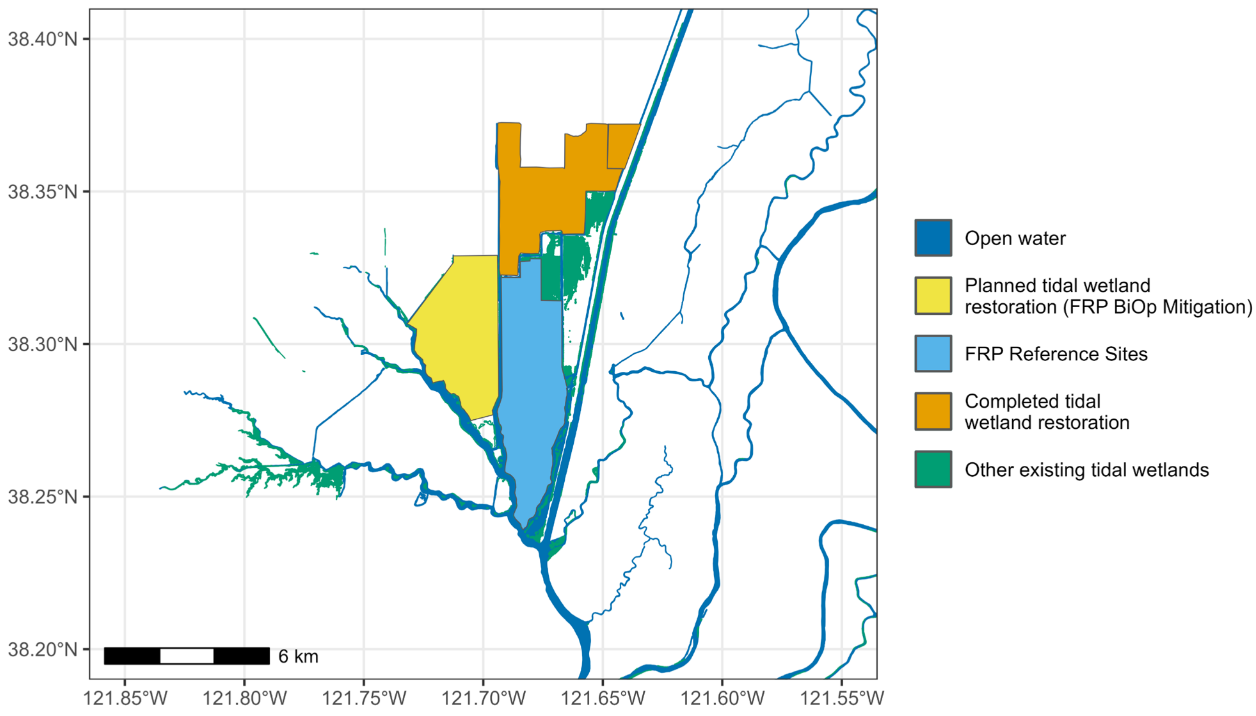
Multi-dimensional modeling approaches also allow for assessing habitat suitability for target species (MacWilliams et al. 2016). The RMA Bay-Delta Model can simulate specific conductivity as a surrogate for salinity, turbidity, and temperature, which are all covariates that inform suitability of habitat for longfin smelt, Delta smelt, and juvenile salmonids.

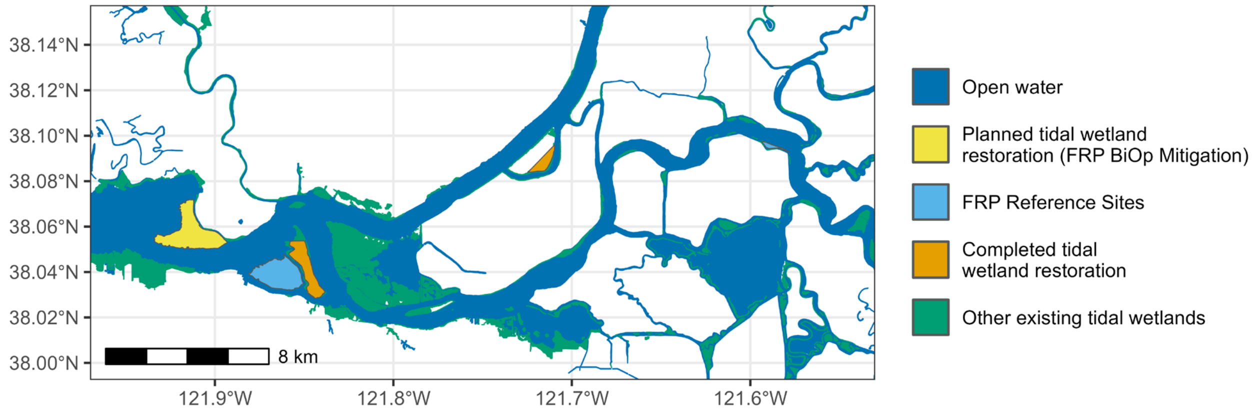
3.1.3.2 Community composition and densities of invertebrates (zooplankton, benthic and epibenthic invertebrates) and fishes along with covariates in tidal wetlands (H_{TW2}, H_{TW3}, H_{TW4}, H_{TW5}).

To evaluate these hypotheses, composition and densities of zooplankton, benthic invertebrates, and epiphytic invertebrates will be sampled in tidal wetland restoration sites and in the surrounding area within the tidal range of the project before and after the restoration occurs, as well as at reference locations. Benthic macroinvertebrate monitoring includes assessment of introduced clams, which can reduce densities of beneficial zooplankton taxa through filter-feeding. The fish community composition must also be sampled at restoration sites, ideally before and after restoration occurs and at reference sites, to determine if restored areas are being utilized by a native fish assemblage. The Fish Restoration Program (FRP) has been sampling the tidal wetlands of the Delta and Suisun Marsh since 2015 and the program is guided by conceptual models (Sherman et al. 2017) and a monitoring framework (IEP TWM PWT 2017).

The FRP monitoring framework uses a Before-After-Control-Impact (BACI) design to assess how newly restored tidal wetland sites function compared to pre-restoration conditions and compared to other, pre-existing wetlands (reference sites). Because of the annual variability in hydrology and climate in the region, multiple years of data are required to detect changes. The FRP monitoring is focused on the Northern and Western (confluence) regions of the Delta and Suisun Marsh (Figure 3). Sampling for zooplankton and invertebrates is conducted in a semi-random fashion at FRP sites and can be compared to sampling conducted as part of other routine monitoring programs in other regions and habitats, such as open-water areas. The fish community is also sampled, following the same design, along with water quality parameters including water temperature, specific conductivity, pH, and turbidity. The FRP also conducts visual assessments for *Microcystis* spp. following a standard protocol for scoring severity (Flynn et al. 2022).

At this time, tidal wetland restoration sites proposed for the VAs are not part of the FRP sampling, though some FRP sites may be useful as reference sites. Adding VA tidal wetland restoration sites to the program would require additional resources to implement FRP standardized sampling and reporting of relevant data, using the existing monitoring framework (IEP TWM PWT 2017).


38.40°N
38.35°N
38.30°N
38.25°N
38.20°N
121.85°W
121.80°W
121.75°W
121.70°W
121.65°W
121.60°W
121.55°W
6 km
Open water
Planned tidal wetland restoration (FRP BiOp Mitigation)
FRP Reference Sites
Completed tidal wetland restoration
Other existing tidal wetlands


38.14°N
38.12°N
38.10°N
38.08°N
38.06°N
38.04°N
38.02°N
38.00°N
121.9°W
121.8°W
121.7°W
121.6°W
8 km
Open water
Planned tidal wetland restoration (FRP BiOp Mitigation)
FRP Reference Sites
Completed tidal wetland restoration
Other existing tidal wetlands

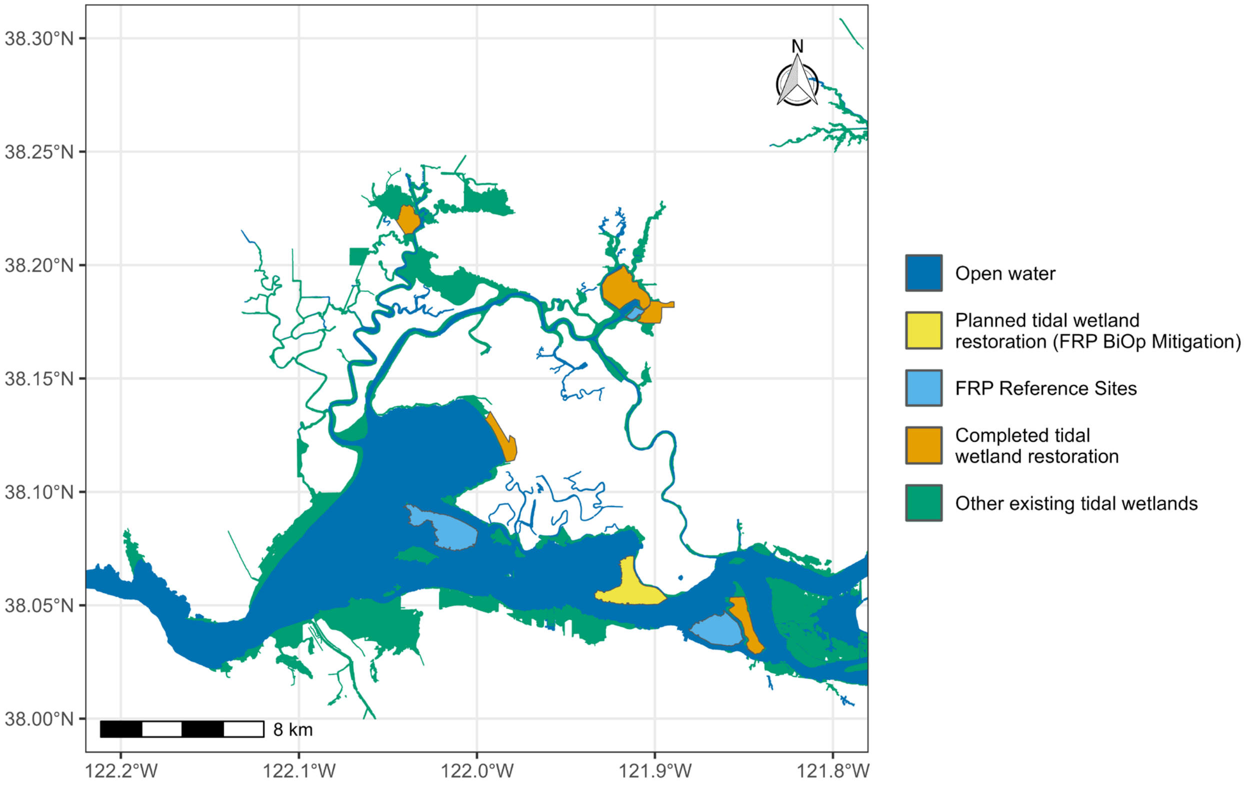


Figure 3. Sampling regions for the CDFW Fish Restoration Program. Reference sites are existing tidal wetland restoration areas in the North Delta (top), Confluence area (middle), and Suisun Marsh (bottom). The program samples for zooplankton, benthic macroinvertebrates, epiphytic invertebrates, and fish at reference sites, completed restoration sites, and in sites planned for tidal wetland restoration as part of the State Water Project's mitigation requirements in the 2019 Biological Opinion.

To compare densities and community compositions of invertebrates and fishes, it is necessary to have concurrent sampling in adjacent pelagic habitats for comparison purposes. VA hypotheses regarding invertebrates and fishes require evaluation of the full tidal footprint of tidal wetland habitat restoration sites, which may include pelagic areas. Long-term monitoring surveys operated by the USFWS, CDFW, and DWR have collected data on zooplankton and benthic invertebrates (Figure 4) and fishes (Figure 5) in these habitats for multiple decades over the entire region, and data from these surveys can be used for comparison of tidal wetland assemblages with adjacent pelagic areas (as approached in Hartman et al. 2022a). A full description of each survey can be obtained at the Interagency Ecological Program website (https://iep.ca.gov/Science-Synthesis-Service/Monitoring-Programs).

