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Spring Management of Spawning Locations Research Strategy

Central Valley Project, California
California-Great Basin Region

Prepared by
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Introduction

This Spring Management of Spawning Locations Research Strategy is designed to establish research to determine if providing colder water in April and May induces earlier peak spawning of Sacramento River winter-run Chinook salmon (SRWC), or if warmer temperatures during this period induces later peak spawning for WYs 2022-2029. The Upper Sacramento Scheduling Team (USST) developed this Research Strategy to improve collaborative implementation of Spring Management of Spawning Locations Conservation Measure included in the U.S. Bureau of Reclamation (Reclamation) and the California Department of Water Resources (DWR) Proposed Action for the Long-term Operations of the Central Valley Project (CVP) and State Water Project (SWP) implemented through Reclamation’s Record of Decision (ROD), dated February 19, 2020. The ROD implements Alternative 1 (Preferred Alternative) as described in the Final Environmental Impact Statement (EIS). Alternative 1 was the Proposed Action consulted upon and analyzed in the Biological Opinions issued in October 2019 by the U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS).

The Upper Sacramento Scheduling Team includes technical staff from the National Marine Fisheries Service (NMFS), California Department of Fish and Wildlife (CDFW), U.S. Bureau of Reclamation (Reclamation), California Department of Water Resources (DWR), U.S. Fish and Wildlife Service (USFWS), and State Water Resource Control Board (SWRCB) with an interest in the Spring Management of Spawning Locations Research Strategy. Technical staff have designed a multiyear approach to help evaluate the potential survival and productivity benefits for winter-run Chinook salmon on the Sacramento River. Other work teams involved in this effort will include but are not be limited to, the Sacramento River Temperature Task Group (SRTTG), Sacramento River Science Partnership, and the Water Operations Management Team (WOMT).

Problem Statement

Modeling indicates that the peak spawn timing of SRWC may be influenced by water management decisions that are intended to conserve cold water for use during the summer temperature management season (Johnson et al. 2017; Windell et al. 2017). Annually, the start timing of SRWC spawning is relatively constant while the peak varies year to year – with cool springtime water temperatures associated with earlier peak spawning, and warm springtime temperatures associated with later peak spawning (Hendrix et al. 2017, Jennings and Hendrix 2020). Specifically, there is evidence that higher April and May water temperatures correspond to increased and delayed peak spawning in July and August. The model using both April and May temperatures as cofactors had the best fit to the observed female spawner data (Jennings and Hendrix 2020). In their historic spring-fed stream habitat, cool spring temperatures are hypothesized to trigger earlier peak in spawning to ensure sufficient time for egg maturation. Conversely, historically (pre-dam), later peak spawning in warm years could have resulted in later peak emergence; this could mean the juvenile fish experienced lower temperatures upon emergence reducing egg and alevin mortality.

However, a cause-and-effect relationship between water temperatures during pre-spawn staging and the timing of peak spawning has not been demonstrated. Randomized experimentation should be used to determine whether manageable changes in water temperatures during the period of pre-spawn staging directly cause changes in the spawn timing of winter-run Chinook salmon and, if so, the level of covariation between these variables. Findings from these investigations may explain a direct linkage between temperature management and SRWC reproductive performance on the Upper Sacramento River (NMFS 2014, Reclamation 2019), as evidence suggests reproductive success is variable (Blankenship et al. 2020). In light of this potential relationship, two possible management strategies are suggested by Jennings and Hendrix (2020):

> *To mitigate winter-run Chinook egg and alevin mortality during drought years, two possible strategies for cool-water management are: (1) release cool water early (April-May) to drive the peak of winter-run spawning earlier in an attempt to achieve emergence from gravel before temperatures increase; or (2) hold cool water until later in the season, when the bulk of spawners begin to deposit eggs… ultimately, models that combine reservoir management dynamics with SRWC spawning and egg incubation will be necessary to understand how reservoir management might affect spawn timing, egg and alevin development, and egg-to-fry survival under various climate conditions.*

Objective & Approach

This Research Strategy identifies a plan for study design, implementation, and reporting related to the Spring Management of Spawning Locations Charter. The goal is to establish research to determine (a) whether providing colder water releases earlier in the year induces earlier peak spawning, or if warmer April/May Sacramento River temperatures induce later peak spawning and (b) if so, how to implement research results to improve temperature management (e.g., identifying and evaluating necessary potential actions and/or modifications to improve temperature management) and consequently reproductive success/population viability of SRWC.

