Sacramento River Science Partnership Science Plan 2020

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List of Abbreviations and Acronyms

2-D	Two-Dimensional
AFSP	Anadromous Fish Screen Program
BY	Brood Year
CS	*Ceratonova Shasta*
CSSP	Coordinated Salmon Science Plan
CVPIA	Central Valley Project Improvement Act
CWP	Cold Water Pool
DTS	Distributed Temperature Sensing
ELAM	Eulerian–Lagrangian–Agent Method
IBM	Individual Based Model
ITP	Incidental Take Permit
JPE	Juvenile Production Estimate
LCM	Life Cycle Model
PBT	Parentage-based tag
PER	Predation Event Recorder
PM	*Parvicapsula Minibicornis*
RBDD	Red Bluff Diversion Dam
RST	Rotary Screw Trap
SDM	Structured Decision Making
SIT	Science Integration Team
TCD	Temperature Control Device
TOPS-WRK	Terrestrial Observation and Prediction System - Weather Research and Forecasting
USBR	US Bureau of Reclamation

Executive Summary

This Plan was developed to support the Sacramento River Science Partnership (Partnership) in their voluntary collaborative research, modeling, monitoring, and synthesis. The geographic scope of interest is the mainstem Sacramento River from Keswick Dam to Verona including the Sutter Bypass. Management actions, processes and effects occurring within the river, including adjacent riparian and floodplain habitats, are considered, recognizing that there are important interactions among management actions and between the mainstem and tributaries. All four species of Chinook Salmon and Steelhead are taken into account, for the most part in general terms due to the direct and indirect ways in which management actions cause change in the system.

Given the complexity of the Sacramento system and the wide array of scientific issues which could be investigated to inform system management, this Plan is focused on several issues identified by the Partnership in their Charter:

- temperature tolerances and other conditions necessary for salmonid egg incubation and early life stages;
- non-temperature sources of mortality; and
- Spring-run Chinook Salmon (Spring-run) emigration survival; and
- quantity, condition, and habitat needs of emerging juvenile fry and smolts.

The Plan is structured around three life stages/geographic areas:

- egg to fry emergence;
- juvenile rearing to outmigration from Keswick Dam to Red Bluff Diversion Dam (RBDD); and
- juvenile rearing to outmigration from RBDD to Sacramento.

This Plan discusses several predictive modeling approaches and how they are used to support management decisions. Recommendations for advancement in this area include supporting the work of the Temperature Modeling Technical Committee and supporting the ongoing development of a Spring-run life cycle model as well as work to increase the use of bioenergetics models to inform planning and design of habitat restoration projects. Further, modeling is expected to be an integral component of several of the Integrated Studies.

Several field surveys and targeted data collection programs are identified. These include:

- temperature profiling, pilot monitoring in Lake Shasta and velocity measurements in the vicinity of the Temperature Control Device;
- surveys of redds in areas or under conditions where they are difficult to observe using current monitoring approaches;
- fish utilization of rearing habitats;
- the effects of floodplain passage on survival; and
- surveys of predators and prey in selected areas of the river under a variety of flow and environmental conditions.

In addition, recommendations include how to enhance existing data or their use in modeling and management decisions, including more specific plans for efficiency tests at the RBDD rotary screw trap, statistical analysis of the relationship between fish passage and environmental conditions, and continued exploration of the use of Parentage Based Tagging methods. An evaluation of how to provide additional information on juvenile fish survival between RBDD and Verona is recommended.

Three Integrated Studies are recommended as opportunities for collaboration and development of mutual understanding within the Partnership and with others. The studies focus on:

1. how river scale management actions translate down toward the scale of the redd;
2. factors influencing fry growth and predation as well as the role of physical stream conditions including those influenced by flow management and habitat restoration management actions; and
3. the benefits and risks of floodplain habitats to juvenile salmon and information to support the refinement of predictive tools for floodplain management actions.

Additional contributions to understanding the effects of management actions can be gained through focused study of a spring flow pulse in dry or below normal years, additional experimental study of active management of agricultural floodplains, and coordinated assessment of habitat use, predation risk, and food availability to better understand survival in the mainstem Sacramento.

This Plan also points to the need to ensure that key data on species of interest are routinely collected to improve monitoring of populations and build long-term data, e.g., assessment of habitat utilization using otoliths (or scales for Steelhead), genetic markers for anadromy in Steelhead, studies related to the effects of pathogens.

Periodic synthesis of available information on key topics to document progress and change in the system is also important. An early need is synthesis of the benefits of habitat restoration actions in the Upper Sacramento. Routine development of summary brood year assessments can also provide an ongoing transparent appraisal of species response to ambient conditions and management actions.

Introduction

Context and Purpose

This Plan was developed to support the Sacramento River Science Partnership (Partnership) in their voluntary collaborative research, modeling, monitoring, and synthesis. It was developed through discussion with Members of the Partnership, staff and contractors of Member organizations, and other experts as well as through review of background documents and scientific reports and papers. The approach to scientific activities – predict, detect, understand – has been used previously to support collaborative science (Reed, 2019). The Plan discusses scientific issues and approaches but purposefully does not address specific study designs.

The purpose of this Plan is to identify scientific activities that will contribute to predicting, detecting, and understanding the effects of management actions, and not to identify management actions that will benefit species. The management actions considered here were identified by the Partnership, and the actions are expected to have a variety of effects, both individually and as they interact. The Sacramento River is managed to meet many economic and societal objectives. This Plan does not address all of these, except as they influence the range of issues being considered and is centered on the effects of some aspects of management on salmonids. Appendix A provides a schematic overview of these action-effect linkages that this Plan seeks to elucidate.

Objectives and Scope

This Plan has two main objectives:

1. Identify a suite of scientific activities which have the potential to inform management actions that seek to improve outcomes for listed salmonids while supporting other uses of the system.
2. Chart a path toward effective use of models, data collection, and synthesis to identify and understand the trade-offs of decisions between different species and water use.

The geographic scope of interest is the mainstem Sacramento River from Keswick Dam to Verona including the Sutter Bypass. Management actions, processes, and effects occurring within the river, including adjacent riparian and floodplain habitats, are considered, recognizing that there are important interactions between the mainstem and tributaries. All four species of Chinook Salmon and Steelhead are taken into account, for the most part in general terms due to the direct and indirect ways in which management actions cause change in the system.

Focus and Approach

Given the complexity of the Sacramento system and the wide array of scientific issues which could be investigated to inform system management, this Plan is focused on several topics identified by the Partnership in their Charter:

- Temperature tolerances and other conditions necessary for salmonid egg incubation and early life stages.
- Non-temperature sources of mortality including, pathogens, predation, lack of suitable spawning habitat, and redd de-watering.
- Conditions necessary for juvenile Spring-run Chinook Salmon (Spring-run) survival.
- Quantity, condition, and habitat needs of emerging juvenile fry and smolts.

Thus, this Plan is structured around three of the life stages identified by Windell et al. (2017): egg to fry emergence, juvenile rearing to outmigration from Keswick Dam to Red Bluff Diversion Dam (RBDD), and juvenile rearing to outmigration from RBDD to Sacramento. These also correspond to the geographic area of interest to the Partnership[1]. However, this Plan does not directly address each of the hypotheses identified by Windell et al. (2017) for each life stage. Rather, this Plan seeks to identify scientific activities which relate the broader scientific issues identified by Windell et al. (2017) to management actions that influence the system. Moreover, the conceptual models articulated by Windell et al. (2017), while providing a useful structure, focus on Winter-run Chinook Salmon (Winter-run). This Plan seeks to provide insight relevant to salmonids more broadly.

For each life stage, relevant management actions are identified, and their potential effects briefly described. Science needs are discussed in terms of three separate but related scientific approaches which are each essential to using processes such as Structured Decision Making (SDM) and other forms of effects analysis:

- The need to ***predict*** the consequences of taking a management action is integral in SDM.
- Surveys and monitoring are used to ***detect*** change in the natural system including those resulting from management actions. Targeted data collection can provide important additional insight into system dynamics beyond those gained from routine monitoring.

BOX 1. INTEGRATED STUDIES

One of the key features of this plan is the collaborative development of Integrated Studies around key topics related to management actions. These topics have been selected to address aspects of the salmonid life cycle which are central to the Partnership's scope and to ultimately inform aspects of salmonid life cycle models used in SDM and other decision-making processes. Currently available life cycle models (LCMs) for salmon (Hendrix et al., 2017; SIT Decisions Support Models) operate on a monthly time step which enables estimation of habitat carrying capacity, for example. The proposed Integrated Studies aim to increase understanding at a finer scale, potentially for use in more detailed decision-support models. Field data, detailed modeling, and experiments can lead to the elucidation of relationships that can inform adjustments in the LCMs.

Three Integrated Studies are described in this Plan that examine:

1. how river-scale management actions translate down to the scale of the redd, and how management actions influence local variations in physical processes and biotic response.
2. factors influencing fry growth and predation, and the role of physical stream conditions including those influenced by flow management.
3. the benefits and risks of floodplain habitats to juvenile salmon.

The information developed is expected to improve action-effects linkages, inform planning and design of habitat restoration management actions, and support the refinement of predictive tools for floodplain management actions. Planning science activities, research logistics, and funding for Integrated Studies in parallel and in collaboration with a wide array of experts and interest groups will ensure alignment and coordinated execution.

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[1] The conceptual model in Windell et al. (2017) extends to Sacramento and includes the Yolo Bypass. The geographic scope of this Plan is more limited.

- Increased scientific ***understanding*** and building an expanded knowledge base on which future actions can be planned and implemented is fundamental to iterative application of SDM and other adaptive management approaches. Increased understanding also underpins refinement of models used in SDM.

Synthesis and evaluation of findings across these three approaches and across life stages in relation to the existing body of knowledge is discussed separately.

This Plan does not include a comprehensive evaluation of existing knowledge, and citations to existing work are selected to illustrate specific points or techniques as context for recommendations. As the focus of this Plan is on building knowledge to inform management actions which change conditions in specific areas, models which consider the whole life cycle of salmonids including the effects of Delta and ocean environments (e.g., Hendrix et al., 2017; Zeug et al., 2012) are not discussed. The way in which such models reflect the effects of management actions can be dependent on assumptions made about the rest of the system.

It is important to note that data collection discussed in this Plan is not intended to replace or alter existing monitoring, especially in cases where it is the basis for regulatory processes. For example, spawning escapement and juvenile abundance monitoring programs serve as the foundation for performance metrics and modeling often used to evaluate management actions. Changes in long term monitoring require careful deliberation but there may be opportunities to improve data and analytic outputs. Thus, targeted data collection to detect the effects of management actions and to explore key cause-effect relationships can provide a foundation for future enhancements in data analysis and/or monitoring program designs. Recommendations for data collection are not directed at a specific agency. Where data collection activities are identified that relate directly to an agency's existing work, e.g., temperature management at Lake Shasta, redd surveys, etc., any additional data collection would be expected to be coordinated with that agency and the additional resource or staffing burden imposed should be acknowledged by the Partnership.

Recommendations for scientific activities provided here have been identified based a limited set of interactions with managers and experts within the scientific community. They are put forth as a solid starting point for the work of the Partnership and are deliberately described only generally so that they can be refined as the details of implementation are developed.

Structure of Report

This Plan describes science activities to promote improved prediction, enhanced detection, and increased understanding around the three life stages, and some needs for system level data collection or synthesis. Within each section, brief discussion of the need for science activities is provided for 'predict', 'detect', and 'understand' followed by specific recommendations for activities and their management relevance. An integrated list of all of the recommended science activities is provided in Appendix B. The final section of the Plan identifies some areas where there is potential for collaboration with other groups on some of the science activities.

Egg to Fry Emergence – Keswick Dam to RBDD

The river channel from Keswick Dam to RBDD varies in width, and much of the current spawning gravel in the area below Keswick Dam has been added as a combination of 'hungry water' and trapping of bedload behind dams leading to coarsening of the bed (Kondolf, 1997; Stillwater Sciences, 2007). The river is a bedrock stream and flows across, and is incised into, older, stable geologic formations.

