Healthy Rivers and Landscapes Science Plan

Final Draft

September 6, 2024

Contents

Preface

Document purpose

This document is the final draft of the Healthy Rivers and Landscapes Science Plan. The Systemwide Governance Committee provides this draft to the State Water Resources Control Board for information, as the State Water Resources Control Board prepares the Program of Implementation text to update the San Francisco Bay/Sacramento-San Joaquin Delta Water Quality Control Plan. The purpose of this Science Plan is to provide the framework and specific approach for assessment of the Flow and Non-Flow Measures and for addressing several important and broad-scale ecosystem management questions, described in the next sections. The hypotheses and associated monitoring described in this Science Plan are intended to describe a full range of potential approaches for assessing the biological and ecological outcomes of the Healthy Rivers and Landscapes Program. This Science Plan will inform the development of tributary, Delta, and project-specific Science Plans; however, it is not anticipated that each of these additional Science Plans will address every hypothesis. Instead, this document is intended to provide guidance to the Science Committee and individual tributary and Delta science programs as they develop plans for priority areas of focus for additional monitoring that provides comparability among datasets, active experiments, decision support modeling, and synthetic data analyses needed to fill knowledge gaps to assess the outcomes of the suite of Program measures and inform ongoing and future decision making. Activities conducted as part of the Healthy Rivers and Landscapes Science Program and under the framework of this Science Plan will provide information and data to be synthesized in the triennial reports provided in Years 3 and 6 of the Program and the Ecological Outcomes Analysis Report, as described in the March 29, 2022, MOU and Term Sheet. These products will be among the materials that inform the State Water Resources Control Board in Year 8 of the Program.

Implementation of new scientific studies and monitoring under the Science Plan will depend on the priorities of the Science Committee, the Systemwide Governance Committee, Tributary and Delta Governance Entities, and available resources. The work of the Science Committee will include the development of recommendations for science funding for consideration by the Systemwide Governance Committee and the coordination of tributary, Delta, and project-specific Science Plans for consistency with this overarching Science Plan. These roles are further described in the Science Committee Charter.

Healthy Rivers and Landscapes Science Plan

1 Introduction and background

The Healthy Rivers and Landscapes Program ("Program"), described in the March 29, 2022 MOU and 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 (WQCP). The scientific rationale for the Program's 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 WQCP (SWRCB 2023), and the forthcoming Draft Scientific Basis Report for the Tuolumne River.

1.1 Healthy Rivers and Landscapes Science Program and Governance

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

- To inform decision-making by the Systemwide Governance Committee, Tributary and Delta Governance Entities, and 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 Parties.

The role and work of the Science Committee is further described in the Science Committee Charter and its appendices.

Individual tributary and Delta science programs will play a key role in generating the base of information necessary to support these functions. Tributary-, Delta-, and project-specific science plans, developed by the Tributary and Delta Governance Entities, will provide the detailed plans for monitoring Program actions by leveraging existing monitoring networks to address hypotheses contained in this Science Plan, fill data gaps, and conduct active experiments for use in systemwide evaluation of the Program. A major role of the Science Program will be to work towards increasing consistency over time in how these tributary- and Delta-focused programs track progress relative to metrics described in this Plan, and enable a broad, synthetic understanding of the outcomes of Program actions. The Science Committee will play a key role in building this consistency by advising on tributary-, Delta- and project-specific science plans, and by directing Program funding (through recommendations to the Systemwide Governance Committee) into specific improvements in the monitoring network. For example, the Science Committee will review project-specific science plans and will recommend changes to ensure that priority management-relevant uncertainties (i.e., those that are most relevant to informing implementation of Flow and Non-flow Measures) are appropriately evaluated, and that the data are collected in a way that facilitates a comparable dataset across watersheds. This comparability will in turn enable a system-wide evaluation of the ecosystem response to similar habitat or flow actions taken in different tributary systems. This broader geographic scale of evaluation will inform the triennial reports and workshops in Year 3 and Year 6 and the Ecological Outcomes Analysis, required in the March 2022 MOU and 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 Program actions.

As described in the Term Sheet, the State Water Resources Control Board will, in Year 8 of the Program, assess whether to continue or modify the Program in consideration of a range of factors related to progress on implementation of Program commitments, availability of required permitting and funding, and protection of flows. In addition, and most relevant to the Science Program, the State Water Resources Control Board will also consider whether synthesis reports and analyses produced by the Science Program support the conclusion that continuation of the Program, together with other actions in the WQCP, will result in attainment of the Narrative Objectives (March 29, 2022 MOU). Information collected by the Science Program on the biological and ecological outcomes of the actions will be instrumental to supporting the State Water Resources Control Board's assessment of the effects of the Program but will not solely determine success or failure of the Program.

The purpose of this Science Plan is to provide the framework and specific approach for evaluating the biological and ecological outcomes of the Flow and Non-Flow Measures and for addressing several important and broad-scale ecosystem management questions, described in the next sections. 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 ecological outcomes; however, it is not anticipated that every Flow and Non-flow Measure will address each relevant hypothesis. Instead, this document is intended to provide guidance to the 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 Program measures, and inform ongoing and future decision making.

1.2 Framework for Healthy Rivers and Landscapes Program objectives, metrics, and targets

The WQCP Update process, in combination with other actions by federal, state, and local agencies, is intended to support attainment of the Narrative Objectives. The Program, as part of the Program of Implementation for the updated WQCP, will contribute to attainment of the Narrative Objectives through the implementation of a range of Flow and Non-flow Measures meant to improve habitat conditions for native fish.

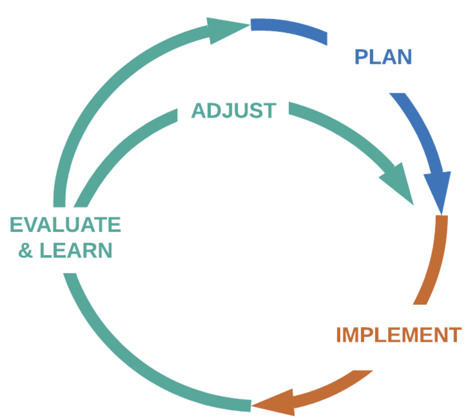
An early task of the Science Committee will be to develop Program Objectives and Targets that will contribute to the Narrative Objectives for the WQCP (Table 1) and any Biological and Ecological Goals developed by the State Water Resource Control Board (in addition to the Final Initial Biological Goals for the Lower San Joaquin River) that are applicable to the Program and consistent with this Science Plan. Metrics, which are the quantifiable parameters used to assess progress toward Program Objectives and Targets (Table 1), are provided in this Science Plan with each individual hypothesis. System specific metrics and targets may be developed using best available science (as described in the Science Committee Charter Appendix B) in the tributary, Delta, and project-specific science plans, to best address local conditions. Tributary and Delta Governance Entities will develop system specific science plans, including appropriate metrics and targets, in coordination with the Science Committee and under the framework of this Science Plan. System specific science plans, including any metric and target development, would be consistent with information contained in applicable regulatory documents (e.g., Biological Opinions) and subject to existing agreements and management authority (e.g., dam operations, flow standards). System specific science plans will allow for adaptive management to accommodate potential future changes associated with updates to applicable regulations, agreements or changes to management authority. Best available science and established models (e.g., decision support models) that allow for prediction of the integrated effects of Flow and Non-flow Measures relative to reference conditions described in the Science Plan will be essential to completing this task.

Table 1. Definitions for terms used to describe the biological and ecological outcomes associated with the Healthy Rivers and Landscapes Program.

Term	Definition	Illustrative Example
Narrative Objectives	Descriptions of water quality and species outcomes, or "water quality objectives" defined in the Porter-Cologne Water Quality Control Act (Water Code 13050h) as "the limits or levels of water quality constituents or characteristics which are established for the reasonable protection of beneficial uses of water or the prevention of nuisance within a specific area."	*The State Water Resources Control Board has developed one Narrative Objective to provide water quality conditions to achieve doubling of the reference salmon population (Salmon Objective). The Parties to the Program have proposed a second Narrative Objective to maintain water quality conditions to support natural production of native fish populations (Native Fish Viability Objective). See the March 29, 2022 MOU for the specific language of each Narrative Objective.*
Program Objectives	Measurable and specific conditions that indicate whether progress towards the Healthy Rivers and Landscapes Program desired outcomes is being achieved.	*Positive trend for salmon cohort replacement rate (CRR) over term of the Program.*
Metrics	Quantifiable parameters defining the unit(s) of measure for tracking performance towards achieving the objectives, responsive to Science Plan hypotheses.	*CRR of adult Chinook salmon at the individual tributary scale (e.g., $H_{TribPop3}$).*
Targets	Desired numerical values of the metrics provided in the Science Plan for each tier of hypotheses (Section 2.1 below), consistent with the larger Program Objectives.	*CRR > 1, calculated as a 3-year geometric mean.*

1.3 Adaptive management and decision support for Flow and Non-Flow Measures

Figure 1. Adaptive management cycle



The 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 Parties are committed to learning from the implementation of Flow and Non-flow Measures over the 8-year term of the Program and using this knowledge to inform future decisions about Program actions. Prior to the end of the 8-year term, the knowledge gained through the implementation of the Program is expected to inform either a renewal of the Program and/or a WQCP update.

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

- **Big Question 1**: Will implementation of individual 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 Flow and Non-flow Measures within a tributary result in improved tributary-level outcomes for native fish (e.g., juvenile Chinook salmon (*Oncorhynchus tshawytscha*) production)?
- **Big Question 3**: Will the combination of Flow and Non-flow Measures within the Delta result in improved outcomes for native fish (e.g., longfin smelt (*Spirinchus thaleichthys*) production)?
- **Big Question 4**: Will changes in fish outcomes at the tributary and Delta scales result in improved population-level outcomes in support of the Narrative Objectives?

Collectively, these Big Questions articulate a bottom-up approach to understanding the aggregated effects of site-specific actions that the Program takes 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 2) will be the primary means through which the Science Committee assesses progress and informs decisions both within and at the end of the term of the Program about whether and how to modify implementation. A variety of methods including monitoring, modeling, and field experimentation will enable assessment of the effectiveness of the Program's 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 Science Committee will contribute to:

- Improved understanding of the ecological response to the suite of Program measures 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 white sturgeon (*Acipenser transmontanus*)) relative to the term of the Program;
- Recommendations to modify Flow and Non-flow Measures within the term of the Program, 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 Program actions in support of the State Water Resources Control Board's assessment process near the end of the Program term and/or related decision making by Parties.

1.4 General description of proposed Flow and Non-flow Measures

In general terms, the Program includes new Flow and Non-flow Measures (summarized in the Strategic Plan, Tables 1 and 25), to support the Narrative Objectives and as a Program of Implementation of the WQCP. This section briefly describes the nature of the Flow and Non-flow Measures. More detail on the Flow measures, including the default flow schedule, is provided in the Flow Measures Description (Section 2 of the Strategic Plan); 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 (Section 3 of the Strategic Plan). The general descriptions below are intended to provide context for the following sections and aid the reader's understanding of the connection between the Program measures and the predicted effects.

1.4.1 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. The 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, including Delta and longfin smelt, as well as ecosystem processes.

1.4.2 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 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 Program actions

2.1 General framework for hypotheses

The Science Plan is based on hypotheses that state the expected outcome of Program 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 Program tributaries and Delta. Given that the Flow and Non-flow Measures of the Program 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 Measures**. These hypotheses will support three types of assessments for habitat improvement actions, which are also described in the Strategic Plan, Section 3.1.3: (1) Accounting for the implementation of proposed Non-flow Measures (i.e., whether the habitat improvement was implemented according to design) to assess progress towards achieving commitments described in the March 29, 2022 MOU and Term Sheet; (2)Consistency assessments for consistency between post-implementation habitat availability at a range of flows (expanded to the tributary scale) with similar estimates in the Scientific Basis Report Supplement (SWRCB 2023); (3) Habitat suitability assessments to evaluate whether habitat improvements are providing suitable habitat conditions with respect to both biotic and abiotic factors for target species; and (4) Habitat utilization and biological effectiveness assessments to evaluate whether the site is being utilized by native fishes (e.g., Chinook salmon, Delta smelt (*Hypomesus transpacificus*), longfin smelt, as well as other native species) and providing intended species benefits in a way that is consistent with predictions. These sets of hypotheses are organized by the specific type of Non-flow Measure undertaken (e.g., salmonid spawning habitat, fish passage improvements, tidal wetlands). These hypotheses are evaluated at an annual scale.
- **Full Tributary and Delta Tier**: These hypotheses are developed to test predictions of how Flow Measures in the tributaries and the Delta will benefit native species. Additional hypotheses at this tier address how Flow and Non-flow Measures in aggregate will contribute to changes in productivity of juvenile salmonids within tributaries. For salmonids, hypotheses are limited to the juvenile life stages, because these life stages reside in the freshwater regions where Program Measures are occurring, and species responses evaluated at this tier do not yet involve out-of-basin influences. Hypotheses regarding increases to actions in the Delta to increase outflow regard predictions for the effects on entrainment risk in South Delta pumping facilities, species abundance, availability of spawning and rearing habitat for managed species, zooplankton composition and distribution, and Harmful Algal Blooms (HABs). 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 Parties recognize that population-level responses may not be observed during the term of the Program because the Non-flow Measures will be incrementally implemented over the proposed eight-year period, and that timeframe 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 timeframe. 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 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 to analyze their potential impact on biological responses. These covariates are generally outside the control of the Parties but may influence the success of the Program actions. If Program 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 Program actions, will be reported in Science Program products, including the Triennial reports planned for Years 3 and 6 of Program implementation. These analyses will be evaluated in adaptive management processes, including prioritization of further investment in Flow and Non-flow Measures.

The hypotheses are not written for specific actions (e.g., pulse flows on a specific tributary or a specific tidal wetland restoration project) and will not be the sole metrics for determining Program success; instead, the Science Plan hypotheses provide a generalized framework for how each action will be assessed, including specific metrics to be used. Tributary, Delta and project-specific science plans with identified actions will be responsive to the Science Plan framework and Program participants may propose to add, modify, or exclude hypotheses for specific Flow or Non-flow Measures. Tributary, Delta and project-specific science plans will be provided as appendices to the Science Plan as they become available, and more information on the oversight and development of science plans is provided in Appendix A of the Science Charter. The Science Plan hypotheses and metrics are written from a western science perspective, but the Science Committee recognizes Indigenous Knowledge as a best available science (see Appendix B of the Science Charter) and plans to support ongoing dialogue that can inform Tribal-non-Tribal partnerships in science, restoration, and management activities.

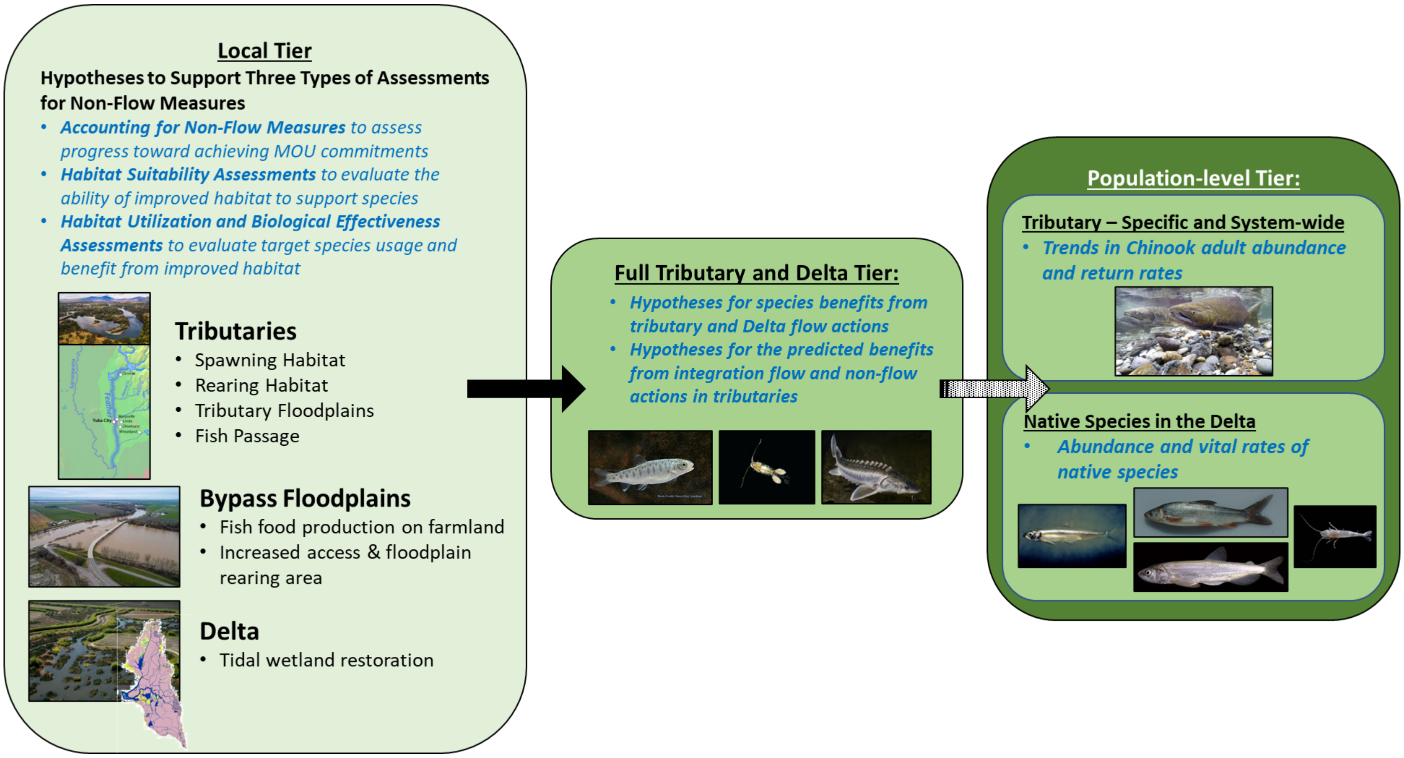


Figure 2 Tiered framework for hypothesis structure of the Science Plan. Local hypotheses will help inform the Full Tributary and Delta Tier hypotheses, as indicated by the black arrow. The gray arrow between the Full Tributary and Delta and the Population-Level Tier indicates increased uncertainty in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

Specific metrics are provided for each hypothesis and at all three tiers. To enable synthesis efforts to evaluate a suite of 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. Another early task of the Science Committee will be to develop a data management plan, intended for Year 1 of Program implementation. Tributary, Delta and project-specific 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 Program actions across Local, Tributary and Delta, and Population-level tiers. Identification of metrics also facilitates the next section of the Science Plan, which identifies where existing monitoring and science efforts provide the needed information, and where data gaps exist (Section 3).