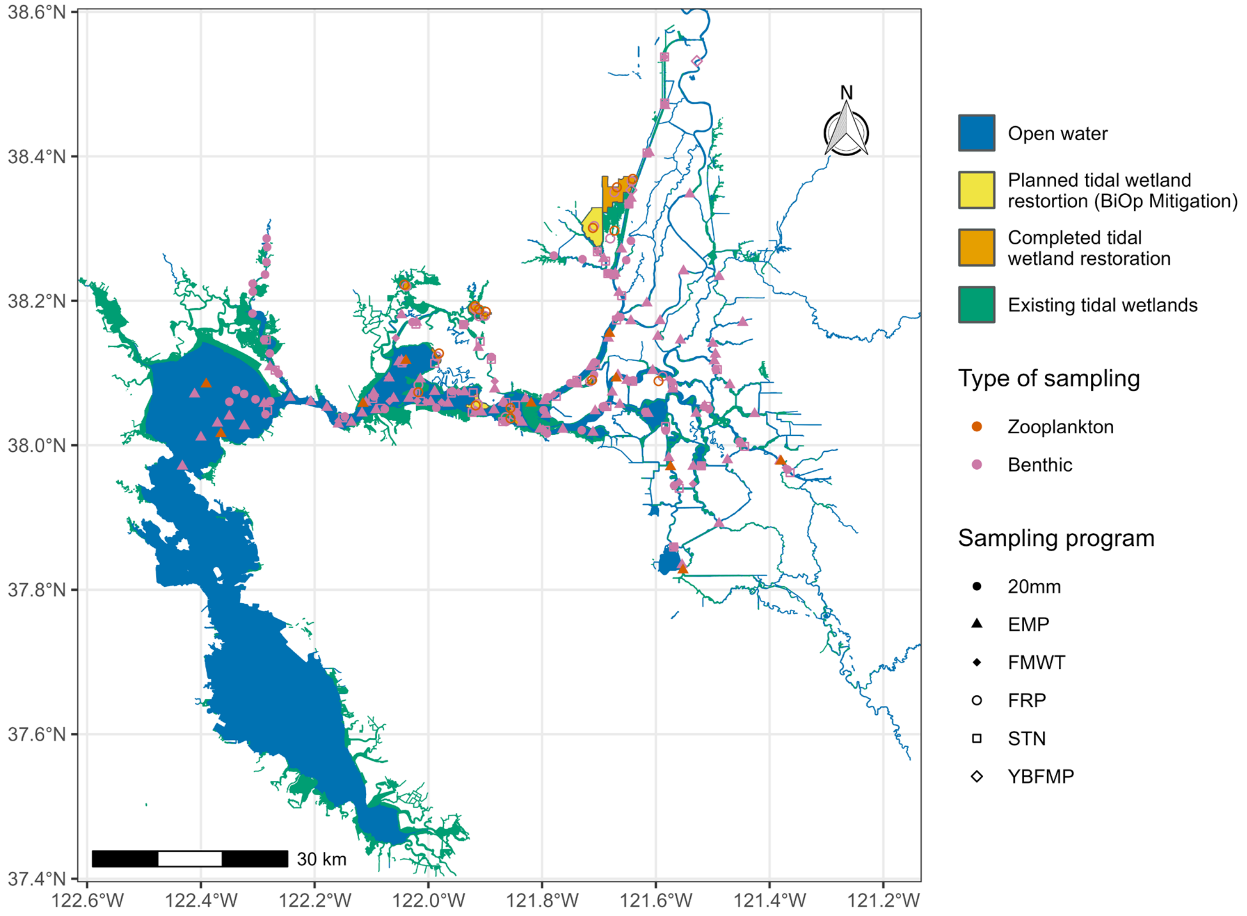


Figure 4. Long-term monitoring surveys collecting benthic invertebrate and zooplankton samples in both tidal wetland and pelagic habitats. 20mm = 20mm Survey, EMP = Environmental Monitoring Program, FMWT = Fall Midwater Trawl, FRP = Fish Restoration Program, STN = Summer Townet Survey, YBFMP = Yolo Bypass Fish Monitoring Program.

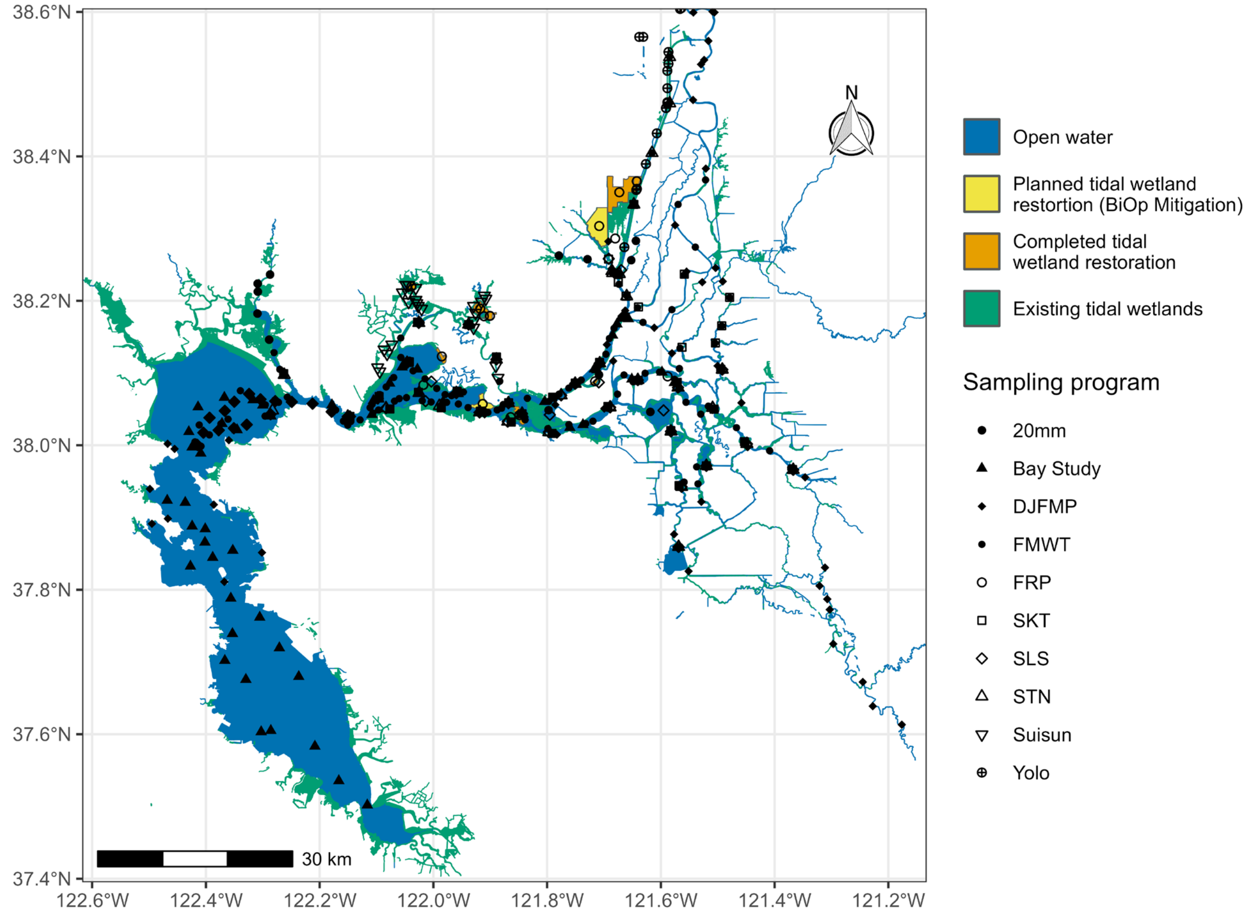


Figure 5. Long-term monitoring surveys collecting fish assemblage and density data through trawling and seining in both tidal wetland and pelagic habitats. 20mm = 20mm Survey, DJFMP = Delta Juvenile Fish Monitoring Program, FMWT = Fall Midwater Trawl, FRP = Fish Restoration Program, SKT = Spring Kodiak Trawl, SLS = Smelt Larval Survey, STN = Summer Townet Survey, Suisun = UC Davis Suisun Marsh Survey, Yolo = Yolo Bypass Fish Monitoring Program.

3.1.3.3 Biological Covariates for Aquatic Vegetation and Predators

Coverage of aquatic vegetation at restoration sites (Covariate for H_{TW5}). Monitoring of aquatic vegetation is conducted via remote sensing techniques (aerial or satellite methods) to capture imagery over a broad region and then classify the imagery to determine the coverage of emergent, floating, and submerged plant communities. Remote sensing techniques require matching field data to train classification algorithms. Field-based surveys using acoustic doppler techniques or manual sampling of the vegetation can cover smaller areas and get more detailed coverage information while also getting species-specific data for submerged species (Khanna et al. 2018). In the Delta and Suisun Marsh, maps based on remote sensing techniques have been produced for the full region or sub-regions in most years since 2003, except for 2009 - 2013 (Figure 6, Table 5).

Capture of regional trends of changes in aquatic vegetation coverage and community composition is important for understanding how the full system is changing and how vegetation responds to variation in hydrology and climate conditions. These broad regional changes influence site-specific changes that are relevant to the outcomes of tidal wetland restoration projects planned for the VAs. However, at a site-specific scale to capture coverage of aquatic vegetation and detect specific plant communities, drones offer a cost-effective approach for capturing high-resolution imagery and can feasibly be done multiple times per year to assess seasonal changes to vegetation (Bolch et al. 2021).

Most of the mapping work for aquatic vegetation in the Delta and Suisun Marsh has been done at the regional scale (Figure 6) and there are relatively few studies that have examined patterns at a more localized scale, such as the project scale of the tidal wetland restoration sites.

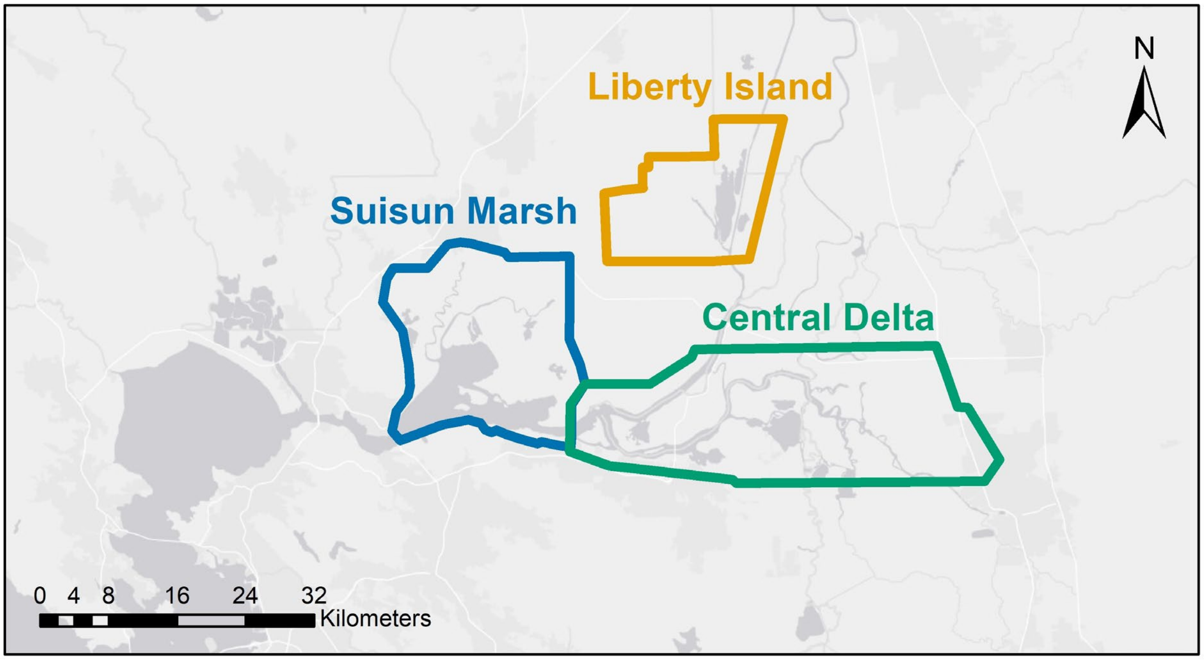


Figure 6. Map of Delta and Suisun Marsh, with delineations of regions that have been consistently mapped in year 2003 – 2008 and 2014 – 2022 (2023 mapping is anticipated, not complete). These regions are referenced in Table 5.

Table 5. History of imagery capture for aquatic vegetation mapping 2003 – 2023. The sensor type has changed over time with the availability of new sensors that can produce finer levels of spatial resolution (pixel size). Image extent corresponds to the above map of Delta regions.

Year	Image acquisition date	Sensor	Pixel Size	Image extent
2003	Jul 1	HyMap	3.0m	Central Delta (narrow) + Suisun (only grizzly island)
2004	Jun 25 – Jul 7	HyMap	3.0m	Full Delta
2005	Jun 22 – Jul 8	HyMap	3.0m	Full Delta
2006	Jun 21 – 26	HyMap	3.0m	Full Delta
2007	Jun 19 – 21	HyMap	3.0m	Full Delta
2008	Jun 29 – Jul 07	HyMap	3.0m	Liberty island to S. Delta
2014	Nov 14-25	AVIRIS-ng	2.5m	Full Delta
2015	Sep 17-21	AVIRIS-ng	2.5m	Full Delta
2016	Oct 8-9	AVIRIS-ng	2.5m	Liberty island, central Delta
2017	Nov 1	AVIRIS-ng	2.5m	Liberty island, central Delta
2018	Oct 6-9	HyMap	1.7m	Liberty island to Lost slough, central Delta, Suisun
2019	Apr 9-12	HyMap	1.7m	Liberty island to Lost slough, central Delta, Suisun
2019	Sep 23-28	HyMap	1.7m	Full Delta
2020	Jul 15-18	Fenix	2.0m	Full Delta
2021	Jul 8-28; Aug 11	Fenix	2.0m	Full Delta + Suisun
2022	Jul 14-18	Fenix	2.0m	Full Delta + Suisun
2023	Aug expected	AVIRIS-3	2.0m	Full Delta + Suisun

Predator densities at tidal wetland restoration sites (Covariate for H_{TW5}). Little spatially-explicit data is available for large-bodied fishes that might provide baseline data for predator densities at tidal wetland restoration sites. The CDFW Striped Bass Study (no longer active, Striped Bass Study (ca.gov)) was an ongoing study since 1969 that used fyke nets to capture, tag, measure, and assess the sex ratio of striped bass in the Sacramento River near Knights Landing, with the most recent field season occurring in 2019 (Danos et al. 2020). This study provides information regarding relative abundance across years but is not useful for assessing predator dynamics at specific locations. Electrofishing is another method for capturing large fish that is spatially explicit and the USFWS, in collaboration with the USGS, has operated a boat electrofishing survey since 2018, using a stratified random sampling design to estimate spatial and temporal trends in species abundance and capture probabilities across littoral habitats in the Delta (McKenzie et al. 2022). This survey may produce data that could be used to model occupancy likelihood for predator species of interest in tidal wetland habitats.

Understanding local densities of predators and their behavior in tidal wetlands is a challenging task because of high spatial and temporal complexity over the tidal cycle, requiring tool development to sample predator movements and relate predation risk to microhabitats. Focused sampling efforts on predators in tidal wetland habitats and adjacent areas have already been producing valuable information on predator densities and predator diets to understand the interaction between predator and prey populations within the complex habitat mosaic of tidal wetlands (Colombano et al. 2021; Young et al. 2022). However, recent studies from other systems have used acoustic cameras such as the Dual Frequency Identification Sonar (DIDSON) camera to assess the species assemblage of predators and their movements at entry/exit points of tidal wetlands (Boswell et al. 2019; Bennett et al. 2021). Because the technology is sonar based, it has been effective even in turbid environments. The DIDSON technology, along with a more recent innovation called Adaptive Resolution Imaging Sonar (ARIS), has been used for similar applications in North Delta tidal wetlands (D. Ayers, USGS and UC Davis, pers. comm.).