Actions and Potential Effects

The main management actions that influence the egg to fry emergence life stage include:

- Summer Cold Water Pool Management (Tiers 1- 4) including Temperature Modeling and Shasta Temperature Control Device (TCD) Operation
- Spring Management of Spawning Locations
- Fall and Winter Refill and Redd Maintenance
- Spawning Gravel Injection

Further details on these actions are described in the 2019 National Marine Fisheries Service Biological Opinion on Long-term Operation of the Central Valley Project and the State Water Project[2]. Many of these actions aim to provide suitable conditions for egg survival for Winter-run. Due to the potential for temperature related egg mortality in Winter-run, there is a focus on conservation and management of cold water pool (CWP) in Shasta Lake. Ensuring available CWP for Winter-run may have implications for other salmonids, e.g., if lower flows during fall and winter to refill Shasta Lake result in dewatering of redds for Fall-run Chinook Salmon (Fall-run), or decreased access to rearing habitat. A summary overview of the potential effects of these actions on habitat, physical conditions, and species response is provided in Appendix A.

Predict

Predictive models are essential tools for management of CWP, and the physically based temperature simulations used to assess scenarios are dependent on uncertain predictions of meteorological conditions. The HEC-5Q model is currently used to forecast water temperature conditions in the Sacramento River for seasonal operations planning. There have been several studies in recent years addressing predicting temperatures in the reservoir and downstream in the spawning reaches (e.g., Hallnan, 2017; Hallnan et al., 2020; Pike et al., 2013), although coarse resolution issues (up to 6m layers in the reservoir and 2km reaches in the river) may limit their ability to fully capture temperature gradients. The Temperature Modeling Technical Committee has been ongoing for several years and aims to utilize existing information and models to develop new models to assist operators managing Shasta Lake, as well as other facilities, for water temperature management in downstream Sacramento River reaches. It provides a forum where data, information, and assumptions related to model development can be shared. The Committee has identified the two-dimensional (2-D), laterally averaged CE-QUAL-W2 model which can represent longitudinal and vertical variations in the reservoirs as an appropriate tool for Shasta Lake and Keswick Reservoir (Deas & Sogutlugil, 2020). Also, US Bureau of Reclamation (USBR)

[2] https://www.fisheries.noaa.gov/resource/document/biological-opinion-reinitiation-consultation-long-term-operation-central-valley

will be initiating a significant temperature modeling development effort in late 2020, including the Upper Sacramento River (R. Field, personal communication).

The influence of river water temperature on eggs is in part dependent on hyporheic flow for which a number of modeling approaches are available (see review by Boano et al., 2014). Bray & Dunne (2017a) have noted the importance of considering the distinct characteristics of river and bar morphology in evaluations of hyporheic flow. In the upper Sacramento, models have rarely been applied to examine gravel bar dynamics (Stillwater Sciences, 2007) which are important to predictions of hyporheic flow. Some detailed modeling of hyporheic conditions is ongoing to explore the relationship between river discharge and interstitial flow as well as the dynamics of interstitial flow at egg scale (E. Danner, personal communication). Few predictive tools are available to predict local (redd-scale) field conditions although the individual based model (IBM) inSALMO (Dudley, 2018, 2019b) simulates conditions resulting in egg mortality from high/low temperature, scour, dewatering, or superimposition at a $20m^2$ scale. The same IBM approach has been used to examine effects of superimposition (Dudley, 2019a). These and other modeling approaches can be used to further enhance understanding of the processes that influence the egg to fry emergence stage in coordination with detailed field investigations, as discussed below.

Predict Recommendations: Egg to Fry Emergence – Keswick Dam to RBDD			
#	**Type**	**Science Activity**	**Management Relevance**
1	Modeling	Support the collaborative model improvement work of the Temperature Modeling Technical Committee.	*Improved prediction* - Extension of the CE-QUAL-W2 modeling of Shasta Lake and Keswick Reservoir to include appropriate river models, creating a linked modeling framework to improve model predictions that assist resource managers.

Detect

An array of existing monitoring programs routinely provides physical and ecological information that informs management of the system in support of the egg to fry emergence life stage. These include carcass and redd surveys (including location and potential for dewatering), temperature measurements in the reservoirs and the river, and discharge monitoring. These ongoing programs deliver key information relied upon in models and other tools and used by agencies in management and operation of the system. However, given the complex interactions of factors that can influence temperature dependent mortality of salmonid eggs, targeted data collection can help improve models and their application and provide insight into the role of causal factors.

For example, Hallnan (2017) used a distributed temperature sensing (DTS) system to obtain high resolution measurements of vertical temperature distribution in the lake to further define cold water pool volumes. Deas & Sogutlugil (2020) note the value of a thermistor string with loggers collecting vertical temperature data at hourly intervals, such as that collected previously in Lake Shasta for modeling. Additional collection of temperature profile data at the Keswick Reservoir log boom, and in the Shasta, McCloud, and Pit River arms of Shasta Lake, is also useful and is being implemented in 2020.

Meteorological and stream inflow data for these tributaries could also be useful to validate or refine some model inputs or dynamics (e.g., TOPS-WRK or National Weather Service data products as discussed in Danner et al. (2012) or wind-driven mixing (Daniels et al., 2018)). USBR has proposed to quantify and assess the quality and statistical nature of the meteorological, river flow, and temperature datasets (simulations and forecasts) currently used to set water-temperature related operating criteria at Shasta Reservoir (R. Field, personal communication).

In addition, vertical temperature gradients may be locally strong within Lake Shasta, especially in mid-to-late summer during drier years, and the resulting density gradients could influence the ways in which water moves through the various gated structures. Further, improved detection of the zone of the reservoir where the vertical temperature gradient changes the fastest is important to ensure that reservoir models are of sufficient resolution to capture this change (Hallnan et al., 2020). Automatic temperature data collection can be challenging due to issues with anchoring and the need for robust communication systems. USBR is working to restore a thermistor string at Shasta Dam and address these challenges. Detailed velocity measurements in the vicinity of the TCD have recently been conducted to characterize the local velocities and vertical (and lateral) extent of withdrawal zones into open TCD gates as well as a high-resolution bathymetric survey of the immediate vicinity of the Shasta Dam forebay (M. Deas, personal communication). A more extensive velocity survey is needed to assess dynamics around TCD gates operating individually and for blending as well as surveys throughout the TCD operating season to assess how the dynamics change as the TCD is operated over time.

In the Sacramento River below Keswick Dam, carcass and redd surveys provide critical information in management that targets the egg to fry emergence life stage. The escapement estimates based on the surveys are used in calculations of egg-to-fry survival (discussed further below). Analysis of detailed surveys of redd distribution can also be used not only to determine whether the extent of spawning gravel is limiting but to refine criteria for predicting or restoring spawning habitat (e.g., Geist et al., 2000). Killam (2019) notes that carcasses are not accessible in some areas of the river due to hazards or deep water and are often bypassed by survey crews. Uncertainty in the adult spawner estimates for brood year (BY) 2017 Winter-run is also noted by Voss & Poytress (2019) due to poor visibility on the carcass survey resulting from high water early in the survey season (when the detection of the first winter-run Chinook salmon spawning is used to determine the onset of CWP management) and prolonged turbidity throughout the survey season. This may be commonly the case during the Late Fall-run spawning period as well. Difficult field survey conditions and ensuing uncertainty are more common for salmonids which spawn during the winter and spring. The proportion of redds found within and downstream of the mark-recapture carcass survey area is used to expand the escapement estimate to account for fish spawning downstream of the carcass survey area. However, aerial redd surveys are focused on location and timing rather than count and do not provide complete counts of redds due to variability in turbidity, water depth, riparian vegetation, weather, wind, and redd superimposition (Bergman et al., 2012; Killam, 2019). Redd dewatering assessment is critical for management actions that specifically target reducing dewatering, and Stompe et al. (2016) noted some of the difficulties encountered including identifying which run made the observed dewatered redds and fluctuating water levels due to storm events.

Supplementing existing programs with periodic targeted boat and snorkel/diver surveys, potentially focused on specific areas or environmental conditions, could be used to evaluate critical assumptions that may bias routine field surveys and thus reduce the effectiveness of management actions reliant on the survey data. While surveys of deeper holes may require specific expertise, the importance of these data for many management decisions means that exploratory data collection is a useful first step. Additional potential enhancements include fitting boats with additional towers/cameras and using boats in conjunction with drones. Such supplemental data may also be useful in understanding how on the ground conditions are reflected in current approaches used to estimate egg-to-fry survival (see discussion below).

Detect Recommendations: Egg to Fry Emergence – Keswick Dam to RBDD			
#	**Type**	**Science Activity**	**Management Relevance**
2	Targeted Data Collection	Pilot monitoring of input stream and local meteorology in the Shasta, McCloud, and Pit River arms of Shasta Lake.	*Increased detection* – Greater resolution of water temperature data above Shasta Dam. *Improved prediction* - Data to validate or refine model inputs and better incorporate the role of meteorological conditions on thermal regime of Shasta Lake and tributary inflows.
3	Targeted Data Collection	Increase vertical resolution for temperature profiling in Lake Shasta especially in mid-to-late summer during drier years.	*Increased detection* - Greater resolution of water temperature and density data within Lake Shasta. *Improved prediction* - Improved characterization of density gradients that could influence the ways in which water moves through the various gated structures.
4	Targeted Data Collection	Conduct velocity surveys to assess dynamics around TCD gates operating individually and for blending, and surveys throughout the TCD operating season to assess how the dynamics change as the TCD is operated over time.	*Increased detection* - Greater resolution of water velocity dynamics around the TCD gates. *Improved prediction* - Improved characterization of local dynamics of withdrawal zones for TCD gates operating individually or for blending, under varying seasonal conditions.
5	Targeted Data Collection	Supplement existing carcass and redd surveys with enhanced boat and in-water surveys, potentially focused on specific areas or environmental conditions.	*Increased detection* – Additional data to support escapement and fecundity estimates. *Improved understanding* - Evaluation of critical assumptions that may bias routine field surveys and thus impact management actions reliant on the survey data.

Understand

The egg-to-fry emergence life stage is critical, and several management actions specifically focus on addressing the potential for temperature mortality and dewatering. Thus, understanding the processes and interactions controlling egg viability and successful hatch is essential. Windell et al. (2017) identify nine hypotheses for this life stage. The work proposed here focuses on a key area where increased understanding can support management actions. It is not proposed as a comprehensive approach to understanding all aspects of process interaction influencing this life stage.

Understanding biotic responses to management actions that target egg-to-fry emergence requires translation of the effects of actions taken at the river or reach scale (e.g., flow releases, gravel augmentation) to the scale of the redd and the egg. Gore et al. (2018) note that eggs within a redd likely experience flow conditions that are spatially variable and temporally dynamic. Many factors are involved which depend on local conditions, limiting the ability to directly transfer knowledge from other systems without local validation. As discussed above, modeling may provide insight into fine scale patterns in environmental conditions around redds, and ongoing flume experiments with artificial redds (E. Danner, personal communication) are exploring how water flows through redds.

Flow around the redds is determined by streambed hydraulic conductivity which exhibits varying magnitude, spatial variability and characteristic vertical patterns, and has been found in some systems to vary by orders of magnitude over the length of a riffle-pool reach (Bray & Dunne, 2017a). Management actions can influence sediment character directly through gravel augmentation and indirectly by altering bedform and bar migration through flow releases. Management actions that alter downriver temperature gradients and water levels influence how the flow and the bed sediment interact at different scales to influence hyporheic flow (Figure 1). This has implications for temperature conditions at the scale of the redd and how it is influenced by water operations.

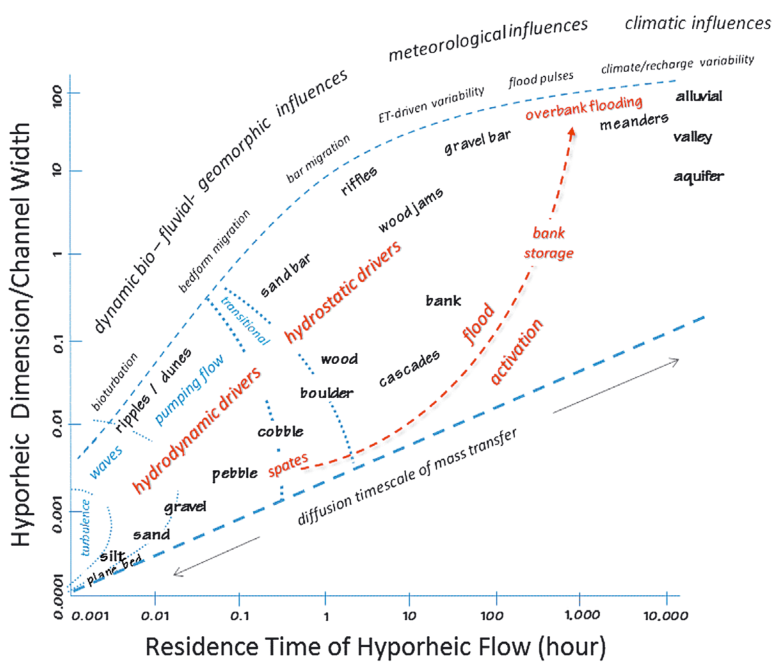

Figure 1. Spatial and temporal scaling of hyporheic flow (Boano et al., 2014)

Egg scale insights can probably best be gained through laboratory experiments. However, understanding how river scale management actions translate down toward the scale of the redd will allow predictive models to better reflect local variations in physical processes, and how the potential biotic response varies with different combinations of management actions.