Finally, to guide analyses, it is necessary to set a baseline that will serve as a reference for understanding the impact of Flow and Non-flow Measures. Therefore, hypotheses and metrics are accompanied by a baseline that will guide analyses. Where appropriate, the 2023 Draft Scientific Basis Report Supplement (SWRCB 2023) 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 2. **Summary of 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 Program actions. Hypothesis ID indicate the action type and/or hypothesis tiers described in Figure 2 (S, R, TribFP, Bypass FP, and TW = Local Tier for Non-Flow Measures; TribFlow, TribWide, and DeltaFlow = Full Tributary and Delta Tier; TribPop and SWPop = Population-level Tier). A prediction of ↑ indicates an increase, ↓ a decrease and ↔ is no change. Generally, water quality parameters include salinity, water temperature, turbidity, and dissolved oxygen with project-specific science plans to name the parameters of interest in tailored hypotheses.

Action Type	Hyp. ID	Metric	Prediction	Basis for Comparison	Covariates
Spawning Habitat	H_{S1}	Acreage meeting water depth, water velocity and substrate size criteria	↑	Existing acreage, defined in the Strategic Plan, Appendix F	N/A
Spawning Habitat	H_{S2}	Water temperature, dissolved oxygen, and turbidity	↔	Reference sites or existing suitability	Flow and air temperature
Spawning Habitat	H_{S3}	Salmon redd density (#/unit area)	↑	Non-project, proximal reference sites measured concurrently	Water depth, velocity, and temperature, dissolved oxygen, turbidity, and adult salmon returns
Rearing Habitat	H_{R1}	Acreage meeting water depth, water velocity and cover criteria	↑	Existing acreage, defined in the Strategic Plan, Appendix F	N/A
Rearing Habitat	H_{R2}	Water temperature and dissolved oxygen	↔	Reference sites or existing suitability	Flow, air temperature, turbidity, canopy cover, and riparian vegetation
Rearing Habitat	H_{R3}	Biomass density of secondary productivity (g/volume)	↑	Non-project, proximal reference sites measured concurrently	Substrate, cover, water temperature, dissolved oxygen, water velocity, primary productivity and juvenile salmonid density
Rearing Habitat	H_{R4}	Juvenile Chinook salmon densities (#/unit area)	↑	Non-project, proximal reference sites measured concurrently	Water temperature, dissolved oxygen, turbidity and the type and density of cover
Tributary Floodplain	$H_{TribFP1}$	Acreage meeting water depth, water velocity, floodplain function, and cover criteria	↑	Existing acreage, defined in the Strategic Plan, Appendix F	N/A
Tributary Floodplain	$H_{TribFP2}$	Water temperature, and dissolved oxygen	↔	Reference sites or existing suitability	Flow, air temperature, turbidity, canopy cover, and riparian vegetation
Tributary Floodplain	$H_{TribFP3}$	Biomass density of drift and benthic macroinvertebrates (g/volume)	↑	In-channel locations measured concurrently	Substrate, cover, water temperature, dissolved oxygen, water velocity, primary productivity and juvenile salmonid density
Tributary Floodplain	$H_{TribFP4}$	Juvenile salmon presence and densities (#/unit area	↑	Non-project, in-channel, proximal reference sites measured concurrently	Water temperature, dissolved oxygen, turbidity and cover

Action Type	Hyp. ID	Metric	Prediction	Basis for Comparison	Covariates
		or #/volume)			
Tributary Floodplain	$H_{TribFP5}$	Growth rate of juvenile salmon	↑	Derived through experimental work using caged fish	Water temperature and secondary productivity
Tributary Floodplain	$H_{TribFP6}$	Number of stranded juvenile salmon as a proportion of the tributary juvenile production estimate (JPE)	↔	Historical estimates of stranding and total population impact based on tributary JPE	N/A
Tributary Floodplain	$H_{TribFP7}$	Catch frequencies of native fishes	↑	Historical period of record for each tributary	Water temperature, turbidity, dissolved oxygen, flow and the timing, magnitude, and frequency of floodplain inundation
Fish Passage	H_{Pass1}	Water velocity at surface water diversions	↓	Pre-project water velocities or the National Marine Fisheries Service 1997 criteria for water velocity at diversion points	N/A
Fish Passage	H_{Pass2}	Native anadromous fish passage efficiency	↑	Pre-project passage efficiency data	N/A
Bypass Floodplain	$H_{BypassFP1}$	Inundated acreage suitable for invertebrate production	↑	Pre-project inundated acreage	N/A
Bypass Floodplain	$H_{BypassFP2}$	Zooplankton and macroinvertebrate densities (# and weight/unit volume)	↑	Adjacent and upstream riverine sites	Dissolved oxygen 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	$H_{BypassFP4}$	Acreage of bypass floodplain habitat*	↑	Existing acreage, defined in the Strategic Plan, Appendix F	N/A
Bypass Floodplain	$H_{BypassFP5}$	Water quality for targeted native fish	↔	Proximal reference sites measured concurrently	Duration and frequency of inundation, flow, air temperature, and cover
Bypass Floodplain	$H_{BypassFP6}$	(1) Hydrologic connectivity (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	$H_{BypassFP7}$	Number of stranded	↔	Historical estimates of stranding and total	N/A

Action Type	Hyp. ID	Metric	Prediction	Basis for Comparison	Covariates
Floodplain		juvenile salmon as a proportion of the upstream JPEs		population impact based on Sacramento Valley JPE (combined from tributary JPEs) – *pending modeling effort to produce this estimate.*	
Bypass Floodplain	$H_{BypassFP8}$	(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.	Water depth, velocity, and temperature
Bypass Floodplain	$H_{BypassFP9}$	(1) Number of juvenile Splittail and Blackfish exiting the Yolo Bypass (2) Number of adult Splittail and Blackfish in the Delta in January through March.	↑	(1) Period of record for Yolo Bypass Fish Monitoring Program (2) Estimates of spawning population of adult Splittail and Blackfish from the Delta Juvenile Fish Monitoring Program (DJFMP) electrofishing catch in the Delta.	Water temperature, turbidity, dissolved oxygen, flow, and the timing, magnitude and frequency of floodplain inundation
Tidal Wetlands	H_{TW1}	Acreage of tidal wetland habitat	↑	Existing acreage, defined in the Strategic Plan, Appendix F	N/A
Tidal Wetlands	H_{TW2}	Water quality conditions for target native fishes.	↔	Proximal reference sites measured concurrently	Modeled water residence time
Tidal Wetlands	H_{TW3}	Densities of beneficial secondary production for native fish diets (zooplankton, epiphytic, and benthic invertebrates)	↑	Fish Restoration Program (FRP) reference sites and pre-project monitoring	Biomass of invasive clams, water temperature, water depth and density of planktivorous fishes
Tidal Wetlands	H_{TW4}	Community composition of native fish diets reflective of their sampled habitat	↔	Diet composition of native fish in non-project, proximal reference sites in pelagic and/or littoral habitat.	N/A
Tidal Wetlands	H_{TW5}	Condition factor and growth rate of native fishes	↑	Experimental studies using caged fish between tidal wetland and pelagic habitats	Densities of diet items and water quality parameters relevant to target fish species
Tidal Wetlands	H_{TW6}	Presence of native fish	↑	FRP reference sites and pre-project monitoring or historical data from the DJFMP	Coverage of submerged and floating aquatic vegetation at entry/exit points of restored areas, density and

Action Type	Hyp. ID	Metric	Prediction	Basis for Comparison	Covariates
					movements of predators.
Tributary Flow Pulses	$H_{TribFlow1}$	Rate of adult Chinook salmon fall upstream migration (spawner abundance/week)	↑	Weekly rates of upstream migration immediately before and after flow action	Water temperatures and dissolved oxygen
Tributary Flow Pulses	$H_{TribFlow2}$	Rate of juvenile salmon outmigration	↑	Weekly rates of outmigration before and after flow action	Fry density, fish size, turbidity, day length, PAR (sunlight), lunar phase and temperature
Tributary Flow Pulses	$H_{TribFlow3}$	Juvenile salmon survival and travel time during outmigration	↑	Survival and travel time of acoustically tagged salmon before and after flow action	Water temperature, turbidity, and dissolved oxygen
Tributary Flow Pulses	$H_{TribFlow4}$	(1) *C. shasta* spore density (#/volume) (2) Clinical infection rate of *C. shasta* in juvenile salmon	↓	Spore densities and infection rates two weeks prior to flow pulses, same year	Water temperature and the movement rate of juveniles
Tributary Ecological Health	$H_{TribWide1}$	Algae Stream Conditions Index (ASCI) and California Stream Condition Index (CSCI) over the term of the Program	↑	ASCI and CSCI values from 2008-2018	N/A
Tributary Juvenile Salmon Production	$H_{TribWide2}$	Trend # estimated outmigrating juveniles / female spawner (≥ 3 years)	↑	Annual values in historical data record prior to Program implementation	Flow, water temperature and dissolved oxygen
Tributary Juvenile Salmon Production	$H_{TribWide3}$	Condition factor of outmigrating Chinook salmon	↑	Available historical data for each tributary	Water temperature
Tributary Juvenile Salmon Production	$H_{TribWide4}$	Coefficient of variation in outmigration timing and body size	↑	Available historical data for each tributary prior to Program implementation	Flow and water temperature
Increased Spring Delta Outflow	$H_{DeltaFlow1}$	Acreage meeting appropriate ranges of water temperature, turbidity, and salinity for Delta and longfin smelt	↑	Modeled habitat area without implementation of Flow Measures as described in the 2023 Draft Scientific Basis Report Supplement (SWRCB 2023)	N/A

Action Type	Hyp. ID	Metric	Prediction	Basis for Comparison	Covariates
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) Period of record of longfin smelt catch in the Smelt Larval Survey and special studies (2) Modeled estimates of larval and juvenile longfin smelt entrainment across variable flow conditions in historical years, 2002 – present	Water temperature, turbidity, and distribution and abundance of longfin smelt spawning population
Increased Spring Delta Outflow	$H_{DeltaFlow3}$	(1) Annual adult abundance estimates of longfin smelt within San Francisco Estuary; (2) Larval densities in the western Delta and Bay regions relative to other areas	↑	Will begin when the necessary sampling program begins, as longfin smelt abundance estimates are under development.	Delta outflow, Bay tributary inflow, water temperature, turbidity, distribution and abundance of longfin spawning population
Increased Spring Delta Outflow	$H_{DeltaFlow4}$	(1) Delta smelt adult, larvae and juvenile entrainment (2) proportional loss of juvenile salmonids	↓	Available historical estimates over a range of hydrologic conditions (from 2002 – present).	(1) Population abundance and distribution, regional hydrodynamics, and water quality. (2) Population abundance, South Delta hydrodynamics, Delta Cross Channel gate operations and water quality.
Increased Spring Delta Outflow	$H_{DeltaFlow5}$	(1) Travel time and (2) survival of juvenile salmon in the tidal Delta	1. ↓ 2. ↑	Published studies and experimental comparisons of acoustically tagged juvenile salmon survival and travel times, associated with spring outflow	Water temperature, dissolved oxygen, turbidity, submerged aquatic vegetation coverage along migration routes, and predator densities at critical junctures
Increased Spring Delta Outflow	$H_{DeltaFlow6}$	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, secondary productivity and the timing, magnitude, and frequency of floodplain inundation
Increased Spring Delta Outflow	$H_{DeltaFlow7}$	White sturgeon age-0 and age-1 year class index strength	↑	Period of record for the San Francisco Bay Study	Spawning population of adult white sturgeon
Increased Spring Delta Outflow	$H_{DeltaFlow8}$	Average regional density of freshwater-associated zooplankton in the Delta	↑	Available historical data of regional densities and community assemblages of zooplankton	Phytoplankton biomass, salinity, water temperature, and turbidity
Increased Spring Delta Outflow	$H_{DeltaFlow9}$	Frequency, magnitude, severity of Harmful Algal Blooms	↔	Period of record of cyanobacterial Harmful Algal Blooms visual observations in routine surveys with corresponding Delta outflow	Water temperature, turbidity, salinity, and nutrient concentrations/ratios Delta outflow, San Joaquin River inflow,

Action Type	Hyp. ID	Metric	Prediction	Basis for Comparison	Covariates
				calculations and similar temperatures	project exports, and installation/operation of barriers/gates
Tributary Adult Chinook Population	$H_{TribPop1}$	Isotopic signature of floodplain rearing in adult population, evident in otoliths and/or eye lenses	↑	Archived samples (otoliths and/or eye lenses) before Program implementation	Multiple interacting out-of-basin factors, see description for hypothesis tier above
Tributary Adult Chinook Population	$H_{TribPop2}$	Natural origin Chinook salmon production estimates (harvest plus escapement) and trend in annual escapement	↑	Period of 1967 – 1991 (Anadromous Fish Restoration Program (AFRP) Doubling Goal years) and since 2010, by tributary	Multiple interacting out-of-basin factors, see description for hypothesis tier above
Tributary Adult Chinook Population	$H_{TribPop3}$	Trend in the Cohort Replacement Rate (CRR) for natural origin fish	↑	Period of record prior to Program implementation and since 2010, by tributary	Multiple interacting out-of-basin factors, see description for hypothesis tier above
Systemwide Chinook Population	H_{SWPop1}	Annual natural origin fall-run Chinook salmon escapement and harvest for Sacramento and San Joaquin valleys	↑	Period of 1967 – 1991 (AFRP Doubling Goal years) and since 2010	Multiple interacting out-of-basin factors, see description for hypothesis tier above
Systemwide Chinook Population	H_{SWPop2}	Trend in CRR for natural origin fish for Sacramento and San Joaquin valleys	↑	Period of 1967 – 1991 (AFRP Doubling Goal years) and since 2010	Multiple interacting out-of-basin factors, see description for hypothesis tier above
Native Delta Species Populations	H_{SWPop3}	Distribution and population estimates for spawning adults and rearing juveniles of native species	↑	Seasonal species abundance indices from 2023 Draft Scientific Basis Report Supplement (SWRCB 2023)	Multiple interacting out-of-basin factors, see description for hypothesis tier above
Native Delta Species Populations	H_{SWPop4}	Ratio of longfin smelt larvae to spawning adults	↑	Period of record in historical data in years with consistently sample habitat area, associated with Delta outflow	Multiple interacting and likely out-of-basin factors, see description for hypothesis tier above

2.2 Local Tier hypotheses: effects of Non-flow Measures 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 the area and suitability of improved spawning habitat and the salmonid response to increased habitat area. The hypotheses are additive in nature, such that the hydraulic metrics considered in assessment of habitat area (H_{S1}) contribute to the suitability of the habitat (H_{S2}) which is also measured by water quality parameters, and all these metrics in turn contribute to the biological effectiveness of the built habitat (H_{S3}).

H_{S1}: The area of 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 water depths and velocities and substrate sizes in the ranges defined in the Strategic Plan, Appendix F, at the flows specified in the project design.

The **baseline** for this hypothesis evaluation will be the quantification of the existing spawning habitat area within the project area boundary (polygon) with water depths and velocities and spawning substrate in the ranges defined in the Healthy Rivers and Landscapes Strategic Plan (e.g., pre-project). This quantification will be accomplished by using available (or newly developed) topographic mapping Digital Elevation Model (DEM) and applying available hydraulic (preferably 2D) models to calculate water depths and velocities within each computational pixel within the project area boundary. This methodology is further described in the Strategic Plan, Appendix F.

H_{S2}: The area of spawning habitat in habitat enhancement areas, will be suitable for both salmonid spawning and egg incubation during their periods of use.

The **metrics** for this hypothesis will be water temperature, dissolved oxygen, and turbidity in the project areas of gravel augmentation for the purpose of salmonid spawning. The area of spawning habitat will be defined according to water depth, velocity, and substrate criteria at design flows, detailed further in the Strategic Plan, Appendix F.

Important **covariates** for this hypothesis will be the mean and range for flow over the project areas and air temperature during the relevant periods for salmonid spawning and egg incubation.

The **baseline** for this hypothesis will be the reference suitability of proximate spawning habitat outside of the project area. Reference areas will be defined by the project- or tributary specific science plans. Additionally, the hypothesis metrics may be measured concurrently at the pre-project locations from H_{S1} to enable comparison.

H_{S3}: The density of salmonid 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 and/or Central Valley steelhead (*Oncorhynchus mykiss*) redds per unit area in habitat enhancement project areas, while also accounting for the potential for redd superimposition.

Covariates for this hypothesis include the parameters listed above for H_{S1} and H_{S2} as well as the estimate of adult salmon returns to the tributary for the year of observation.

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. 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. For each type of habitat action (in-channel rearing habitat and tributary floodplain), hypotheses and metrics are additive in nature: that is, the hydraulic metrics considered in assessment of habitat area (e.g., H_{R1}) contribute to the suitability of the habitat (e.g., H_{R2}) which is also measured by water quality parameters, and all these metrics in turn contribute to the biological effectiveness of the built habitat (e.g., H_{R3} and H_{R4}).

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, velocity, and cover 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, velocity, and cover criteria described in the Strategic Plan, Appendix F.

The **baseline** for this hypothesis evaluation will be the quantification of the existing rearing habitat area within the project area boundary (polygon). This quantification will 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. Cover features with a Habitat Suitability Index (HSI) value of 0.5 or greater (described in Strategic Plan Appendix F), will be mapped for development of a cover raster. Methodology for assessing hydraulic characteristics and cover features is detailed further in the Strategic Plan, Appendix F.

H_{R2}: Habitat enhancements for juvenile salmonid rearing within channels and in side-channels will be suitable for juvenile salmonid growth and survival during their rearing periods.

The **metrics** for this hypothesis will be water temperature, and dissolved oxygen in project locations for restored salmonid juvenile rearing habitat. Project- or tributary-specific science plans may include additional metrics of suitability such as densities of potential predators (avian or piscivorous fishes). The area of rearing habitat will be defined according to water depth, velocity, and cover criteria at design flows, detailed further in Section 3.1.4 of the Strategic Plan and Appendix F.

Covariates for this hypothesis include flow rates, air temperatures, and turbidity during the periods of salmonid rearing, as well as canopy cover, and riparian vegetation in project areas.

The **baseline** for this hypothesis will be the reference suitability of proximate rearing habitat outside of the project area. Reference areas will be defined in the project- or tributary specific science plans. Additionally, the hypothesis metrics may be measured concurrently at pre-project locations from H_{R1} to enable comparison.

H_{R3}: 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.

Covariates for this hypothesis include the substrate in the project or other study locations, the riparian vegetation, and the type and density of cover elements (aquatic vegetation, large woody debris, etc.). Water quality parameters of water temperature, dissolved oxygen, turbidity, and indices of primary productivity (e.g., chl-*a)*, as well as flow rates through the study locations, are also potential covariates, as all these factors may influence local densities of secondary productivity. Finally, juvenile salmonid densities are also covariates, as they may be consuming the drift and benthic macroinvertebrates that are being measured.

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

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

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

Covariates for this hypothesis will be the water temperature, dissolved oxygen, turbidity, as well as the type and density of cover elements in the project areas.