In addition to predator diets and sonar imaging, tethered prey stationed across habitat types using Predation Event Recording Systems (PERS, Demetras et al. 2016) has also been used in the Delta to quantify relative predation risk (Michel et al. 2020) and can be applied to tidal wetland habitats as well.

To address the potential for predators to occupy tidal wetlands and use the newly created habitat as a foraging opportunity will require continued special studies at VA tidal wetland restoration sites. These studies will utilize recent technologies of sonar imaging, PERS, and diet analyses that may leverage from genetic approaches for a full characterization of the species assemblage in predator diets.

3.2 Monitoring Needed for Full Tributary and Delta Tier of Hypotheses

3.2.1 Juvenile Salmon Outmigration Survival, Productivity, Condition, and Diversity ($H_{TribFlow2}$, $H_{TribFlow3}$, $H_{TribWide1}$, $H_{TribWide2}$, $H_{TribWide3}$)

Many of the hypotheses at the Full Tributary Tier require an assessment of the juvenile salmon population exiting each tributary. Rotary screw traps (RSTs), which are anchored at a specific location and designed to capture a portion of the fishes traveling downstream with a rotating, screened cone leading to a live collection box, are a common method for capturing a portion of the outmigrant population to assess timing of outmigration, body size, and abundance. If batches of tagged fish are released as part of an assessment of the juvenile salmon response to pulse flows, capture at the RST can provide data on travel time, survival, and outmigration rate. However, it is necessary to have estimates of RST efficiency to estimate the proportion of the population being captured and in turn overall abundance. Trap efficiency estimates are obtained through a mark-recapture approach in which marked fish of a similar size as outmigrating fish (typically hatchery fish) are released above the trap, and the number of marked fish re-captured in the trap provides the efficiency estimate. Efficiency is affected by flow rates, size and life stage of fish, debris load on the trap, turbidity, wings or other infrastructure on the trap to guide water and fish toward the cone, time of day, and trap noise (Volkhardt et al. 2007). Because the factors that affect trap efficiency are dynamic, trap efficiency experiments need to be frequent and use large release groups (> 100 fish). High trap efficiencies are necessary for the precision of the abundance estimate of outmigrating juvenile salmon (Newcomb and Coon 2001), which is an essential annual data point for each VA tributary in assessing population trends.

As RST capture efficiencies increase, juvenile abundance estimates improve in precision. At minimum, capture efficiencies should be 5% in order to carry out a mark-recapture approach to trap efficiency estimation (Newcomb and Coon 2001; Willete and Templin 2013). Efficiency estimates should be carried out multiple times per trapping season to adequately inform models for juvenile abundance, and covariate information (e.g., river discharge, turbidity), should also be recorded to inform statistical models of abundance. Supportive trap infrastructure for safe operation under higher flow conditions (debris booms, anchors, etc.) is also essential and can improve efficiency.

Each VA tributary system operates at least one RST in its lower reaches. The locations and summary of the information gathered at each RST monitoring station is provided in Figure 7. The Upper Sacramento system has an RST at Red Bluff Diversion Dam, and two tributaries to the Upper Sacramento (Upper and Lower Clear Creek, and Battle Creek) also operate their own RSTs such that it may be possible to distinguish population contributions from each of these secondary systems. Some systems operate 2 or 3 RSTs in tandem to cover a greater proportion of the channel width (Red Bluff Diversion Dam, Feather, Yuba, Mokelumne, American, Tuolumne). Additional RSTs (not shown in Figure 7) are located in the lower Sacramento River at Knights Landing and Tisdale Weir, as well as in the perennial Tule Canal of the lower Yolo Bypass.

An overview of the RST methodologies across tributaries reveals variation in efficiency and juvenile abundance estimations. While trap efficiency for fry is obtained for nearly all RST monitoring stations (with the exception of Putah Creek, future evaluation is planned), estimates for the American, Tuolumne River, and all RSTs on the Upper Sacramento River conducted fewer than 10 efficiency trials per year, while other systems are conduct up to 30 trials per year. Only the Mokelumne and American River report fry trap efficiencies of >5%, with the majority of others estimating their efficiency to be in the range of 2-5%. Older juveniles (>65mm), for which trap efficiency is likely to be lower because of their increased ability to avoid the trap, is estimated at a smaller subset of RST monitoring stations, and missing at Putah Creek, Yuba River, and Feather River. Finally, statistical models that utilize the efficiency trial data to produce abundance estimates are not available for all systems (missing for the Feather, Yuba, Mokelumne, Putah, and Clear and Battle Creeks). Where an efficiency model is available (for the American, Tuolumne, Red Bluff Diversion Dam), different covariates are used, revealing that statistical approaches for using RST information vary in addition to field methodologies.

In addition to population abundance information, RSTs also present an opportunity to characterize the juvenile salmon because the fish need to be handled and processed before being released. Body length and weight can be measured, thus providing fish condition information ($H_{TribWide2}$). Tissue samples may also be collected and used for genetic run assignment or other genetic diversity information. All RST stations collect body length data from all or a subsample of juvenile salmonids, but body weight is logistically challenging in the field and only collected routinely at RSTs on the American, Mokelumne, and Tuolumne Rivers as well as Putah Creek (Figure 7). The Yuba, American, and Tuolumne River RSTs collect tissue samples routinely from a subsample of the captured salmonids, and the other RSTs can collect tissues samples if requested. Finally, as RSTs capture other species besides salmonids, they also present an opportunity to characterize general community composition of fishes in each system, though trap efficiencies are variable across species and not measured. All RSTs on VA systems record information on non-salmonids.

In summary, RST monitoring stations on VA tributaries are positioned to provide the necessary information for evaluating hypotheses regarding flow pulse events and trends in juvenile salmon abundance and life history diversity. However, significant attention and changes to current protocols are required to achieve consistency and improved information from all stations. Specifically, RSTs need consistent methodologies and increased effort for fry RST efficiency estimation, increased effort for estimating RST efficiencies for larger juveniles, and consistent methodologies for statistical approaches to processing efficiency and trap data to estimate abundance. Furthermore, as shown in Figure 7, RST monitoring stations are not consistently posting data to public data repositories. This step is essential to data management for the VA Science Program and facilitates efficient synthesis of information for VA reporting.

Figure 7. Locations and information summaries for Rotary Screw Traps (RSTs) on Voluntary Agreement tributaries to the Bay-Delta. The "upon request" symbol is used where juvenile salmon body mass data is collected only when requested, and when RST data are not available online and must be requested from survey leads.

3.2.2 Monitoring Needed for Increased Spring Delta Outflow

3.2.2.1 Modeling Habitat area ($H_{Deltaflow1}$)

The hypothesis for acreage of appropriate spawning and larval rearing habitat for Delta Smelt and longfin Smelt will use the network of existing monitoring stations to parameterize models of appropriate salinity, temperature, and turbidity to map total acreage of suitable habitat using the methods described in the 2023 Draft Scientific Basis Report (SWRCB 2023). Data for parameterizing these models may come from discrete water quality data collection taken as part of routine surveys for water quality, fish, and invertebrates (Figure 4, Figure 5), as well as the extensive network of in-situ water quality sondes maintained by USGS and DWR (Figure 8). Models of habitat acreage may use the same RMA model used by the 2023 Draft Scientific Basis Report (SWRCB 2023), or other 3-dimensional hydrodynamic models, if appropriate. For example, SCHISM (Semi-implicit Hydroscience Integrated System Model) is an open-source, 3-dimensional modeling system (Zhang and Baptista 2008; Zhang et al. 2016) that can be used for estimating the area of habitat with specific suitability criteria across varying hydrological conditions, and has been validated for the San Francisco Bay-Delta (Chao et al. 2017).

Notably, water quality and flow monitoring stations (Figure 8) will provide important covariate data for many of the hypotheses regarding restored tidal wetlands in the Delta and Suisun Marsh, and increased Delta outflow. Flow sensors can be used to parameterize hydrodynamic models such as DAYFLOW (https://data.cnra.ca.gov/dataset/dayflow), or to directly assess flows through particular regions of the Delta.

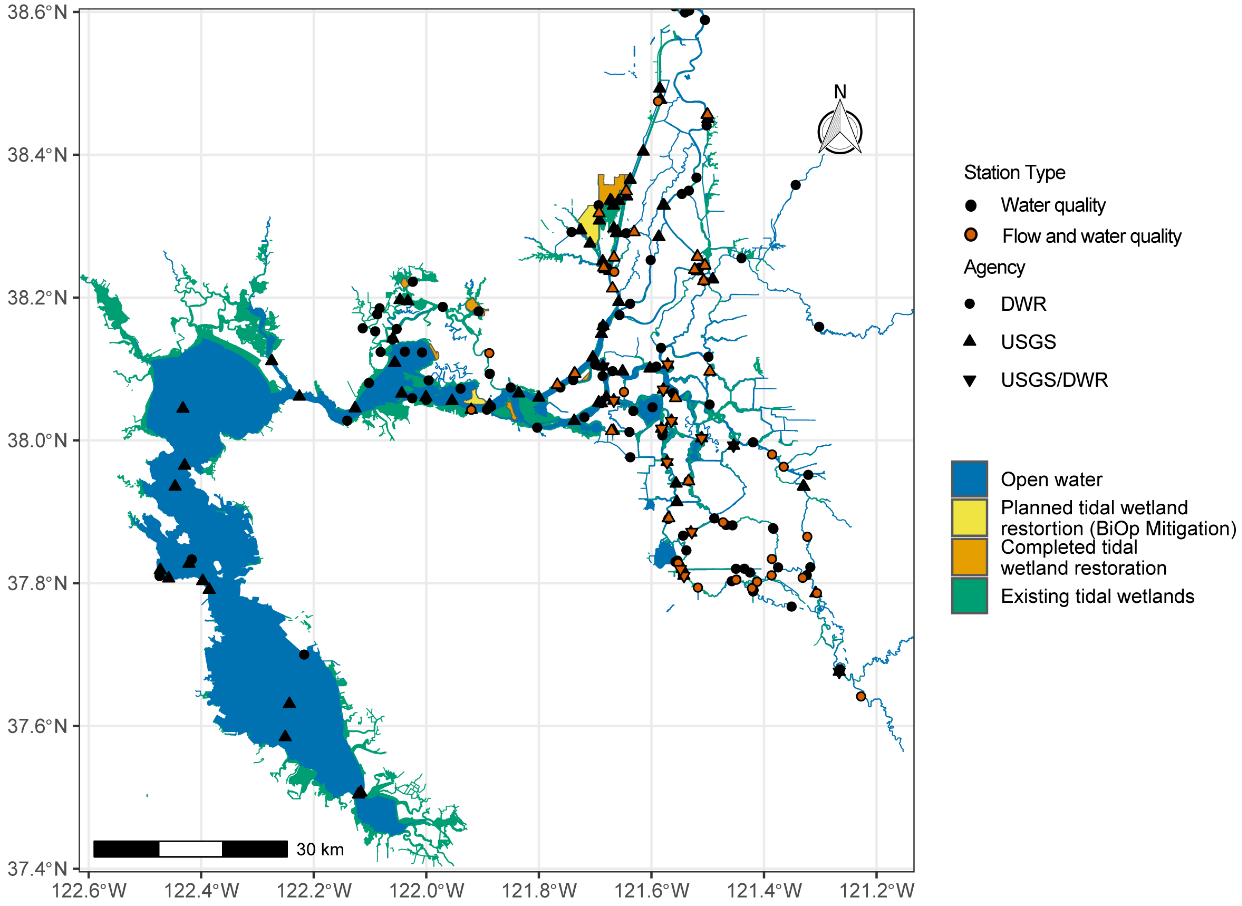


Figure 8. Map of in-situ flow and water quality stations in the Delta. The stations indicated above are installed on site and collect data at regular intervals (e.g., 15 min, 1 hour) throughout the day and night. Many stations are telemetered such that the data can be accessed in real-time, typically on the California Data Exchange Center (CDEC, California Data Exchange Center). Point color denotes flow (red) and water quality (black).

Other water quality and biological parameters that may effect ecosystem processes, such as phytoplankton biomass, temperature, turbidity, and dissolved oxygen are monitored through the discrete values recorded by long-term monitoring surveys (Figure 4, Figure 5), and the network of continuous water quality sondes.

3.2.2.2 Monitoring and Modeling Transport and entrainment of fish ($H_{DeltaFlow2,\ 3}$)

The hypothesis for transport and entrainment of larval and juvenile longfin smelt, Delta Smelt, and Chinook salmon will rely on the expanded Enhanced Delta Smelt Monitoring Survey, Smelt Larval Survey and 20mm Survey (Figure 5). Rates of entrainment of juvenile salmon will use data collected by the fish salvage facilities, which are expanded for estimated entrainment. In addition, the expanded Smelt Larval Survey for the Longfin Smelt Science Program conducted for the 2020 Incidental Take Permit for the State Water Project, issued by CDFW to DWR, will provide data to parameterize and validate models of larval entrainment. Other long-term surveys for juvenile and adult smelt and salmon (Figure 5) will assist in parameterizing the Delta Smelt life cycle model and the Longfin Smelt life-cycle model (currently in development as part of the Longfin Smelt Science Program) that will further validate models of larval entrainment.