Integrated Study #1

The issue of how river-scale management actions translate down to the scale of the redd, and this influence temperature-dependent mortality, lends itself well to an integrated study. Leveraging existing field, lab, and modeling approaches to document variations in river and subsurface environmental conditions (including how they vary with season, flow, and instream morphology), and to assess biotic responses (including key determinants of mortality such as flow, temperature, and dissolved oxygen) can provide increased understanding of the mechanisms influencing redd-specific egg-fry survival. The integrated study should be conducted in several reaches along a longitudinal river gradient between Keswick Dam and RBDD. Each reach should comprise gravel bars and pools and could include areas of gravel augmentation. The objective is not necessarily to apply a statistically valid experimental design to field studies but to identify sites which characterize the variety of areas where spawning occurs, and where temperature and depth are managed to reduce temperature-dependent mortality and reduce redd dewatering. Existing redd surveys could provide context for the location, but areas potentially suitable for spawning which may not be adequately encompassed by routine monitoring (e.g., deeper areas), and those where there is potential for redd dewatering, should be included provided there are reliable previous observations of redd occurrence.

The scale of the study will depend on available resources (expertise, equipment, funding) and the ability to leverage ongoing research and monitoring efforts. The planning and design of such studies should be undertaken by a diverse expert workgroup with backgrounds in physical processes and biotic response:

- Field measurements could be used to understand variations in temperature, depth and hyporheic flows that influence conditions ate the scale of redds. For example:
    - Surveys of topography, bathymetry and bed sediment character, and velocity measurements to support spatially distributed predictions of water surface elevation using hydraulic models, e.g., SRH-2D.
    - High-resolution spatiotemporal measurements of near bed water temperature, e.g., using DTS (Bray & Dunne, 2017b). Note DTS may also be used to examine gravel transport.
    - Measurements, using samples or sensors as appropriate, of water quality such as dissolved oxygen and turbidity.
    - Measurements of hydraulic connectivity, e.g., with a backpack permeameter and standpipes.
- Biotic response is difficult to measure directly for wild Winter-run. Alternatively, the field study could initially focus on other runs or use eggs from hatchery-origin fish as surrogates.
    - An option for experimentally examining biotic response would be to deploy incubation boxes or egg tubes across gradients in flow, water depth, or other environmental factors.
    - Redd caps, potentially for Fall-run, could be used to measure emergence of naturally spawned eggs across the flow/depth gradients encompassed by the study.
    - Laboratory experiments with hatchery-spawned eggs (e.g., Del Rio et al., 2019) could be used to assess response to the measured physical conditions, including temporal variation in temperature and dissolved oxygen.

The integrated approach described here focuses on understanding the physical-biological linkage at places where synchronized measurements can be conducted to reduce uncertainty regarding spatial and temporal variability in the factors influencing redd-specific egg to fry survival. For any season (and temperature condition/management regime) measurements on selected parts of the river will not be able to capture details of along-river gradients in temperature and potential for dewatering. These targeted physical and biotic response measurements support improved modeling of instream surface and subsurface physical conditions along critical sections of the river, and testing of models currently used to inform management decisions. Model simulations of near-redd scale conditions can illuminate the interaction of factors such as flow velocity, water temperature, and inundation depth and further understanding of the effects of management actions on instream conditions and egg to fry survival.

Understand Recommendations: Egg to Fry Emergence – Keswick Dam to RBDD			
#	**Type**	**Science Activity**	**Management Relevance**
6	Integrated Study	Collaboratively plan and conduct a multi-year Integrated Study to understand how river-scale management actions translate down to the scale of the redd, e.g., detailed field measurement and model simulations of physical conditions, surveys, and field and laboratory experiments to assess biotic response.	*Improved understanding* - Evaluation of how river-scale management actions, individually and in combination, that alter flow, temperature, DO, and substrate translate down to the scale of the redd and influence redd-specific egg-to-fry survival.

Rearing-Out Migrating Juveniles – Keswick Dam to RBDD

In addition to the spawning gravels, the Sacramento River from Keswick Dam to RBDD includes alluvial features. Downstream of Redding, the river cuts through sedimentary deposits and banks can be vertical and several hundred feet high. In other areas, where the river can move its channel several thousand feet before encountering more resistant deposits, banks are erodible unless armored.

Actions and Potential Effects

Many of the management actions listed for egg to fry emergence that address temperature also influence this life stage. Additional management actions influencing rearing-out migrating juveniles between Keswick and RBDD are:

- Rice Decomposition Smoothing
- Winter Minimum Flow
- Spring Base Flow
- Side Channel Habitat Restoration
- Small Screen Program[3]

Further details on these actions are described in the 2019 National Marine Fisheries Service Biological Opinion on Long-term Operation of the Central Valley Project and the State Water Project[4]. Many of these actions address the quality of, and salmonid access to/from in-channel habitats for rearing. Habitat focused actions seek to improve the conditions supporting growth and survival of juveniles, while those focused on flow in the winter and spring are intended to conserve water in the reservoir for use at other times of year. These uses include deliveries, meeting Delta water quality requirement, and supporting egg-fry emergence. Flow management and seasonal flow reductions have the potential to result in stranding and/or delayed out migration of juveniles which may make them more vulnerable to predation. Low flows can also limit access to habitat. A summary overview of the potential effects of these actions on habitat, physical conditions, and species response is provided in Appendix A.

Predict

Broad predictions of in-channel habitat conditions are often based on habitat area relationships, e.g., DWR (2016). Suitable rearing habitat is often estimated using measured hydrology and modeled hydraulic relationships between flow and inundation area to calculate areas of inundation with appropriate timing, duration, and frequency to support juvenile salmon as in the Estimated Annual Habitat approach (Matella & Jagt, 2014). One-dimensional hydraulic models, such as HEC-RAS, can generate water surface profiles which are used with topography to determine inundation frequency and

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[3] The small screen program directly addresses potential mortality at water intakes and will not be discussed here due to extensive existing work under the CVPIA Anadromous Fish Screen Program (AFSP).

[4] https://www.fisheries.noaa.gov/resource/document/biological-opinion-reinitiation-consultation-long-term-operation-central-valley

duration. Specific frequency criteria can be assessed as well as metrics that reflect a range of frequencies.

More detailed 2-D hydraulics models, such as SRH2D, based on Lidar and supplementary on-site surveys, are used to design habitat projects and can be used to analyze depth and velocity conditions at lower flows (e.g., base flows or minimum flows targeted in management actions). Legleiter et al. (2011) note that uncertainty in topographic information can propagate through flow models to produce highly uncertain evaluations of habitat quality meaning future use of existing models may require updated survey data.

Newly emerged fish transition from shallow, slow-moving water to deeper, faster water as they increase in size (Cramer & Ackerman, 2009). Habitat complexity (e.g., woody debris, overhanging vegetation, and seasonally inundated areas) provides juveniles with hiding, resting, and feeding habitat which increases their ability to grow, develop, and survive emigration. Reflecting such habitat complexity, and the way in which it influences growth and survival is extremely challenging. IBMs, such as inSALMO, can model very complex systems with numerous environmental inputs. They can be spatially and temporally explicit and can include many biological processes and analysis of the parameters that describe those processes (Dudley, 2018). For predicting action-effect linkages, IBMs are particularly useful to explore the mechanisms through which parameters or environmental drivers alter the behavior of the system, not solely the final effect on the system. In addition, models with parameters based on physiology, like inSALMO, can be readily updated as new estimates of those parameters are generated by research studies.

More detailed insight into the response of juveniles to local flow and habitat changes can be gained through the application of models such as the Eulerian–Lagrangian–Agent method (ELAM) which mechanistically simulates three-dimensional movement patterns of individual fish responding to abiotic stimuli (Goodwin et al., 2006). ELAM is being developed for application to understand the effects of structures on fish movement in other parts of the system[5] and could eventually be applied to in-stream rearing habitat complexity (see Integrated Study below).

Managing the system requires assessing many competing needs for water, with support for beneficial rearing habitat being one among many. In the near-term, insight into the effects of flow management and its interaction with in-channel morphology to provide beneficial rearing habitat can best be advanced by building on the types of 2-D analysis conducted for project planning. Bioenergetics models are widely used to simulate changes in growth and consumption in response to environmental conditions and food availability (Deslauriers et al., 2017). Rosenfeld et al. (2016) demonstrated that habitat suitability curves generated using bioenergetics modeling outperformed frequency-based habitat suitability curves (using depth and velocity) as well as those adjusted for growth. Spanjer et al. (2018) used a bioenergetics modeling approach to evaluate how environmental factors influenced juvenile salmon growth across a number of streams. However, Holsman & Danner (2016) explored how

[5] https://www.usbr.gov/research/projects/detail.cfm?id=19105
https://www.usbr.gov/mp/bdo/docs/fy19-special-study.pdf

reliance on mean daily temperatures in bioenergetics models may lead to overestimation of some non-linear physiological rates. Linking bioenergetics modeling with 2-D simulations of in-channel physical processes would allow in-channel restoration projects to be planned and designed to better account for how changes in thermal regime, flow conditions, and food availability affect fish growth and provide information on the potential effects of different flow management decisions on rearing habitat.

Predict Recommendations: Rearing-Out Migrating Juveniles – Keswick Dam to RBDD			
#	**Type**	**Science Activity**	**Management Relevance**
7	Modeling	Identify, refine, and test suitable bioenergetics models for use in conjunction with flow models of in-channel and off-channel habitats.	Improved prediction – Promote models that support planning and evaluation of habitat restoration projects by accounting for how changes in thermal regime, flow conditions, and food availability affect fish growth. Information on the potential effects of different flow management decisions on rearing habitat.

Detect

Existing monitoring programs routinely provide physical and ecological information that informs management of the system for this life stage. Stranding surveys provide information on location, extent, and characteristics of stranding sites including points of connectivity or opportunity for reconnection. In addition, monitoring of new habitat restoration sites includes snorkel surveys based on stream edge habitat (and associated visibility, water elevation, and temperature measurements) that have been supplemented with kayak video surveys in areas where vegetation prohibits snorkel survey. These surveys generally identify fish based on size. Side channel control sites are also surveyed to assess the performance of restored side channels or provide baseline information for restoration. Together, stranding surveys and restoration site surveys provide insight into utilization of in-channel habitats by juveniles. However, they provide only snapshots of fish utilization. The consequences of flow management, i.e., the magnitude of minimum flows or the pace at which flow decreases, for in-stream rearing habitat utilization could be better detected by targeted additional sampling. This sampling should measure similar metrics as existing surveys to enable comparability and improve understanding about magnitude of utilization. Such additional sampling could be conducted in coordination with the stranding surveys, which are initiated immediately following a reduction in flows from Keswick to document fish at known stranding sites prior to their isolation from flow. There may need to be some adjustments in sampling as rescue techniques (seines, electrofishing, and dip nets) are designed to retrieve and relocate fish. This additional sampling to detect utilization would not need to target all fish. Repeated samples in the same locations as flows decline could indicate how flow decreases change rearing habitat utilization prior to potential stranding. Associating the additional sampling/detection with the higher frequency stranding surveys (daily) vs. the weekly assessments of habitat performance (which are also presently limited to specific locations) provides more refined information on habitat use by juveniles and the potential identification of thresholds in environment-use relationships, especially if similar metrics, e.g., density, can be used.

Box 2. The Role of Disease

Two endemic myxozoan parasites of salmonids, *Ceratonova shasta* (CS) and *Parvicapsula minibicornis* (PM), are associated with severe disease in juvenile salmon in other systems. The parasites have been detected in all runs of adult salmon and juvenile Fall-run sampled in March and April in the Sacramento River (Foott, 2016). Foote et al. 2019 note that even trace spore concentrations (< 1 spore / L) produced an average of 16% CS infection demonstrating that CS in the Sacramento River is efficient at transmission.

CS has a complex life cycle, involving an invertebrate polychaete host as well as the vertebrate salmon host. Infected polychaetes release actinospores into the water where they can attach to the salmon's gill tissue, invade into the blood, replicate, and later migrate to the intestinal tract which can result in intestinal problems and anemia. Myxospores released from infected fish after death are ingested by the polychaete and complete the life cycle. PM shares the same polychaete host and it infects the salmon kidney.