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 availability of suitable rearing habitat for juvenile salmonids, as well as increased secondary productivity, which will be beneficial for salmonids and other native fishes. These outcomes are hypothesized to occur through the following mechanisms.

$H_{TribFP1}$: The area of tributary floodplain habitat that conforms to specified criteria for water depth, velocity, floodplain function, and cover will increase as a result floodplain enhancement actions at design flows.

The **metric** for this hypothesis will be the acreage of floodplain habitat subject to inundation during periods of juvenile salmonid rearing. The tributary floodplain rearing habitat area will be defined according to criteria for water depth, velocity, floodplain function, and cover described in the Strategic Plan, Appendix F. Floodplain function refers to the frequency and duration of inundation, and the intention is to design tributary floodplain habitat consistent with achieving the criteria for Meaningful Floodplain Events, described in the 2023 Draft Scientific Basis Report Supplement (SWRCB 2023).

The **baseline** for this hypothesis will be the quantification of existing acreage of tributary floodplain habitat within the project area boundary (polygon). This quantification will 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. Cover features with a HSI value of 0.5 or greater (Strategic Plan Appendix F), will be mapped for development of a cover raster. Methodology for assessing hydraulic characteristics, inundation regimes, and cover features is detailed further in the Strategic Plan, Appendix F.

$H_{TribFP2}$: Tributary floodplain enhancement areas will be suitable for juvenile salmonid growth and survival during their rearing periods.

The **metrics** for this hypothesis will be water temperature, and dissolved oxygen in project locations for restored salmonid juvenile rearing habitat. Project- or tributary-specific science plans may include additional metrics of suitability such as densities of potential predators (avian or piscivorous fishes). The area of tributary rearing habitat will be defined according to water depth, velocity, floodplain function and cover criteria at design flows, detailed further in the Strategic Plan, Appendix F.

Covariates for this hypothesis include flow rates, air temperature and turbidity during the periods of salmonid rearing, as well as canopy cover, and riparian vegetation in project areas.

The **baseline** for this hypothesis will be the reference suitability of proximate tributary floodplain rearing habitat outside of the project area. Reference areas will be defined in the project- or tributary specific science plans. Additionally, the hypothesis metrics may be measured concurrently at pre-project locations from $H_{TribFP1}$ to enable comparison.

$H_{TribFP3}$: Biomass densities 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 floodplain habitats.

Covariates for this hypothesis include the substrate in the project or other study locations, the riparian vegetation, and the type and density of cover elements (aquatic vegetation, large woody debris, etc.). Water quality parameters of water temperature, dissolved oxygen, turbidity, and indices of primary productivity (e.g., chl-*a)*, as well as flow rates through the study locations, are also potential covariates, as all these factors may influence local densities of secondary productivity. Finally, juvenile salmonid densities are also covariates, as they may be consuming the drift and benthic macroinvertebrates that are being measured.

The **baseline** for this hypothesis 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.

$H_{TribFP4}$: Juvenile salmonids 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 salmonids 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 salmonid densities between floodplain habitats and in-channel rearing habitats.

Covariates to measure for a comprehensive understanding of the use of inundated floodplain habitat will include water temperature, dissolved oxygen, turbidity, as well as the type and density of cover elements in the project areas.

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 higher 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.

$H_{TribFP5}$: Growth of juvenile salmonids 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 rates 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.

$H_{TribFP6}$: 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 high-resolution Light Detection and Ranging (LiDAR) technology 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 outmigrate 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 outmigrate 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.

$H_{TribFP7}$: 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 (*Pogonichthys macrolepidotus*), Sacramento hitch (*Lavinia exilicauda exilicauda*), Sacramento blackfish (*Orthodon Microlepidotus*), Sacramento pikeminnow (*Ptychocheilus grandis*), Chinook salmon, Sacramento sucker (*Catostomus occidentalis*)) in routine surveys (community composition in beach seine, snorkel surveys, backpack electrofishing, and/or Rotary Screw Trap (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 (*Micropterus sp.*), common carp (*Cyprinus carpio*), mosquitofish (*Gambusia affinis*)) also utilize tributary floodplain habitats but are more prevalent in later spring months (e.g., May and June).

Covariates to measure to evaluate this hypothesis include water quality variables in floodplain habitats (water temperature, turbidity, dissolved oxygen, and flow), as well as the timing, magnitude, and frequency of floodplain inundation.

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 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 National Marine Fisheries Service (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 (*Acipenser medirostris*), and Pacific lamprey (*Entosphenus tridentatus*). 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 the 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 Science Committee 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).

As with the hypotheses in the above sections, some hypotheses in this section are additive in nature such that the hydraulic metrics considered in assessment of habitat area (e.g., $H_{BypassFP4}$) contribute to the suitability of the habitat (e.g., $H_{BypassFP5}$) which is also measured by water quality parameters, and all these metrics in turn contribute to the biological effectiveness of the enhanced habitat (e.g., $H_{BypassFP6}$).

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 which is suitable 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 the 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 available for native fishes will increase through Bypass floodplain enhancement actions.

The **metrics** for this hypothesis will be the acreage of floodplain habitat available to targeted species of native fishes, as specified in project-specific designs and science plans. Bypass floodplain habitat enhancements may include modifications to weir or fish passage structures such that the duration or expected timeframes of inundation are expanded or changed to increase availability of the habitat to targeted species. Individual bypass floodplain enhancement projects will identify specific criteria for design, which will be assessed at the project's completion and approved by the design criteria review process described in the Strategic Plan, Appendix F.

The **baseline** for this hypothesis will be the pre-project conditions with respect to the design criteria identified in the design criteria review process.

$H_{BypassFP5}$: Bypass floodplain habitat resulting from efforts to increase availability of the habitat to targeted native fishes will be suitable for their growth, survival, and/or reproduction as required by the targeted life stage.

The **metrics** for this hypothesis will be the water quality variables identified in project-specific science plans and based on best available science for the life stage and species targeted by the project.

Covariates for this hypothesis will include rates and periods (e.g., duration, frequency) of inundation and flow in the project area as well as air temperature during the period when target species are expected to occupy the project. Covariates may also include physical features, such as canopy cover, and riparian vegetation in project areas.

The **baseline** for this hypothesis will be the reference water quality of proximate habitat outside the project area for the identified metrics in the project-specific science plans. Reference areas will also be identified in project-specific science plans.

$H_{BypassFP6}$: 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.

$H_{BypassFP7}$: 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 outmigrate from the 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.

$H_{BypassFP8}$: 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 (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).

$H_{BypassFP9}$: Native fish spawning success will increase through bypass floodplain enhancement actions.

The **metric** for this hypothesis will be (1) the number of juvenile Splittail and Sacramento Blackfish exiting the Yolo Bypass, and (2) the number of adult Splittail and Blackfish in the Delta in January, February, and March.

Covariates to measure to consider the various environmental factors that may influence the proportion of juvenile Splittail and Blackfish produced by enhanced floodplain spawning habitats include water quality variables in floodplain habitats (water temperature, turbidity, dissolved oxygen, and flow), as well as the timing, magnitude, and frequency of floodplain inundation. Moyle et al. 2004 hypothesized that Splittail require a specific combination of inundation timing and frequency (both intra and inter-annual) to produce a strong year class, such as (1) attraction flows for adults in January, February, or early March, (2) extensive inundation of floodplains during March and April for spawning to occur, and (3) continuous inundation for 6-8 weeks to allow for spawning and rearing of early life history stages (including flooding prior to the onset of larval feeding). Further, it is thought that each female spawns several times during the spawning period in response to pulses of water in flooded areas, but that most fish do not spawn two years in a row (e.g., consecutive years of flooding may not lead to multiple strong year classes, Moyle et al. 2004). Analysis of the Yolo Bypass Fish Monitoring Program (YBFMP) RST alone has yielded variable results (Feyrer et al. 2006), however, the incorporation of adult data to estimate spawner abundance is also needed to fully understand the impact of floodplain enhancement actions.

Little is known about Blackfish, but it is assumed that they spawn in floodplains such as the Yolo Bypass (Feyrer et al. 2006) at a later time and in slightly warmer water (juveniles are observed in late-April and May, (Crain et al. 2004) than Splittail.

The **baseline** for this hypothesis will be the period of record for the YBFMP, as well as estimates of the spawning population of adult Splittail and Blackfish from the Delta Juvenile Fish Monitoring Program (DJFMP) electrofishing catch in the Delta. This may also include modeled estimates of abundance if a life cycle model for Splittail or Blackfish is developed.

2.2.4 Tidal wetlands restoration

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, and Chinook salmon. Other native fishes that will be beneficiaries of tidal wetlands include tule perch (*Hysterocarpus traskii*), Sacramento sucker, Sacramento hitch, Sacramento pikeminnow, Sacramento splittail, and prickly sculpin (*Cottus asper*). Hypotheses below describe the mechanisms through which these outcomes will occur. The list of species that will benefit from individual projects may vary across projects and is expected to be defined in project-specific science plans with hypotheses developed in a species-specific manner. As with the hypotheses in the above sections, some hypotheses in this section are additive in nature such that the hydraulic metrics considered in assessment of habitat area (H_{TW1}) contribute to the suitability of the habitat (H_{TW2}) which is also measured by water quality parameters, and all these metrics in turn contribute to the biological effectiveness of the built habitat (e.g., H_{TW3}).

Tidal wetlands are expected to contribute to native fish population benefits in part through increased production of invertebrate food sources that include epiphytic and epibenthic (e.g., amphipods of genera *Hyallela* and *Gammarus*, chironimids) and benthic types as well as zooplankton (e.g., mysids, daphnia, *Eurytemora, Pseudodiaptomus, Sinocalanus*). As with fish, the specific taxa of invertebrates to be studied may vary by project and will be named in project-specific science plans. Where invertebrates are referenced in the below hypotheses, the intention is to maintain the possibility that project-specific science and monitoring activities may focus predominantly on epiphytic, epibenthic, benthic, and/or zooplankton taxa and the hypotheses provided here are intended as starting places for refined hypotheses tailored for specific projects.

Additionally, water quality parameters are often important covariates for assessing suitability for fish and invertebrate taxa. These parameters include salinity, water temperature, turbidity, and dissolved oxygen and are referenced in the hypotheses below generally as “water quality” with project-specific science plans to name the parameters of interest in tailored hypotheses.

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.

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.

The **covariate** for this hypothesis is the modeled tidal range of the project area post construction. This value will define the hydrologic footprint of the project area, which is referenced in the hypotheses below to guide the spatial area of study needed to evaluate the full impact of restoration.

The **baseline** for this hypothesis will be quantified by a DEM representing pre-project topography. As described in the Strategic Plan, Appendix F, wetted area will be defined by inundation levels relative to mean high-high water.

H_{TW2}: Restored tidal wetlands will be suitable for project-specific objectives and target species.

The **metric** for this hypothesis will be the water quality conditions in restored tidal wetlands and relevant to the restoration projects’ target native fishes. For projects targeting Delta smelt, longfin smelt, and juvenile Chinook salmon, water quality variables will include those in the 2023 Scientific Basis Draft Supplement Report (SWRCB 2023). Projects targeting other native fishes will be based on species-specific best available science.

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 high water residence times, 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.

Covariates for this hypothesis will include modeled water residence time (Downing et al. 2016) as it is related to water quality and likelihood of cyanoHAB occurrence.

The **baseline** for this hypothesis is the reference suitability of proximate habitat outside of the project area. Reference areas will be defined in the project-specific science plan for the target native fishes and objectives of the project.

H_{TW3}: 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 on the assemblage and abundance of zooplankton food resources (e.g., *Potamocorbula amurensis* and *Corbicula fluminea* densities and modeled grazing rate). From observations of clam densities, their impact on the biomass of zooplankton can be estimated (Greene et al. 2011; Kimmerer and Thompson 2014). To fully evaluate this hypothesis for zooplankton, the impact of filter-feeding clams should be estimated (clam biomass, water temperature, water depth and grazing rate) and compared with estimates for productivity. Another covariate is the density of planktivorous fishes because they may also impact food availability for target species.

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 Fish Restoration Program (FRP, Hartman et al. 2018).

H_{TW4}: Beneficial taxa for native fish diets (zooplankton and benthic or epiphytic invertebrates) will be present in the diets of 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 reference locations).

H_{TW5}: 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 Fulton’s condition factor or gut fullness. Condition metrics will be derived from fish sampled on or near restored areas. To determine growth rate and 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.

Covariates to measure include densities of diet items for target fish species (zooplankton, invertebrates, and/or forage fishes), as well as water quality parameters relevant to target fish species habitat suitability.

The **basis for comparison** will be measured growth rates in other habitat types, such as riverine channels. While growth rates of many native fishes have been published in the scientific literature, they are generally not habitat-specific (except for juvenile salmon), 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_{TW6}: 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 in restored tidal wetland habitats and their hydrologic footprint. Presence may be measured by sampling conducted through traditional methods such as beach seines or tagging studies (Hering et al. 2010; McNatt et al. 2016), 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 (*Morone saxatilis*), Largemouth bass (*Micropterus salmoides*) or other *Micropterus* species, or Sacramento pikeminnow) at these locations. Predators along migration routes and dense aquatic vegetation can 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 assessed using imaging sonar technology such as Dual Frequency Identification Sonar (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 (Zeug et al. 2021). 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 native fish densities measured at reference sites and during pre-project monitoring activities conducted by the FRP (Hartman et al. 2018). Historical data on fish assemblage and frequency of native species detection can also be obtained from the DJFMP, 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 and metrics

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 Measures within tributaries will affect indicators of ecological health and support the productivity, condition and life history diversity of juvenile salmonids. 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 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 River and Putah Creek) 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 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 rates of parasite infection. 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 one week subsequent to the release to capture potential lag-phasing of the 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 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 the response. It is anticipated that migration rates will be calculated using 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 Program 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 the 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:* (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); and (3) the relative risk of infection, based on a dose-response model (Atencio et al., in prep) or another novel approach may potentially be used as a method for estimating the impact of pathogen density if verified to reliably relate to clinical infection.

Covariates that may affect the impact of flow increases on *C. shasta* include water temperature and the movement rate of juveniles (e.g., acoustically tagged fish released during the flow increase), which would be beneficial for understanding exposure time, and the impact of flow increases on exposure to pathogens.

The **baseline** for this hypothesis will be existing spores per liter of *C. shasta* and relative rate of clinically infected Chinook salmon juveniles in tributaries up to two weeks before flow pulses occur. Where historical data are available, both *C. shasta* densities and clinical infection rates can be assessed for flow rates. Similarly, differences in the relative risk of infection can also be evaluated with a dose-response model (Atencio et al., in prep).

2.3.1.2 Tributary ecological health and juvenile salmon productivity, condition, and diversity

Generally, the suite of habitat enhancement measures for a tributary, along with spring flow pulses, are expected to collectively result in improved ecological health of the tributary systems as measured by standardized, statewide indicators based on primary and secondary invertebrate productivity (Mazor et al. 2016; Peek et al. 2022). The improved tributary condition is expected to contribute to 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 migration timing of juvenile anadromous salmonid annual outmigrant populations.

$H_{TribWide1}$: The suite of Program measures implemented within a tributary will result in an increase in the index values derived from plant and invertebrate sampling (e.g., the Algae Stream Conditions Index (ASCI) and the California Stream Condition Index (CSCI)).

The **metrics** for this hypothesis will be the values of the ASCI and the CSCI at the tributary-wide scale, as well as the change in these metrics from the baseline period to the term of the Program. These metrics are based on standardized collections of algae (ASCI) and benthic macroinvertebrates (BMI) to enable consistent calculation of indices that are indicative of stream ecosystem health. The health assessments are based on thresholds developed from reference sites throughout the state (Mazor et al. 2016; Theroux et al. 2020) and have been used in conjunction with physical and chemical parameters for the development of an overall Stream Quality Index (Beck et al. 2019). Since development of the indices and health thresholds, analyses relating index values to functional flow metrics have shown that flow metrics addressed by the Program, such as the timing and magnitude of spring flows, have a significant influence on ASCI and CSCI values (Peek et al. 2022).

Alternative **metrics** for this hypothesis, if baseline data are not available for CSCI values specifically, include other published metrics based on BMI sampling data. These include the ratio of observed to expected BMI taxa (Hawkins et al. 2000) and predictive multivariate indices (Vander Laan and Hawkins 2014).

Many important **covariates** for primary and secondary productivity are already included in the calculation of ASCI and CSCI, such as latitude and longitude, geological site characteristics, elevation, topography, and other physical aspects of the system are already integrated into the calculation of the indices (Mazor et al. 2016; Theroux et al. 2020).

Data for the ASCI and CSCI have been consistently collected and compared with a consistent set of reference sites since 2008, and the 2008 – 2018 time period will serve as a **baseline** to test this hypothesis (Rehn 2021). However, some of the Program tributary systems may be lacking historical data (CSCI data available at Surface Water Ambient Monitoring Program (SWAMP) Data Dashboard (ca.gov) and the California Data Exchange Network (CEDEN, https://www.sfei.org/projects/california-environmental-data-exchange-network-ceden). In these cases, the historical data will be examined for appropriate reference sites that are proximate to the Program tributary systems (e.g., sites within basin on higher order systems).

$H_{TribWide2}$: The suite of Program 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, spawning and escapement data (e.g., carcass surveys, redd surveys, and/or direct observation such as video/VAKI Riverwatcher™/counting weirs, Blankenship et al. 2024). 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. Notably, evaluation of this hypothesis will require accurate identification of hatchery and natural origin individuals and their age to assign juvenile outmigrants to the correct spawning cohorts.

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 Program measures.

$H_{TribWide3}$: Increased habitat quality and associated primary and secondary production to support the base food web will result in improved condition of Chinook salmon outmigrating 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 outmigrating from tributaries into the Delta system.

An important **covariate** to measure for assessing condition factor is water temperature.

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

$H_{TribWide4}$: The suite of Program 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 migrant population over the annual period of outmigration. 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. 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).

Covariates for this hypothesis will be flow and water temperature.

The **baseline** for this hypothesis will be coefficients of variation in the timing and body size of the juvenile Chinook salmon migrant population over the annual period of outmigration for those years when data is available prior to implementation of Program 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 adult spawning and larval rearing habitat for Delta smelt and longfin smelt.

The **metric** for this hypothesis will be modeled acreage of 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 approach described in the 2023 Draft Scientific Basis Report Supplement (SWRCB 2023) or, given uncertainties about spawning habitat suitability, newer peer reviewed literature may be used if available. 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 Flow Measures, 2023 Draft Scientific Basis Report Supplement (tiered approach to integrate CalSim and the Resource Management Associates (RMA) Bay Delta Model, described in Figure 5-4, SWRCB 2023).

$H_{DeltaFlow2}$: Increased Delta outflows in the spring will facilitate transport of larval and juvenile longfin smelt 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. If monitoring networks are developed for population estimates (described in below section on Priority Information and Monitoring Gaps), a useful metric will be the proportion of the population that is located downstream of the confluence area of the Delta. Longfin smelt environmental DNA or other novel approach may potentially be used as a method for presence and distribution if verified to reliably relate to fish presence.