3.2.2.3 Special studies for assessing effects of increased spring outflow on salmonid survival and habitat use ($H_{DeltaFlow4,5}$)

The hypothesis for survival and travel time for juvenile salmonids through the tidal region of the Delta will require study designs of comparing the survival and travel time of acoustically tagged juvenile salmonids using a study design that allows for targeted examination of these metrics at different levels of Delta outflow. There is an existing network of acoustic telemetry receivers throughout the Delta, available through the Central Valley Enhanced Acoustic Tagging Project (CalFishTrack website: https://oceanview.pfeg.noaa.gov/CalFishTrack/). This network includes receivers at the fish collection facilities in the South Delta near the pumping operations, in the Old and Middle River corridor, the Central Delta, and at the confluence of the Sacramento and San Joaquin Rivers (Chipps Island). This array allows detection of acoustically tagged fish in the tidal regions, including their responses to pulse flows. On the CalFishTrack website, tagged fish can be tracked in real time as they move through the system, along with survival and routing probability.

Similarly, the hypothesis regarding evidence of floodplain rearing will require special studies, but will rely on existing fish surveys to collect biological samples from outmigrating fish (eye lenses, otoliths, Bell-Tilcock et al. 2021) that can be used to assess the prevalence of floodplain rearing. It is anticipated that samples for this analysis will be sourced through the USFWS Delta Juvenile Fish Monitoring Program (DJFMP, Figure 5), which trawls for juvenile salmon and other species at the confluence of the Sacramento and San Joaquin Rivers (Chipps Island Trawl, Speegle et al. 2022). As needed, other special studies can be used to increase sample size when floodplain conditions allow.

3.2.2.4 Monitoring status and trends of sturgeon, zooplankton, and prevalence of cyanoHABs ($H_{DeltaFlow6-8}$)

The hypothesis for increased year class indices of white sturgeon will be assessed through data collected by the San Francisco Bay Study (Figure 5, https://wildlife.ca.gov/Conservation/Delta/Bay-Study). This survey collects monthly otter trawls and midwater trawls throughout the estuary and calculates an annual index of white sturgeon population size (Fish 2010).

The effect of increased flow on zooplankton will also leverage the long-term monitoring (Figure 4): the Environmental Monitoring Program's Zooplankton Survey, the Fall Midwater Trawl, Summer Townet, and 20mm Survey's zooplankton samples and FRP zooplankton sampling. These programs collect zooplankton across the estuary once or twice per month. These data can be used to statistically assess changes in zooplankton abundance with increased spring flows or used to parameterize models of zooplankton transport as per Kimmerer et al. (2018).

The hypothesis for frequency and distribution of cyanoHABs will be evaluated primarily through visual assessments carried out as part of routine fish and water quality surveys (as described by Hartman et al. 2022b). Together, these surveys provide over 800 point samples per summer across the estuary that give a qualitative assessment of relative abundance of *Microcystis* and *Aphanizomenon*, which are two of the most common cyanoHAB taxa in the Delta. These visual assessments are only semi-quantitative, rating the density of *Microcystis* on a scale of 1-5 (Flynn et al. 2022), but can be used to track broad-scale trends in *Microcystis* over time and conditions, including varying temperatures and flow regimes (Hartman et al. 2022b). Some routine monitoring of cyanotoxins is conducted at important locations, such as Big Break Regional Shoreline and State Water Project Facilities which can be used to supplement visual observations, however no regular monitoring for cyanotoxins across the estuary is currently in place.

3.3 Monitoring Needed for Population-level Tier Hypotheses

3.3.1 Adult Chinook Salmon Populations ($H_{TribPop1}$, $H_{TribPop2}$, $H_{TripPop3}$, H_{SWPop1}, H_{SWPop2})

The hypotheses for population level effects for Chinook salmon require tracking the abundance and return rates of natural-origin Chinook adults by tributary and at the system-wide scale (Sacramento and San Joaquin Valleys). As noted above, the Constant Fractional Marking Program provides an estimate of natural-origin fish and hatchery-origin fall run Chinook salmon based on a 25% marking rate. Central Valley recoveries of coded-wire tagged salmon, with estimates for the proportion of the population made up of hatchery-origin fish are summarized annually (most recent report, Letvin et al. 2021).The coded-wire tagging approach allows for all tagged fish to be identified to the source hatchery (and hence tributary), but untagged fish cannot be identified to tributary source without geochemical analysis of otolith samples (Barnett-Johnson et al. 2008), which is labor intensive and expensive. Therefore, increasing the marking rate to 100% would improve accuracy of estimates for natural origin fish and better address the hypotheses regarding tributary and Valley-wide populations of Chinook salmon.

Evaluation of tributary populations of Chinook salmon requires monitoring the escapement, which are the adults that have escaped harvest and successfully migrated to their natal tributary system or straying into a non-natal system. Escapement is monitored using a variety of methods that include direct counts at passage structures, surveys of redds accompanied by fish counts, and by counting carcasses and conducting carcass mark-recapture studies to develop efficiency estimates of the surveys such that a range of potential adult abundances can be calculated. A number of reasons may contribute to the decision to take on a specific approach or combination of approaches for estimating adults, including funding, conditions and feasibility of any given approach, including a suitable location for conducting direct counts.

With carcass surveys, and in some direct counting efforts of live adults, the fish are handled and there may be an opportunity to collect biological samples that can further help characterize the population. Tissue and scale samples can be collected non-lethally and provide information on genetics and age structure for each individual sampled, while otolith and eye lens samples are lethal samples and are usually collected from carcasses. Carcasses can also be examined for fin clips to identify them as hatchery-origin, and heads can be collected for locating coded-wire tags. These measures provide a way to estimate the proportion of the population that is natural-origin.

The VA tributary systems all have monitoring programs in place for adult Chinook salmon and have at least one method for estimating abundance (Table 6). For the purpose of the VA hypotheses on adult salmon, there is not a need to have wholly consistent methods across each tributary system as long as abundance estimates are developed. However, the utility of abundance estimates depends on whether their accuracy is estimated such that the abundance estimate can be framed with an approximation of the level of uncertainty around the abundance number. Additionally, it is important that the abundance estimate include an estimate of the natural-origin adults, because natural-origin Chinook salmon are the target beneficiaries of the VA Program. On the Upper Sacramento, only Battle Creek obtains accuracy estimates (none on mainstem or Clear Creek), reporting a rate of ±50%. The Feather, Yuba, and American Rivers all obtain accuracy estimates (albeit through different methods) and report a general accuracy level of ±10%. Importantly, however, abundance of natural origin adult salmon is not consistently estimated: Putah and the upper Sacramento mainstem examine a relatively small number of carcasses for hatchery marks or tags (<50), while the American, Feather, and Mokelumne Rivers inspect over 500 carcasses. Given that there are existing sampling efforts on all systems, the greatest improvement and utility towards robust evaluation of hypotheses regarding adult Chinook salmon would be investment in estimating and improving accuracy of abundance estimates, with a concerted effort towards estimating abundance specifically of natural-origin salmon.

Tissues, scales, and otolith samples are collected in all systems. Eye lenses, a relatively new type of biological sample used for geochemical analyses, are only collected in Putah Creek (Table 6). A close examination of archived samples for each system may be helpful in determining whether they can be used for retrospective analyses of the proportion of the population that was natural origin or examination of life history characteristics. Such studies may be helpful for establishing a baseline of population attributes for each tributary system.

Table 6. Overview of adult Chinook salmon sampling methods for escapement, with corresponding abundance estimate accuracies, and biological sample collections, by VA tributary system. Biological sampling efforts are represented by "T/O/S/E", indicating presence or absence of **T**issue, **O**tolith, **S**cale, and **E**ye lens collections.

Tributary	Redd Survey (Y/N, Abundance Estimate Accuracy)	Carcass Mark-Recapture (Y/N, Abundance Estimate Accuracy, T/O/S/E samples)	Direct Count via Video (Y/N, Total Abundance Estimate Accuracy, Natural Origin Abundance Accuracy, T/O/S/E samples)
Upper Sacramento: Mainstem	No redd surveys	90% Confidence Interval generated by PSMFC, no accuracy estimate for Carcass Mark Recapture T/O/S/E: Upon Request/Yes/Yes/Upon Request	Direct Counts at individual, smaller tributaries, no accuracy estimate for total or natural origin abundance T/O/S/E: No/No/No/No
Upper Sacramento: Battle Creek	Redd surveys, no abundance estimates	No Accuracy Estimate T/O/S/E: Yes/Yes/Yes/No	(1) Video observations: No accuracy estimate for Chinook salmon total or natural origin abundance. T/O/S/E: No/No/No/No (2) Direct Count (fish are handled): +/- 50% accuracy for both total and natural origin abundance. T/O/S/E: Tissue samples collected for all runs, Otoliths collected for late-fall run, no scale or eye samples collected
Upper Sacramento: Clear Creek	Redd surveys, no abundance estimates	No Accuracy Estimate T/O/S/E: Yes/Yes/Yes/No	Direct counts, no accuracy estimates T/O/S/E: No/No/No/No
Feather River	No redd surveys	+/-10% Accuracy T/O/S/E: Yes/Yes/Yes/No	No Direct Counts
Yuba River	Redd surveys, no abundance estimates	Accuracy estimated, is variable T/O/S/E: Yes/Yes/Yes/No	+/- 10% Accuracy of total abundance, Natural-origin abundance not estimated

Tributary	Redd Survey (Y/N, Abundance Estimate Accuracy)	Carcass Mark-Recapture (Y/N, Abundance Estimate Accuracy, T/O/S/E samples)	Direct Count via Video (Y/N, Total Abundance Estimate Accuracy, Natural Origin Abundance Accuracy, T/O/S/E samples)
			T/O/S/E: No/No/No/No
American River	Redd surveys, +/- 10% accuracy of abundance estimate.	+/-10% Accuracy T/O/S/E: Yes/Yes/Yes/No	No Direct Counts
Mokelumne River	Redd surveys	No Carcass Mark-Recapture	+/- 10% Accuracy of overall abundance and +/- 50% accuracy of natural origin abundance T/O/S/E: Upon Request/Upon Request/Yes/Upon Request
Putah Creek	Redd surveys in subset areas	No Carcass Mark-Recapture	+/- 50% Accuracy for overall abundance, Natural-origin abundance not estimated, but a study is in progress at UC Davis T/O/S/E: Yes/Yes/No/Yes
Tuolumne River	Redd surveys, Abundance estimates from escapement survey or weir counts, no abundance estimates from redd counts	Carcass Mark-Recapture. Abundance estimates with uncertainty using CJS model O/S collected annually, T only for special studies.	T/O/S/E: No/No/No/No

3.3.2 Monitoring Needed for Native Species Communities in the Delta

The metric for this hypothesis is population estimates of starry flounder, Bay shrimp, Sacramento splittail, and longfin smelt, and Delta smelt. Notably, population estimates of these native species are not all currently available, except for Delta smelt through the enhanced Delta smelt monitoring program (EDSM, operated by the USFWS). All species have historically been tracked by the long-term fisheries surveys described in Figure 5, and the annual abundance indices derived from the Fall Midwater Trawl and San Francisco Bay Study conducted by CDFW have been reported for purposes of tracking population trajectories of these species. These indices are correlated with design-based estimators of population abundance (Melwani et al. 2022). In future, developing population abundance estimates for these species may be important in identifying the effectiveness of increased spring outflow, parameterizing life cycle models, and identifying limiting factors for populations (see information gaps, below) which can inform prioritization of habitat and flow investments (see information gaps, below). However, developing population estimates for these species will require rigorous review of existing monitoring programs and how they align with the needs for spatial balance in sampling across the geographic distribution for each species and life stage, as well as review of the gear efficiencies for sampling the target species. This level of effort and analysis to achieve surveys designed for population estimates needs to be evaluated and prioritized along with other monitoring and information gaps for the VA Science Program.

3.4 Priority Monitoring and Information Gaps

The monitoring needs discussed above provide a coarse look at how increased investment in science and monitoring will be needed to develop the VA Science Program to provide all the needed information. Given the comprehensive list of hypotheses and associated monitoring, the VA Science Committee will need to conduct a more detailed examination of information gaps and prioritize which gaps should be given attention first. However, given the monitoring needs discussed above, several high-level gaps have emerged that will be important for the VA Science Program to work toward filling, leading up to and early in the implementation of the VA Program. Each of these gaps has implications for the ability of the VA Science Program to draw broad inferences about the effects of the VA Flow and Non-Flow Measures in support of the Narrative Objectives, and therefore on the ability to adequately inform the State Water Board's assessment process near the end of the term of the VA Program. These gaps include:

- **Ability to differentiate natural-origin and hatchery-origin adults for each tributary**. A primary intention of the suite of VA Flow and Non-Flow Measures is to increase juvenile salmonid production from the tributaries and to increase condition and survival during outmigration. However, the Narrative Salmon Doubling Objective describes desired populations of returning adult salmon populations. Understanding how actions taken with the VA program relate to adult returns, for each tributary system and for the entire Sacramento and San Joaquin Valleys requires an ability to track which returning adults are the product of increased juvenile production and which are the product of hatchery operations. Currently, relative contributions of natural-origin and hatchery-origin Chinook salmon are estimated through the constant fractional marking program because only 25% of hatchery-origin fall-run Chinook salmon are marked (e.g., with fin clips or coded-wire-tags) or are physically identifiable. One of the primary objectives of the constant fractional marking program is to determine the proportions of hatchery- and natural-origin salmon in spawner returns to CV hatcheries and natural areas. To determine the contribution of hatchery- and natural-origin salmon, all *CWT* are summed to estimate the total number of hatchery salmon in each survey. The contribution of natural-origin salmon for each survey can then be determined by subtracting the total number of hatchery salmon from the total escapement estimate (Letvin et al. 2021). Refinement of these estimates could be made through a 100% marking program, but until that program is implemented, the current CFM program provides the best estimates, and is supported by the use of baseline data from 2010, the first year of complete CFM tagged returns, in H_{SWPop1} and H_{SWPop2}. Release of the data summary from this program in a timelier manner would aid in analysis of the VA program.