Studies using sentinel juvenile hatchery fish exposed to river water and water sampling to detect the presence of spores using eDNA have been conducted for several years (e.g., Voss & Poytress, 2019). BY2016 monitoring showed increasing prevalence of infection downstream, from Anderson to RBDD, which was also reflected in water sample spore concentrations although concentrations were low above Anderson. Water sample and sentinel infection data collected from below Anderson to Tisdale Weir in Fall 2018 suggested the reach above Red Bluff Diversion Dam had the highest infectivity and likely contains a greater concentration of infected polychaetes (Foott et al. 2019). Moreover, actinospores remain infectious for at least 7 days and can move a great distance downstream from the infected polychaetes.

Johnson et al. (2017) call for monitoring of the pathogen load fish and water samples in the Upper Sacramento River to identify zones and periods of high virulence, and the ITP calls for pathology monitoring to provide information on disease in Spring-run. How pathogens affect salmon mortality is yet to be resolved. However, increased awareness and understanding of how this known factor influences survival throughout the life cycle can provide insight into the effectiveness of specific management actions or whether flow management could be adjusted, given other constraints, to reduce the risk of infection. Ongoing research is examining pathogen exposure and immune response in salmon as well as using a disease transmission model to explore disease mortality and interaction with environmental conditions such as water temperature (M. Daniels, personal communication).

Evidence from sentinel fish over a number of years with differing flow conditions suggests that disease and potentially mortality may be more prevalent during conditions such as those experiences in WY2014 (Israel et al., 2015).

Increased understanding of this potential source of impaired health or mortality can be obtained through integrated use of predictive models, field sampling, and experimental studies, i.e., with sentinel fish. In addition to ongoing work, collecting intestinal tract samples from carcasses (Foott et al. 2016) and an examination of how changes in flow conditions could disrupt polychaete habitat (https://www.usbr.gov/mp/cvpia/docs/appendix-b-fisheries-public-charters.pdf) could further enable a broader appreciation of the conditions under which these pathogens influence the effectiveness of management actions.

Sampling of juvenile anadromous fish at RBDD supports year-round production and passage estimates of juvenile Winter-run Chinook salmon and Steelhead (Voss & Poytress, 2019). Winter-run egg to fry survival estimates also rely on data used to estimate the number of viable eggs as well as factors such as fry:smolt survival. Passage estimates based on rotary screw trap (RST) data rely on estimates of efficiency which are conducted under a variety of river discharge levels and trap effort combinations as fish numbers and staffing levels allow. Each year the trap efficiency model is updated with new observations from mark-recapture trials. However, it is unclear how efficiency varies between Chinook salmon and Steelhead smolts, for example, or between fry and smolts, and how it is influenced by factors such as turbidity Johnson et al. (2017) recommended combined use of acoustic tagged fish and coded wire tag fish to estimate gear efficiency for the Chipps Island trawl survey and noted that this analysis may determine the applicability of the approach for use of RSTs on the mainstem Sacramento. The small size of many fish passing RBDD limits the use of acoustic tagging, but the results of studies at Chipps Island should be tracked for insight into additional methods for estimating efficiency at RBDD RTS. Further analysis of existing RBDD juvenile monitoring data to assess relationship between flow and other abiotic variables and passage is discussed below.

Predation of fry is potentially an important determinant of the number of out-migrating juveniles. Detecting the presence of potential predators in the river above RBDD and the type of in-channel habitats with which they are associated can provide important information for planning habitat related projects that seek to improve conditions for juvenile rearing. On the San Joaquin River, boat-based predator surveys, using acoustic techniques, have provided relative predator fish densities and maps of predator associations with river channel characteristics (Cutter et al., 2017). While the small size of juvenile salmon above RBDD may make their detection challenging, surveys of predators and how their distribution changes with varying flows could help interpret response of juvenile passage to flow management as well as supporting planning and implementation of projects that seek to improve in-channel rearing habitats.

Detect Recommendations: Rearing-Out Migrating Juveniles – Keswick Dam to RBDD			
#	**Type**	**Science Activity**	**Management Relevance**
8	Targeted Data Collection	Document the consequences of flow management, i.e., the magnitude of minimum flows or the rate of flow decrease, on utilization of in-stream rearing habitat (potentially expanding on stranding surveys and restoration site surveys) including sampling as flows decline.	*Increased detection* - Refined information on habitat use by juveniles. *Improved understanding* - Potential identification of thresholds in environment-use relationships to improve planning and design of habitat restoration projects.

Detect Recommendations: Rearing-Out Migrating Juveniles – Keswick Dam to RBDD			
#	**Type**	**Science Activity**	**Management Relevance**
9	Targeted Data Collection	Document the relative abundance and distribution of potential predators in the river above RBDD and the types of in-channel habitats with which they are associated with varying flows and environmental conditions.	*Increased detection* - Improved identification of the response of juvenile passage to flow management, i.e., predation as a potential source of non-temperature mortality. *Improved understanding* - Support planning and implementation of projects that seek to improve in-channel rearing habitats.
10	Targeted Data Collection	Assess the role of pathogens and disease through targeted sampling of intestinal tract samples from carcasses, and evaluation of how changes in flow conditions could disrupt polychaete habitat.	*Increased detection* - Increased appreciation of the conditions under which pathogens and disease may influence the effectiveness of management actions.

Understand

This section of the river is the focus of management actions targeting spawning, egg survival, and fry emergence. Metrics of egg to fry survival rely on information collected on spawning grounds and by the RSTs at RBDD where fry and smolt passage reflects all the conditions that occur between spawning and that point in the river. While side channel habitat restoration projects have been conducted and are planned to improve rearing habitat, there is lack of detailed understanding of the way in which abiotic and biotic factors contribute to survival and the direct and indirect effects of management actions. Windell et al. (2017) identify nine hypotheses for rearing-out migrating juveniles in this part of the river including the role of pathogens and disease (Box 2).The work proposed here focuses on several areas where increased understanding can support management actions; these are not proposed as a comprehensive approach to understanding all aspects of process interaction influencing this life stage.

Estimating Egg to Fry Survival

The importance of the egg to fry survival estimate has already been noted. Figure 2 illustrates how data from different sources feed into estimates of eggs and fry. Details of the statistical analysis to derive some of these data, e.g. mark-recapture in the carcass survey, or how to analyze them are not shown and are well described elsewhere (O'Farrell et al., 2018; Voss & Poytress, 2019). Gore et al. (2018) also discuss uncertainties in some of the data and how they are used in modeling.

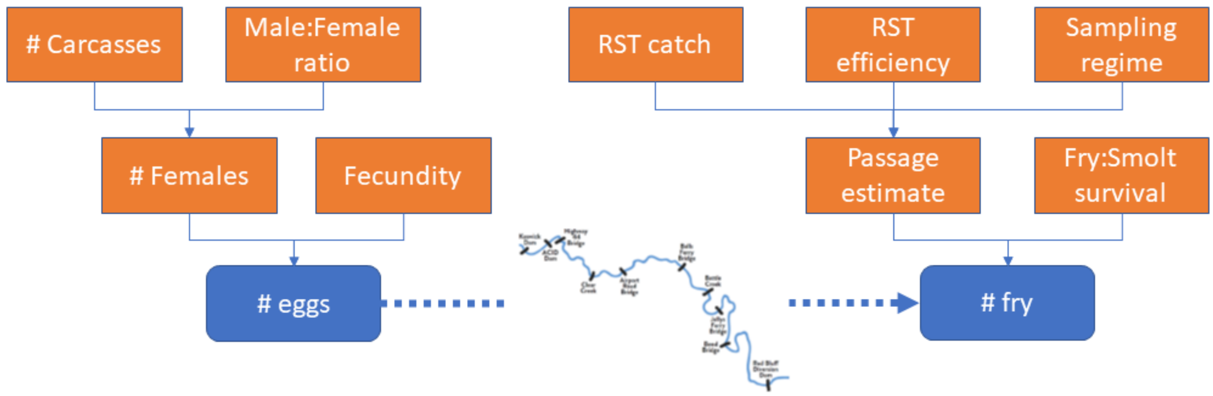

Figure 2. Simplified depiction of the data used to estimate egg to fry survival

Discussions with experts identified two areas where additional analyses could contribute to increased understanding of what the estimated values represent or for potential adjustments to information presently used:

- *Further analysis of existing RBDD juvenile monitoring data* – Analysis could be conducted to assess the relationship between abiotic variables (including flow) and RST catch to validate current approaches to imputing data when conditions prevent RST operation. During periods when fish density is high, elevated river flows, or heavy debris loads, routine trap operations are modified, e.g., subsampling protocols to reduce take and incidental mortality (Voss & Poytress, 2019). Randomized temporal sub-sampling can be applied during storm events, and statistical techniques are used to extrapolate to un-sampled data. If RST operation is discontinued for days or weeks, e.g., due to river conditions, mean daily passage estimates are imputed for missed days based on weekly or monthly interpolated mean daily estimates, respectively. When sampling is not conducted due to high river conditions, imputing in this way may overestimate fish passage or may not account for increased passage stimulated by flow events. However, making such an adjustment requires an understanding of the relationship between fish passage and flow. This cannot be simply assumed as, depending on run timing and the degree to which a run's outmigrants have already passed RBDD, fewer or greater fish could pass during any particular event depending on factors such as the timing and prior storm activity. A detailed analysis of the role of environmental factors in emigration of Pacific lamprey related daily catch at RBDD over a 10 year period to a set of candidate variables including flow, number of days from rain event, turbidity, temperature, precipitation, and moon phase (Goodman et al., 2015). Analyses of this type for juvenile salmonids could be used to refine the current approach to account for missing RST data. Conditions such as high flows and turbidity may be poorly represented in the existing data, and this analysis could also point to the need for additional data to better understand the role of environmental conditions, such as high flow and turbidity, on catch.
- *Parentage-based tag methods* - Genetic analyses are already conducted on sampled fish to support run identification at RBDD. Johnson et al. (2017) note that parentage-based tag (PBT) methods can provide information on the reproductive success of individual spawners which is potentially useful in refining the data uses in Figure 2. Existing work using PBT linked adults

sampled at the Keswick Dam trap and in the carcass survey with juveniles sampled at RBDD for BY2016. Preliminary analysis showed approximately 44% of adults were estimated to have successfully produced recruits to RBDD and hatchery-origin females also produced fewer recruits than expected given their abundance relative to natural-origin females (S. Blankenship, personal communication). However, samples collected in 2016 were collected in late September and based on 18 years of data on run timing, 38% (+/-18%) of the run may have already passed prior to starting genetic collections. Consequently, the preliminary analysis may include a negative bias on the number of fish contributing to juveniles captured at RBDD. Continued exploration of this approach could be useful, as discussed by Johnson et al. (2017), to evaluate how spawn timing, location, and origin (hatchery or wild) influence reproductive success.

Predation

Predation of fry could be an important source of mortality influencing catch at RBDD. Grossman (2016) notes that identifying whether predation is the proximate or the ultimate cause of individual mortality can be problematic, and few surveys of predators or predation studies are available for this section of the River. Developing insight into the potential role of predation requires detection of predator distribution and abundance relative to fry (as described above), and the degree to which predatory fish are consuming fry.

Prey items in the guts of predators can be studied using nonlethal gastric lavage in combination with visual or genetic identification of contents (Stompe et al., 2020). In a detailed study of predation on the Tuolumne River, acoustic tags were inserted into predators caught by hook and line and an array of hydrophones was used to calculate the 2-D position of the fish (FISHBIO, 2013). This allowed habitat use by the predators to be evaluated. In the Tuolumne study, Chinook Salmon were also tagged, and the overlap between predator and prey distributions was assessed. Fry in this section of the river are too small to bear acoustic tags using current technology, but the approach to documenting predator movements in combination with assessments of prey in the predators gut could provide insight into the relative role of predation on fry in response to changing environmental conditions including those associated with management actions.

Recent development of a Predation Event Recorder (PER) provides a way of examining patterns of relative predation across factors such as water depth and may provide information on predator species (Demetras et al., 2016). PERs have been used to assess relative ‘predation risk’ in the Delta and to support the development of statistical models to estimate predation potential for the South Delta landscape at a 1-day and 1-km resolution (Michel et al., 2020). MicroPERs are a miniaturization of the original PER design and are small enough to be attached to a spinning rod and deployed by casting then allowing them to float through habitats to detect predation in different in-stream conditions (C. Michel, personal communication). However, caution should be used when drawing conclusions from the use of PERs. While PERs can provide relative information, tethering effects may limit understanding of how effective predators are at capturing juvenile salmon (Baker & Waltham, 2020) and local conditions may make the technique more effective in some conditions than others. However, using PERs or MicroPERs in combination with other techniques described above could provide additional insight given the ability to deploy them in shallow water and size limitations on tagging.