Covariates for this hypothesis will be water temperatures and turbidity during the larval and juvenile rearing season, and the distribution and abundance of adult longfin smelt in the preceding spawning period. Other covariates related to the distribution of larval transport are DAYFLOW variables QWEST and OMRI, and Project exports (see DAYFLOW documentation for 1997 – present: https://data.cnra.ca.gov/dataset/06ee2016-b138-47d7-9e85-f46fae674536/resource/776b90ca-673e-4b56-8cf3-ec26792708c3/download/current-dayflow-documentation.pdf).

The **baseline** for this hypothesis will be the period of record of larval longfin smelt catch in the Smelt Larval Survey (SLS) 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 Flow Measures, 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 spring Flow Measure implementation and historical years for the same months but with lower outflow conditions. The years used to define the historical dataset will be 2002 – present.

$H_{DeltaFlow3}$: Increased spring Delta outflows will improve recruitment for longfin spawning and will result in increased adult abundance

The **metrics** for this hypothesis will be (1) annual adult abundance estimates inclusive of the full geographic range of longfin smelt within San Francisco Estuary; and (2) increased larval densities in the western Delta and Bay regions relative to other known spawning areas for the species, such as the Napa River.

Covariates for this hypothesis will be Delta outflow, Bay tributary inflow during longfin smelt spawning, water temperatures, and turbidity during the larval and juvenile rearing season, and the distribution and abundance of adult longfin smelt in the preceding spawning period.

The **baseline** for this hypothesis will begin when the necessary sampling program begins, as longfin smelt abundance estimates are currently under development.

Sampling design and analytical methods for this hypothesis require estimates of longfin smelt adult abundance in major spawning areas in the winter and early spring months (approximately January – April) with gear that is effective in shallow marsh habitats (e.g., otter trawl, lampara net). Juveniles/sub-adults collected in the San Fransico Bay Study or Fall Midwater Trawl (FMWT) could provide a second source of sampling for adult spawners. Additional sampling methods to support adult abundance estimates may also be developed, such as Close-Kin Mark-Recapture (CKMR, Bravington et al. 2016b). Adult abundance estimates may also be estimated with the development of a species-specific life cycle model, which is currently under development as part of the Longfin Smelt Science Plan (2020 – 2030) for the State Water Project (DWR et al. 2020). To obtain densities of larval longfin smelt, sampling is necessary in each regional spawning area.

Existing sampling activities, as well as the needs for additional data collection to support evaluation of this hypothesis, are further discussed below in Section 3.2.2.2.

$H_{DeltaFlow4}$: 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 (1) the estimated entrainment of Delta smelt adults in early spring months, and for Delta smelt larvae and juveniles, and (2) 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 Flow Measures, and outflow levels lower than those levels. Prior years selected for baseline comparison will be selected from 2002 – present. Previously published studies can also serve as a basis for comparison (Kimmerer 2008; Smith 2019; Grimaldo et al. 2021; Korman et al. 2021).

$H_{DeltaFlow5}$: 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). Estimated coverage of floating aquatic vegetation along migration routes may also be included as a covariate.

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 Flow Measure 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.

$H_{DeltaFlow6}$: 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 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).

$H_{DeltaFlow7}$: 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 (CDFW). The number of larvae and juvenile sturgeon is positively correlated with Delta outflow during winter and early spring months (Fish 2010).

Covariates to measure for this hypothesis will be estimates of spawning adult white sturgeon, including modeled estimates of abundance if a life cycle model for white sturgeon is developed. The severity and intensity of HABs in the San Francisco Bay and Delta may also be related to the San Fransico Bay Study data.

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 Flow Measures and compared with years with lower outflows.

$H_{DeltaFlow8}$: Increased Delta outflow in the spring will result in transport of freshwater-associated zooplankton taxa (e.g., *Daphnia* spp., *Eurytemora carolleeae* 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 and summer months during and after implementation of 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., *Eurytemora carolleeae* 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 *Sinocalanus* spp., *Bosmina logirostris* and the mysid shrimp *Neomysis mercedis*.

Covariates to measure to assess conditions influencing zooplankton community composition include phytoplankton biomass, 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 Flow Measure implementation and compared with the same months and regions for lower outflow conditions.

$H_{DeltaFlow9}$: Provision of increased spring outflows in the Delta will not be related to the prevalence of cyanoHABs in the Delta or HABs in the Bay, or their toxicity during summer and fall months of the same year.

The **metric** for this hypothesis will be the relative frequency, magnitude, and severity of HABs in the Delta, Suisun Marsh and Bay regions, as measured by consistent visual observations of *Microcystis* presence during routine Delta monitoring surveys, such as the Environmental Monitoring Program, Summer Townet Survey, San Francisco Bay Study, and the FMWT (Hartman et al. 2022b). Another metric may be the cyanobacteria index estimated by the San Francisco Estuary Institute satellite data platform, available at https://fhab.sfei.org/.

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 Program will affect the abundance of *Microcystis* or other cyanobacteria taxa and associated toxicity levels later in the same year. Additionally, the nature of the interactions between standing stock of Microcystis, flows, nutrients, and temperature and how they affect the likelihood of HAB occurrence is an active area of study, as are the efficacy of potential HAB mitigation measures (Preece et al. 2024a). These investigations, as well as additional and more cohesive monitoring for HABs and associated toxins being identified in the Delta Stewardship Council's draft monitoring strategy (https://deltacouncil.ca.gov/pdf/science-program/information-sheets/2022-10-21-draft-delta-harmful-algal-bloom-monitoring-strategy.pdf), will likely contribute to understanding effective measures for HABs management and may lead to refinements in this hypothesis and its evaluation.

Covariates to measure to evaluate this hypothesis include Delta outflow through the spring season when Flow Measures are implemented, as well as during the cyanoHAB season. Other flow metrics, including San Joaquin River inflow, project exports, and installation/operation of barriers/gates may be locally important to formation of cyanoHABs. 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 the 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 WQCP.

At the full system-wide and population-level scale, a goal of the Program is that the aggregate of Flow and Non-flow Measures contribute to a trend of increased abundance. To this end, metrics of population abundance (listed below) will be tracked, and the 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 the 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 means that it will not be realistic to expect significant changes in trends to population-level metrics within the 8-year term of the Program. 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 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 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 Term Sheet and the Salmon Narrative Objective for the update for the WQCP, 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 Program 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 Program 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 Program 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 population estimates (harvest plus escapement) calculated over the period of implementation of Program measures, and the trend in annual Chinook salmon escapement estimates calculated over the period of implementation of Program 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 CFM 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 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 Program 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.

The **metric** for this hypothesis will be the trend in annual Chinook salmon CRR for natural origin fish, calculated over the period of implementation of Program 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 PSMFC and CDFW on the estimated proportion of the adult population comprised of hatchery fish, based on the CFM Program (Letvin et al. 2021) will be the basis for estimated natural origin fish. Because the 8-year term of the 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 CRR calculated over the period of record prior to the implementation of Flow and Non-flow 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 salmon population-level response

H_{SWPop1}: Implementation of the full suite of Program 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 Program implementation.

The **baseline** for this hypothesis will be the average of natural origin escapement values associated with the AFRP 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 Program 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 Program 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 AFRP (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 EDSM (operated by the USFWS). For Delta smelt, some change in abundance is expected regardless of the implementation of Flow and Non-Flow Measures 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 (SWRCB 2023). 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 Program 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 Flow and Non-Flow Measure 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 Program metrics

The Science Program has a geographic scope spanning the upper watersheds of the Central Valley tributaries (below rim dams) to Suisun and San Pablo Bay. The 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 Flow and Non-flow 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 Measures.

Throughout the watershed, an extensive suite of monitoring programs already exists 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 the evaluation of metrics outlined by the hypotheses, it is necessary to evaluate existing monitoring efforts through the lens of what is needed for addressing those hypotheses. 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 four 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 salmonid utilization of enhanced rearing habitat, along with the native fish community assemblage; and (4) adult salmonid 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_{S1}, H_{R1}, $H_{TribFP1}$) and suitability (H_{S2}, H_{R2}, $H_{TribFP2}$).

To achieve a consistent estimate of available spawning and rearing habitat and to assess changes in the available area after Non-flow Measures targeting these habitat types have been implemented, 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 tributaries to have consistently produced maps and to measure change in habitat area in a consistent way: (1) a DEM, (2) a 2-dimensional hydraulic model, (3) a cover map that illustrates habitat features identified in Appendix F of the Strategic Plan (H_{R1}, $H_{TribFP1}$) or a substrate map characterizing substrate composition (H_{S1}), and (4) a hydrology model simulating operations and hydrology scenarios in order to determine the available habitat area under different flow conditions. The general methodology for quantifying spawning and rearing habitat area for the purpose of the Accounting assessment and evaluating hypotheses H_{S1}, H_{R1}, and $H_{TribFP1}$ is described in the Strategic Plan, Appendix F.

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 3).

In addition to the variables mapped for Accounting Assessment purposes, water quality parameters must be assessed to fully evaluate suitability of built habitat (Suitability Assessment, Strategic Plan Section 3.1.3). Tributary and project-specific science plans will detail the approach for evaluating water temperature, dissolved oxygen, and turbidity to evaluate hypotheses H_{S2}, H_{R1}, and $H_{TribFP2}$, which address the Suitability Assessment for Non-Flow Measures in tributaries. Generally, these parameters will be measured in project sites using continuously installed sensors that record data at set intervals (e.g., hourly or at 15-minute intervals) and compared with reference sites that are detailed in individual science plans.

Table 3. Summary of habitat mapping efforts by tributary. SRH-2D = Sedimentation and River Hydraulics – Two Dimensional Model (USBR 2008); TUFLOW = proprietary hydraulic model (https://www.tuflow.com/); TUFLOW GPU = TUFLOW model with Graphical Processing Unit add-on; HecRAS = US Army Corps of Engineers Hydrologic Engineering Center River Analysis System (https://www.hec.usace.army.mil/). All models are two-dimensional.

Tributary	DEM availability/source	Hydraulic Model Platform	Cover Map Available	Hydrologic Model, Period of Simulation
Upper Sacramento	Yes/ 2017 Lidar, 2018 Sonar	SRH-2D	No	CALSIM2, 1922 – 2003
Feather	No	In development, HecRAS	Underway	CALSIM3
Yuba	Yes/ 2017 LiDAR and multibeam echo sounder	TUFLOW GPU	Yes	Yuba Daily Operations Model, 1922-2021
American	Yes/ 2017 and/or 2023 LiDAR and single/multi-beam SONAR upon request	HecRAS	Yes	CALSIM2, 1922-2003
Mokelumne	Yes/ 2015 LiDAR and ground survey	HecRAS	Partial	HEC-HMS, calibrated to events of Feb 1986, Jan 1997, Feb 2017
Putah	Yes/2005 LiDAR	HecRAS	Partial	No hydrologic model used
Tuolumne	Yes/ 2012 and 2013 LiDAR	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_{R3}, $H_{TribFP3}$).

Assessing the response of secondary producers in tributaries to Non-Flow Measures to provide in-channel and floodplain rearing habitat 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 on the SWAMP data dashboard (SWAMP Data Dashboard (ca.gov)) and the California Environmental Data Exchange Network (California Environmental Data Exchange Network (CEDEN) | San Francisco Estuary Institute (sfei.org)). 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). The ASCI, which synthesizes composition and abundance of primary producers, is not yet available online.

Despite development of standardized indices, an overview of current BMI sampling efforts in tributaries reveals that data are not consistently collected and when data are collected, methodologies vary (Table 4). In addition, the historical dataset for the CSCI index may not be inclusive of all tributary systems of the

Program. The upper Sacramento River and the Tuolumne River are the only systems reporting routine BMI monitoring (Table 4). Most other systems collect BMI data on an as needed basis for special studies or restoration effectiveness monitoring, or CSCI data may be available for small, higher order systems to the main tributary. Most of the data are not yet 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 Healthy Rivers and Landscapes Non-flow Measures. Existing efforts need to be spatially relevant to project sites.

For site-specific evaluations of the response of the BMI community to Non-flow Measures, 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 reference sites as described in the desired baselines for hypotheses H_{R3} and $H_{TribFP3}$. However, for Triennial Reports and the Ecological Outcomes Analysis Report (described in the Strategic Plan), and for reporting at a system scale using ASCI and CSCI as indicators of overall tributary ecological health with the potential to compare across systems and over time (see hypothesis $H_{TribWide1}$), development of new sampling locations for standardized indices may be necessary.

Table 4. Overview of benthic macroinvertebrate sampling efforts by tributary. Contact information for tributary data is detailed if available. If not currently available, "Upon Request" is noted to indicate that status of data availability. In the first year of the Program, the Science Program will produce a data management plan that is consistent with the Science Committee Charter, Appendix D, which details requirements for data to be posted in public data repositories.

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; Killam, Doug.Killam@wildlife.ca.gov, anticipated posting of some data to SWAMP Data Dashboard and CEDEN database
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	Technical reports available upon request; contact@waterforum.org.
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 salmonid habitat use and densities on tributaries (H_{R4}, $H_{TribFP4}$, $H_{TribFP6}$, $H_{TribFP7}$)

Juvenile salmonid 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 hypotheses concerning juvenile salmonid response to in-channel and floodplain Non-flow Measures, it will be necessary to pair sampling between project sites and reference sites, such as nearby tributary locations without restored habitat but that exhibit similar suitability (e.g., water temperature).

Juvenile salmonid habitat use is assessed in all tributaries, primarily through snorkeling efforts (Table 5) that cover in-channel habitats. In most systems, tributary floodplain habitat is not covered in routine monitoring efforts, presenting a gap in monitoring needs for understanding how juvenile salmonids utilize restored floodplain habitat ($H_{TribFP4}$). For in-channel Non-Flow Measure projects, existing monitoring efforts, depending on its location relative to project sites, may be appropriate for juvenile salmonids habitat use (H_{R4}). 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.

Notably, it may be possible to address other Local Tier hypotheses on the tributaries through snorkel surveys, electrofishing, and/or seining conducted for juvenile salmonid 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 tributary floodplain Non-flow Measures by other native fishes ($H_{TribFP7}$). In fact, these surveys may be the most likely opportunity for obtaining information on non-salmonid timing, presence and distribution. Otherwise, non-salmonids are only tracked at RSTs 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 floodplains ($H_{TribFP6}$) after hydraulic connectivity with the mainstem has ceased also requires empirical observation of juvenile salmonids in these areas, and this can be done with snorkel or seining surveys.

Table 5. Overview of approaches for assessing juvenile salmon habitat use and densities across tributaries. Contact information for tributary data is detailed if available. If not currently available, "Upon Request" is noted to indicate that status of data availability. In the first year of the Program, the Science Program will produce a data management plan that is consistent with the Science Committee Charter, Appendix D, which details requirements for data to be posted in public data repositories.

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.	Upon request; Doug.Killam@wildlife.ca.gov
Feather	Snorkel, seine, backpack electrofishing	Presence/absence, distribution, relative abundance, juvenile salmon density (#/reach)	All in-channel habitats (pool, riffle, side channels). Floodplains not sampled.	Snorkel available (https://portal.edirepository.org/nis/mapbrowse?packageid=edi.1705.2), otherwise upon request
Yuba	Snorkel	Presence/absence, habitat use, density (#/reach)	All in-channel habitats (pool, riffle, side channels). Floodplains not sampled.	Upon request; Yuba Water Agency
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 from EBMUD
Putah	Snorkel, seine, hydroacoustic tags to assess potential barriers to juvenile salmon outmigration and habitat use	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)

Tributary	Survey Type	Metric	Habitat Types Sampled	Data Availability
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_{S3}).

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, Mokelumne, Yuba, and Tuolumne Rivers (Table 6). However, redd surveys are conducted in a subset of areas on the Feather River and in Putah Creek. Where spawning habitat Non-flow Measures are planned as part of the Healthy Rivers and Landscapes Program commitments (Sacramento River, American, Feather, Tuolumne, and Putah), redd surveys will be included as part of the tributary-specific science plans at project and reference locations, at minimum.

As appropriate, redd surveys or other visual observations of adult anadromous fishes will 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}).

Table 6. Overview of adult Chinook salmon sampling methods for escapement, with corresponding abundance estimate accuracies, and biological sample collections, by 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,)
Upper Sacramento: Mainstem	No redd surveys	90% Confidence interval generated by PSMFC, no accuracy estimates 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
Feather River	Redd surveys, in subset of areas, no abundance estimates	+/-10% accuracy T/O/S/E: Yes/Yes/Yes/Yes	Direct counts, no accuracy estimates
Yuba River	Redd surveys, no abundance estimates	+/-20% accuracy 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,)
American River	Aerial redd surveys, +/- 1% accuracy of abundance estimate.	+/-10% accuracy, data available upon request T/O/S/E: Yes/Yes/Yes/Yes	No direct counts
Mokelumne River	Redd surveys	No carcass mark-recapture T/O/S/E: Yes/Yes/Yes/No	+/- 10% accuracy of overall abundance and +/- 50% accuracy of natural origin abundance
Putah Creek	Redd surveys in subset areas	Ad-hoc carcass surveys prior to 2024, adult estimates not available T/O/S/E: Yes/Yes/No/Upon request	Direct counts are planned, permits in place for 2024
Tuolumne River	Redd surveys, abundance estimates from escapement survey or weir counts, no abundance estimates from redd counts	+/- 20% accuracy T/O/S/E: Special studies/Yes/Yes/No	Direct count, no accuracy estimates or natural origin abundance

3.1.2 Monitoring needed for bypass enhancements for increased floodplain habitat access

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 the California Department of Water Resources (DWR) and United States Bureau of Reclamation (USBR) for the 2009 NMFS Biological Opinion for the Central Valley Project, 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 the frequency and duration of inundation. A similar baseline model has been developed for the Sutter Bypass and Butte Sink as part of the Floodplains Reimagined Program (https://floodplainsreimagined.org/resources/reports-data/).

3.1.2.2 Measuring ecological connectivity between floodplain bypasses and river mainstem ($H_{BypassFP5-8}$)

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 and migrate 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 Non-flow Measures increase utilization of the bypass system by juvenile fishes and allow upstream passage of adult anadromous fishes (Johnston et al. 2020). 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 salmonid utilization of and egress from the bypasses, monitoring the population exiting the bypass is needed (e.g., using a RST) 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 migration 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 will include sonar imagery (e.g., using acoustic cameras such as the DIDSON camera, or the Adaptive Resolution Imaging Sonar (ARIS) technology) at fish passage structures. Concurrent with imagery, water depth, velocity, and temperature will be monitored at weir structures to assess conditions and compliance with passage criteria for anadromous fishes (NMFS 2023). Acoustic telemetry is also a useful tool when evaluating migration success and stranding risk of adult salmon and sturgeon (Johnston et al. 2020). In addition to being useful for assessing ecological connectivity and utilization of bypass floodplains, they may also be useful for assessing and accounting for Non-Flow Measures that involve modification of weirs or existing fish passage structures (H_{Pass2}).