  Retrospective analyses of otoliths for growth patterns characteristic of natural-origin fish (Barnett-Johnson et al. 2007), and for tributary-specific microchemistry (Barnett-Johnson et al. 2008) provides an approach for identifying natural vs. hatchery origin by tributary, and could provide supporting analyses to address population-level hypotheses for Chinook salmon. However, this approach is labor intensive for sample sizes needed for population-level analyses and without the ability to rapidly identify all hatchery origin salmon as such and to their natal tributary system, hypotheses that relate VA actions at the individual Tributary scale and Systemwide Scale ($H_{TribPop1}$ – $H_{TribPop3}$, H_{SWPop1}, and $H_{SWPop2,}$ respectively) will be difficult to address.

- **Consistency of monitoring approaches across tributaries to support system-level analysis.** As described in Section 1, a primary benefit of the VA Program is the coordination of science across tributaries to better understand the effects of VA measures. Consistency in monitoring approaches to estimate core metrics relevant to the hypotheses will be an important contributor to this broad and synthetic understanding. Consistency in several specific dimensions will need to be improved:

- *Juvenile production estimates*: Rotary Screw Traps (RSTs) are currently used in the tributaries to assess juvenile abundance during outmigration. However, improved consistency across specific points of monitoring protocols is needed in order to provide robust juvenile production estimates, which are critical metrics for each tributary system. Areas of monitoring that need enhancement and increased consistency include whether and how estimates of capture efficiency are made for larger juveniles, rigor of fry efficiency estimates, and the regularity of fish condition assessments.
- *Adult population estimates*: Adult estimates within tributaries are currently conducted using a variety of methods and have varying accuracy across the tributaries (Table 6). In many cases, the accuracy of abundance estimates is not assessed, and fish origin (hatchery or natural origin) is not consistently identified or is not possible to identify given that hatchery-origin fall-run Chinook salmon are only marked at a 25% rate. Identifying ways to standardize approaches and improve accuracy will be an early priority of the VA Science Committee.
- *Invertebrate communities*: Production of benthic invertebrates and zooplankton is not currently assessed in all tributaries (Table 3) and is generally only done for special studies. Standardizing approaches to assess food web processes at the site scale and instituting monitoring to support assessment of broader measures of river and stream health (e.g., invertebrate community indices) will be a priority for the VA Science Committee.

As stated above and in Table 2 - Table 6, VA tributary systems vary in the degree and approach for all categories of data collection for evaluating Local tier, non-flow habitat measures and for developing estimates for both juvenile and adult Chinook salmon life stages, and the adjustments needed to achieve consistent and sufficient information for priority information gaps also varies across tributary systems. Table 7 provides a summary of the opportunities for investments in the monitoring network within each of the tributaries to provide consistent evaluation of key metrics articulated in metrics table in Section 2.

Table 7. Summary of where changes are needed to obtain consistent information to address VA hypotheses for tributary systems. The symbology in the table is as follows: Teal indicates few or only minimal adjustments required, **yellow** indicates modest changes required, and **orange** indicates significant changes required. (White cells pending input).

	Juvenile Production Estimates	Adult Population Estimates	Tributary Juvenile Habitat Use	Tributary Invertebrate Sampling	Habitat Mapping
	Teal *= Both size classes have efficiency estimates and data are online;* ***Yellow*** *= Larger juvenile efficiency estimate missing and/or data are not online;* ***Orange*** *= Efficiency estimates missing for both size classes.*	***Teal*** *= Accuracy estimates exist, including for natural-origin fish;* ***Yellow*** *= Accuracy estimate missing for natural-origin fish;* ***Orange*** *= Accuracy estimates are missing*	***Teal*** *= Habitat use is assessed through regular surveys and density data are produced;* ***Yellow*** *= Juvenile habitat use is assessed only a project-specific basis and/or only presence/absence data are produced;* ***Orange*** *= Very limited or no habitat use surveys occur*	***Teal*** *= Sampling is routine and data are online;* ***Yellow*** *= Sampling is episodic over time and data are not available online;* ***Orange*** *= Limited or no sampling occurs*	***Teal*** *= DEM based on LiDAR with 2D model platform, full cover map is available;* ***Yellow*** *= Cover map or other mapping elements are partial;* ***Orange*** *= Full component of habitat mapping (Table 4) is missing*
Upper Sacramento	🟩	🟨	🟩	🟩	🟨
Feather	🟨	🟨	*input pending*	🟨	*input pending*
Yuba	🟨	🟨	🟨	🟨	🟩
American	🟩	🟨	🟩	🟨	🟩
Mokelumne	🟩	🟩	🟨	🟧	🟩
Tuolumne	🟨	🟨	🟩	🟩	🟨
Putah	🟧	🟨	🟩	🟨	🟩

- **Design of population estimates for non-salmonid target species in the Delta.** Population-level hypotheses for responses to the VA Flow and Non-Flow measures in the Delta require population estimates with associated uncertainty estimates for the California Bay shrimp, Sacramento splittail, longfin smelt, and Delta smelt. However, for all species except the Delta smelt, current surveys only provide abundance estimates, and it is not clear whether these estimates are correlated with true population abundance, and they lack uncertainty estimates. To adequately address these information gaps, it will be necessary assess the monitoring network for each species, and determine what measures are needed to develop population estimates (efficiency estimates for current monitoring approaches for each life stage, spatial coverage of monitoring over the species' ranges in the Delta system, and sampling design). Based on detailed examinations of the monitoring networks, the VA Science Committee can recommend necessary steps to evaluating the feasibility of achieving population estimates for these target species.

  Notably, the monitoring network for Delta smelt has already been undergoing this process through a major review, and in 2016 added the Enhanced Delta Smelt survey (eDSM), which samples the subadult and adult Delta smelt population using a stratified randomized design and produced population estimates (McKenzie et al. 2022).

  As part of the SWP 2020 Incidental Take Permit issued to DWR by CDFW in 2020, a Longfin Smelt Science Program is also underway, endeavoring to develop datasets to inform a Life Cycle Model, similar to the models that exist for Delta smelt and Winter-run Chinook salmon and that allow predictive capacity for evaluating climate and management scenarios. The Longfin Smelt Science Program is implementing an expanded Smelt Larval Survey to enhance coverage of the survey in the

Suisun, San Pablo, and San Francisco Bays to better cover the full geographic distribution for the species. This effort along with others of the Longfin Smelt Science Program are advancing the ability to track vital rates (e.g., survival) across life stage transitions for the species and may inform population-level trends for longfin smelt, including spawning success (H_{SWPop4}).

- **Data availability and centralization to support coordinated analysis and reporting.** An important gap in the VA Science Committee's ability to complete triennial synthesis is the availability and storage of data in a centralized location and in consistent formats. In order to position the VA Science Committee to produce synthetic information and to promote the operating guideline of Open and Transparent Data, increasing data centralization through a public data repository will be an early priority of the VA Science Committee.

4 VA Science Committee Reporting and Analysis

4.1 Assessment of Non-Flow Measures

The VAs will result in new Non-flow Measures, including habitat restoration and enhancements, that are intended to contribute to the achievement of the Narrative Objectives, and which will be implemented in specific geographic locations overseen by Tributary/Delta Governance Entities (Tributary/Delta GEs). Coordinated by the VA Science Committee, the Tributary/Delta GEs will conduct accounting and assessments of Non-flow Measures as follows:

- **Accounting for Non-flow Measures** will be conducted to inform the Systemwide Governance Committee and State Water Board on progress relative to the VA Parties' Non-flow Measure commitments as described in the March 2022 VA Term Sheet and applicable amendments, summarized in Table 19 of the Strategic Plan. The Non-flow Measure accounting process is described further in Section 3.1.4 of the Strategic Plan. The specific methodology quantifying the added acreage of new or enhanced habitat and accounting for other non-flow measures such as fish passage will be described in the next draft of the VA Science Plan.
  - **Habitat suitability assessments**, described in Section 4.1.1 of the VA Science Plan, consider habitat suitability design criteria, as well as additional factors (covariates) that may affect species utilization and their ability to feed, grow, avoid predators, and reproduce in the new or enhanced habitat. These covariate suitability metrics are additional to the metrics informing the habitat accounting procedures and often regard water quality (e.g., water temperature). For example, covariate suitability metrics for spawning habitat, in-channel rearing habitat, tributary floodplain habitat, bypass floodplain habitat, and tidal wetland habitat are described in VA Science Plan Hypotheses H_{S1}, H_{R1}, $H_{TribFP1}$, $H_{BypassFP4}$, and H_{TW1}, respectively. The habitat suitability assessment is separate from the habitat accounting method described in Section 3.1.4 of the Strategic Plan because it considers suitability metrics that may not be possible to control through project design but may affect utilization and biological effectiveness. The results of the habitat suitability assessments will be provided in VA Program reports as described in Section 9.4 of the VA Term Sheet as well as the ecological outcomes analysis to be provided prior to Year 7 of the VA Program, as described in Appendix 4 of the VA Term Sheet.
  - **Habitat utilization and biological effectiveness assessments** described in Section 4.1.2 of the VA Science Plan, will be conducted to determine whether target species are using the new or enhanced habitat areas, are exhibiting expected near-term benefits (e.g., improved fish passage, increased growth rate) that can be attributed to the completed habitat action, and whether these measures are achieving or are likely to achieve the anticipated ecological outcomes by creating, restoring, or enhancing the habitat of one or more target species and lifestages. For example, Hypothesis H_{R4} in the VA Science Plan tests whether the new or enhanced rearing habitat for Chinook salmon has higher juvenile salmon densities compared to areas outside of the new or enhanced habitat project locations. The results of the habitat utilization and biological

effectiveness assessments will be provided in VA Program reports as described in Section 9.4 of the VA Term Sheet as well as the ecological outcomes analysis to be provided prior to Year 7 of the VA Program, as described in Appendix 4 of the VA Term Sheet.

This section describes the general methodological framework by which suitability, utilization, and biological effectiveness metrics will be applied to assess the effective suitability and biological effectiveness of habitat enhancement measures, respectively. It is recognized that each Governance Area Entity will build upon this methodological framework to develop detailed assessment protocols tailored to the specific habitat enhancement measures being implemented within their respective governance area. The methodological framework presented below is intended to be applied at the site-specific scale, as well as at the reach and/or tributary scales to enable assessments of total suitable habitat acreage increases over time at the system-specific level (tributary, Bypass, Delta). Results of the site-specific implementation analyses will be summarized for each system.

4.1.1 Methods for Assessing Habitat Suitability

Suitability of a habitat enhancement measure is determined by evaluating conformance with design criteria (e.g., water depth, velocity, substrate, cover), as well as other abiotic factors that may affect species utilization and their ability to feed, grow, avoid predators, and reproduce in the enhanced habitat. Therefore, evaluation of the factors affecting habitat suitability also involves assessment of covariates described for each habitat enhancement action, such as water temperature, dissolved oxygen, or other conditions listed in Table 1.

The VA Science Committee will summarize non-flow measure implementation by system and then over time, examine whether habitat enhancement projects continue to meet suitability criteria (including design criteria and covariate factors affecting suitability). Compiling a summary of the total number of acres of enhanced habitat on a system-specific basis requires quantification of site-specific habitat enhancement measures using the approaches described in the VA Strategic Plan (Section 3.1.4).

The persistence of habitat enhancement sites meeting suitability criteria will be assessed over time. Where site-specific suitability diminishes over time relative to initial implementation, consideration will be given to assessing suitability persistence for the reach in which the habitat enhancement project was implemented. This could be done to explore the phenomenon of spatial “dynamic equilibrium”. For example, gravel placed at a spawning enhancement site could be transported downstream rendering the site less suitable over time, but the downstream area receiving the transported gravel could exhibit new or increased suitability. Site- and/or reach-specific assessments will be conducted by the VA Science Committee periodically during the duration of the VA Program following project construction. The continued assessment of habitat enhancement projects’ ability to meet suitability criteria over time allows evaluation of trends in the persistence of enhancement projects and informs adaptive management considerations for the VA Program.

Covariate data will be collected and reported for expected periods of utilization, assessed for consistency with species- and lifestage-specific suitability indices using published literature, and reported along with implementation summaries, as well as utilization and biological effectiveness assessments for each habitat enhancement project. Covariate data to describe habitat suitability will also be assessed over time to examine changes in suitability across seasons and across years with different hydrological conditions.

4.1.2 Methods for Assessing Habitat Utilization and Biological Effectiveness

Constructed VA habitat enhancement measures will be assessed over time to evaluate whether each project is effective in achieving anticipated biological outcomes. In general, it is assumed that utilization and biological effectiveness assessments will be based primarily on empirical data and observations obtained through monitoring, but may also include simulation modeling.

Triennial reports generated in Year 3 and Year 6 of VA implementation will include updated assessments of utilization and effectiveness as much as possible given their implementation status at the time of reporting. Triennial reports will document status and trends in the utilization of habitat measures and will inform adaptive management of these measures. For the Year 3 and Year 6 triennial reports, the ecological outcomes (i.e., effectiveness) of the VA habitat measures at the local scale will be analyzed using the metrics described in Section 2.2 on Hypotheses, Metrics, and Baselines for Local Tier Hypotheses for Non-flow measures. The synthesis reports will also describe whether continuation of the VAs beyond Year 8 would help improve species abundance, ecosystem conditions, and contribute to meeting the narrative objectives, and use existing and improved life cycle models as appropriate to provide quantitative evaluations of continuing the VA program across a range of hydrological conditions. This synthesis report will inform the SWRCB's evaluation of the VAs and proposed pathway after Year 8, as described in Section 7.4.B of the MOU Term Sheet (Green, Yellow, and Red options).