A focused study of predation in different environments of the river, under varying flows and seasonal temperature conditions, could substantially increase understanding of the role of predation mortality and when and where it may impact the success of management actions. However, quantifying predation mortality such that it could be used as part of the calculation described in Figure 2 would require substantial additional study**.** The study described here is a first step and could be designed and implemented independently or as part of an Integrated Study as described below.

Integrated Study #2

Several habitat restoration projects have been implemented, including side channels and placement of root wads to increase habitat complexity, and more are planned. Management actions that alter flows interact with existing and newly restored habitat features and understanding how these interactions can contribute to a coordinated approach to system restoration and management. An Integrated Study could leverage existing field, lab, and modeling approaches and provide information to improve prediction of action-effect linkages relative to juvenile survival and growth. For rearing-out-migrating juveniles above RBDD, a reach of river including a variety of in-channel features should be selected. This could include restored habitat features, features that restoration projects seek to mimic, e.g. reference sites, or a combination of the two. The goal would be to integrate study of several sources of mortality already discussed including disease and predation with additional measurement of food availability and, potentially, growth of fry.

A coordinated field campaign on a selected portion of the river could include:

- Field measurements in combination with modeling to understand variations in environmental conditions (such as temperature, depth, velocity) including those targeted by management actions. For example:
    - Surveys of topography, bathymetry and bed sediment character, and velocity measurements to support spatially distributed predictions of water surface elevation using hydraulic models, e.g., SRH-2D
    - Measurements, using samples or sensors as appropriate, of water quality such as dissolved oxygen and turbidity
- Ecological measurements could include:
    - Surveys of terrestrial and submerged vegetation
    - Water samples and sentinel studies to document prevalence and potential infection rates for *C. shasta* (Box 2)
    - Utilization of different habitats by fry. This could use non-contact methods such as snorkel or kayak video surveys, but for some species, dip nets and seines could provide more specific information including size, overall condition, etc.
    - Documentation of predator abundance movement and gut contents (discussed above)
    - Nets and/or traps to document available food, including drifting insects, and the association of food availability within channel biotic and abiotic conditions
    - Measurement of growth in non-listed species using otoliths

Specific survival estimates for fry are difficult due to their small size although this may be possible with larger fish (O'Farrell et al., 2018). However, insight into factors influencing growth and predation, in tandem with variation on physical stream conditions, could be used to reduce the uncertainty in fine scale models such as ELAM and decision support tools such as inSALMO. Dudley (2018) notes few data were available on the concentration of food and the rate at which drift food regenerates. Such information could also be used in the bioenergetics analyses suggested above for habitat restoration planning and design.

Such an Integrated Study could be planned in several ways depending on the resources available. Being able to link food production areas with downstream availability, could be examined at the habitat/ intrahabitat scale, or across longer stretches of river enabling examination of food sources in reservoir releases vs. those produced within channel habitats. Parallel studies of sections of river, e.g., closer to Redding and closer to RBDD, may provide insight on larger within river gradients (as identified in the studies of *C. shasta* – Box 2) and how those gradients vary with seasons and management of flow. If an Integrated Study site incorporated a restored area that is being monitored, the additional data could provide an opportunity to validate ongoing weekly sampling or suggest additional low-effort data collection.

Understand Recommendations: Rearing-Out Migrating Juveniles – Keswick Dam to RBDD			
#	**Type**	**Science Activity**	**Management Relevance**
11	Analysis	Plan, support, and implement a structured approach for efficiency tests at RBDD RST across run/size, flow conditions, etc.	*Increased detection* - Increased confidence in egg-to-fry survival estimates. *Improved understanding* - Evaluation of critical assumptions that may bias routine field surveys and thus impact management actions reliant on the survey data.
12	Analysis	Analyze existing RBDD juvenile monitoring data to assess the relationship between flow and environmental conditions and fish passage.	*Improved understanding* - Validate current approaches to imputing data when conditions prevent RST operation.
13	Analysis	Continue exploration of parentage-based tag methods to provide information on the reproductive success of individual spawners.	*Improved understanding* - Evaluation of how management actions that influence spawn timing, location, and origin (hatchery or wild) affect reproductive success. *Improved prediction* - Potential refinement of egg-to-fry survival estimates.

Understand Recommendations: Rearing-Out Migrating Juveniles – Keswick Dam to RBDD			
#	**Type**	**Science Activity**	**Management Relevance**
14	Focused Study	Plan and conduct a focused study to understand predator distribution and predation in different environments of the river under varying flows and seasonal temperature conditions potentially including gut analysis of predators, predation activity, and tracking predator movements with changing environmental conditions, including those associated with management actions.	*Improved understanding* - Evaluation of when and where predation mortality of salmonids can impact the success of management actions.
15	Integrated Study	Collaboratively plan and conduct a multi-year Integrated Study to understand how managed flows interact with existing and newly restored habitat features to benefit rearing fry, including detailed field measurement and model simulations of physical conditions, and surveys of habitat utilization by fry and potential predators, growth rates (non-listed species), and prevalence and potential infection rates for *C. shasta*.	*Improved understanding* – Assessment of factors influencing fry growth and predation, and the role of physical stream conditions including those influenced by flow management. *Improved prediction* – Incorporate understanding of factors into the planning and design of habitat restoration management actions.

Rearing-Out Migrating Juveniles - RBDD to Verona

This section of the river includes areas of broad meanders with active migration, areas of hardened channel banks, and a long stretch of river downstream of Colusa largely characterized by a narrow deep channel confined by earthen levees and riprap. The Sutter Bypass is flooded via Moulton, Colusa, and Tisdale Weirs at different river stages leading to great variations in habitat availability to rearing salmon depending on river discharge.

Actions and Potential Effects

Management actions influencing rearing-out migrating juveniles between RBDD and Verona include:

- Winter Minimum Flow
- Spring Base Flow
- Rice Decomposition Smoothing
- Spring Pulse Flow
- Side Channel Habitat Restoration
- Riparian Habitat
- Floodplain Habitat
- Managed Floodplains for Food Production
- Small Screen Program[6]

Further details on many of these actions are described in the 2019 National Marine Fisheries Service Biological Opinion on Long-term Operation of the Central Valley Project and the State Water Project[7] and the Central Valley Flood Protection Plan Conservation Strategy[8]. Most of these actions influence flows within the system and habitat condition. In addition, flows in this section of the river can be influenced by Sacramento River diversions, winter flood control releases from dams, and flows from unregulated tributaries. In addition, plans are being considered to add modifications or notches to the flood control weirs that allow flows into the Sutter Bypass. Flows influence the quality of and salmonid access to/from in-channel habitats for rearing, and the spring pulse flow specifically targets out-migration of Spring-run. Habitat focused actions seek to improve the conditions supporting growth and survival of juveniles, and for this section of the river could include in-channel habitats and opportunities in the Sutter Bypass. Managing floodplains for food production is an approach designed to increase food availability in the channel to increase growth of salmonids using managed inundation of adjacent lands. A summary of the potential effects of many of these actions on habitat, physical conditions, and species response is provided in Appendix A.

Predict

In this section of the river many of the actions affect access to, or the quantity and quality of rearing habitats. Some habitat planning tools (e.g., Whipple et al., 2019) have moved beyond quantification of inundated area or the area that meets specific depth/velocity criteria to include floodplain connectivity (e.g., the opportunity for volitional ingress and egress) and thus can be used to consider stranding

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[6] The small screen program directly addresses potential mortality at water intakes and will not be discussed here due to extensive existing work under the AFSP.

[7] https://www.fisheries.noaa.gov/resource/document/biological-opinion-reinitiation-consultation-long-term-operation-central-valley

[8] https://water.ca.gov/Programs/Flood-Management/Flood-Planning-and-Studies/Conservation-Strategy

potential. However, these are largely still based on physical aspects of habitat, despite substantial information of the multiple benefits of floodplains (e.g., Grosholz & Gallo, 2006). As discussed above, linking bioenergetics modeling with 2-D simulations of in-channel and floodplain physical processes would allow habitat restoration and flow management to be planned and designed to better account for how changes in physical conditions including flow, seasonal temperatures, and food availability affect fish growth.

The 2020 Incidental Take Permit for the Long-Term Operation of the State Water Project (ITP) calls for the development of a LCM for Spring-run. While the model is not required under the ITP until 2025, development is already underway. The Spring-run LCM will be a valuable tool for the Partnership to understand the implications of management actions for Spring-run originating in Mill and Deer Creeks as they pass through the mainstem Sacramento. Tracking and contributing to discussions regarding the development of the LCM could allow the Partnership to ensure that the model appropriately reflects the role of management actions that change conditions in the mainstem Sacramento. Further, ensuring that the Spring-run LCM could work in concert with other tools to allow assessment of tradeoffs in hydrology and biological response in relation to the Spring Pulse Flow (such as CWP availability for Winter-run and effects on fall flows for Winter-run, Spring-run, and Fall-run) would enable transparent decision making processes such as SDM to be used for these complex decisions.

Predict Recommendations: Rearing-Out Migrating Juveniles - RBDD to Verona			
#	**Type**	**Science Activity**	**Management Relevance**
16	Modeling	Identify, refine, and test suitable bioenergetics models for use in conjunction with flow models of in-channel and floodplain habitats.	*Improved prediction* - Improved planning and evaluation of habitat restoration and flow management actions by allowing planning and design to better account for how changes in thermal regime, flow conditions, and food availability affect fish growth.
17	Modeling	Foster communication and information sharing to support the ongoing development of the Spring-run LCM. Identify additional data or research needed to appropriately reflect the role of the mainstem Sacramento River conditions and management actions in the model, such that it could eventually be used to assess tradeoffs and support SDM.	*Improved prediction* - Ensure that the Spring-run LCM appropriately reflects the role of management actions that change conditions in the mainstem Sacramento and thus support future management decision making.

Detect

There are relatively few regular and effective sampling locations between RBDD and Verona. RSTs at Glenn-Colusa Irrigation District, Tisdale Weir, and Knight's Landing provide data on fish out-migration timing, but trap efficiencies are either unknown or low. The ITP calls for the collection of genetic samples at Tisdale Weir and Knight's Landing RST to improve run identification and support the proposed Spring-run Juvenile Production Estimate (JPE) and emphasizes the Tisdale Weir RST as an important location to monitor fish that then move through the weir and into the Sutter Bypass. Combined use of acoustic tags and coded wire tagged releases for efficiency studies, discussed above in relation to RBDD, is also included in the ITP. Methods for estimating JPE for Winter-run (O'Farrell et al., 2018) are limited by data availability, especially passage at Sacramento reflecting survival as far as the Delta. A refined JPE does not directly inform action-effect linkages in the mainstem Sacramento River, but the current Winter-run JPE, and potentially the proposed Spring-run JPE, incorporate information that reflects the effectiveness of management actions of interest to the Partnership. Being able to assess the survival of outmigration of juveniles before they reach the Delta could provide an overall assessment of how ambient conditions and management actions in the Sacramento influence outmigration (including passage through Sutter Bypass) as well as supporting JPE estimates, possibly using Method 3 proposed by O'Farrell et al. (2018). Such assessment could be achieved through deployment of a new monitoring location, that would also encompass the effects of other tributaries for some runs depending on the location selected, or more intensive acoustic tagging studies of survival.

In-channel survival has been the topic of several research studies. Michel et al. (2015) calculated percent survival per 10 km of the mainstem Sacramento River in 2007-2011 using acoustic tagging and found lower survival rates upstream of Colusa vs. between Colusa and the Delta for hatchery-origin Late Fall-run juveniles. Using similar methods, Notch et al. (2020) found lower survival between Hamilton City and Colusa in wild Spring-run emerging from Mill Creek in 2013-2017. While these studies do not track the causes of mortality, Notch et al. show that survival increases with movement speed related to flow. Michel et al. (2015) propose that higher survival in the parts of the river confined by levees and armored banks is a result of smolts migrating in the center of the channel, due to lack of rearing conditions, while predators associate with channel margins. Studies like these point to variations in survival along the river which could be the focus of targeted surveys of predators using boat-based surveys (as described previously). Data on how predator abundance and distribution changes through different reaches of the river, and in relation to flow, could help planning and implementation of projects that seek to improve in-channel rearing habitats.

