Long-Term Operation – Initial Alternatives

Appendix O – Tributary Habitat Restoration

Central Valley Project, California

Interior Region 10 – California-Great Basin

U.S. Department of the Interior

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Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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1. Introduction

Tributary habitat restoration addresses spawning and rearing habitat on the Sacramento River, American River, Stanislaus River, and Clear Creek. Project activities primarily include side channel and floodplain creation, expansion, and grading, spawning gravel and large cobble additions, and woody material additions.

The U.S. Bureau of Reclamation (Reclamation)'s management questions for the formulation of an alternative include the following.

- Where is a tributary habitat limitation affecting life stages?
- Does habitat restoration increase primary and secondary productivity and improve growth?
- Does habitat restoration provide refuge habitat and improve survival?
- How does habitat restoration affect operations for flood conveyance, water supply, water quality, and/or hydropower?
- Where can connectivity be restored to provide fish access to suitable habitats and reduce potential habitat restoration needs downstream?

Reclamation has authorities for habitat restoration, most specifically through the Central Valley Project Improvement Act (CVPIA), Public Law 102-575.

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2. Performance Metrics

Performance metrics describe criteria that can be measured, estimated, or calculated relevant to informing trade-offs for alternative management actions.

2.1 Habitat

- Suitable spawning habitat for salmonids and steelhead
- Suitable rearing habitat for salmonids and steelhead

2.2 Biological

Biological metrics consider direct observations and environmental surrogates including the following.

- Juvenile Chinook salmon and steelhead
    - Individual growth rates
    - Rearing survival
    - Life-history diversity, as measured by variabilities in growth (i.e., length and weight) and movement

2.3 Water Supply

Water supply metrics consider the possibility of multipurpose beneficial uses of tributary habitat restoration, including the following.

- South-of-Delta agricultural deliveries (average and critical/dry years)
- Sacramento river settlement contractor and CVPIA refuge deliveries
- *Bay-Delta Water Quality Control Plan* (Bay-Delta Plan) (D-1641) standards (SWRCB 2000)

2.4 National Environmental Policy Act Resource Areas

Analysis of the range of alternatives, as required by the National Environmental Policy Act is anticipated to describe changes in multiple resource areas. Key resources are anticipated to include: surface water supply, water quality, air quality, aquatic resources, terrestrial biological resources, regional economics, land use and agricultural resources, recreation, cultural resources, hazards and hazardous material, and climate change.

3. Methods

In spring 2022, Reclamation solicited input for two knowledge base papers, *Central Valley Tributary Habitat Restoration Effects on Salmonid Growth and Survival* and *Summer and Fall Habitat Management Actions on Delta Smelt Growth and Survival*, included as attachments. Knowledge base papers compile potential datasets, literature, and models for analyzing potential effects from the operation of the Central Valley Project (CVP) and State Water Project (SWP) on species, water supply, and power generation.

3.1 Datasets

The Upper Sacramento River Anadromous Fish Habitat Restoration Program restoration and monitoring dataset has been used to evaluate the growth, survival, and life-history diversity of juvenile Chinook salmon and steelhead. Monitoring datasets can be found at the Red Bluff Fish and Wildlife Office, U.S. Fish and Wildlife Service website (doi.net).

3.2 Literature

Tributary habitat restoration can affect the growth, survival, and life-history diversity of Central Valley Chinook salmon. Examples of tributary habitat restoration in the Sacramento River and San Joaquin River basins include creation of new habitat through excavation (e.g., creation of new side channels in the Sacramento River), adding more substrate to existing habitat (e.g., gravel augmentation), and increasing the frequency of floodplain inundation through hydrologic alterations (Bay-Delta Office, U.S. Bureau of Reclamation 2021). Figure 1 (below) provides a conceptual model for effects of habitat conditions on fish responses during the transition from rearing to outmigrating in upper river systems. Tributary habitat restoration is expected to influence aspects of habitat conditions, including turbidity, shallow-water habitat, and food production and retention.