Utilization metrics focus on whether, and the extent to which, constructed habitats are being used by the target populations and lifestages across the range of design flows. For application to the assessment of VA habitat measures, biological effectiveness refers to how well the constructed habitat is performing in achieving the intended biological outcomes. Utilization and biological effectiveness metrics address biological responses at the site-specific scale and are generally expressed as a rate (e.g., number of individuals per unit area). Inherent variability in initial abundance of annual cohorts (e.g., number of spawning adults, number of juveniles) directly influence the values of the biological response variables (i.e., expected outcomes). For example, redd density in restored spawning sites is dependent on the number of returning adult spawners that, in turn, is dependent on out-of-basin conditions upon which site-specific habitat measures have no bearing. Similarly, the number of juveniles per unit area is directly influenced by the number of spawners and survival from spawning through post-emergent fry. Consequently, pre-project values of biological metrics may have limited utility to serve as a baseline for assessments of site-specific utilization and biological effectiveness. The basis of comparison for the evaluation of utilization metrics will therefore be adjacent, non-enhanced habitat areas, with metrics being measured concurrently at both project sites and comparison locations.

The assessment of biological effectiveness includes consideration of utilization and observed outcomes while accounting for covariates that may affect the biological outcome. As such, utilization and biological effectiveness assessment methods also involve evaluation of the abiotic habitat conditions (e.g., water temperature, dissolved oxygen, described for individual hypotheses above and listed in Table 1) that potentially influence the utilization and/or effectiveness of habitat enhancement measures. Covariate monitoring will determine the frequency and magnitude under which covariate conditions constrain the suitability or effectiveness of constructed habitat enhancement sites across the range of design flows.

4.2 Schedule for Reporting

Consistent with the March 29, 2022 MOU Term Sheet for the VAs, the VA Science Committee will contribute to Annual Reports and Triennial Reports for Years 3 and 6 of VA implementation. Science Committee contributions to these reports will help fulfill requirements of these reports to do the following from Section 9.4.A of the MOU and Term Sheet:

- Inform adaptive management;
- Be technical in nature, identify actions taken, monitoring results, and milestones achieved
- Document status and trends of native fish

VA Science Committee reports and their contents will also inform public workshop proceedings of the SWRCB as well as professional reviews of the scientific rationale for the VAs, such as the Delta Independent Science Board.

4.3 Data Management Plan

The VA Science Committee will produce a detailed data management plan within the first year of adoption of the VA Program. In keeping with the VA Science Committee's participation principle of Transparency and Communication, the data management plan will adopt guiding principles of Findability, Accessibility, Interoperability, and Reusability (FAIR, Wilkinson et al. 2016). Data management plans will also be required to protect the sovereignty of Tribes and not disclose sensitive or confidential information. For projects based on traditional and tribal knowledges, the project team will prepare a data sharing agreement that defines how project results and deliverables will be used, in alignment with the CARE data principles (Collective benefit, Authority to control, Responsibility, and Ethics, (Carroll et al. 2020). As noted above, a priority information gap for the VA Science Committee is data availability and centralization to support coordinated data analysis and reporting. A first step to filling this gap is for individual monitoring efforts (such as rotary screw trapping efforts for juvenile abundance estimation on VA tributaries, Figure 7) to provide their data in an open data repository.

For individual project science and monitoring plans provided to the VA Science Committee, the expectation is that each project will include a data management plan that has components of data and metadata description, plan for backing up and archiving data, explanation of the data format, data quality assurance protocols, and plan for sharing data. This review step will allow the Science Committee to assess how well the project's methodologies will provide data that is interoperable with other data collection efforts for VA flow or non-flow measures. The project's plan for sharing data should explain how the data can be accessed via public platforms such as the Environmental Data Initiative, CEDEN (CEDEN, CEDEN AdvancedQueryTool (ca.gov), California Data Exchange Center (California Data Exchange Center), and the CalFish Track (CalFishTrack (noaa.gov)), or the California Natural Resources Agency Open Data Portal (Welcome - California Natural Resources Agency Open Data).

The VA Science Committee will explore the potential for a data platform that would collectively gather and/or link to data that will be needed to evaluate the hypotheses and metrics for the VA Science Plan (Table 1). This platform would be open to the public and allow for searching and visualization of quality-assured data relevant to flow and non-flow measures of the VA Program.

4.4 Evaluation of Hypotheses for Decision-Making to Inform Adaptive Management

4.4.1 Annual and Triennial Synthesis Reports

The VA Science Committee will contribute to Annual Reports and Triennial Reports for Years 3 and 6 of VA implementation. These reports will provide a synthesis of the evaluated hypotheses at Local (project scale), Full Tributary and Delta tiers. These reports will also contain a summary of observed trends at the population level scale native species, as compared with appropriate baselines (Table 1). Based on Triennial Reports from Years 3 and 6, the VA Science Committee will submit a synthesis report on the scientific data and information generated by the VA Science Program that analyzes the ecological outcomes of the VA actions and examines whether continuation of the VAs beyond Year 8 would help improve species abundance, ecosystem conditions, and contribute to meeting the narrative objectives. This report will inform the SWRCB's evaluation of the VAs and proposed pathway after Year 8, as described in Section 7.4.B of the MOU Term Sheet (Green, Yellow, and Red options).

Syntheses will inform recommendations to the Systemwide Governance Committee on outstanding information gaps and how they should be addressed, specifying the areas of uncertainty that the Science Committee would prioritize in order to better inform decision-making processes. Furthermore, syntheses and scientific information gained through the VA Science Program will be used to parameterize and structure quantitative aspects of decision-making processes of the Science Committee.

4.4.2 Structured Decision-Making Processes within the VA Science Committee

Recommendations from the Science Committee will be the outcome of structured decision-making processes, as appropriate. The Science Committee will test hypotheses related to VA Flow and Non-flow Measures so that experiments and monitoring can inform decision support models (See section 4.4.3). By statistically designing study plans, measuring consistently collected metrics, and providing accessible data, information generated by VA Science Plan activities can be leveraged into these models. Decision support models can then predict information regarding metrics at Local, Full Tributary and Delta, and Population-Level tiers, which can inform the importance of specific hypothesized mechanisms and relationships linking management actions to biological and ecosystem outcomes. By incorporating VA Science Plan generated information, decision support models can also assess the value of additional information gathering to continue explore the most influential hypotheses for outcomes. By documenting the importance of management action mechanisms and the value of science action information to supporting the achievement of biological objectives, the Science Committee can contribute information to VA structured decision-making processes. In turn, these structured decision-making processes will feed recommendations for adjustments in management and science actions using the new science generated by the Science Program.

4.4.3 Use of Decision Support Models for Habitat Enhancement Actions for Salmonids

Salmonid decision support models use the best available information to predict how actions might improve populations. These models can be used to estimate population level responses of VA assets, at both juvenile and adult lifestages, to help estimate the relative degree that different VA actions are likely to contribute to overall population level changes. They can also be used to prioritize restoration actions (Peterson and Duarte 2020), for example by understanding how populations respond to changes in floodplain habitat vs tributary rearing habitat, and/ or to evaluate how VA habitat actions will interface with other large scale management actions such as commercial and recreational harvest and hatchery production. Several decision support models are available for use in the VA Science Program and are briefly described in this section. The VA Science Committee will evaluate the appropriate model for individual decision-making processes to develop evidence-based recommendations to the VA Systemwide Governance Committee. These model descriptions are provided to serve as examples of the available modeling tools and illustrate that model outputs are relevant to VA Science Plan hypotheses at the Full Tributary and Delta and Population-level Tiers.

4.4.3.1 Central Valley Project Improvement Act Science Integration Team Decision Support Models (CVPIA SIT DSM)

The CVPIA Salmonid Decision Support Models[1] are stochastic, stage-based models that operate on a monthly time step and simulate populations on a 20-year horizon. The model includes the mainstem Sacramento River and San Joaquin River and their major tributaries, the Sutter and Yolo Bypasses, and the North and South Delta. Model inputs include flow data, CalSim modeled flows (1980 to 2000 hydrology which includes both wet and dry multi-year cycles and operational rules per the 2019 Biological Opinion), temperature data, Hec5q and additional temperature modeling where needed, habitat data, and habitat acres from various sources.

---

[1] More information on the CVPIA SIT Decision Support Models can be found here: https://cvpia.scienceintegrationteam.com/cvpia-sit/ , under “Resources” with links to: Documents, Interactive Web Apps, DSM R Packages, FAQs, and Data Assets. The SIT decision support models are intended to be transparent and open source. They are available to download, use, and modify for user-specific purposes. Changes to the model can be documented through language developed by SIT, found in the FAQ section.

Model outputs include: number of spawners, juvenile biomass at Chipps Island, and proportion of natural origin spawners. There are four decision support models, one representing each run of Chinook salmon (fall-run, late-fall-run, winter-run, and spring-run) and models for Central Valley steelhead and green sturgeon. The late-fall-run, Central Valley steelhead, and green sturgeon DSMs are still considered in "beta" mode and has not yet been used to evaluate candidate restoration strategies. The DSMs differ with respect to timing of life history events, inputs, yearling dynamics, and juvenile movement rulesets.

The Science Integration Team (SIT) developed 13 candidate restoration strategies to evaluate in the Chinook salmon decision support models. These strategies define potential sets of primarily habitat-based restoration actions to improve Chinook salmon habitat or survival with the goal of maximizing the model outputs of number of spawners and juvenile biomass at Chipps Island. Each candidate strategy was simulated in the fall-run, winter-run, and spring-run models and the SIT evaluated the model output to inform the development of priorities in the CVPIA SIT Near-term Restoration Strategy. The SIT is an open participatory group working to propose model revisions, evaluate scenarios with the models, and assess information needs for the models.

In each yearly timestep, the following modeling actions occur in the Chinook Decision Support Models: As adults return from the ocean to the watershed, the en route survival submodel represents prespawn mortality as it is applied to adults returning to their natal tributaries and the pre-spawn survival submodel represents mortality while adults are at the spawning grounds. The modeling approach to en route survival and pre-spawn mortality is as follows, with links provided for accessing more detailed information:

- En route survival is a function of migratory temperatures, whether the bypasses are overtopped (this represents fish loss due to stranding), and the adult harvest rate.
- Pre-spawn mortality is a function of temperature, specifically the number of degree days that a fish experiences before spawning.

The number of juveniles produced is calculated based on the number of spawners, fecundity, and an egg-to-fry survival sub model. Egg-to-fry survival is a function of the temperature, the probability of the nest being scoured, and the proportion of natural fish spawning.

In each monthly timestep, the following modeling actions occur: Juveniles rear in-channel or on the floodplain or migrate downstream depending on habitat availability and size of the juvenile. Tributary habitat capacity to support juvenile rearing is determined based on the total habitat in a tributary and a size-dependent territory requirement. Habitat availability varies by month and year and is based on flow levels. More info on habitat can be found in the Decision Support Model habitat package[2]. Growth is applied to juveniles each month and differs with habitat type: seasonally inundated (floodplain, including tributary floodplain habitat and habitat in the Yolo and Sutter bypasses) and perennially inundated (in-channel), prey density, and temperature. Juveniles rearing on floodplains grow at a faster rate than juveniles who rear in-channel. Rearing survival is a tributary-specific function based on water temperature, water diversions, weeks of floodplain inundation (when applicable), and predator prevalence. When habitat capacity is non-limiting, fish outmigrate when they reach the "very large" size class or at the end of the rearing season. The exception is for the spring-run Decision Support Model where fish that are still small or medium size in their natal tributaries at the end of the outmigration window will remain in the natal tributaries as yearlings until the next year's outmigration window. The remaining juveniles not assigned to rear in natal tributaries will leave the watershed and migrate downstream and a migratory survival is applied.

---

[2] https://cvpia-osc.github.io/DSMhabitat/

After a juvenile makes it out to the ocean, ocean survival is applied, and they are assigned to return to their natal tributary one to three years later.

4.4.3.2 Reorienting to Recovery Decision Support Models (R2R DSM)

The California Central Valley Salmonid Recovery Project, nicknamed the Reorienting to Recovery (R2R project), is currently modifying the CVPIA SIT fall-run model for their project purposes[3]. These code modifications and model outputs were not reviewed or interpreted by the CVPIA Science Integration Team but have been reviewed by R2Rs Science Advisory Team. Model modifications include the addition of functionality that enables evaluation of the isolated and combined effects of a broader range of recovery actions than the CVPIA SIT base-model, including increase and refinement of habitat, habitat expansion beyond existing levee confinements within the state system of flood control, reintroduction of historical independent populations above rim-dams, changes to in-river and ocean harvest, changes in hatchery production (production numbers, release timing, and release location) , and modifications to flows (magnitude and timing in different water years types). The R2R project seeks to develop an effective and implementable strategy for recovering listed and non-listed salmonids in California's Central Valley that draws on and integrates the full range of potential recovery actions while considering the diverse range of other social, ecological, and economic values within the region. The R2R model has performance metric outputs related to salmonid biological objectives, habitat and ecological process objectives, recreational and commercial harvest, access of land and water, economic objectives related to water supply, agricultural production, and power generation, and regulatory, public health, and infrastructure objectives. In addition to the model outputs available in the CVPIA DSM, the model has been modified to enable the following outputs: adult return ratio and juvenile to adult return ratio.

4.4.3.3 Winter-run Life Cycle Model (WRLCM)

The winter-run life cycle model (WRLCM)[4] is a stochastic stage-structured model that operates on a monthly time step and simulates over an 80 year time period, dependent on the hydrology inputs (i.e., 82 years if using CalSim II or 94 years if using CalSim 3). The spatial structure of the model includes five different geographic areas within the Sacramento River watershed (Upper mainstem Sacramento River, Lower mainstem Sacramento River, Yolo Bypass, Delta, and Bay), as well as the Ocean. Model inputs include monthly modeled flows (CalSim II or CalSim 3), Delta modeled hydrology (DSM2), and temperature data (Hec5q or USBR's Sacramento River Water Quality Model (SRWQM)). The WRLCM also relies on inputs from several submodels, including habitat capacity models to estimate monthly habitat capacity in each of the five geographic areas, and a submodel to estimate monthly outmigration survival through the Delta. The model tracks abundance for each lifestage, geographic area, and timestep. Model outputs are relative to a baseline and include number of spawners (abundance), cohort replacement rate (CRR), and freshwater productivity (smolts/spawner). The WRLCM was specifically designed to assess the effects of water operations and habitat restoration as defined by the Operations Criteria and Plan (OCAP), Biological Opinion (BiOp), and Reasonable and Prudent Alternatives (RPA) on long-term population dynamics of winter-run Chinook salmon.