One of the expected benefits of habitat restoration projects is the generation of food for juvenile salmonids and monitoring of restoration sites may include sampling for prey, e.g., Bullock Bend. However, few data are available on existing prey resources to provide context for such monitoring. Targeted data collection campaigns to provide data on patterns of abundance of drift insects and zooplankton (especially in association with habitat features such as side channels, bars, bank slopes, etc.) would provide useful background data for restoration planning projects as well as providing a foundation for future examination of the effects of management actions. Extending data collection to floodplains during periods of inundation, while opportunistic and difficult to plan for, would provide valuable baseline information for projects that seek to increase food resources for salmonids.

A number of studies have documented increased growth of juvenile salmonids that occupy floodplain habitats in the Cosumnes and the Yolo Bypass (e.g., Henery et al., 2010; Jeffres et al., 2008), and there is some evidence that this may be the case for juveniles that migrate through the Sutter Bypass (Cordoleani et al., 2020). Question remain as to whether juvenile salmon experiencing increased growth due to passage through the Sutter Bypass perform any better than juvenile salmon that outmigrate through the main channel. Where habitats are open to juvenile access, comparing the number and size of fish captured across the habitats does not provide unambiguous evidence of differences in growth or survival. For the Yolo Bypass, Sommer et al. (2001) used paired releases of coded-wire-tagged juvenile salmon in Yolo Bypass and the Sacramento River. This approach allowed comparisons of growth among fish of similar origin and provided a relative estimate of migration time and survival. Such studies for the Sutter Bypass could provide direct documentation of the potential benefits of floodplain passage on survival or out-migrating fish, and whether any benefits of increased growth are negated by conditions in the downstream migratory corridor, e.g., poo temperature conditions in the mainstem Sacramento from Verona to the Delta.

Detect Recommendations: Rearing-Out Migrating Juveniles - RBDD to Verona			
#	**Type**	**Science Activity**	**Management Relevance**
18	Analysis	Convene an expert group to evaluate the need for additional juvenile passage monitoring locations on the mainstem Sacramento River in relation to other potential approaches, e.g., additional measurement of survival, modeling.	*Increased detection* - Data to provide an overall assessment of how ambient conditions and management actions in the Sacramento influence outmigration (including passage through Sutter Bypass). *Improved prediction* - Support for refined JPE estimates.
19	Targeted Data Collection	Strategically plan and conduct boat-based surveys of predators to identify how predator abundance and distribution changes through different reaches of the river.	*Increased detection* – Provide greater resolution of river reach-specific predator densities. *Improved understanding* - Support for planning and implementation of projects that seek to improve in-channel rearing habitats
20	Targeted Data Collection	Strategically plan and conduct data collection campaigns to identify patterns of abundance of drift insects and zooplankton in association with habitat features such as side channels, bars, bank slopes, etc. Consider extending data collection to floodplains during periods of inundation.	*Increased detection* - Improved background data for planning restoration projects. Specifically, baseline data for future examination of the effects of management actions that seek to increase food resources for salmonids.
21	Targeted Data Collection	Conduct a series of paired releases of tagged hatchery fish into the Sutter Bypass during flooding and the adjacent Sacramento River, to detect whether passage through the Sutter Bypass increases survival for out-migrating juvenile salmonids	*Increased detection* - Documentation of the potential benefits of floodplain passage on survival of out-migrating fish.

Understand

The varied nature of this stretch of river means generalizations over large areas are difficult, as shown in the survival studies mentioned above. Windell et al. (2017) identify nine hypotheses for factors influencing survival, out-migration timing, and growth of Winter-run. Scientific activities have already been identified in this Plan to increase understanding of similar processes above RBDD and many could be readily transferable to the river further downstream. Several areas for additional work are provided here including an Integrated Study of floodplain habitats in the Sutter Bypass. Box 3 describes a particular opportunity to increase understanding associated with a management action.

BOX 3. MANAGEMENT ACTION SPECIFIC STUDIES: SPRING PULSE FLOWS

The 2019 Biological Opinion for the Central Valley Project includes management actions that have not previously been routinely applied. Improved understanding of the effects, both intended and unintended, will be valuable to the Partnership as they continue their work through SDM and other collaborative processes. As some management actions are applied differently depending on water storage or other factors, there is an opportunity to learn by studying the response of the system to the actions across a gradient of implementation conditions.

The Biological Opinion includes, as part of Reclamation's proposed action, implementation of a spring pulse flow under certain hydrologic conditions to improve the survival of out-migrating juvenile salmonids, specifically Central Valley Spring-run Chinook salmon. In addition, several Members have participated in the development of an experiment to coincide peak smolt out-migration from Mill and Deer Creek with a short-duration pulse of water through the Sacramento River in order to increase survival rates through the mainstem Sacramento River in the spring. Migrating Fall-run smolts could also benefit from the pulse. Field sampling would include not only tracking the survival of the fish but additional measurements of potentially important factors to outmigration such as turbidity. The greatest response is expected in dry or below-normal water years (such as 2012-2016). However, the Biological Opinion indicates the spring pulse flow would be considered when Shasta Reservoir total storage on May 1 is projected to be sufficient for cold water pool management (i.e., greater than 4 million acre-feet) which may not occur in dry or below normal years, potentially limiting broader understanding of the benefits of spring pulse flows.

Mainstem Habitat Utilization and Benefits

Several studies have identified salmonid utilization of specific habitats. Merz et al. (2016) noted differences in use of Steelhead and juvenile Chinook salmon in the Lower Mokelumne River as well as differential response to temperature. In the Sacramento River, Zajanc et al. (2013) found that Steelhead had a higher probability of holding in habitats where the bank slope was steeper and large woody material density was lower. The presence of submerged vegetation also influenced Steelhead holding time. How and where to invest in habitat restoration or enhancement, and design of projects to provide species benefit, requires more information on specific habitat utilization. The following elements should be included in coordinated field studies at different areas including the broader meandering reaches above Colusa and the leveed reaches above Knight's Landing:

- Measurements of abiotic conditions including flow, water temperature, DO, etc.

- Acoustic tagging of juveniles with specific deployment of receivers to detect holding times in habitat in selected areas, possibly identified based on high and low survival from whole river studies (Michel et al., 2015; Notch et al., 2020). These could be conducted in association with active surveys, e.g., beach seines or electrofishing, across a wider area (in the absence of listed species) to examine within river variation.
- Assessments of predation on salmonids using predator gut content by hook and line sampling. This could be combined with boat-based predator distribution surveys and deployment of MicroPERs to enable the types of analyses conducted by Michel et al. (2020) to estimate patterns of potential predation associated with different habitats. Predation could be linked with the detailed utilization surveys by including the use of predator tag technology (Daniels et al., 2019).
- Surveys of prey availability including drift nets and zooplankton nets (thrown or towed).

This type of coordinated field sampling across diel cycles and seasons can support bioenergetics modeling for planning and design of habitat restoration as well as provide a foundation for more detailed modeling, e.g., using IBMs, and potential refinement of transitions in LCMs.

Actively Managed Agricultural Floodplains

Recent experimental studies of food resources (Corline et al., 2017; Katz et al., 2017) point to the potential benefits of managing the flooding of agricultural fields to provide food and habitat for juvenile salmonids. Managing inundation of field in different ways has been shown to provide valuable habitat for waterbirds during periods of limited habitat availability (Sesser et al., 2018). Given the dramatic reduction in available habitat in the Central Valley for out-migrating juvenile salmonids, as well as the value of habitat for juveniles in the Yolo Bypass during flooding, studies have explored whether agricultural areas within floodways can be more actively managed to enhance this benefit. A multiyear study has been conducted on standard rice and winter wheat fields, adjacent fallow lands, and rice fields with different harvest practices or other experimental modifications to test fish and food web responses within different land management scenarios (Sommer et al., in press). The flooded farm fields produced high levels of biological productivity (Corline et al., 2017) and fish growth was rapid (Katz et al., 2017). However, these studies found that flooded fields are not viable rearing habitat unless wild juvenile salmonids are able to find the fields as well as safely emigrate before drawdown and that avian predator and temperature refugia may be important features of the management design. Volitional access is a key issue with locations in proximity to channels that are viable migration corridors, and where egress at focal points and times does not attract high predator densities, reducing survival. Evaluating the tradeoff between the potential growth advantage against focused predation risk could be explored through modeling although additional information is needed to identify how potential risks can be decreased through design and management. A focused study, in cooperation with landowners and incorporating different experimental management approaches, would provide additional insight on these tradeoffs and the potential net benefit to out-migrating juveniles.

Integrated Study #3

Potential additional floodplain access for out-migrating salmonids may occur through modifications to Tisdale Weir. In 2019, Cordoleani et al. (2020) found four runs of Chinook Salmon were captured during flood events in either the Butte Sink or Sutter Bypass using seines and fyke nets. This indicates the potential importance of these habitats for all four runs of Central Valley Chinook Salmon. The same study found that both managed wetlands and flooded agricultural habitats provided high growth rates during the flood event and that high abundance of zooplankton in the off-channel Butte Sink and Sutter Bypass locations serves as a food resource for the juvenile salmon. Moving from individual studies towards understanding what can be used in an LCM or other decision support tool requires mechanistic understanding of the circumstances under which benefits to juveniles are provided and when other concerns, such as stranding or increased susceptibility to disease as temperatures warm, may dominate. Moreover, relatively frequent flooding of the Sutter Bypass provides an opportunity to understand how variations in floodplain inundation influence the benefits gained (Whipple et al., 2017) which could be used to better plan and design active management of floodplains using structures and managed inundation.

Integrated Study #3 directly targets the improvement of existing habitat assessment tools that might be applied to habitat restoration planning and foundational information for improved consideration of habitats within LCMs. Key elements include:

- Utilize 2-D models and 'suitability' approaches to identify areas of the Sutter Bypass that might be expected to provide high-low quality habitat for juvenile salmon for different flood conditions.
- Focus field sampling during one or more flood events across these gradients in predicted habitat quality to:
    - Document abiotic conditions including water depth, velocity (parameters used in the LCM and some habitat assessment tools), contaminant loading, and temperature
    - Survey fishes and prey (e.g., following methods used in Cordoleani et al., 2020) across areas of high-low quality. Growth of non-listed juveniles can be documented using caged fish (Jeffres et al., 2008) or otolith studies (Limm & Marchetti, 2009)
    - Assess predation potential using PER approaches for nekton and cameras to document potential avian predation
    - If plausible, given the unpredictable nature of Bypass flooding, deploy receivers and use acoustically tagged fish to determine survival in segments of the floodplain characterized by high vs. low quality
- Utilize field data to consider whether gradients in the initial modeled quality assessment captured measured patterns of utilization prey availability, growth, potential predation, and whether abiotic conditions were likely to result in disease (see Box 2).

Laboratory studies or additional bioenergetics modeling could also be used to assess potential for growth across the gradients of conditions found in the field. Initial field campaigns could be more broadly based, with the results being used to design more detailed components in subsequent flood events, e.g., the addition of sentinel studies of potential pathogen effects. Known spatial gradients not related to the abiotic factors should also be considered in field sampling design. For example, Cordoleani et al. (2020) noted lateral banding from west to east within the Sutter Bypass associated with the mixing of different source waters entering the Bypass. This Integrated Study could also be paired with Science Activity #21 (see above) to determine the overall impact of the floodplain passage on survival.

Directly linking field studies with modeling and engaging both field scientists and modeling experts in the design of the study can help ensure that the findings can ultimately be incorporated into models to support SDM and other decision-making processes. This type of integration of field information on growth and survival, with inundation information, into models was used in the Yolo Bypass Salmonid Habitat Restoration and Fish Passage Project EIR/EIS to support evaluation of the trade-off between the risk of mortality by rearing for an extended period in Yolo Bypass to gain greater size versus the benefit of greater survival at later life stages associated with extended rearing and growth in the Yolo Bypass (Hinkelman et al., 2017). Using the Integrated Study to explore the role of floodplain structure and complexity providing shelter to rearing juveniles from piscivorous fishes and birds, in the Sutter Bypass, would also support future adaptive management of the system (Tompkins et al., 2017).