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 projects for food webs is not included in hypotheses. However, both fish species composition and invertebrate densities have been regularly monitored by the YBFMP since 1998 (https://iep.ca.gov/Science-Synthesis-Service/Monitoring-Programs/Yolo-Bypass). As floodplain enhancement projects proceed in the Sutter Bypass, the YBFMP can serve as a model for designing a comparable monitoring program as appropriate for bypass floodplain projects there.

3.1.3 Monitoring needed for tidal wetland restoration (H_{TW1-6})

Evaluating the Local Tier hypotheses for tidal wetland Non-flow Measures requires three general types of assessment, monitoring, or experimental approaches to acquiring information: (1) ability to accurately model habitat area according to physical habitat criteria of water depth 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}, H_{TW2}).

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 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 Estuary (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 Non-flow Measure implementation to update the elevations for the RMA Bay Delta model.

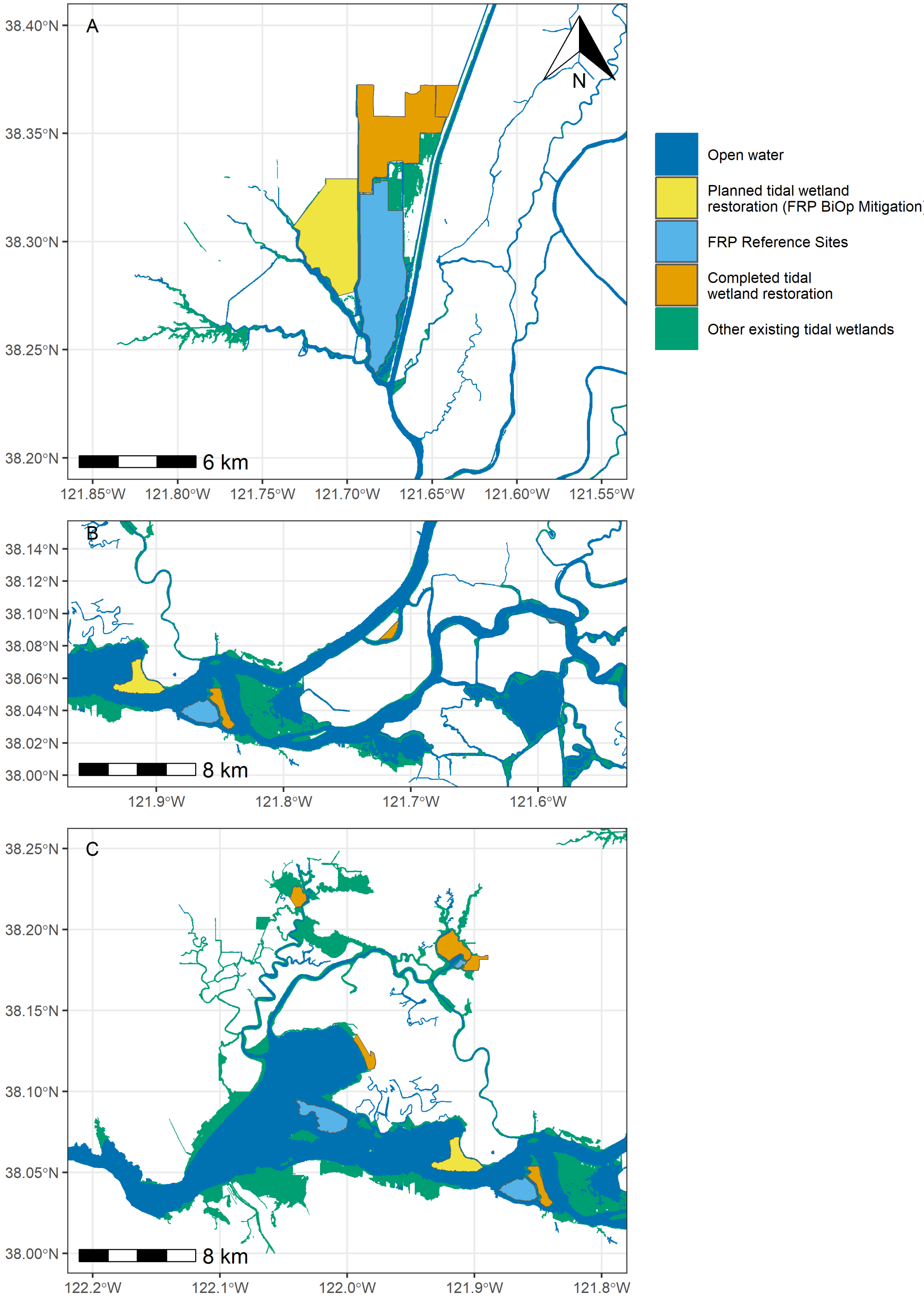
Multi-dimensional modeling approaches also allow for assessing habitat suitability for target species (MacWilliams et al. 2016). The RMA Bay Delta Model can simulate specific conductivity as a surrogate for salinity, turbidity, and temperature, which are all covariates that inform suitability of habitat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

3.1.3.2 Monitoring community composition and densities of invertebrates (zooplankton, benthic and epibenthic invertebrates) and fishes along with covariates in tidal wetlands (H_{TW3}, H_{TW4}, H_{TW5}, H_{TW6}).

To evaluate these hypotheses, composition and densities of zooplankton, benthic invertebrates, and epiphytic invertebrates will be sampled in tidal wetland Non-flow Measure sites and in the surrounding area 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 native fish assemblages. The FRP has been sampling the tidal wetlands of the Delta and Suisun Marsh since 2015 and 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 (i.e., 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 Non-flow Measure sites proposed for the Healthy Rivers and Landscapes Program are not part of the FRP sampling, though some FRP sites may be useful as reference sites. Adding Healthy Rivers and Landscapes tidal wetland restoration sites to the FRP would require additional resources to implement FRP standardized sampling and reporting of relevant data, using the existing monitoring framework (IEP TWM PWT 2017).



A
N
6 km
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
Open water
Planned tidal wetland restoration (FRP BiOp Mitigation)
FRP Reference Sites
Completed tidal wetland restoration
Other existing tidal wetlands
B
8 km
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
C
8 km
38.25°N
38.20°N
38.15°N
38.10°N
38.05°N
38.00°N
122.2°W
122.1°W
122.0°W
121.9°W
121.8°W

Figure 3. Sampling regions for the Fish Restoration Program. Reference sites are existing tidal wetland restoration areas in the North Delta (A), Confluence area (B), and Suisun Marsh (C). 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. Figures are reproducible, data and code are available within the Science Program's GitHub repository: https://github.com/Healthy-Rivers-and-Landscapes-Science.

To compare densities and community compositions of invertebrates and fishes, it is necessary to have concurrent sampling in adjacent pelagic habitats for comparison purposes. Hypotheses regarding invertebrates and fishes require evaluation of the full tidal footprint of tidal wetland Non-flow Measure sites, which may include pelagic areas. Long-term monitoring surveys operated by the USFWS, CDFW, and DWR have collected data on zooplankton and benthic (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).

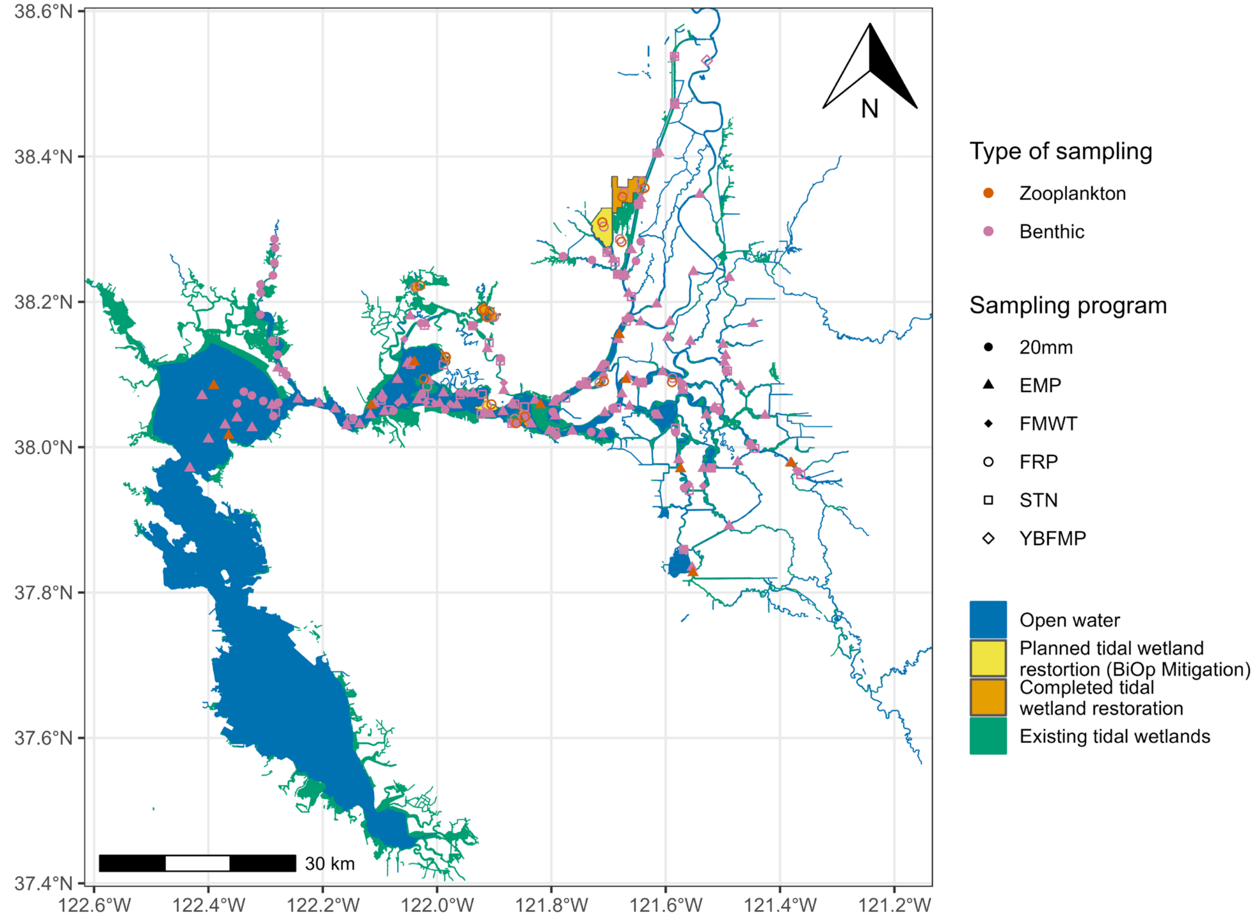


Figure 4. Long-term monitoring surveys collecting benthic invertebrate and zooplankton samples in both tidal wetland and pelagic habitats. 20mm = 20mm Survey, EMP = Environmental Monitoring Program, FMWT = Fall Midwater Trawl, FRP = Fish Restoration Program, STN = Summer Townet Survey, YBFMP = Yolo Bypass Fish Monitoring Program. Figures are reproducible, data and code are available within the Science Program's GitHub repository: https://github.com/Healthy-Rivers-and-Landscapes-Science.

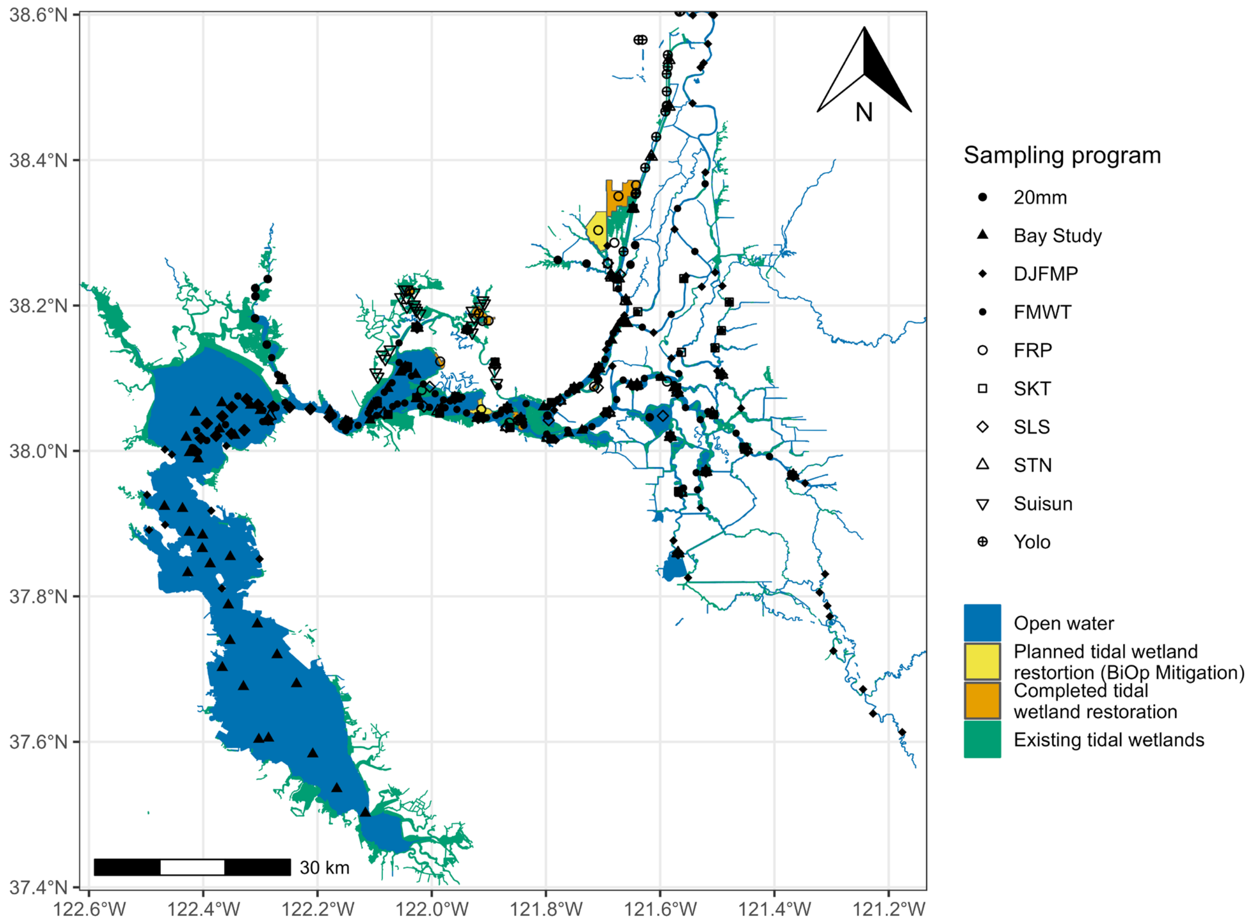


Figure 5. Long-term monitoring surveys collecting fish assemblage and density data through trawling and seining in both tidal wetland and pelagic habitats. 20mm = 20mm Survey, DJFMP = Delta Juvenile Fish Monitoring Program, FMWT = Fall Midwater Trawl, FRP = Fish Restoration Program, SKT = Spring Kodiak Trawl, SLS = Smelt Larval Survey, STN = Summer Townet Survey, Suisun = UC Davis Suisun Marsh Survey, Yolo = Yolo Bypass Fish Monitoring Program. Figures are reproducible, data and code are available within the Science Program's GitHub repository: https://github.com/Healthy-Rivers-and-Landscapes-Science.

3.1.3.3 Biological covariates for aquatic vegetation and predators

Coverage of aquatic vegetation at restoration sites (Covariate for H_{TW6}). 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).

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 Non-flow Measures planned for the Healthy Rivers and Landscapes Program. 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.

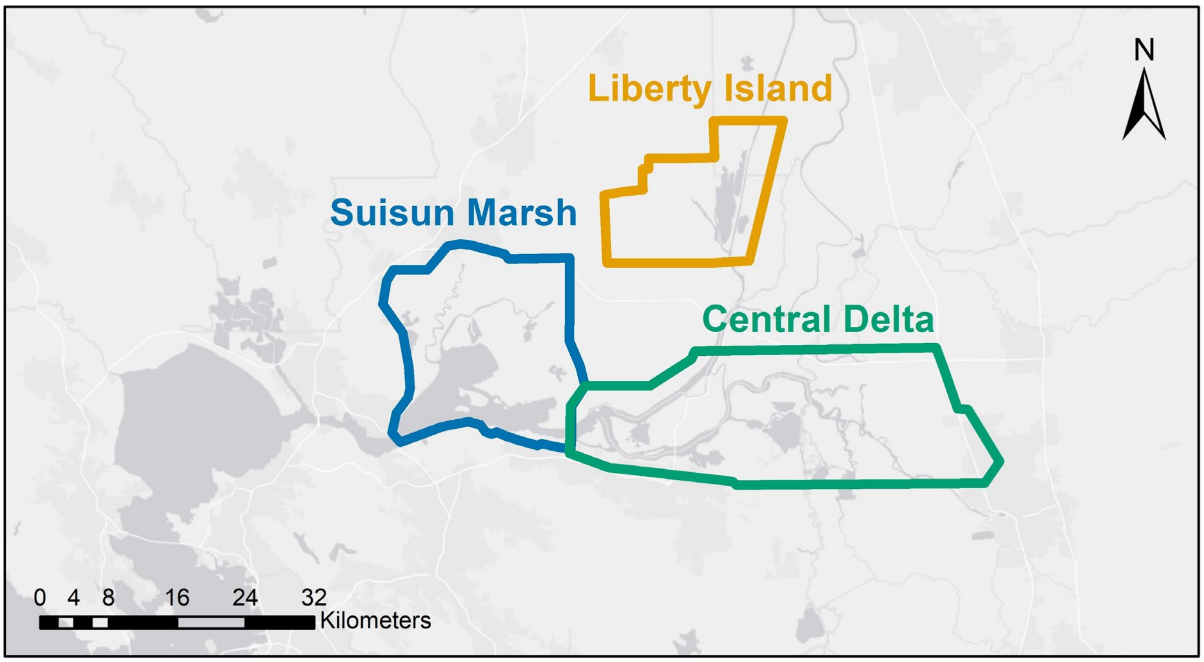


Figure 6. Map of Delta and Suisun Marsh, with delineations of regions that have been consistently mapped in year 2003 – 2008 and 2014 – 2024. These regions are referenced in **Table 7** (Khanna et al. 2022). Hyperspectral imagery and classification for mapping through 2025 is funded by the California Department of Water Resources (Agreement #4600014166).

Table 7. History of imagery capture for aquatic vegetation mapping 2003 – 2024. 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 map in **Figure 6** of Delta regions. Vegetation classification maps for 2004 – 2008 and 2014-2021 are available online (Khanna et al. 2022). Hyperspectral imagery and classification for mapping through 2025 is funded by the California Department of Water Resources (Agreement #4600014166).