---

[3] Documentation on the R2R models being used can be found here: https://reorienting-to-recovery.gitbook.io/documentation-site/zCZ2Z2yqFYMUQrtZdTlg/

[4] More information on the model can be found here https://oceanview.pfeg.noaa.gov/wrlcm/intro, with tabs explore, simulate, learn, and resources, to learn more and explore the model.

5 References

Barnett-Johnson R, Grimes CB, Royer CF, Donohoe CJ. 2007. Identifying the contribution of wild and hatchery Chinook salmon (Oncorhynchus tshawytscha) to the ocean fishery using otolith microstructure as natural tags. Can J Fish Aquat Sci. 64:1683–1692. https://doi.org/10.1139/f07-129

Barnett-Johnson R, Pearson TE, Ramos FC, Grimes CB, Bruce MacFarlane R. 2008. Tracking natal origins of salmon using isotopes, otoliths, and landscape geology. Limnology and Oceanography. 53:1633–1642. https://doi.org/10.4319/lo.2008.53.4.1633

Bashevkin SM, Hartman R, Thomas M, Barros A, Burdi CE, Hennessy A, Tempel T, Kayfetz K. 2022a. Five decades (1972–2020) of zooplankton monitoring in the upper San Francisco Estuary. PLOS ONE. 17:1–27. https://doi.org/10.1371/journal.pone.0265402

Bashevkin SM, Mahardja B, Brown LR. 2022b. Warming in the upper San Francisco Estuary: Patterns of water temperature change from five decades of data. Limnology and Oceanography. 67:1065–1080. https://doi.org/10.1002/lno.12057

Bell-Tilcock M, Jeffres CA, Rypel AL, Willmes M, Armstrong RA, Holden P, Moyle PB, Fangue NA, Katz JV, Sommer TR. 2021. Biogeochemical processes create distinct isotopic fingerprints to track floodplain rearing of juvenile salmon. PloS one. 16:e0257444.

Bennett MA, Becker A, Gaston T, Taylor MD. 2021. Connectivity of large-bodied fish with a recovering estuarine tidal marsh, revealed using an imaging sonar. Estuaries and Coasts. 44:1579–1587.

Bolch EA, Hestir EL, Khanna S. 2021. Performance and feasibility of drone-mounted imaging spectroscopy for invasive aquatic vegetation detection. Remote Sensing. 13:582.

Boswell KM, Kimball ME, Rieucau G, Martin JG, Jacques DA, Correa D, Allen DM. 2019. Tidal stage mediates periodic asynchrony between predator and prey nekton in salt marsh creeks. Estuaries and Coasts. 42:1342–1352.

Botkin D, Peterson D, Calhoun J. 2000. The scientific basis for validation monitoring of salmon for conservation and restoration plans. Olympic Natural Resources Technical Report University of Washington, Olympic Natural Resources Center Forks, Washington, USA.

Bunt CM, Castro-Santos T, Haro A. 2012. PERFORMANCE OF FISH PASSAGE STRUCTURES AT UPSTREAM BARRIERS TO MIGRATION. River Research and Applications. 28:457–478. https://doi.org/10.1002/rra.1565

California Hatchery Scientific Review Group. 2012. California hatchery review report. Prepared for the US Fish and Wildlife Service and Pacific States Marine Fisheries Commission. 100.

Carlson SM, Satterthwaite WH. 2011. Weakened portfolio effect in a collapsed salmon population complex. Canadian Journal of Fisheries and Aquatic Sciences. 68:1579–1589.

Carroll SR, Garba I, Figueroa-Rodríguez OL, Holbrook J, Lovett R, Materechera S, Parsons M, Raseroka K, Rodriguez-Lonebear D, Rowe R, Sara R, Walker JD, Anderson J, Hudson M. 2020. The CARE Principles for Indigenous Data Governance. Data Science Journal. https://doi.org/10.5334/dsj-2020-043

Carter JL, Resh VH. 2001. After site selection and before data analysis: sampling, sorting, and laboratory procedures used in stream benthic macroinvertebrate monitoring programs by USA state agencies. Journal of the North American Benthological Society. 20:658–682.

CDFW. 2019. Summary of fish rescues conducted with the Yolo Bypass, 2018 Water Year. Prepared for the United States Bureau of Reclamation. California Department of Fish and Wildlife, Region 2 Anadrmous Fisheries. 12pp.

Chao Y, Farrara JD, Zhang H, Zhang YJ, Ateljevich E, Chai F, Davis CO, Dugdale R, Wilkerson F. 2017. Development, implementation, and validation of a modeling system for the San Francisco Bay and Estuary. Estuarine, Coastal and Shelf Science. 194:40–56. https://doi.org/10.1016/j.ecss.2017.06.005

Colombano DD, Handley TB, O'Rear TA, Durand JR, Moyle PB. 2021. Complex tidal marsh dynamics structure fish foraging patterns in the San Francisco Estuary. Estuaries and Coasts. 44:1604–1618.

Cordoleani F, Holmes E, Bell-Tilcock M, Johnson RC, Jeffres C. 2022. Variability in foodscapes and fish growth across a habitat mosaic: Implications for management and ecosystem restoration. Ecological Indicators. 136:108681.

Corline NJ, Sommer T, Jeffres CA, Katz J. 2017. Zooplankton ecology and trophic resources for rearing native fish on an agricultural floodplain in the Yolo Bypass California, USA. Wetlands Ecology and Management. 25:533–545. https://doi.org/10.1007/s11273-017-9534-2

Danos A, Chalfin J, DuBois J. 2020. 2019 Adult Striped Bass Tagging Field Season Report. California Department of FIsh and Wildlife Bay Delta Region (Stockton). [accessed 2023 May 04]. [accessed 2023 May 4]. Available from: https://wildlife.ca.gov/Conservation/Delta/Striped-Bass-Study/Bibliography

Delta Independent Science Board. 2022. Review of the Monitoring Enterprise in the Sacramento-San Joaquin Delta. Report to the Delta Stewardship Council Sacramento, California. [accessed 2023 May 12]. Available from: https://deltacouncil.ca.gov/pdf/isb/products/2022-03-22-isb-monitoring-enterprise-review.pdf

Demetras NJ, Huff DD, Michel CJ, Smith JM, Cutter GR, Hayes SA, Lindley ST. 2016. Development of underwater recorders to quantify predation of juvenile Chinook Salmon (Oncorhynchus tshawytscha) in a river environment.

Eakin M. 2021. Assessing the distribution and abundance of larval longfin smelt: what can a larval monitoring program tell us about the distribution of a rare species. Calif Fish Game. 107:182–202.

Esteban EM, Marchetti MP. 2004. What's on the Menu? Evaluating a Food Availability Model with Young-of-the-Year Chinook Salmon in the Feather River, California. Transactions of the American Fisheries Society. 133:777–788. https://doi.org/10.1577/T03-115.1

Fish M. 2010. SF Bay Study White Sturgeon Year Class Strength Index vs. Outflow. State of California Memorandum to Marty Gingras, Supervising Biologist. 9.

Flosi G, Downie S, Hopelain J, Bird M, Coey R, Collins B. 2009. California Salmonid Stream Habitat Restoration Manual. Part XII: Fish Passage Design and Implementation. California Department of Fish and Game, Wildlife and Fsiheries Division. [accessed 2023 May 23].

Flynn T, Lehman PW, Lesmeister S, Waller S. 2022. A Visual Scale for Microcystis Bloom Severity. Figure available on Figshare. [accessed 2023 May 12]. [accessed 2023 May 12]. Available from: https://figshare.com/articles/figure/A_Visual_Scale_for_Microcystis_Bloom_Severity/19239882/1

Foott JS, Freund SR, Barreras M. 2021. Prevalence and severity of Ceratonova shasta and Parvicapsula minibicornis infection in Feather River Juvenile Chinook Salmon (January – May 2020). US Fish & Wildlife Service California – Nevada Fish Health Center, Anderson, CA.

Goodwin RA, Nestler JM, Anderson JJ, Weber LJ, Loucks DP. 2006. Forecasting 3-D fish movement behavior using a Eulerian–Lagrangian–agent method (ELAM). Ecological Modelling. 192:197–223. https://doi.org/10.1016/j.ecolmodel.2005.08.004

Grimaldo LF, Smith WE, Nobriga ML. 2021. Re-Examining Factors That Affect Delta Smelt (Hypomesus transpacificus) Entrainment at the State Water Project and Central Valley Project in the Sacramento–San Joaquin Delta. San Francisco Estuary and Watershed Science. 19.

Gross E, Kimmerer W, Korman J, Lewis L, Burdick S, Grimaldo L. 2022. Hatching distribution, abundance, and losses to freshwater diversions of longfin smelt inferred using hydrodynamic and particle-tracking models. Marine Ecology Progress Series. 700:179–196.

Hance DJ, Perry RW, Pope AC, Ammann AJ, Hassrick JL, Hansen G. 2022. From drought to deluge: spatiotemporal variation in migration routing, survival, travel time and floodplain use of an endangered migratory fish. Canadian Journal of Fisheries and Aquatic Sciences. 79:410–428.

Hartman R, Barros A, Avila M, Tempel T, Bowles C, Ellis D, Sherman S. 2022a. I'm not that Shallow–Different Zooplankton Abundance but Similar Community Composition Between Habitats in the San Francisco Estuary. San Francisco Estuary and Watershed Science. 20.

Hartman R, Rasmussen N, Bosworth D, Berg M, Ateljevich E, Flynn T, Wolf B, Pennington T, Khanna S. 2022b. Temporary Urgency Change Petition of 2021 and Emergency Drought Salinity Barrier: Impact on Harmful Algal Blooms and Aquatic Weeds in the Delta. California Department of Water Resources October 14 2022. 188 pp + appendix.

Hartman R, Sherman S, Contreras D, Ellis D. 2018. Fish catch, invertebrate catch, and water quality data from the Sacramento-San Joaquin Delta collected by the Fish Restoration Monitoring Program, 2015 - 2017. Environmental Data Initiative. [accessed 2023 April 06]. https://doi.org/10.6073/pasta/86810e72766ad19fccb1b9dd3955bdf8

Hassrick JL, Ammann AJ, Perry RW, John SN, Daniels ME. 2022. Factors Affecting Spatiotemporal Variation in Survival of Endangered Winter-Run Chinook Salmon Out-migrating from the Sacramento River. North American Journal of Fisheries Management. 42:375–395. https://doi.org/10.1002/nafm.10748

Herbold B, Carlson SM, Henery R, Johnson RC, Mantua N, McClure M, Moyle PB, Sommer T. 2018. Managing for salmon resilience in California's variable and changing climate. San Francisco Estuary and Watershed Science. 16.

Heublein J, Bellmer R, Chase R, Doukakis P, Gingras M, Hampton D, Israel J, Jackson Z, Johnson RC, Langness O, Luis S, Mora E, Moser M, Rohrbach L, Seesholtz A, Sommer T, Stuart J. 2017. Life History and Current Monitoring Inventory of San Francisco Estuary Sturgeon. NOAA-TM-NMFS-SWFSC-589. https://doi.org/10.7289/V5/TM-SWFSC-589

Holmes EJ, Saffarinia P, Rypel AL, Bell-Tilcock MN, Katz JV, Jeffres CA. 2021. Reconciling fish and farms: Methods for managing California rice fields as salmon habitat. Plos one. 16:e0237686.

Huber ER, Carlson SM. 2015. Temporal trends in hatchery releases of fall-run Chinook salmon in California’s Central Valley. San Francisco Estuary and Watershed Science. 13.

IEP TWM PWT. 2017. Tidal Wetland Monitoring Framework for the Upper San Francisco Estuary, Version 1.0. Interagency Ecological Program Tidal Wetlands Monitoring Project Work Team.

Johnson RC, Windell S, Brandes PL, Conrad JL, Ferguson J, Goertler PA, Harvey BN, Heublein J, Israel JA, Kratville DW. 2017. Science advancements key to increasing management value of life stage monitoring networks for endangered Sacramento River Winter-run Chinook salmon in California. San Francisco Estuary and Watershed Science. 15.

Johnston M, Frantzich J, Espe MB, Goertler P, Singer G, Sommer T, Klimley AP. 2020. Contrasting the migratory behavior and stranding risk of White Sturgeon and Chinook Salmon in a modified floodplain of California. Environmental Biology of Fishes. 103:481–493. https://doi.org/10.1007/s10641-020-00974-9

Katz JV, Jeffres C, Conrad JL, Sommer TR, Martinez J, Brumbaugh S, Corline N, Moyle PB. 2017. Floodplain farm fields provide novel rearing habitat for Chinook salmon. PloS one. 12:e0177409.

Khanna S, Conrad JL, Caudill J, Christman M, Darin G, Ellis D, Gilbert P, Hartman R, Kayfetz K, Pratt W, Tobias V, Wasserman A. 2018. Framework for Aquatic Vegetation Monitoring in the Delta.

Kimmerer WJ. 2008. Losses of Sacramento River Chinook salmon and delta smelt to entrainment in water diversions in the Sacramento–San Joaquin Delta. San Francisco Estuary and Watershed Science. 6.

Kimmerer WJ. 2011. Modeling Delta Smelt losses at the south Delta export facilities. San Francisco Estuary and Watershed Science. 9.