Understand Recommendations: Rearing-Out Migrating Juveniles - RBDD to Verona			
#	**Type**	**Science Activity**	**Management Relevance**
22	Focused Study	Support science to understand the effects of the spring pulse flow action including during drier conditions than those identified in the Biological Opinion.	*Improved understanding* - Evaluate the effects of the new management action under varying water year conditions, thus supporting evaluation of tradeoffs among water management benefits and impacts for different runs of salmon.
23	Focused Study	Plan and conduct coordinated field sampling to identify patterns of habitat use within the mainstem Sacramento, including the broader meandering reaches above Colusa and the leveed reaches above Knight's Landing, and assessment of predation potential and prey availability.	*Improved understanding* - Support for bioenergetics modeling for planning and design of habitat restoration and flow management actions. *Improved prediction* - Provision of information to apply/refine decision support tools, e.g., use of IBMs, refinement of transitions in LCMs.
24	Focused Study	Plan and conduct experimental studies of the effects of actively-managed agricultural floodplain utilization on out-migrating salmonids including potential for avian predation, channelized and managed floodplain-mainstem egress on subsequent predation, and tradeoffs between enhanced growth and delays in outmigration associated with extended durations of floodplain access.	*Increased detection* – Focused monitoring of juvenile salmonid utilization of actively-managed agricultural floodplain. *Improved understanding* - Identification of the potential benefits and risks to salmonids of actively managed access to/use of agricultural floodplains.
25	Integrated Study	Collaboratively plan and conduct a multi-year Integrated Study to understand how variations in passive inundation of the Sutter Bypass influences the benefits gained, including model simulations of habitat quality, surveys of habitat utilization and potential for predation and disease, juvenile growth rates, and data to support improved modeling of habitat quality.	*Increased detection* – Focused monitoring of juvenile salmonid utilization of passively inundated floodplains. *Increased understanding* - Evaluation of the benefits and risks of passive access to floodplain habitats to juvenile salmon. *Improved prediction* - Information to support the refinement of predictive tools for supporting floodplain management decisions.

System-Level Assessment

There are several areas where the Partnership could benefit from information which also serves a wider set of interests in relation to Central Valley Chinook Salmon and Steelhead that are not focused on a specific life stage. Some have been discussed previously (Box 2) and others described here include synthesis activities which cross life stages or issues to contribute to shared learning by the Members.

Ongoing Data Needs

Otolith studies have proved useful in identifying the size of individuals during out-migration from tributaries, time- and size-selective mortality along the migratory corridor, and rearing in non-natal habitats (Phillis et al., 2018; Sturrock et al., 2015, 2020). Johnson et al. (2017) pointed to the need for annually collecting otoliths to quantify survival and relative contributions of different rearing strategies. This effort has been piloted as part of the SAIL projects (Johnson et al. 2017) to improve the monitoring program and measure viability metrics. The work is ongoing, and discussions indicate it is proving useful to Members of the Partnership. Sustaining this effort will underpin the work of the Partnership as well as that of others.

The ways in which management actions potentially influence Steelhead is in some part dependent on whether fish are anadromous or resident. The relationship between anadromous and resident Steelhead is poorly understood. Further sampling and analysis of scales described in the California Department of the Fish and Wildlife Steelhead Monitoring Plan could be used to identify whether fish have migrated to the ocean. In addition, recent studies have identified the chromosome Omy5 in a genomic region strongly associated with the prevalence of resident or anadromous life history traits in coastal California Steelhead populations (Pearse et al., 2014), and these have been used to identify life history patterns in other systems (Abadía-Cardoso et al., 2016; Apgar et al., 2017). Further application of these techniques will provide context for Steelhead response to management actions throughout the system.

Brood Year Assessments

The BY2013 assessment for Winter-run (Israel et al., 2015) provides a useful example of how monitoring data and other information can be collaboratively drawn into an evaluative framework to provide a transparent appraisal of species response to ambient conditions and management actions. The BY2013 report was drought focused, and since its compilation, adjustments have been made in some aspects of data collection, e.g., genetic testing to correct for length-at-date criteria and misassignment of winter-run as spring-run. In addition, it was for a single run, and as the report notes, the species of greatest concern may not be a good conservation surrogate for all species.

The focus should be on documenting what happened, with comparison to model predictions if available, and statistical analysis across years if data are adequate. Metrics to be tracked could include: number of spawners; prespawn mortality; number for broodstock; redd distribution including information on dewatering; estimated egg to fry survival (using multiple approaches/models); timing and size distribution of juvenile passage at RBDD, Tisdale, and Knights Landing (and any other available points in the system); timing of movement and size distribution past Chipps Island; and estimated duration of rearing/speed of emigration through parts of the system. Discussion or inference in relation to causality can be included and may require the inclusion of alternative interpretations of cause-effect. Limitations of the data or assumptions in analysis should be clearly documented.

Useful aspects of the BY2013 assessment which should be carried forward with support of the Partnership include:

- A focus on the environmental conditions, management actions, and operational events in relation to species freshwater and estuarine life stages including the specifics of management actions, especially those that vary in character from year to year.
- Comparison of data to the previous 5 years.
- Identification of science needs or monitoring gaps which, if filled, could improve future assessments.

An assessment for BY2019 is presently being undertaken by the Partnership and may utilize different approaches from those proposed here. Key features of such assessments should stay consistent to provide an ongoing way of tracking system change, but new approaches may be beneficial to the Partnership and may override the facets discussed here.

Synthesis

While the findings of individual scientific endeavors provide valuable information, synthesis across studies or management actions can be an effective mechanism for greater insight into system dynamics. Synthesis can integrate not only the findings of work conducted under this Plan but other relevant scientific developments on the Sacramento River and beyond. Conceptual models are often seen as synthesis tools for capturing current knowledge in a structured manner (e.g., Windell et al., 2017), and numerical models can play a similar role if they are routinely updated as knowledge develops. However, reports and papers are one of the most common and accessible synthesis products.

Over a number of years, and in support of SDM, a series of reports could be produced for: key issues such as egg to fry survival or the benefits of floodplain inundation, important locations (e.g., the Sutter Bypass), and individual life stages or transitions (e.g., to collectively assess new developments such as those proposed in this Plan). The brood year assessments discussed above are one example and, given the extensive activity on habitat restoration in the Sacramento and continued investments, a synthesis of the effectiveness if restoration projects on the Upper Sacramento would be of value. Others include benchmark scientific reviews such as those commissioned by the Delta Science Program for the State of Bay Delta Science series, e.g., Perry et al. (2016). Identifying and prioritizing synthesis efforts requires the articulation of management needs and concerns, the availability of appropriate data and information, and the interest of scientists. The Partnership has the ability access or develop all of these and use synthesis to progressively show how shared learning can support the management of system.

Recommendations: System-Level Assessment			
#	**Type**	**Science Activity**	**Management Relevance**
26	Targeted Data Collection	Ensure routine collection of genetic markers for anadromy in Steelhead.	*Increased detection* – Identification and collection of genetic markers for anadromy in Steelhead. *Improved understanding* - Consideration of the effects of management actions on anadromous vs. resident Steelhead.

Recommendations: System-Level Assessment			
#	**Type**	**Science Activity**	**Management Relevance**
27	Targeted Data Collection	Ensure routine collection of otoliths (or scales for Steelhead) for assessment of habitat utilization.	*Increased detection* – Collection of samples/data to support assessment of habitat utilization using otoliths (or scales for Steelhead). *Improved understanding* - Quantification of survival and relative contributions of different rearing strategies.
28	Targeted Data Collection	Ensure routine collection of data needed to assess the effects of pathogens.	*Increased detection* – Collection of samples/data to support assessment of the effects of pathogens. *Improved understanding* - Establish the role of disease influencing salmonid populations.
29	Synthesis	Routinely develop summary brood year assessments.	*Improved understanding* - Ongoing transparent appraisal of species response to ambient conditions and management actions.
30	Synthesis	Develop a synthesis report on the effectiveness of restoration projects in the Upper Sacramento based on monitoring and other available data, including any lessons learned in relation to project evaluation, monitoring or implementation.	*Improved understanding* – Provide accessible information on the field-verified benefits of habitat restoration approaches, to support planning and design of future projects.
31	Synthesis	Identify, prioritize, and conduct additional synthesis efforts.	*Improved understanding* - Periodic evaluation of scientific progress, effects of management actions, and change in the system providing context for management actions and enabling the development of new science questions.

Potential for Collaboration

Existing work by a number of organizations was leveraged in identifying the scientific activities included in this Plan. The array of ongoing science spearheaded by these organizations is impressive and it provides an opportunity for the Partnership to move forward with the science activities recommended here using a collaborative approach. There are common science interests between the Partnership and the Science Integration Team (SIT) for the Central Valley Project Improvement Act, the Collaborative Science and Adaptive Management Program, and the Central Valley Salmon Habitat Partnership, for example. Each of these groups has a different mission from the Partnership but is using science to inform their work. The SIT is planning for restoration and research charters for the next five years, and the Collaborative Adaptive Management Team is developing a Coordinated Salmon Science Plan (CSSP) to be completed in 2020. While the details are still in development several common topics appear to be emerging:

- How habitat improvements benefit rearing and out-migrating juveniles is an area addressed by several of the recommended science activities. The SIT recognizes the need for information on whether juvenile habitat improvements in lower-mid and lower Sacramento River would result in increased survival, and the CSSP is interested in prey availability for juvenile salmonids across different habitats.
- Survival of fishes as they move through the system is an area where acoustic tagging has provided substantial information, and additional science activities are identified in this Plan to make use of this technology and also to detect patterns of predator abundance and whether they consume juvenile salmonids. The CCSP deems science to quantify predation mortality beneficial, and the SIT can benefit from additional survival information for use in its decision support models.

In addition, within areas of the Partnership's interest area, there are opportunities to work together, for instance on spawning and rearing habitat in the Upper River, documenting anadromy in Steelhead (both of interest to the SIT), and active management of agricultural 'floodplain' habitats (of interest to CSSP). Other organizations working in the Central Valley are also interested in additional science information that can help predict, detect, and understand the effects of management actions.

The Partnership is founded on resolving challenges through science and engages managers directly in scientific discussion, helping them to better use new information. Some of the science activities identified in this Plan are relevant beyond the mainstem Sacramento River, and the Partnership may as lead or support the work of others. It is beyond the scope of this Plan to determine those roles, and how collaborative science work should move forward. Rather, providing a list of recommended activities, and the management information to be provided, can serve as a focus for collaboration on specific topics or studies, leveraging skills, resources, and knowledge of many.

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Appendix A. Overview of Action-Effects Linkages

The magnitude of the expected benefits of management actions (green) and potential negative effects (orange) will depend on ambient conditions and the way in which the action is implemented.

Action		Potential Effect														
		Habitat			Physical Conditions			Species Response								
2019 Biological Opinion		Food prod.	Avail. /access	Refuge	Flow	Summ. Temp	DO	Pred-ation	Egg survival	Migration survival	Life hist. diversity	Health	Food access	Fecund.	Growth	Recruit-ment
Seasonal Operation	Winter Minimum Flow		orange			green			green	orange						
	Spring Base Flow		orange			green			green	orange						
	Summer CWP Tiers 1-3		orange			green			green							
Fall and Winter Refill and Redd Maintenance			orange			green			green							
Operation of Shasta Dam Raise						green			green	green						
Rice Decomposition Smoothing			green													
Spring Pulse Flow			green		green					green						
Spring Management of Spawning Locations									green							
Cold Water Pool Management	Temperature Modeling Platform								green	green						
	Shasta TCD Perf. Eval.								green	green						
	Battle Creek Restoration and Reintroduction				green	green			green	green	green					
	Lower Intakes nr. Wilkins Slough									green						
Spawning and Rearing Habitat Restoration	Spawning Gravel Injection								green							
	Side Channel Habitat Restoration		green	green				orange					green		green	green
	Small Screen Program									green						
	Knights Landing Outfall Gates									green						
Summer CWP Management: Tiers 3&4	Winter run conservation hatchery										green					
	Adult rescue									green						
	Juvenile trap and haul									green						
Voluntary Agreements (Preliminary)																
Gravel Augmentation							green		green							
In Channel Habitat				green				orange		green			green			
Riparian Habitat		green		green		green		orange		green			green			
Side Channel Habitat Restoration				green				orange		green						
Floodplain Habitat		green		green				orange		green			green			
Managed floodplain for food production																

Appendix B. Summary Table of Recommended Science Activities

Activity Number	Activity Type	Report Section	Recommended Science Activity	Management Relevance
1	Modeling	Egg to Fry Emergence – Keswick Dam to RBDD	Support the collaborative model improvement work of the Temperature Modeling Technical Committee	*Improved prediction* - Extension of the CE-QUAL-W2 modeling of Shasta Lake and Keswick Reservoir to include appropriate river models, creating a linked modeling framework to improve model predictions that assist resource managers.
2	Targeted Data Collection	Egg to Fry Emergence – Keswick Dam to RBDD	Pilot monitoring of input stream and local meteorology in the Shasta, McCloud, and Pit River arms of Shasta Lake	*Increased detection* – Greater resolution of water temperature data above Shasta Dam. *Improved prediction* - Data to validate or refine model inputs and the better incorporate the role of meteorological conditions on thermal regime of Shasta Lake and tributary inflows.
3	Targeted Data Collection	Egg to Fry Emergence – Keswick Dam to RBDD	Increase vertical resolution for temperature profiling in Lake Shasta especially in mid-to-late summer during drier years	*Increased detection* - Greater resolution of water temperature and density data within Lake Shasta. *Improved predictions* - Improved characterization of density gradients that could influence the ways in which water moves through the various gated structures.
4	Targeted Data Collection	Egg to Fry Emergence – Keswick Dam to RBDD	Conduct velocity surveys to assess dynamics around TCD gates operating individually and for blending, and surveys throughout the TCD operating season to assess how the dynamics change as the TCD is operated over time.	*Increased detection* - Greater resolution of water velocity dynamics around the TCD gates. *Improved predictions* - Improved characterization of local dynamics of withdrawal zones for TCD gates operating individually or for blending, under varying seasonal conditions.
5	Targeted Data Collection	Egg to Fry Emergence – Keswick Dam to RBDD	Supplement existing carcass and redd surveys with enhanced boat and in-water surveys, potentially focused on specific areas or environmental conditions	*Increased detection* – Additional data to support escapement and fecundity estimates. *Improved understanding* - Evaluation of critical assumptions that may bias routine field surveys and thus impact management actions reliant on the survey data.