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

Year	Image acquisition date	Sensor	Pixel Size	Image extent
2022	Jul 14-18	Fenix	2.0m	Full Delta + Suisun
2023	Sept 12-14	AVIRIS-3	2.4m	Full Delta + Suisun
2024	July 17-21	AVIRIS-3	~2.0m	Full Delta + Suisun

Predator densities at tidal wetland restoration sites (Covariate for H_{TW6}). 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 (Sacramento River near Knights Landing) and a creel survey (Delta) to capture, tag, measure, and assess the sex ratio of striped bass, with the most recent field season occurring in 2019 (Danos et al. 2020). This study provides information regarding relative abundance and migration timing (Goertler et al. 2021) 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 tidal wetland Non-flow Measure 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 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. 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 an appropriate sampling design and estimates of RST efficiency to estimate the proportion of the population being captured and in turn overall abundance (Table 8). Trap efficiency estimates are obtained through a mark-recapture approach in which marked fish of a similar size as outmigrating 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, use large release groups (> 100 fish), and consider fish size. 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 tributary in assessing population trends.

Table 8. The minimum and gold standards for tributary juvenile monitoring within Science Program to meet the Science Committee needs for comparable juvenile production estimates across participating tributaries. The – symbol denotes that the minimum and gold standards are the same for that topic.

Topic	Minimum	Gold	Rationale
Juvenile abundance accuracy/precision	Juvenile production estimate ±20% of true value	Juvenile production estimate ±10% of true value	Appropriate for evaluating effects of typical management actions (Kohler and Hubert 1999)
Monitoring location	Far enough downstream to represent juveniles rearing in the tributary without including fish from other tributaries	-	The most appropriate monitoring location will vary among tributaries, and must consider tradeoffs
Trap efficiency	>3% average trap efficiency	>5% average trap efficiency	Trap efficiencies needed to satisfy juvenile abundance estimate accuracy/precision (Korman et al. in prep)
Efficiency trials: frequency	Weekly trap efficiency trials	Twice weekly or more frequent trap efficiency trials with changing flow or turbidity	Frequency of efficiency trials strongly influences accuracy and precision of juvenile production estimates (Korman et al. in prep)

Topic	Minimum	Gold	Rationale
Efficiency trials: fish released	Marked fish released per trial to satisfy coefficient of variation in trap efficiency target (# to be determined by simulation tool)	-	Variability in trap efficiency estimates can be reduced by releasing more individuals with each efficiency trial (Korman et al. in prep)
Larger juvenile representation	Secondary sampling method or paired acoustic-CWT hatchery releases to estimate abundance of larger juveniles (>75mm)	Capture of larger juveniles (>75mm) is sufficient to support regular efficiency trials	Larger juveniles can be an important component of overall juvenile production, and may not be adequately represented without size-specific efficiency trials or by additional sampling
Sampling gaps	Sampling gaps do not exceed three days, except when overbank flows occur	Sampling gaps do not exceed two days, except when overbank flows occur	Necessary to achieve required accuracy/precision for juvenile abundance estimates (Korman et al. in prep)
Genetic sampling	Genetic samples collected weekly from representative subsamples (# to be determined by power analysis)	-	For run identification or genetic parentage analysis
Trapping season	Consistent trapping season that adequately represents tails of juvenile outmigration	-	Important that entirety of juvenile migration season by represented by sampling and standard requirement for sub-sampling within a larger population (Sokal and Rohlf 1995)
Fish weights	None	Fish weights collected weekly from representative sub-samples	Needed for assessing growth and condition factor of juveniles, number sampled will be refined through statistical power analysis

As RST capture efficiencies increase, juvenile abundance estimates improve in precision. At minimum, capture efficiencies should be 3% 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, fish size) 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 tributary system operates at least one RST in its lower reaches (Figure 7). The Upper Sacramento system has an RST at Red Bluff Diversion Dam. Some systems operate two or three RSTs in tandem to cover a greater proportion of the channel width (Red Bluff Diversion Dam, Feather, Yuba, Mokelumne, Tuolumne). Additionally, there are RSTs (not shown in Figure 7) in tributaries to the upper Sacramento

River (Upper and Lower Clear Creeks, Battle Creek), the lower Sacramento River at Knights Landing and Tisdale Weir, as well as in the perennial Tule Canal of the lower Yolo Bypass, and the lower Feather River below the confluence with the Yuba River. These additional RSTs may provide ancillary information to the main RSTs shown in Figure 7 expected to be used for estimating juvenile production.

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 (except for Putah Creek), estimates for the American, Tuolumne River, and all RSTs on the Upper Sacramento River generally conduct fewer than 10 efficiency trials per year, while other systems may conduct up to 30 trials per year. Only the Mokelumne and American River report fry trap efficiencies of >5%, with most others estimating their efficiency to be in the range of 2-5%. Trap efficiencies for older juveniles (>65mm), which 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 Red Bluff Diversion Dam, 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 Tuolumne (Robichaud and English 2017), and Red Bluff Diversion Dam (Voss and Poytress 2022), 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 condition of juvenile salmonids because the fish need to be handled and processed before being released. Body length and weight can be measured, thus providing fish condition information ($H_{TribWide3}$). Tissue samples may also be collected and used for genetic run assignment, parentage genetics, or 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 Healthy Rivers and Landscapes systems record information on non-salmonids.

In summary, RST monitoring stations 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 efficiency estimation, consistently representing larger juveniles, improvements such that no more than three consecutive days pass without active sampling, and consistent methodologies for statistical approaches to processing efficiency and trap data to estimate abundance (Table 8). 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 Science Program and facilitates efficient synthesis of information for reporting.

The Science Committee is currently taking steps to achieve comparable juvenile and adult Chinook salmon estimates from participating tributaries because these estimates are fundamental to evaluating both the salmon and viability Narrative Objectives of the Healthy Rivers and Landscapes Program. A December 2023 workshop provided a space for information sharing between the Science Committee and tributary monitoring programs. Subsequent individual meetings with tributary representatives have further clarified information needs. This higher resolution understanding of priority information gaps, and the resources necessary to fill them, was then be used to inform standards for tributary rotary screw trap and adult surveys (e.g., standardized data collection methods, schemas, encodings and processing protocols, machine-readable metadata and timely accessible data publications). This process has already incorporated key findings from the State Water Project's Long Term Operations Incidental Take Permit (ITP)'s spring-run Chinook salmon juvenile production estimate (JPE) Science Plan. For example, several juvenile monitoring standards identified previously were based on spring-run JPE draft work products (see rationale, Table 8). New insights from the spring-run JPE program will be integrated as additional results become available. The status of this effort is reflected in Table 8 and Table 9, and further detail is expected in tributary-specific Science Plans.

Figure 7. Locations and information summaries for Rotary Screw Traps (RSTs) on Program tributaries. 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) or, given uncertainties about spawning habitat suitability, newer criteria published in the peer reviewed literature may be used if available. 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 Estuary (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 specific regions of the Delta.

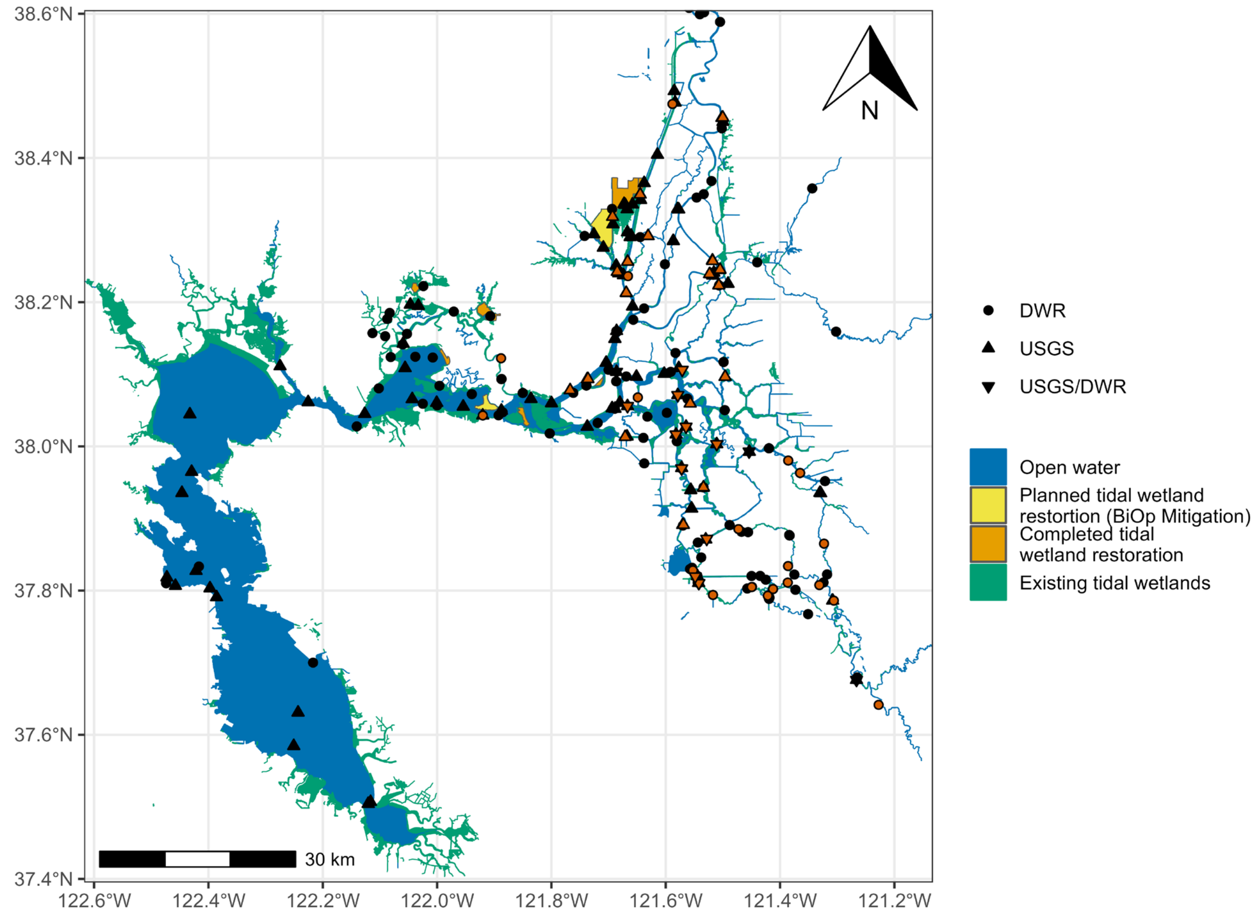


Figure 8. Map of in-situ flow and water quality stations in the Delta. The stations indicated above are installed on site and collect data at regular intervals (e.g., 15 min, 1 hour) throughout the day and night. Many stations are telemetered such that the data can be accessed in real-time, typically on the California Data Exchange Center (CDEC, California Data Exchange Center). Point color denotes flow (orange) and water quality (black). Figures are reproducible, data and code are available within the Science Program's GitHub repository: https://github.com/Healthy-Rivers-and-Landscapes-Science.

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 the transport and entrainment of fish ($H_{DeltaFlow2, 4}$) and estimating abundance of adult longfin smelt ($H_{DeltaFlow3}$)

The hypothesis for transport and entrainment of larval and juvenile longfin smelt, Delta smelt, and Chinook salmon will rely on the expanded EDSM, SLS 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 SLS 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 salmonids (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 Plan, DWR et al. 2020) that will further validate models of larval entrainment.

The current monitoring network for longfin smelt requires augmentation to obtain estimates of longfin smelt abundance ($H_{DeltaFlow3}$). Existing monitoring that contributes to the information need includes juvenile and sub-adult collection in the San Francisco Bay Study and the FMWT (Figure 5), as well as adults captured by the EDSM (Erly et al. 2023) and the Chipps Island Trawl. However, these surveys do not yet collectively provide an estimate of abundance in major spawning areas during the spawning season of January – April. In addition to the use of the Longfin Smelt life cycle model to provide modeled adult abundance estimates, it may be possible to use a CKMR framework to obtain a sample-based estimate of abundance. This approach would need to be piloted to explore its utility for broader application. However, it may be desirable because it is not limited by fish size or tag loss, and each individual fish that is genotyped effectively provides a “mark” for its parents, its offspring, and its siblings. In its simplest application, parent-offspring pairs detected among independent samples of adults and juveniles can be analyzed in the familiar mark-recapture framework to estimate abundance (Bravington et al. 2016b; Bravington et al. 2016a; Prystupa et al. 2021). CKMR would require that tissue and scales be collected from adult longfin smelt, and tissue samples would be preserved such at that DNA can be extracted and analyzed. Limitations to this approach include the CKMR assumption of a closed population, the need to develop genetic tools for accurate identification of kinship among individuals, and the need to ensure representative genetic sampling of the longfin smelt population. Because of these various limitations, the Science Plan will consider the CKMR approach but will also consider other sample-based and model-based approaches for estimating adult abundance. A priority will be integration and coordination with the Longfin Smelt Science Plan (2020 – 2030).

Larval longfin smelt densities (also a metric for $H_{DeltaFlow3}$) are currently sampled in the SLS and information can also be obtained from the 20-mm Survey (Figure 5). To obtain data in additional habitats and regions not covered by existing routine surveys, additional sampling through special studies (e.g., Grimaldo et al. 2017; Lewis et al. 2020) or expansion of current monitoring networks may be necessary.

3.2.2.3 Special studies for assessing effects of increased spring outflow on salmonid survival and habitat use ($H_{DeltaFlow4}$, $H_{DeltaFlow5}$, $H_{DeltaFlow6}$)

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 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 ($H_{DeltaFlow7-9}$)

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 long-term monitoring (Figure 4, Figure 5), including the Environmental Monitoring Program's Zooplankton Survey, the FMWT, Summer Townet Survey, 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 and Rose (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.

The Science Program will contribute to advancing HABs-related science in a manner that is integrated with and builds on other emerging efforts. For example, the Delta Stewardship Council has published a draft monitoring strategy for the Delta that identifies science actions and monitoring needs to address current information gaps (https://deltacouncil.ca.gov/pdf/science-program/information-sheets/2022-10-21-draft-delta-harmful-algal-bloom-monitoring-strategy.pdf). Members of the Science Committee will collaborate with other entities that are advancing improvement monitoring and assessment of HABs, such as the NOAA-supported Monitoring and Event Response for Harmful Algal Blooms Research Program (MERHAB, https://coastalscience.noaa.gov/science-areas/habs/merhab/) which is working to improve the sensor network for HABs observations and developing capabilities for HAB forecasting. These expected advancements in science and monitoring are targeting advancement of the knowledge base on key factors' influence on HABs and promising prevention and mitigation strategies (Preece et al. 2024a; Preece et al. 2024b; Preece and Hartman 2024); the Science Program's expects to provide a contribution to the development of these strategies in a manner that is integrated with other ongoing efforts.

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 CFM 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 (e.g. Barnett-Johnson et al. 2008), which is labor intensive and expensive. Abundance of natural origin Chinook salmon cannot be precisely estimated from the CFM Program, particularly when natural origin fish represent a smaller fraction (<25%) of the population. Therefore, increasing the marking rate and implementing parentage based tagging for any hatchery production that cannot be marked is needed to adequately address hypotheses regarding natural origin tributary and system-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 are 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 adult abundances can be estimated. Several 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. As with juvenile monitoring, the Science Committee has reviewed monitoring methods and met with tributary monitoring leads to define standards needed to assess adult population-level responses to the Healthy Rivers and Landscapes Program (Table 9).

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 and heads can be collected for locating coded-wire tags to identify hatchery-origin individuals. Along with an appropriate marking and tagging program of hatchery-produced salmon, these measures provide a way to estimate the proportion of the population that is natural origin.

The 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 purposes of the 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 for any system depends on whether their accuracy is estimated such that the 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 Healthy Rivers and Landscapes Program. The Feather, American, and Mokelumne Rivers all obtain accuracy aggregate abundance estimates (albeit through different methods) and report a general accuracy level of ±10% (Table 6). Importantly, however, abundance of natural origin adult salmon is not assessed consistently: for example, 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 (Table 9), with a concerted effort towards estimating abundance specifically of natural origin salmon.

Table 9. The minimum and gold standards for tributary adult monitoring within the Science Program to meet the Science Committee needs for comparable adult population estimates across participating tributaries. The – symbol denotes that the minimum and gold standards are the same for that topic.

Topic	**Minimum**	**Gold**	**Rationale**
Adult abundance accuracy/precision	Adult population estimate ±20% of true value	Adult population estimate ±10% of true value	Appropriate for evaluating effects of typical management actions (Kohler and Hubert 1999)
Origin-specific abundance estimates	Natural origin component of adult population estimated ±20% of true value	Natural origin component estimated ±10% of true value	Appropriate for evaluating effects of typical management actions (Kohler and Hubert 1999)
Adult abundance estimation method	Carcass mark-recapture survey following Bergman et al. (2012) sampling design protocols, daily field work led by an experienced biologist, sampling effort tracked and reported	Direct count of adults at weir or fish ladder	Methods which can satisfy respective adult abundance accuracy/precision criteria (Bergman et al. 2012)
Condition of biological samples	Fresh carcasses only subsampled for CWT, scales, eyes and/or otoliths	-	Decayed carcasses can yield poor quality biological data (Bergman et al. 2012)
Number of biological samples	Minimum of 1,000 fish per year. For smaller runs, sample as large a fraction of individuals as possible without exceeding 1,000.	Minimum of 2,000 fish per year. For smaller runs, sample as large a fraction of individuals as possible without exceeding 2,000.	Approximate samples needed for adult abundance by age and origin
Sampling design for biological samples	Samples stratified by week to represent temporal distribution of spawning, and sex-size classes	-	A standard requirement for sub-sampling within a larger population (Sokal and Rohlf 1995)

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 the Feather and American rivers, with some samples collected on Putah Creek on an as needed basis (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.