Kimmerer WJ, Gross ES, Slaughter AM, Durand JR. 2019. Spatial Subsidies and Mortality of an Estuarine Copepod Revealed Using a Box Model. Estuaries and Coasts. 42:218–236. https://doi.org/10.1007/s12237-018-0436-1

Kimmerer WJ, MacWilliams ML, Gross ES. 2013. Variation of fish habitat and extent of the low-salinity zone with freshwater flow in the San Francisco Estuary. San Francisco Estuary and Watershed Science. 11.

Kimmerer WJ, Rose KA. 2018. Individual-based modeling of delta smelt population dynamics in the Upper San Francisco Estuary III. Effects of entrainment mortality and changes in prey. Transactions of the American Fisheries Society. 147:223–243.

Korman J, Gross ES, Grimaldo LF. 2021. Statistical Evaluation of Behavior and Population Dynamics Models Predicting Movement and Proportional Entrainment Loss of Adult Delta Smelt in the Sacramento–San Joaquin River Delta. San Francisco Estuary and Watershed Science. 19.

Kudela RM, Howard MD, Monismith S, Paerl HW. 2023. Status, Trends, and Drivers of Harmful Algal Blooms Along the Freshwater-to-Marine Gradient in the San Francisco Bay–Delta System. San Francisco Estuary and Watershed Science. 20.

Lehman PW, Kurobe T, Teh SJ. 2022. Impact of extreme wet and dry years on the persistence of Microcystis harmful algal blooms in San Francisco Estuary. Quaternary International. 621:16–25. https://doi.org/10.1016/j.quaint.2019.12.003

Letvin A, Palmer-Zwahlen M, Kormos B, McHugh P. 2021. Recovery of coded-wire tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2019. California Department of Fish and Wildlife and Pacific States Marine Fisheries Commission. [accessed 2023 May 25]. Available from: https://www.calfish.org/ProgramsData/ConservationandManagement/CentralValleyMonitoring/CentralValleyCFMProgram.aspx#:~:text=The%20Central%20Valley%20Constant%20Fractional,employed%20in%20the%20Central%20Valley.

Lewis LS, Willmes M, Barros A, Crain PK, Hobbs JA. 2020. Newly discovered spawning and recruitment of threatened Longfin Smelt in restored and underexplored tidal wetlands. Ecology. 101:e02868–e02868. https://doi.org/10.1002/ecy.2868

MacWilliams ML, Ateljevich ES, Monismith SG, Enright C. 2016. An overview of multi-dimensional models of the Sacramento–San Joaquin Delta. San Francisco Estuary and Watershed Science. 14.

Mazor RD, Rehn AC, Ode PR, Engeln M, Schiff KC, Stein ED, Gillett DJ, Herbst DB, Hawkins CP. 2016. Bioassessment in complex environments: designing an index for consistent meaning in different settings. Freshwater Science. 35:249–271. https://doi.org/10.1086/684130

McKenzie R, Speegle J, Nanninga A, Holcome E, Stagg J, Hagen J, Huber E, Steinhart G, Arrambide A. 2022. Interagency Ecological Program: USFWS Delta Boat Electrofishing Survey, 2018 - 2022 ver 3. Environmental Data Initiative. [accessed 2023 May 04]. Available from: https://doi.org/10.6073/pasta/4886dbb80cf709a4c6e5906ff94eacdc

Melwani A, Tillotson M, Hobbs JA, Slater SB, Hennessy A, Schreier B, Arend K, McLain J. 2022. Evaluation and Analysis of Five Long-Term Biological Monitoring Studies in the Upper San Francisco Estuary. 2021 Final Report. Available from: https://csamp.baydeltalive.com/docs/25928

Merz J, Caldwell L, Beakes M, Hammersmark C, Sellheim K. 2019. Balancing competing life-stage requirements in salmon habitat rehabilitation: Between a rock and a hard place. Restoration Ecology. 27:661–671.

Michel CJ, Henderson MJ, Loomis CM, Smith JM, Demetras NJ, Iglesias IS, Lehman BM, Huff DD. 2020. Fish predation on a landscape scale. Ecosphere. 11:e03168. https://doi.org/10.1002/ecs2.3168

Moyle PB, Crain PK, Whitener K. 2007. Patterns in the use of a restored California floodplain by native and alien fishes. San Francisco Estuary and Watershed Science. 5.

Nagarajan RP, Bedwell M, Holmes AE, Sanches T, Acuña S, Baerwald M, Barnes MA, Blankenship S, Connon RE, Deiner K, Gille D, Goldberg CS, Hunter ME, Jerde CL, Luikart G, Meyer RS, Watts A, Schreier A. 2022. Environmental DNA Methods for Ecological Monitoring and Biodiversity Assessment in Estuaries. Estuaries and Coasts. 45:2254–2273. https://doi.org/10.1007/s12237-022-01080-y

Nash RD, Valencia AH, Geffen AJ. 2006. The origin of Fulton's condition factor—setting the record straight. Fisheries. 31:236–238.

Newcomb TJ, Coon TG. 2001. Evaluation of Three Methods for Estimating Numbers of Steelhead Smolts Emigrating from Great Lakes Tributaries. North American Journal of Fisheries Management. 21:548–560. https://doi.org/10.1577/1548-8675(2001)021<0548:EOTMFE>2.0.CO;2

NMFS. 1997. Fish Screening Criteria for Anadromous Salmonids. National Marine Fisheries Service Southwest Region. Available from: https://media.fisheries.noaa.gov/dam-migration/southwest_region_1997_fish_screen_design_criteria.pdf

NMFS. 2023. NOAA Fisheries West Coast Region Anadromous Salmonid Passage Design Manual. National Marine Fisheries Service. WCR, Portland, Oregon:183pp.

Nobriga ML, Michel CJ, Johnson RC, Wikert JD. 2021. Coldwater fish in a warm water world: Implications for predation of salmon smolts during estuary transit. Ecology and Evolution. 11:10381–10395. https://doi.org/10.1002/ece3.7840

Perry RW, Pope AC, Romine JG, Brandes PL, Burau JR, Blake AR, Ammann AJ, Michel CJ. 2018. Flow-mediated effects on travel time, routing, and survival of juvenile Chinook salmon in a spatially complex, tidally forced river delta. Canadian Journal of Fisheries and Aquatic Sciences. 75:1886–1901. https://doi.org/10.1139/cjfas-2017-0310

Peterson JT, Duarte A. 2020. Decision analysis for greater insights into the development and evaluation of Chinook salmon restoration strategies in California’s Central Valley. Restoration Ecology. 28:1596–1609. https://doi.org/10.1111/rec.13244

Schreier BM, Baerwald MR, Conrad JL, Schumer G, May B. 2016. Examination of predation on early life stage Delta Smelt in the San Francisco estuary using DNA diet analysis. Transactions of the American Fisheries Society. 145:723–733.

Sellheim K, Watry C, Rook B, Zeug S, Hannon J, Zimmerman J, Dove K, Merz J. 2016. Juvenile salmonid utilization of floodplain rearing habitat after gravel augmentation in a regulated river. River Research and Applications. 32:610–621.

Sellheim K, Zeug S, Merz J. 2020. Informed water management alternatives for an over-allocated river: Incorporating salmon life stage effects into a decision tree process during drought. Fisheries Management and Ecology. 27:498–516.

Sherman S, Hartman R, Contraras D, editors. 2017. Effects of Tidal Wetland Restoration on Fish: A Suite of Conceptual Models. Interagency Ecological Program Technical Report 91.

SJRRP. 2012. Minimum Floodplain Habitat Area: For Spring and Fall-Run Chinook Salmon. San Joaquin River Restoration Program. [accessed 2023 May 07]. Available from: https://www.restoresjr.net/?wpfb_dl=408

Slater SB, Baxter RD. 2014. Diet, prey selection, and body condition of age-0 delta smelt, Hypomesus transpacificus, in the Upper San Francisco Estuary. San Francisco Estuary and Watershed Science. 12.

Smith SG, Muir WD, Hockersmith EE, Zabel RW, Graves RJ, Ross CV, Connor WP, Arnsberg BD. 2003. Influence of River Conditions on Survival and Travel Time of Snake River Subyearling Fall Chinook Salmon. North American Journal of Fisheries Management. 23:939–961. https://doi.org/10.1577/M02-039

Smith WE. 2019. Integration of transport, survival, and sampling efficiency in a model of South Delta entrainment. San Francisco Estuary and Watershed Science. 17.

Sommer T, Schreier B, Conrad JL, Takata L, Serup B, Titus R, Jeffres C, Holmes E, Katz J. 2020. Farm to fish: lessons from a multi-year study on agricultural floodplain habitat. San Francisco Estuary and Watershed Science. 18.

Sommer TR, Harrell WC, Nobriga ML. 2005. Habitat Use and Stranding Risk of Juvenile Chinook Salmon on a Seasonal Floodplain. North American Journal of Fisheries Management. 25:1493–1504. https://doi.org/10.1577/M04-208.1

Sommer TR, Nobriga ML, Harrell WC, Batham W, Kimmerer WJ. 2001. Floodplain rearing of juvenile Chinook salmon: evidence of enhanced growth and survival. Canadian Journal of Fisheries and Aquatic Sciences. 58:325–333.

Speegle J, McKenzie R, Nanninga A, Holcome E, Stagg J, Hagen J, Huber E, Steinhart G, Arrambide A. 2022. Interagency Ecological Program: Over four decades of juvenile fish monitoring data from the San Francisco Estuary, collected by the Delta Juvenile Fish Monitoring Program, 1976 - 2022. Environmental Data Initiative. [accessed 2023 April 06]. https://doi.org/10.6073/pasta/57b6c257edd72691702f9731d5fe4172

Steel AE, Anderson JJ, Mulvey B, Smith DL. 2020. Applying the mean free-path length model to juvenile Chinook salmon migrating in the Sacramento River, California. Environmental Biology of Fishes. 103:1603–1617. https://doi.org/10.1007/s10641-020-01046-8

Sturrock AM, Satterthwaite WH, Cervantes-Yoshida KM, Huber ER, Sturrock HJ, Nusslé S, Carlson SM. 2019. Eight decades of hatchery salmon releases in the California Central Valley: Factors influencing straying and resilience. Fisheries. 44:433–444.

SWRCB. 2023. Draft Scientific Basis Report Supplement in Support of Proposed Voluntary Agreements for the Sacramento River, Delta, and Tributaries Update to the San Fancisco Bay/Sacramento-San Joaquin Delta Water Quality Control Plan. State Water Resources Control Board, California Department of Water Resources, and California Department of FIsh and Wildlife Sacramento, CA. 358.

Takata L, Sommer TR, Louise Conrad J, Schreier BM. 2017. Rearing and migration of juvenile Chinook salmon (Oncorhynchus tshawytscha) in a large river floodplain. Environmental Biology of Fishes. 100:1105–1120.

USBR. 2008. SRH-2D version 2: Theory and User's Manual. US Department of the Interior Preapred by Yong G Lai, Technical service Center Sedimentation and River Hydraulics Group. [accessed 2023 May 23]. Available from: https://www.usbr.gov/tsc/techreferences/computer%20software/models/srh2d/downloads/Manual-SRH2D-v2.0-Nov2008.pdf

USBR, DWR. 2019. Yolo Bypass Salmonid Habitat Restoration and Fish Passage. Final Environmental Impact Statement/Environmental Impact Report. US Department of Interior and California Department of Water Resources. [accessed 2023 May 25]. Available from: https://www.usbr.gov/mp/nepa/nepa_project_details.php?Project_ID=30484

Volkhardt GC, Johnson SL, Miller BA, Nickelson TE, Seiler DE. 2007. Rotary screw traps and inclined plane screen traps. Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations American Fisheries Society, Bethesda, Maryland. 6:235–266.

Wilkinson MD, Dumontier M, Aalbersberg IjJ, Appleton G, Axton M, Baak A, Blomberg N, Boiten J-W, da Silva Santos LB, Bourne PE, Bouwman J, Brookes AJ, Clark T, Crosas M, Dillo I, Dumon O, Edmunds S, Evelo CT, Finkers R, Gonzalez-Beltran A, Gray AJG, Groth P, Goble C, Grethe JS, Heringa J, ’t Hoen PAC, Hooft R, Kuhn T, Kok R, Kok J, Lusher SJ, Martone ME, Mons A, Packer AL, Persson B, Rocca-Serra P, Roos M, van Schaik R, Sansone S-A, Schultes E, Sengstag T, Slater T, Strawn G, Swertz MA, Thompson M, van der Lei J, van Mulligen E, Velterop J, Waagmeester A, Wittenburg P, Wolstencroft K, Zhao J, Mons B. 2016. The FAIR Guiding Principles for scientific data management and stewardship. Scientific Data. 3:160018. https://doi.org/10.1038/sdata.2016.18

Willete M, Templin B. 2013. Keni River Smolt Abundance - Phase 3. Statement of Work Preapred for Alaska Sustainable Salmon Fund. [accessed 2023 May 14].

Young MJ, Feyrer F, Smith CD, Valentine DA. 2022. Habitat-Specific Foraging by Striped Bass (Morone saxatilis) in the San Francisco Estuary, California: Implications for Tidal Restoration. San Francisco Estuary and Watershed Science. 20.

Yuba County Water Agency. 2013. Technical Memorandum 3-2: Aquatic Macroinvertebrates Downstream of Englebright Dam. Yuba River Development Project FERC Project No 2246. 46 pp.

Zeug SC, Cavallo BJ. 2014. Controls on the Entrainment of Juvenile Chinook Salmon (Oncorhynchus tshawytscha) into Large Water Diversions and Estimates of Population-Level Loss. PLOS ONE. 9:e101479. https://doi.org/10.1371/journal.pone.0101479

Zhang Y, Baptista AM. 2008. SELFE: A semi-implicit Eulerian–Lagrangian finite-element model for cross-scale ocean circulation. Ocean modelling. 21:71–96.

Zhang YJ, Ye F, Stanev EV, Grashorn S. 2016. Seamless cross-scale modeling with SCHISM. Ocean Modelling. 102:64–81.