Activity Number	Activity Type	Report Section	Recommended Science Activity	Management Relevance
6	Integrated Study	Egg to Fry Emergence – Keswick Dam to RBDD	Collaboratively plan and conduct a multi-year Integrated Study to understand how river-scale management actions translate down to the scale of the redd, e.g., detailed field measurement and model simulations of physical conditions, surveys, and field and laboratory experiments to assess biotic response.	*Improved understanding* - Evaluation of how river-scale management actions, individually and in combination, that alter flow, temperature, DO, and substrate translate down to the scale of the redd and influence redd-specific egg-to-fry survival.
7	Modeling	Rearing-Out Migrating Juveniles – Keswick Dam to RBDD	Identify, refine, and test suitable bioenergetics models for use in conjunction with flow models of in-channel and off-channel habitats.	*Improved prediction* – Promote models that support planning and evaluation of habitat restoration projects by accounting for how changes in thermal regime, flow conditions, and food availability affect fish growth. Information on the potential effects of different flow management decisions on rearing habitat.
8	Targeted Data Collection	Rearing-Out Migrating Juveniles – Keswick Dam to RBDD	Document the consequences of flow management, i.e., the magnitude of minimum flows or the rate of flow decrease, on utilization of in-stream rearing habitat (potentially expanding on stranding surveys and restoration site surveys) including sampling as flows decline.	*Increased detection* - Refined information on habitat use by juveniles. *Improved understanding* - Potential identification of thresholds in environment-use relationships to improve planning and design of habitat restoration projects.
9	Targeted Data Collection	Rearing-Out Migrating Juveniles – Keswick Dam to RBDD	Document the relative abundance and distribution of potential predators in the river above RBDD and the types of in-channel habitats with which they are associated with varying flows and environmental conditions.	*Increased detection* - Improved identification of the response of juvenile passage to flow management, i.e., predation as a potential source of non-temperature mortality. *Improved understanding* - Support planning and implementation of projects that seek to improve in-channel rearing habitats.
10	Targeted Data Collection	Rearing-Out Migrating Juveniles – Keswick Dam to RBDD	Assess the role of pathogens and disease through targeted sampling of intestinal tract samples from carcasses, and evaluation of how changes in flow conditions could disrupt polychaete habitat.	*Increased detection* - Increased appreciation of the conditions under which pathogens and disease may influence the effectiveness of management actions.

Activity Number	Activity Type	Report Section	Recommended Science Activity	Management Relevance
11	Analysis	Rearing-Out Migrating Juveniles – Keswick Dam to RBDD	Plan, support, and implement a structured approach for efficiency tests at RBDD RST across run/size, flow conditions, etc.	*Increased detection* - Increased confidence in egg-to-fry survival estimates. *Improved understanding* - Evaluation of critical assumptions that may bias routine field surveys and thus impact management actions reliant on the survey data.
12	Analysis	Rearing-Out Migrating Juveniles – Keswick Dam to RBDD	Analyze existing RBDD juvenile monitoring data to assess the relationship between flow and environmental conditions and fish passage.	*Improved understanding* - Validate current approaches to imputing data when conditions prevent RST operation.
13	Analysis	Rearing-Out Migrating Juveniles – Keswick Dam to RBDD	Continue exploration of parentage-based tag methods (PBT) to provide information on the reproductive success of individual spawners.	*Improved understanding* - Evaluation of how management actions that influence spawn timing, location, and origin (hatchery or wild) affect reproductive success. *Improved prediction*s - Potential refinement of egg-to-fry survival estimates.
14	Focused Study	Rearing-Out Migrating Juveniles – Keswick Dam to RBDD	Plan and conduct a focused study to understand predator distribution and predation in different environments of the river under varying flows and seasonal temperature condition potentially including gut analysis of predators, predation activity, and tracking predator movements with changing environmental conditions, including those associated with management actions.	*Improved understanding* - Evaluation of when and where predation mortality of salmonids can impact the success of management actions.

Activity Number	Activity Type	Report Section	Recommended Science Activity	Management Relevance
15	Integrated Study	Rearing-Out Migrating Juveniles – Keswick Dam to RBDD	Collaboratively plan and conduct a multi-year Integrated Study to understand how managed flows interact with existing and newly restored habitat features to benefit rearing fry, including detailed field measurement and model simulations of physical conditions, and surveys of habitat utilization by fry and potential predators, growth rates (non-listed species), and prevalence and potential infection rates for *C. shasta*.	*Improved understanding* – Assessment of factors influencing fry growth and predation, and the role of physical stream conditions including those influenced by flow management. *Improved prediction* – Incorporate understanding of factors into the planning and design of habitat restoration management actions.
16	Modeling	Rearing-Out Migrating Juveniles - RBDD to Verona	Identify, refine, and test suitable bioenergetics models for use in conjunction with flow models of in-channel and floodplain habitats.	*Improved prediction* - Improved planning and evaluation of habitat restoration and flow management actions by allowing planning and design to better account for how changes in thermal regime, flow conditions, and food availability affect fish growth.
17	Modeling	Rearing-Out Migrating Juveniles - RBDD to Verona	Foster communication and information sharing to support the ongoing development of the Spring-run LCM. Identify additional data or research needed to appropriately reflect the role of the mainstem Sacramento River conditions and management actions in the model, such that it could eventually be used to assess tradeoffs and support SDM.	*Improved prediction* - Ensure that the Spring-run LCM appropriately reflects the role of management actions that change conditions in the mainstem Sacramento and thus support future management decision making.
18	Analysis	Rearing-Out Migrating Juveniles - RBDD to Verona	Convene an expert group to evaluate the need for additional juvenile passage monitoring locations on the mainstem Sacramento River in relation to other potential approaches, e.g., additional measurement of survival, modeling.	*Increased detection* - Data to provide an overall assessment of how ambient conditions and management actions in the Sacramento influence outmigration (including passage through Sutter Bypass). *Improved prediction* - Support for refined JPE estimates.

Activity Number	Activity Type	Report Section	Recommended Science Activity	Management Relevance
19	Targeted Data Collection	Rearing-Out Migrating Juveniles - RBDD to Verona	Strategically plan and conduct boat-based surveys of predators to identify how predator abundance and distribution changes through different reaches of the river.	*Increased detection* – Provide greater resolution of river reach-specific predator densities. *Improved understanding* - Support for planning and implementation of projects that seek to improve in-channel rearing habitats
20	Targeted Data Collection	Rearing-Out Migrating Juveniles - RBDD to Verona	Strategically plan and conduct data collection campaigns to identify patterns of abundance of drift insects and zooplankton in association with habitat features such as side channels, bars, bank slopes, etc. Consider extending data collection to floodplains during periods of inundation.	*Increased detection* - Improved background data for planning restoration projects. Specifically, baseline data for future examination of the effects of management actions that seek to increase food resources for salmonids.
21	Targeted Data Collection	Rearing-Out Migrating Juveniles - RBDD to Verona	Conduct a series of paired releases of tagged hatchery fish into the Sutter Bypass during flooding and the adjacent Sacramento River, to detect whether passage through the Sutter Bypass increases survival for outmigrating juvenile salmonids	*Increased detection* - Documentation of the potential benefits of floodplain passage on survival or outmitgrating fish.
22	Focused Study	Rearing-Out Migrating Juveniles - RBDD to Verona	Support science to understand the effects of the spring pulse flow action including during drier conditions than those identified in the Biological Opinion.	*Improved understanding* - Evaluate the effects of the new management action under varying water year conditions, thus supporting evaluation of tradeoffs among water management benefits and impacts for different runs of salmon.
23	Focused Study	Rearing-Out Migrating Juveniles - RBDD to Verona	Plan and conduct coordinated field sampling to identify patterns of habitat use within the mainstem Sacramento, including the broader meandering reaches above Colusa and the leveed reaches above Knight's Landing, and assessment of predation potential and prey availability	*Improved understanding* - Support for bioenergetics modeling for planning and design of habitat restoration and flow management actions. *Improved prediction* - Provision of information to apply/refine decision support tools, e.g., use of IBMs, refinement of transitions in LCMs.

Activity Number	Activity Type	Report Section	Recommended Science Activity	Management Relevance
24	Focused Study	Rearing-Out Migrating Juveniles - RBDD to Verona	Plan and conduct experimental studies of the effects of actively-managed agricultural floodplain utilization on outmigrating salmonids including potential for avian predation, channelized and managed floodplain-mainstem egress on subsequent predation, and tradeoffs between enhanced growth and delays in outmigration associated with extended durations of floodplain access.	*Increased detection* – Focused monitoring of juvenile salmonid utilization of actively-managed agricultural floodplain. Improved understanding - Identification of the potential benefits and risks to salmonids of actively managed access to/use of agricultural floodplains.
25	Integrated Study	Rearing-Out Migrating Juveniles - RBDD to Verona	Collaboratively plan and conduct a multi-year Integrated Study to understand how variations in passive inundation of the Sutter Bypass influences the benefits gained, including model simulations of habitat quality, surveys of habitat utilization and potential for predation and disease, juvenile growth rates, and data to support improved modeling of habitat quality.	*Increased detection* – Focused monitoring of juvenile salmonid utilization of passively inundated floodplains. Increased understanding of the Increased understanding - Evaluation of the benefits and risks of passive access to floodplain habitats to juvenile salmon. *Improved prediction* - Information to support the refinement of predictive tools for supporting floodplain management decisions.
26	Targeted Data Collection	System-Level Assessment	Ensure routine collection of genetic markers for anadromy in Steelhead.	*Increased detection* – Identification and collection of genetic markers for anadromy in Steelhead. *Improved understanding* - Consideration of the effects of management actions on anadromous vs. resident Steelhead.
27	Targeted Data Collection	System-Level Assessment	Ensure routine collection of otoliths (or scales for Steelhead) for assessment of habitat utilization.	*Increased detection* – Collection of samples/data to support assessment of habitat utilization using otoliths (or scales for Steelhead). *Improved understanding* - Quantification of survival and relative contributions of different rearing strategies.
28	Targeted Data Collection	System-Level Assessment	Ensure routine collection of data needed to assess the effects of pathogens.	*Increased detection* – Collection of samples/data to support assessment of the effects of pathogens. *Improved understanding* - Establish the role of disease influencing salmonid populations.

Activity Number	Activity Type	Report Section	Recommended Science Activity	Management Relevance
29	Synthesis	System-Level Assessment	Routinely develop summary brood year assessments	*Improved understanding* - Ongoing transparent appraisal of species response to ambient conditions and management actions.
30	Synthesis	System-Level Assessment	Develop a synthesis report on the effectiveness of restoration projects in the Upper Sacramento based on monitoring and other available data, including any lessons learned in relation to project evaluation, monitoring or implementation.	*Improved understanding* – Provide accessible information on the field-verified benefits of habitat restoration approaches, to support planning and design of future projects.
31	Synthesis	System-Level Assessment	Identify, prioritize, and conduct additional synthesis efforts	*Improved understanding* - Periodic evaluation of scientific progress, effects of management actions, and change in the system providing context for management actions and enabling the development of new science questions.