3.3.2 Monitoring needed for native species communities in the Delta (H_{SWPop3})

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 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 FMWT 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 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 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 Science Program to provide the needed information for evaluation of the hypotheses. Given the comprehensive list of hypotheses and associated monitoring, the Science Committee, along with the Tributary and Delta Governance Entities during development of the system and project-specific Science Plans, will need to conduct a more detailed examination of information gaps. However, given the monitoring needs discussed above, several high-level gaps have emerged that will be important for the Science Program to work toward filling, leading up to and early in the implementation of the Healthy Rivers and Landscapes Program. Each of these gaps has implications for the ability of the Science Program to draw broad inferences about the effects of the Flow and Non-Flow Measures in support of the Narrative Objectives, and therefore on the ability to adequately inform the State Water Resources Control Board's assessment process near the end of the term of the Healthy Rivers and Landscapes Program. These gaps include:

- **Ability to differentiate natural origin and hatchery-origin adults for each tributary**. A primary intention of the suite of 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 Healthy Rivers and Landscapes 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 CFM Program where only 25% of hatchery-origin fall-run Chinook salmon are marked (e.g., with fin clips and coded-wire-tags). One of the primary objectives of the CFM Program is to determine the proportions of hatchery- and natural origin salmon in spawner returns to hatcheries and natural areas. To determine the contribution of hatchery- and natural origin salmon, recovered *CWT* are expanded based on the tagging rate and the proportion of the run sampled 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). However, the abundance of natural origin Chinook salmon cannot be precisely estimated from the CFM Program, particularly when natural origin fish represent a smaller fraction (<25%) of the population. For precise estimates of natural origin abundance, it will be necessary to increase the marking rate and implementing parentage-based tagging for any hatchery production that cannot be marked by adipose fin clip. Until an updated hatchery marking program is implemented, the current CFM program provides rough estimates, and is supported by baseline data from 2010, the first year of complete CFM tagged returns (e.g., $H_{TribWide2}$, H_{SWPop1} and H_{SWPop2}). Release of the data summary from this program in a timelier manner would aid in analysis of the Science 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 Flow and Non-flow Measures 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 Healthy Rivers and Landscapes Program is the coordination of science across tributaries to better understand the effects of Flow and Non-flow 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*: RSTs are currently used in the tributaries to assess juvenile abundance during outmigration. However, improved consistency across specific points of monitoring protocols is needed 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, reducing sampling gaps and improving regularity of fish condition assessments. The minimum and gold standards identify what the Science Program will require of the tributary monitoring programs (Table 8) and the Science Committee will leverage the analytical framework developed for the Spring-run JPE to produce comparable estimates (Korman et al. in prep).
  - *Adult population estimates*: Adult estimates within tributaries are currently conducted using a variety of methods and have varying accuracy across the tributaries (Table 6). 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. The minimum and gold standards identify what monitoring elements the Science Program will require of the tributary monitoring programs (Table 9) and these elements will need to be accompanied by an analytical framework, to be developed.
  - *Invertebrate communities*: Production of benthic invertebrates and zooplankton is not currently assessed in all tributaries (Table 4) 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 Science Committee.

As stated above and in Table 3 through Table 6, tributary systems vary in the degree and approach for all categories of data collection for evaluating Local Tier, Non-flow 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 10 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 Table 2.

Table 10. Summary of where changes are needed to obtain consistent information to address 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.

	Juvenile Production Estimates	**Aggregate Adult Population Estimates**	**Tributary Juvenile Habitat Use**	**Tributary Invertebrate Sampling**	**Habitat Mapping**
	Teal = *Both size classes have efficiency estimates;* ***Yellow =*** *Larger juvenile efficiency estimate missing;* ***Orange*** *= Efficiency estimates missing for both size classes.*	***Teal =*** *Accuracy estimates with basis for uncertainty;* ***Yellow =*** *Accuracy estimate without basis for uncertainty;* ***Orange*** *= Estimates appear to be incomplete*	***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;* ***Yellow =*** *Sampling is episodic over time;* ***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 2) is missing*
Upper Sacramento					
Feather					
Yuba					
American					
Mokelumne					
Tuolumne					
Putah					

- **Design of population estimates for non-salmonid target species in the Delta.** Population-level hypotheses for responses to the 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 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 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 SLS 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}). The fact that absolute abundance and spatial distribution of longfin smelt contributing to the Distinct Population Segment (DPS) is poorly understood- presents a challenge for evaluating effects of non-flow and flow actions in the Delta on the longfin smelt populations. Simulations and pilot studies using novel methods, such as Close-Kin-Mark-Recapture (described in $H_{DeltaFlow3}$) may be useful for improving the ability of monitoring programs to evaluate abundance, spatial distribution, and dispersal/migration between spawning and rearing areas for this species.

- **Data availability and centralization to support coordinated analysis and reporting.** An important gap in the 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 Science Committee to produce synthetic information and to promote the operating guideline of Open and Transparent Data, increasing data centralization through encouraging Parties to publish data in a public data repository will be an early priority of the Science Committee (see Science Committee Charter for the Science Program commitment to Open Data). Further, a data management plan will be developed by the Science Committee in the first year of implementation.

4 Science Committee reporting and analysis

4.1 Assessment of Non-Flow Measures

The Healthy Rivers and Landscapes Program 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 and Delta Governance Entities. Coordinated by the Science Committee, the Tributary and Delta Governance Entities 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 Resources Control Board on progress relative to the Parties' Non-flow Measure commitments as described in the March 2022 Term Sheet and applicable amendments, summarized in Table 25 of the Strategic Plan. The Non-flow Measure accounting process is described further in Appendix F of the Strategic Plan.
- **Consistency assessments** will be conducted to evaluate the degree to which the post-implementation availability of habitat acreage over a range of flows, as measured at the tributary scale, is consistent with similar estimates made in the Scientific Basis Report Supplement (SWRCB 2023).
- **Habitat suitability assessments**, described in Section 4.1.1 of the Science Plan, consider **Non-flow Measure accounting** design criteria, as well as additional **metrics** that may affect species occupancy and their ability to feed, grow, avoid predators, and reproduce in the new or enhanced habitat. These suitability metrics are additional to the metrics informing the accounting procedures and often regard water quality (e.g., water temperature). For example, suitability metrics for spawning habitat, in-channel rearing habitat, tributary floodplain habitat, bypass floodplain habitat, and tidal wetland habitat are described in Science Plan Hypotheses H_{S2}, H_{R2}, $H_{TribFP2}$, $H_{BypassFP5}$, and H_{TW2}, respectively. The habitat suitability assessment is separate from the accounting method described in 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 Healthy Rivers and Landscapes Program triennial synthesis reports as described in Section 9.4 of the Term Sheet as well as the Ecological Outcomes Analysis to be provided prior to Year 7 of the Healthy Rivers and Landscapes Program, as described in Appendix 4 of the Term Sheet.
- **Habitat utilization and biological effectiveness assessments,** described in Section 4.1.2, of the 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 Flow or Non-flow Measure, and whether these measures are achieving or are likely to achieve the anticipated ecological outcomes. For example, Hypothesis H_{R4} tests whether the new or enhanced rearing habitat for Chinook salmon has higher

juvenile salmon densities compared to areas outside of project locations. The results of the habitat utilization and biological effectiveness assessments will be provided in Healthy Rivers and Landscapes Program triennial synthesis reports as described in Section 9.4 of the Term Sheet as well as the Ecological Outcomes Analysis to be provided prior to Year 7 of the Healthy Rivers and Landscapes Program, as described in Appendix 4 of the 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 Non-flow Measures, respectively. It is recognized that each Tributary/Delta GE will build upon this methodological framework to develop detailed assessment protocols tailored to the specific Non-flow Measure being implemented within their respective 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 assessment of a Non-flow Measures are determined by evaluating conformance with design criteria (e.g., water depth, velocity, substrate, cover, floodplain function), 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 water quality metrics, such as water temperature, dissolved oxygen, or other metrics listed in Table 2.

The Science Committee will summarize Non-flow Measure implementation by system and over time to examine whether projects continue to meet the suitability of target species and life stages. Compiling a summary of the total number of acres of enhanced habitat on a system-specific basis requires quantification of site-specific Non-flow Measures using the approaches described in the Strategic Plan, Appendix F.

The persistence of Non-flow Measure project sites' suitability will be assessed over time and based on best available science (as defined in the Science Committee Charter). 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 project was implemented. This could be done to explore the phenomenon of spatial "dynamic equilibrium". For example, gravel placed at a spawning Non-flow Measure 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 reported by the Science Committee during the duration of the Healthy Rivers and Landscapes Program following project construction. The continued assessment of Non-flow Measure projects' suitability over time allows evaluation of trends in the persistence of projects and informs adaptive management considerations for the Healthy Rivers and Landscapes Program.

These data on suitability metrics will be collected and reported for expected periods of utilization, assessed for consistency with species- and lifestage-specific suitability needs, and reported along with implementation summaries, as well as utilization and biological effectiveness assessments for each Non-flow Measure project. Covariate data to describe habitat suitability (Table 2) 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 Non-flow Measure sites 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 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 Non-flow 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 Non-flow 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 triennial synthesis reports will also describe whether continuation of the Healthy Rivers and Landscapes Program 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 Healthy Rivers and Landscapes Program across a range of hydrological conditions. This synthesis report will inform the State Water Resources Control Board's evaluation 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 Non-flow 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 influences 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 Non-flow 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 2) that potentially influence the utilization and/or effectiveness of Non-flow Measures.

4.2 Schedule for reporting

Consistent with the March 29, 2022 MOU Term Sheet for the Program and as described in Section 4 of the Strategic Plan, the Science Committee will contribute to Annual Reports, Triennial Reports for Years 3 and 6 of implementation and the Ecological Outcomes Analysis. 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

Science Committee reports and their contents will also inform public workshop proceedings of the State Water Resources Control Board as well as professional reviews of the scientific rationale for the Healthy Rivers and Landscapes Program, such as the Delta Independent Science Board.

4.3 Data Management Plan

The Science Committee will produce a detailed data management plan within the first year of adoption of the Program. In keeping with the 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 that include Indigenous knowledge, 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 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 RST efforts for juvenile abundance estimation on participating tributaries, Figure 7) to provide their data in an open data repository.

For individual project and tributary-specific science plans provided to the 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 (additional guidance is provided in the Science Committee Charter). 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 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 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 Science Plan (Table 2). 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 Healthy Rivers and Landscapes Program.

4.4 Evaluation of hypotheses for decision-making to inform adaptive management

4.4.1 Annual and Triennial synthesis reports

Section 4 of the Strategic Plan provides the schedule and content of regular reports to be provided to the State Water Resources Control Board. The Science Committee will contribute to Annual Reports and Triennial Reports for Years 3 and 6 of 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 scale for native species, as compared with appropriate baselines (Table 2). Based on Triennial Reports from Years 3 and 6, the Science Committee will submit a synthesis report prior to Year 7 on the scientific data and information generated by the Science Program that analyzes the ecological outcomes of the Flow and Non-flow Measures and examines whether continuation of the Healthy Rivers and Landscapes Program beyond Year 8 would help improve species abundance, ecosystem conditions, and contribute to meeting the Narrative Objectives. This report will be submitted for external peer review, and is intended to inform the State Water Resources Control Board's evaluation 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.

4.4.2 Adaptive management processes supported by 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 Flow and Non-flow Measures by evaluating monitoring data and the results of targeted experiments. By appropriately designing study plans, measuring consistently collected metrics, and providing accessible data, information generated by Science Plan activities can be leveraged for use with a variety of decision support models. Decision support models can then integrate 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 Science Plan generated information, decision support models can also assess the value of additional information gathering to prioritize information gathering where there are relatively high levels of uncertainty. By documenting the importance of management action mechanisms and the value of science action information in supporting the achievement of Program objectives, the Science Committee can contribute information to 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 Decision support models for adaptive management

Decision support models (DSMs) are specialized frameworks used in adaptive management processes to understand, manage, and conserve fish and wildlife populations (Walters 1986). Generally, DSMs help decision makers evaluate different options, explore potential outcomes, and assess risks or uncertainties associated with various choices (Conroy and Peterson 2013). They are helpful to use in decisions that involve multiple objectives, conflicting trade-offs, or uncertainties. DSMs can track key performance indicators and feedback loops which allow decision-makers to evaluate the effectiveness of their decisions over time and make adjustments as necessary in a transparent framework. DSMs aid in population assessments, can estimate consequences of management actions and conservations measures, can be used to evaluate trade-offs among actions, and explore uncertainties. Finally, DSMs provide a transparent framework to facilitate public engagement and collaboration in decision-making processes. Decision processes can involve diverse interest groups, including government agencies, Tribal nations, non-profit organizations, and the public in developing and implementing management plans (Conroy and Peterson 2013; Gregory et al. 2012). This engagement fosters transparency, inclusivity, and consensus-building, leading to more effective and socially acceptable management decisions (Conroy and Peterson 2013; Gregory et al. 2012). Collectively, these characteristics make DSMs valuable tools for adaptive management processes.

DSMs vary in complexity and application, ranging from sophisticated life cycle models or life stage specific models to simple spreadsheet models or conceptual models (Conroy and Peterson 2013; Gregory et al. 2012). Life cycle models are built to represent the full life cycle of target organisms—representing unique characteristics and behaviors by life stage (e.g. salmon spawning, rearing, migration), each with its own set of logic, activities, and decision points. However, DSMs need not be full life cycle models. For example, several models representing specific life stages (e.g. egg survival and juvenile production models or the age-1 starry flounder (*Platichthys stellatus*) abundance and Delta outflow), are available and in use. Survival of juvenile salmon through the Delta is another life-stage specific topic that is well represented by existing models.

DSMs use the best available information to help understand and predict how actions effect biological outcomes. These models can be used to estimate population level responses of Flow and Non-flow Measures, at different lifestages, to help estimate the relative degree that different actions are likely to contribute to overall population level changes. They can also be used to prioritize planned or future restoration actions (e.g., Peterson and Duarte 2020) by evaluating how populations respond to changes in floodplain habitat versus tributary rearing habitat, or to evaluate how habitat actions will interface with other large scale management actions such as commercial and recreational harvest and hatchery production. Below are examples of how DSMs are useful to predict the consequences of alternative actions on performance measures and enable a discussion around the objective trade-offs that exist. For a decision about how to best increase overall salmon abundance through alternative flow actions, a DSM could be used to estimate the consequences of alternatives focused on supporting juvenile migration survival (through spring pulses) compared with alternatives focused on supporting adult pre-spawn survival (e.g., through fall cold water releases). These results allow decision makers to have a discussion around the predicted outcomes of alternatives, express their preferences, identify underlying values that are driving those preferences, and explore alternatives that may better balance the objectives and metrics being tracked.

DSMs are also useful tools for filling knowledge gaps and conducting sensitivity analyses to explore how sensitive model outputs are to certain inputs (Peterson and Duarte 2020). For example, in the Central Valley, some tributaries are well studied while others are not. In a DSM, the user can borrow logic from one tributary and apply it to a tributary that may lack information or data. An example of this would be applying a flow to survival relationship from a tributary where the biological response (e.g. salmon outmigration survival) of a flow pulse has been measured to a tributary where this action has yet to be applied and assessed. This enables a prediction of how juvenile salmon may respond in a system that has not yet conducted a flow pulse action. As actions are implemented and monitored in systems lacking information, data collected from these can replace hypothesized outcomes in the DSM.

DSMs should go through iterative refinement, where they are continually updated with best available information to ensure that they remain accurate and relevant (Carl Walters 1986). This can be done by updating data or logic used in the DSM to better reflect emerging population dynamics, environmental conditions, biological parameters, etc. Updated information may come from data collected through the participating monitoring programs, model validation, or feedback from experts.

In the Science Program, all changes made to DSMs will be documented to ensure transparency and reproducibility of modeling. Documentation will include citing data sources, outlining modifications to parameters or equations, and explaining the rationale behind changes or updates. Changes made to DSMs will be validated by calibrating models and conducting sensitivity analyses to ensure changes represent the real-world system as best they can and parameters or assumptions that have significant influence on model outcomes can be assessed and verified. Sufficient documentation and metadata will be provided for development or modification of any DSM. This will enable interested parties to accurately interpret the work of the Program and use the created DSM correctly. Examples of DSMs with thorough, public documentation include Central Valley Project Improvement Act Science Integration Team (CVPIA SIT) and Reorienting to Recovery (R2R).

Below, we identify the DSMs that are currently available for use to evaluate Flow and Non-flow Measures and their impacts on species of interest, provide model descriptions, examples of how DSMs can be used and identify additional models that might be used depending on information needs for the Science Program and availability of DSMs. These model descriptions are provided to serve as examples of the available modeling tools and illustrate that model outputs are relevant to the Science Plan hypotheses at the Full Tributary and Delta and Population-level tiers. It is important to note that interpretation of different management actions (DSM model outputs) are intended to be considered relative to one another. For example, the CVPIA SIT Salmon DSM (described in Section 4.4.3.1) developed 13 candidate restoration strategies and a no action strategy for their Near-term Restoration Strategy; they compared model outputs across those strategies to assess which combination of actions and locations led to the highest predicted increases of juvenile biomass and natural production compared to other combinations of actions and locations. The Science Committee will be reviewing available DSMs and selecting the most appropriate ones to use for salmonids (Section 4.4.3.1 – 4.4.3.3). For non-salmonid species, the Science Committee will coordinate with any existing DSM processes (e.g., such as for Delta Smelt) and will consider use of available models if the degree of uncertainty and relevance of potential management scenarios warrants their use. Adoption of individual DSMs by the Science Committee will involve engaging appropriate technical expertise (most likely in subcommittees or through existing groups already utilizing the DSMs) and deliberate development of a process for gathering input on scenarios to be applied. DSM output will be shared in Triennial reports and the Ecological Outcomes Analysis. As new DSMs are developed, including for species that currently lack DSMs (e.g. longfin smelt), the Science Committee can consider how they may be used to assess the contribution of Flow and Non-flow Measures to the achievement of Program objectives (Section 1.2, Table 1).

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

The CVPIA salmonid DSMs may be relevant to addressing hypotheses at the Full tributary and Delta and Population-level tiers: at the Full Tributary and Delta Tier hypotheses, the CVPIA SIT DSM can be useful to predict effects of Flow Measures in tributaries and the Delta, and tributary responses to combined Flow and Non-flow Measures ($H_{TribFlow1,\ 2,\ and\ 3}$, $H_{TribWide2}$, $H_{DeltaFlow4}$, $H_{DeltaFlow5}$) because the model includes relationships between Chinook salmon and habitat area as well as flow relationships. As the Local Tier hypotheses are addressed (e.g., $H_{S1\ and\ 3}$, $H_{R1\ and\ 4}$, $H_{TribFP1\ and\ 4}$, $H_{BypassFP4\ and\ 5}$, $H_{TW1\ and\ 5}$), the resulting information on available habitat area at design flows and species utilization of the Non-flow Measures can be provided to improve and update the model, making it even more robust for evaluation of Full tributary and Delta and Population-level hypothesis tiers. At the Population-level Tier, hypotheses this DSM can be useful to predict trends in native species populations in tributaries, the Delta, and the system-wide scale ($H_{TribPop2}$, $H_{TribPop3}$, H_{SWPop1}, H_{SWPop2}).

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.

Model outputs include: number of spawners, juvenile biomass at Chipps Island, and proportion of natural origin spawners. There are four DSMs, one representing each run of Chinook salmon (fall-run, late-fall-run, winter-run, and spring-run). The late-fall-run, Central Valley steelhead, and green sturgeon DSMs are still considered in "beta" mode and have not yet been used to evaluate candidate restoration strategies.

---

[1] More information on the CVPIA SIT DSMs 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 DSMs 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.

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.