Note that the conservation measure is titled as spawning locations but specifies actions related to spawning timing. Since these two factors are related (for example, similar temperatures could exist downstream early in the Spring but be limited to upstream later in the Summer), the Charter document specified that the objective is to understand both spawn timing and locations.

This research strategy recommends a phased approach to better understanding the relationship between water temperatures during winter-run Chinook salmon staging and the timing of peak spawning.

1) Implement necessary studies to determine whether a functional (cause and effect) relationship exists and what is the nature and strength (variability) of that relationship.
2) Develop analytical tools to evaluate potential management opportunities that could use the functional relationship (if it exists) to benefit the reproductive success of winter-run Chinook salmon. This phase of the investigation may involve assessments of the interaction between multiple life stages with different water operation scenarios.

The first phase of the research strategy could include a literature review or analysis of temperature data and information to assess effects to Chinook salmon migration timing. Another initial step could include manipulative, randomized experimentation to evaluate the relationship between water temps during adult staging and spawn timing. Such a study's objective would be to demonstrate a cause-and-effect relationship through a controlled, manipulative experimentation in a captive environment, such as a hatchery, where individual fish can be randomly assigned to treatment groups consisting of different water temperatures.

Modeling will be an important tool for the second phase of the proposed research strategy. Modeling operational scenarios will help plan the action by estimating the potential effect(s) of operational actions on smolts survival across different hydrological conditions. Modeling will also be used to evaluate any potential increases to winter-run Chinook salmon temperature-dependent mortality (TDM) and estimate potential decreases in the Shasta Reservoir Cold Water Pool (CWP) as a result of different operational actions. The modeling may also consider possible impacts to pre-spawn mortality from running warmer earlier in the season. An evaluation of the modelling tools will be assessed by comparing predictions with monitoring data which will be documented in Reclamation's Shasta Cold Water Pool Seasonal Report or/and Shasta Storage Rebuilding Seasonal Report.

Improving models and decision-support tools will help evaluate tradeoffs of implementing different scenarios. In 2021, these improvements will include:

- Integrate a WRCS spawn timing predictor tool based into the SacPAS Fish Model to better evaluate effects of proposed operation scenarios.
  http://www.cbr.washington.edu/sacramento/fishmodel/
  http://www.cbr.washington.edu/sacramento/fishmodel/redd.forecasting.pdf
- Confirm model assumptions for carcass observations (e.g., how many carcasses per redd and timing offset).
- Integrate historical WRCS carcass data into SacPAS Fish Model and CVTEMP TDM models. Carcass data is oftentimes a better representation of the spawning distribution than redd data, which may not detect redds that cannot be viewed from the aerial surveys.