4.4.3.2 Salmonid Reorienting to Recovery Decision Support Models (R2R DSM)

Similar to the CVPIA SIT DSM, the R2R DSM may be relevant to addressing hypotheses at the Full tributary and Delta and Population-level tiers and is able to predict effects of Flow and Non-flow Measures for the same hypotheses ($H_{TribFlow1,\ 2,\ and\ 3}$, $H_{TribWide2}$, $H_{DeltaFlow4}$, $H_{DeltaFlow5,}$ $H_{TribPop2}$, $H_{TribPop3}$, H_{SWPop1}, H_{SWPop2}). As with the CVPIA SIT DSM, the R2R DSM will benefit from evaluation of the hypotheses on the local tier level to bolster that habitat-species relationships with additional data (e.g., $H_{S1\ and\ 3}$, $H_{R1\ and\ 4}$, $H_{TribFP1\ and\ 4}$, $H_{BypassFP4\ and\ 5}$, $H_{TW1\ and\ 5}$).

The California Central Valley Salmonid Recovery Project, also called the Reorienting to Recovery (R2R) project, is currently modifying the CVPIA SIT fall-run model for their project purposes[2]. These code modifications and model outputs were not reviewed or interpreted by the CVPIA SIT but have been reviewed by the R2R Science Advisory Team, which is composed of agency, academic, and Indigenous Knowledge experts. 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 Additional decision support models used for salmonids actions

The winter-run life cycle model (WRLCM)[3] 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,

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

[3] 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.

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. WRLCM runs may be used within the Science Program to evaluate the relative benefits of Non-flow Measures for winter-run Chinook salmon (e.g., benefits of providing spawning habitat for increasing the area actively used for spawning, $H_{S3,}$ or providing tributary floodplain habitat for juvenile rearing, $H_{TribFlow4}$), though it is more likely that models designed for fall-run Chinook salmon will be used. Potentially, WRLCM runs used for BiOp purposes may be relevant to evaluations of Program measures and agencies will coordinate and leverage these related efforts as much as possible.

Egg survival and juvenile production models use laboratory studies and/or field observations to predict the number of juveniles produced as a function of spawner abundance and environmental covariates (e.g., river discharge and water temperature). Currently, such models are used most often for winter-run Chinook salmon (Martin et al. 2017; Anderson et al. 2022), but comparable models could be applied directly or modified for use on fall-run Chinook salmon (e.g., H_{S3}). Egg survival and juvenile production models could be applied to assess how factors like water temperature and density dependence may influence patterns observed in the evaluation of Flow and Non-flow Measures. For example, decreased production of juveniles can occur when spawning adults exceed the carry capacity of a tributary (Dahm et al. 2019). The evaluation of these tradeoffs is relevant to hypotheses $H_{S3,}$ $H_{R4,}$ $H_{TribFP4,5}$). Further, acoustic tagging studies conducted over the last decade provide robust information regarding patterns of survival among Chinook salmon smolts outmigrating through Central Valley rivers. Models that can predict salmon smolt survival as a function of environmental conditions and fish size have been developed for the Sacramento River (e.g. Michel et al. 2021). These models can be used to help assess and adaptively manage experimental flow pulses ($H_{TribFlow2}$, $H_{TribFlow3}$). As with migration through rivers, acoustic tagging studies have been used to develop models of survival, routing, and migration rate in the Delta. These models (ecoPTM, STARS, DPM) are often used to evaluate water project operations. Predictive models that account for water temperature effects will aid in interpreting findings from spring outflow hypotheses, such as $H_{DeltaFlow4}$ and $H_{DeltaFlow5}$. For example, Buchanan and Whitlock 2022 suggest that water temperature can influence survival in the tidal estuary.

4.4.3.4 Use of decision support models for Non-Salmonids

The Longfin Smelt Life Cycle Model is in the initial phases of development and is intended to model relationships between longfin smelt abundance and environmental conditions (Longfin Smelt Life Cycle Model Modeling Team, Tobias et al. 2023). This model is being developed as a DSM to predict and evaluate the effect of proposed management actions on the population dynamics of longfin smelt and to understand the effects of historical conditions. Management actions and other scenarios intended to be modeled include hydrology, habitat restoration, entrainment and climate change. Drawing on methods for causal inference, the Longfin Smelt Life Cycle Model Modeling Team has used graphical causal models as a framework to develop the life cycle model. Graphical causal models are conceptual models composed of nodes and directed edges which represent causal relationships. Graphical models are qualitative representations of relationships among data that can be parameterized into a statistical model. Advancements in this model may be relevant to addressing hypotheses $H_{Deltaflow2,3}$, $H_{SWPop3,4}$).

Further research associated with refining this model may yield valuable information about suitable adult spawning and larval rearing habitat ($H_{Deltaflow1}$).

The Delta Smelt Life Cycle Model with Entrainment (LCME) is a hierarchical state-space life cycle model (Smith et al. 2021), which was developed to compare Delta Smelt population growth rate under the State Water Project Proposed Action (Environmental Impact Report for the 2024 Incidental Take Permit for the State Water Project) to the population growth rate under Baseline Conditions (operations under the existing 2020 Incidental Take Permit for the State Water Project). The LCME includes five Old and Middle River (OMR) covariates representing entrainment risk's effect on probability of transition to the next life stage for five different life stages covering the period from early subadults in December–January to late postlarvae in June. The LCME also includes June–August Delta outflow, representing a general indicator of outflow-related habitat influencing the transition from postlarval to juvenile life stages. The LCME could be used to address Science Plan hypotheses regarding Delta smelt entrainment ($H_{DeltaFlow2}$). Summer Delta outflow is included in this model and considered a primary driver for Delta Smelt population growth (Polansky et al. 2024).

A stochastic, age structured white sturgeon population model was developed to predict the response in population growth rate to changes in life cycle parameters (i.e., recruitment, growth, and mortality) on an annual basis (Blackburn et al. 2019). This modeling approach was developed to evaluate population response to changes in exploitation rate from the recreational fishery (e.g., bag limits and length restrictions). With additional monitoring data and model refinement, other management scenarios can be evaluated and could help to address the following hypotheses: $H_{DeltaFlow7,}$ $H_{TribFloodPlain7,}$ H_{SWPop3}. White sturgeon population characteristics (i.e., delayed maturity, longevity, and variable recruitment) and a lack of basic data on vital rates and population demographics introduce challenges to effective population modeling. To evaluate Science Plan hypotheses regarding restoration or flow actions for white sturgeon, some data and information gaps would need to be addressed, including additional empirical data collected from the Sacramento and San Joaquin valleys on white sturgeon sex ratios, fecundity, and mortality for different size classes. Additionally, the model was not developed to assess population growth rate in response to changes in habitat or flow, so empirical relationships would need to be established linking population growth rate to flow and habitat directly.

5 References

Anderson JJ, Beer WN, Israel JA, Greene S. 2022. Targeting river operations to the critical thermal window of fish incubation: Model and case study on Sacramento River winter-run Chinook salmon. River Research and Applications. 38:895–905. https://doi.org/10.1002/rra.3965

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

Beck MW, Mazor RD, Theroux S, Schiff KC. 2019. The Stream Quality Index: A multi-indicator tool for enhancing environmental management. Environmental and Sustainability Indicators. 1–2:100004. https://doi.org/10.1016/j.indic.2019.100004

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.

Blackburn, S.E., Gingras, M.L., DuBois, J., Jackson, Z.J., Quist, M.C. 2019. Population Dynamics and Evaluation of Management Scenarios for White Sturgeon in the Sacramento–San Joaquin River Basin. North Am J Fish Manage. 39:896–912. https://doi.org/10.1002/nafm.10316

Blankenship SM, Scherer A, Dean C, Sellheim K, Sweeney J, Merz J. 2024. Applying parentage methods to detect gravel augmentation effects on juvenile Chinook Salmon recruitment rates. River Research & Apps. 40:791–808. https://doi.org/10.1002/rra.4264

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.

Bravington MV, Grewe PM, Davies CR. 2016a. Absolute abundance of southern bluefin tuna estimated by close-kin mark-recapture. Nature communications. 7:13162.

Bravington MV, Skaug HJ, Anderson EC. 2016b. Close-kin mark-recapture.

Buchanan RA, Whitlock SL. 2022. Understanding Salmon Migration Dynamics in a Data-Limited Environment. North American Journal of Fisheries Management. 42:1111–1133. https://doi.org/10.1002/nafm.10799

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

C. C. Kohler, W. A. Hubert. 1999. Inland Fisheries Management in North America, 2nd edition. American Fisheries Society.

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:.

Carl Walters. 1986. Adaptive management of Renewable Resources. New York, NY: MacMillan Publishing Company.

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

Crain PK, Whitener K, Moyle PB. Use of a Restored Central California Floodplain by Larvae of Native and Alien Fishes.

Dahm, C., Kimmerer, W., Moyle, P., Ruggerone, G., Simenstad, C. Developing Biological Goals for the Bay-Delta Plan: Concepts and Ideas from an Independent Scientific Advisory Panel: A final report to the Delta Science Program.

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]. [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.

Downing BD, Bergamaschi BA, Kendall C, Kraus TE, Dennis KJ, Carter JA, Von Dessonneck TS. 2016. Using continuous underway isotope measurements to map water residence time in hydrodynamically complex tidal environments. Environmental science & technology. 50:13387–13396.

DWR, CDFW, SWC, USFWS. 2020. Longfin Smelt Science Plan, 2020 - 2030. Developed collaboratively by California Department of Water Resources, California Department of Fish and Wildlife, State Water Contractors, and the United States Fish and Wildlife Service. Available from: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/State-Water-Project/Files/ITP/ITP-Longfin-Science-Plan_SWP_12232020_-FINAL.pdf

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.

Erly K, Cook R, Speegle J, Bigham G, Goodman D, Senegal T. 2023. Interagency Ecological Program and US Fish and Wildlife Service: San Francisco Estuary Enhanced Delta Smelt Monitoring Program data, 2016 - 2023 ver 10. Environmental Data Initiative. https://doi.org/10.6073/pasta/dc09bc11182f998e9902fb9e2d5d6e5a

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

Ferrari MC, Ranåker L, Weinersmith KL, Young MJ, Sih A, Conrad JL. 2014. Effects of turbidity and an invasive waterweed on predation by introduced largemouth bass. Environmental Biology of Fishes. 97:79–90.

Feyrer F, Sommer T, Harrell W. 2006. Managing floodplain inundation for native fish: production dynamics of age-0 splittail (Pogonichthys macrolepidotus) in California's Yolo Bypass. Hydrobiologia. 573:213–226. https://doi.org/10.1007/s10750-006-0273-2

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]. [accessed 2023 May 23]. Available from: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=22660

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.

Goertler P, Mahardja B, Sommer T. 2021. Striped bass (Morone saxatilis) migration timing driven by estuary outflow and sea surface temperature in the San Francisco Bay-Delta, California. Sci Rep. 11:1510. https://doi.org/10.1038/s41598-020-80517-5

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

Greene V, Sullivan L, Thompson J, Kimmerer W. 2011. Grazing impact of the invasive clam Corbula amurensis on the microplankton assemblage of the northern San Francisco Estuary. Mar Ecol Prog Ser. 431:183–193. https://doi.org/10.3354/meps09099

Gregory, Failing, Harstrone, Long, McDaniels, Ohlson. 2012. Structured Decision Making: A Practical Guide to Environmental Management Choices. John Wiley & Sons.

Grimaldo L, Feyrer F, Burns J, Maniscalco D. 2017. Sampling uncharted waters: examining rearing habitat of larval longfin smelt (Spirinchus thaleichthys) in the upper San Francisco Estuary. Estuaries and Coasts. 40:1771–1784.

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

Hawkins CP, Norris RH, Hogue JN, Feminella JW. 2000. DEVELOPMENT AND EVALUATION OF PREDICTIVE MODELS FOR MEASURING THE BIOLOGICAL INTEGRITY OF STREAMS. Ecological Applications. 10:1456–1477. https://doi.org/10.1890/1051-0761(2000)010[1456:DAEOPM]2.0.CO;2

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:.

Hering DK, Bottom DL, Prentice EF, Jones KK, Fleming IA. 2010. Tidal movements and residency of subyearling Chinook salmon (Oncorhynchus tshawytscha) in an Oregon salt marsh channel. Can J Fish Aquat Sci. 67:524–533. https://doi.org/10.1139/F10-003

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.

Jennifer M. Bergman, Ryan M. Nielson, Alice Low. 2012. Central Valley Chinook salmon in-river escapement monitoring plan.

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.

Khanna S, Ustin SL, Hestir EL, Santos MJ, Andrew M, Lay M, Tuil J, Bellvert J, Greenberg J, Shapiro KD, Rajapakse S. 2022. The Sacramento-San Joaquin Delta genus and community level classification maps derived from airborne spectroscopy data. Knowledge Network for Biocomplexity. https://doi.org/doi:10.5063/F1N014ZX

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.

Kimmerer WJ, Thompson JK. 2014. Phytoplankton Growth Balanced by Clam and Zooplankton Grazing and Net Transport into the Low-Salinity Zone of the San Francisco Estuary. Estuaries and Coasts. 37:1202–1218. https://doi.org/10.1007/s12237-013-9753-6

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]. [accessed 2023 May 25]. Available from: https://www.calfish.org/ProgramsData/ConservationandManagement/CentralValleyMonitoring/ CentralValleyCFMProgram.aspx#:~:text=The%20Central%20Valley%20Constant%20Fractional,em ployed%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:.

Martin BT, Pike A, John SN, Hamda N, Roberts J, Lindley ST, Danner EM. 2017. Phenomenological vs. biophysical models of thermal stress in aquatic eggs. Ecology Letters. 20:50–59. https://doi.org/10.1111/ele.12705

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]. [accessed 2023 May 4]. Available from: https://doi.org/10.6073/pasta/4886dbb80cf709a4c6e5906ff94eacdc

McNatt RA, Bottom DL, Hinton SA. 2016. Residency and Movement of Juvenile Chinook Salmon at Multiple Spatial Scales in a Tidal Marsh of the Columbia River Estuary. Trans Am Fish Soc. 145:774–785. https://doi.org/10.1080/00028487.2016.1172509

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.

Michael J. Conroy, James T. Peterson. 2013. Decision Making in Natural Resource Management: A Structured, Adaptive Approach: A Structured, Adaptive Approach. John Wiley & Sons.

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

Michel CJ, Notch JJ, Cordoleani F, Ammann AJ, Danner EM. 2021. Nonlinear survival of imperiled fish informs managed flows in a highly modified river. Ecosphere. 12:e03498. https://doi.org/10.1002/ecs2.3498

Moyle PB, Baxter RD, Sommer T, Foin TC, Matern SA. 2004. Biology and Population Dynamics of Sacramento Splittail (Pogonichthys macrolepidotus) in the San Francisco Estuary: A Review. San Francisco Estuary and Watershed Science. [accessed 2024 August 05];2:. https://doi.org/10.15447/sfews.2004v2iss2art3

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

Peek R, Irving K, Yarnell SM, Lusardi R, Stein ED, Mazor R. 2022. Identifying Functional Flow Linkages Between Stream Alteration and Biological Stream Condition Indices Across California. Front Environ Sci. 9:790667. https://doi.org/10.3389/fenvs.2021.790667

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

Polansky L, Mitchell L, Nobriga ML. 2024. Identifying minimum freshwater habitat conditions for an endangered fish using life cycle analysis. Conservat Sci and Prac. 6:e13124. https://doi.org/10.1111/csp2.13124

Preece EP, Cooke J, Plaas H, Sabo A, Nelson L, Paerl HW. 2024a. Managing a cyanobacteria harmful algae bloom "hotspot" in the Sacramento–San Joaquin Delta, California. Journal of Environmental Management. 351:119606.

Preece EP, Hartman R. 2024. Exploring factors that affect Microcystis abundance in the sacramento san joaquin delta. Harmful Algae. 138:102682. https://doi.org/10.1016/j.hal.2024.102682

Preece EP, Otten TG, Cooke J. 2024b. Use of multiple sampling techniques for cyanobacteria and cyanotoxin monitoring in the Sacramento-San Joaquin Delta under different hydrologic regimes. Marine Pollution Bulletin. 205:116585. https://doi.org/10.1016/j.marpolbul.2024.116585

Prystupa S, McCracken GR, Perry R, Ruzzante DE. 2021. Population abundance in arctic grayling using genetics and close-kin mark-recapture. Ecology and Evolution. 11:4763–4773.

Rehn AC. 2021. An Ecological Assessment of California's Perennial Wadeable Streams and Rivers (2008-2018). Available from: https://www.waterboards.ca.gov/water_issues/programs/swamp//bioassessment/docs/final_psa _report_2008-2018.pdf

Robert R. Sokal, F. James Rohlf. 1995. Biometry: the principles and practices of statistics in biological research. New York: W.H. Freeman and Company.

Robichaud D, English K. 2017. Re-analysis of Tuolumne River Rotary Screw Trap Data to examine the relationship between river flow and survival rates for Chinook smolts migrating between Waterford and Grayson (2006-14).

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.

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:.

Smith WE, Polansky L, Nobriga ML. 2021. Disentangling risks to an endangered fish: using a state-space life cycle model to separate natural mortality from anthropogenic losses. Can J Fish Aquat Sci. 78:1008–1029. https://doi.org/10.1139/cjfas-2020-0251

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, Nussl 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.

Theroux S, Mazor RD, Beck MW, Ode PR, Stein ED, Sutula M. 2020. Predictive biological indices for algae populations in diverse stream environments. Ecological Indicators. 119:106421. https://doi.org/10.1016/j.ecolind.2020.106421

Tobias V, Mitchell L, Polansky L, Smith W, Miller J, O'Donnell D, Meyer S. Longfin Smelt Life Cycle Model Modeling Team:

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]. [accessed 2023 May 23]. Available from: https://www.usbr.gov/tsc/techreferences/computer%20software/models/srh2d/downloads/Man ual-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]. [accessed 2023 May 25]. Available from: https://www.usbr.gov/mp/nepa/nepa_project_details.php?Project_ID=30484

Vander Laan JJ, Hawkins CP. 2014. Enhancing the performance and interpretation of freshwater biological indices: An application in arid zone streams. Ecological Indicators. 36:470–482. https://doi.org/10.1016/j.ecolind.2013.09.006

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.

Voss SD, Poytress WR. 2022. 2019 Red Bluff Diversion Dam Rotary Trap Juvenile Anadromous Fish Abundance Estimates. Report of US Fish and Wildlife Service to US Bureau of Reclamation, Sacramento, CA.

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]. [accessed 2023 May 14]. Available from: http://akssf.org/default.aspx?id=2503

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, Beakes M, Wiesenfeld J, Greenwood M, Grimaldo L, Hassrick J, Collins A, Acuña S, Johnston M. 2021. Experimental Quantification of Piscivore Density and Habitat Effects on Survival of Juvenile Chinook Salmon in a Tidal Freshwater Estuary. Estuaries and Coasts. 44:1157–1172. https://doi.org/10.1007/s12237-020-00836-8

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.