Conceptual Model & Additional Supporting Research

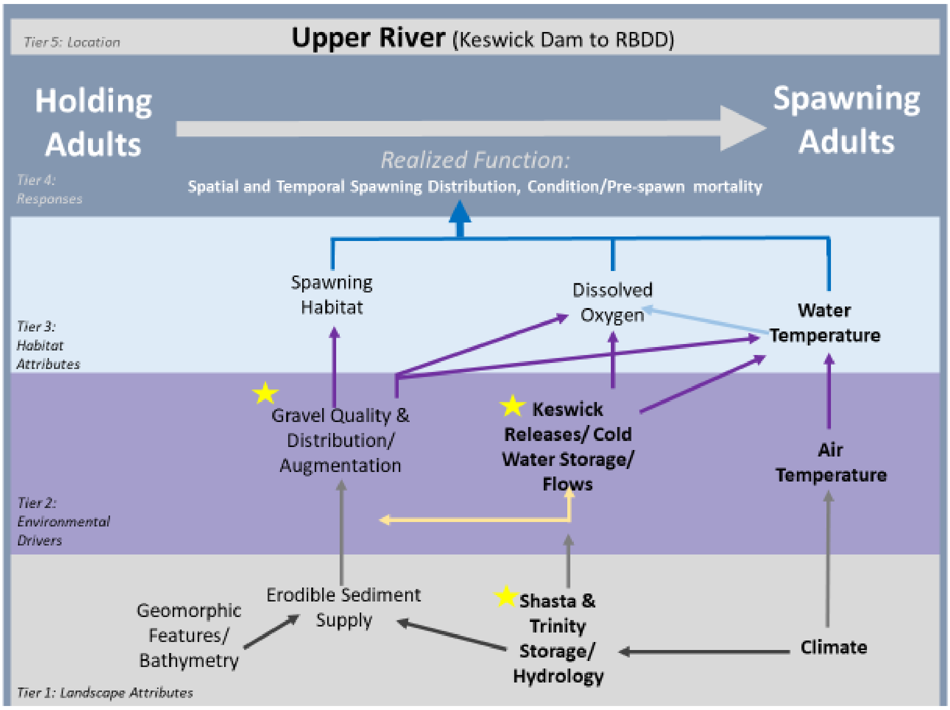

Figure 1. Hypothesized conceptual model to describe factors affecting spawning distribution adapted from SAIL effort (Windell et al 2017).

The conceptual model in Figure 1 helps to illustrate some of the hypothetical and known relationships described below.

<u>Factors that affect water temperatures</u>

- Primary influencing factors: Water temperatures are influenced by dam discharge temperature (particularly upstream), air temperature (more so downstream), and solar radiation (Daniels & Danner, 2020). Climate affects Shasta and Trinity Reservoir storage. Shasta and Trinity storage affects Keswick releases, cold water pool and flows. Air temperature in combination with Keswick releases, cold water pool and flows affects water temperature.
- On a finer scale, gravel and riparian habitat can provide cooler water temperatures (Burkerholder et al. 2008).

<u>Water temperature affects spawn timing:</u>

- Providing cooler water could induce earlier spawn timing. Redds that are exposed to cooler temperatures take longer to emerge and are susceptible to threats in the Upper Sacramento River for a longer period of time.
- Providing warmer temperatures could delay spawning and contribute to pre-spawning mortality. Delaying spawning could push the majority of WCRS fry emergence dates into fall time period when CWP runs out and can no longer manage temperatures.

Water temperature affects juvenile emergence timing

- Juvenile emergence timing is dependent on water temperature during egg and fry development in the redd. Eggs and fry in cooler water take longer to develop than those in warmer water. However, water temperatures above 53.5 degrees Fahrenheit can result in egg/fry temperature dependent mortality. Winter-run juvenile emergence timing can take up to 100 days in cool temperatures. In warmer temperatures emergence timing can vary considerably for winter-run but for emergence periods less than 84 days there are likely to be some temperature dependent mortality impacts.

Water temperature affects spawning distribution:

- Providing cooler water temperatures to a smaller spatial extent may limit spawning spatial distribution; however, managing to a larger spatial extent would result in using up more cold water pool and would likely reduce the ability to manage cooler temperatures to provide suitable temperature for a longer time period.
- Providing cooler water temperatures to a smaller spatial extent may result in increased redd superimposition if spawning habitat is limited spatially or temporally.

Factors related to heritable traits:

- Within a generation, climate, water operations, hatcheries, harvest, and other factors may select for WRCS that experience only specific run timing and spawn timing. For instance, there could be adverse effects when those fish return and are exposed to water temperature regimes that are different than what their parents experienced. A mechanism linking spring water temperatures and spawn timing is unclear, as the capacity for the WRCS holding spawners to respond to spring temperature changes has not yet been characterized in a controlled experimental setting.
- Statistical modeling shows that a temperature covariate has a meaningful relationship to peak spawning timing, which may influence reproductive success of individuals and the population.
- Reaction norms (i.e., range of phenotypes expressed by genotypes along an environmental gradient) of the WRCS population’s thermal tolerance may not encompass the range in temperatures that population is expected to experience.
- Information on quantitative diversity that selection can act upon to move the mean value of population trait is lacking. Little is known about “quantitative diversity”, which is the category of diversity that pertains to complex traits, and selections experiments have not been conducted, so the capacity of WRCS to respond to temperature changes through genetic, epigenetic, and/or phenotypic plasticity is not well characterized.

During the second phase of the research strategy, hypothetical tradeoff scenarios may include preserving cold water until peak spawning and emergence occurs to reduce TDM impacts to early life stages. At certain warm temperatures, pre-spawn mortality may occur.

Annually, real-time operations monitoring will be implemented to measure biological and operational responses relevant to evaluating the relationship between spring water temperatures and spawning timing and location. These include spawning timing, spawner condition, redd location, water temperatures, and egg-to-fry survival.

Reports as part of this multiyear Research Strategy will communicate the operational effects of the water and temperature management actions taken for managing WRC spawning and other observed biological and ecological responses. Modeling and decision support tools can highlight the magnitude of uncertainty related to mechanisms behind spawn timing that may warrant experiments to better understand the potential impacts of managing spawning behavior.

The primary objective of these activities will determine if keeping water colder earlier induces earlier spawning, or if keeping April/May Sacramento River temperatures warmer induces later spawning. It would be valuable to be able to identify and quantify if spawning timing contributes to or limits reproductive success to better assess proportional sources of mortality by separating pre-spawning water temperature effects from other variables (e.g., thiamine deficiency, incubation temperatures, redd superimposition, habitat restoration, water quality, hatchery effects, etc.). The research strategy may support learning about reproductive success, more broadly, as an additional objective.

The USST study planning team identified the following to address the primary objective:

- Summarize available literature on thermal tolerance for adult SRWC to understand drivers of spawning behavior, gamete viability, epigenetics, and prespawning stress/mortality.
- Experimentation to evaluate effects of water temperatures on spawning timing of winter-run Chinook salmon.
- Review available data and/or measure Shasta spring operations effects of temperatures on adult Chinook salmon (e.g., pre-spawning stress/mortality, changes in spatial and temporal spawning distribution). May include acoustic telemetry study of adult behavior or observations from carcass survey.

The USST study planning team identified the following to address uncertainties about reproductive success and its relationship to spawning timing:

- Calculate SRWCS birth date distributions, which could be accomplished by otolith analyses of juvenile Chinook salmon collected at Red Bluff Diversion Dam (RBDD). This would provide information on whether there was disproportionate survival of progeny from the temporal distribution of adult spawners (e.g., early vs. late spawning). Genetic method could also help test for disproportionate survival of progeny from early vs late spawning females.
- Genetic analyses (i.e., parentage and relatedness approaches of adults and juveniles) to see which juveniles survive from which spawning adults (specifically associated with spawning location, time, sex, and origin).
- Reconstruction of temperature histories of juveniles at RBDD or returning adults to assess the temperatures individuals experienced at emergence. Oxygen isotope measurements in otoliths can provide this temperature reconstruction. Paired with

thermal landscapes, one can assess mortality (lack of representation) of individuals sampled at a later point in time.

Winter-run Chinook salmon Spawn Timing and Location Workflow

Need	**Models**	**Status** Designated for near-term implementation in Study Plan?	**Monitoring/Experiments (for validation of model(s))**	**Status**	**Notes**
Forecast river habitat conditions for upcoming management season	Temperature and flow models	Established	N/A	N/A	Determines options for temperature management
Forecast number of spawners for upcoming management season[1]	WR escapement forecast	Available in March from PFMC (not sure appropriate precision) -- follow up needed	N/A	N/A	Required to capture any density dependent effects
Reproductive success - adults: pre-spawn mortality associated with temperature[1]	?	Needed	Conduct hatchery experiment on adults held at different temperatures and document spawn timing/gamete development/disease	Needed	N/A
Spawn timing[1]	Dusek Jennings and Hendrix	Established, but not in an operational/ forecasting sense, and for timing only (on SacPAS).	Conduct hatchery experiment on adults held at different temperatures and document spawn timing/gamete development/disease	Needed	N/A
Spawn timing[1]	SacPAS Predictor Tool	Needed (identified for implementation in study plan)	Confirm model assumptions for carcass observations?	N/A	N/A
Spawn timing and location[1]	Bayesian statistical framework, potentially incorporating Resource Selection Function (Dudley at al. 2021)	In development at SWFSC	N/A	N/A	N/A
Reproductive success - eggs: forecast impacts of timing/location on egg survival	TDM egg models	Established	Otolith back-calculation of hatch date distributions in juveniles at RBDD. This would quantify the extent to which early vs late spawners did not produce progeny in a given year. Parentage Based Tagging. Genotypes of early vs. late spawning carcasses compared to juveniles at RBDD	Otolith back-calculation (Needed); PBT funded to Cramer by Sacramento River Settlement Contractors, also source of an Ad hoc committee with the SRSP.	N/A
Reproductive success - temperature impacts	TDM egg models	Established	Otolith temperature reconstructions of winter run survivors [adults] in droughts and wet years. Can follow this BY2021 cohort into escapement to test the temperatures that survivors experienced linked to temperature model to quantify temperature landscape vs. survival landscape	Established (R. Johnson) with funding by State Water Board	N/A
Determine population level impacts	WRLCM	Established	N/A	N/A	N/A

- [1]*Indicates focus of the sub-team.*

Schedule

To implement this research strategy, a phased schedule of identified milestones has been developed. Reclamation will coordinate with NMFS and other stakeholders [e.g., through SRTTG, Sacramento River Science Partnership (SRSP), Upper Sacramento Scheduling Team (USST), etc.] to:

- Phase 1: Evaluate hypotheses relating spring temperatures to spawning timing to further describe the significance of the relationship between temperature and the population response of interest. This activity will be done through metanalysis of existing studies and data. This will examine existing information for fishery and water management literature related to thermal tolerance for adult salmonids (specifically SRWC, when available) to understand relationship to spawning behavior, gamete maturation, and spawning timing.
- Phase 2: Based on findings from Phase 1, consider experiments to understand relationships between spring temperatures and winter-run Chinook spawning timing as part of competitive science solicitation processes for informing Sacramento River fish and water management.
- Integrate findings from both phases into decision support tools to assess potential impacts to SRWC in a structured, systematic approach that evaluates tradeoffs associated with different operations scenarios.

Date	Milestones
June 2021	Identify Technical Team Membership (Completed)
June 2021	Identify all necessary Federal and state environmental requirements.
September 2021	Integrate a WRCS spawn timing predictor tool into the SacPAS Fish Model to better evaluate effects of proposed operation scenarios.
November (2021-2023)	Reporting of brood year 2020-2022 PBT results to evaluate spawner success
December 2021	Request that the LTO interagency group review this Research strategy.
December 2021	Review and seek input on SacPAS spawning distribution tool. http://www.cbr.washington.edu/sacramento/fishmodel/redd.forecasting.pdf
Annually, beginning in December 2021	Update information in seasonal report (e.g., Shasta Cold Water Pool Seasonal Report (December) and/or Shasta Winter Refill Seasonal Report (June) regarding activities, results, and evaluation of the spring temperature management study.

Date	Milestones
Spring – Summer 2022	Develop metanalysis study plan for reviewing literature and data to evaluate hypothesized relationship between seasonal pre-spawning temperature and spawning
September 2022	Initiate meta-analysis of literature and data
September 2023	Meta-analysis report to the LTO Coordination Group
2024	Consider Phase 2 activities through competitive science solicitation.
2024	Consider as potential topic for 4-year review panel
2028	Consider as potential topic for 8-year review panel

Funding Disclaimer: Nothing in this Plan is intended or shall be construed to authorize or require the obligation, appropriation, reprogramming, or expenditure of any funds by any Member. Pursuant to the Anti-Deficiency Act, 31 U.S.C. 1341, 1342, and 1517, all commitments made by Federal signatories to this Charter are subject to the availability of appropriated funds. Any funding commitment or services, if pursued, will be handled in accordance with applicable laws, regulations, and procedures.

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