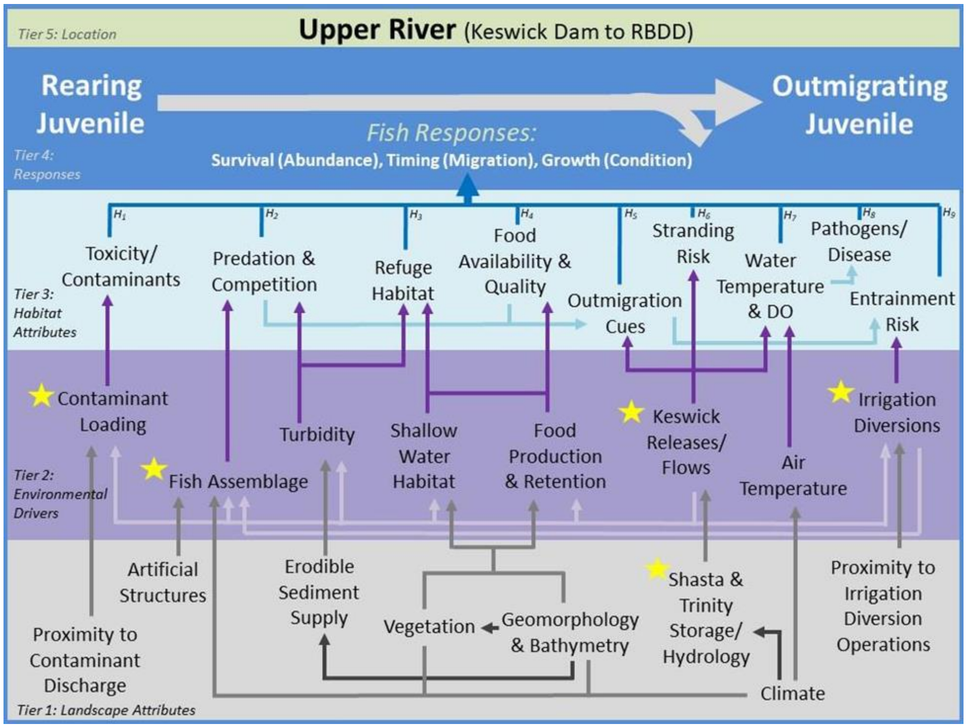

Figure 1. Conceptual model of attributes affecting the transition of winter-run Chinook salmon from rearing in Upper River habitats (i.e., in this case, tributaries) to outmigration (copied from Windell et al. 2017).

Based on this conceptual model, increasing habitat availability and heterogeneity through restoration has the potential to increase salmon survival by providing refuge habitat from predators and adverse environmental conditions. Potential increases in food production and retention also can positively affect rearing survival.

Habitat restoration can affect juvenile salmon growth as well through effects on food production and retention. For example, creation of new floodplain habitat can increase local growth rates, given observed differences in food production and growth between floodplain and channel habitat (Jeffres et al. 2008). Gravel augmentations also can increase observed macroinvertebrate biomass (Merz and Chan 2005). Constructed side channels can create new food resources capable of being utilized by juvenile salmon (Heady and Merz 2007).

Habitat restoration also can support greater life-history diversity. For example, floodplain habitats have been observed to support greater life-history diversity, based on observations of size variability in the Yolo Bypass as a function of inundation period and temperature variability (Goertler et al. 2017). Habitat restoration can more broadly influence phenotypic and life-history expression by modifying the distribution of resources (Watters et al. 2003).

3.3 Models

3.3.1 Egg-to-Fry Survival and Temperature-Dependent Mortality

The Martin et al. (2017) or Anderson et al. (2022) models can be used to predict egg-to-fry survival as a function of temperature-dependent egg mortality, background mortality, and density-dependent mortality. Both models specify egg mortality as a function of temperature, applied over either the entire embryonic developmental period or only part of it, based on an estimated minimum temperature at which no temperature-dependent mortality occurs and a slope term that describes how much increasing temperatures above the minimum affects egg mortality. Density-dependent mortality is specified following the Beverton-Holt function, with a corresponding carrying capacity–density term. Model parameters were estimated using known redd locations, estimated temperatures, and annual estimates of egg-to-fry survival (Poytress 2016). The model can be run using the Sacramento Prediction and Assessment of Salmon (SacPAS) fish model (http://www.cbr.washington.edu/sacramento/fishmodel/). Estimation of temperature-dependent mortality in current and reintroduction-based spawning reaches can inform viability of existing habitat upstream of existing barriers to support successful reintroduction.

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4. Lines of Evidence

4.1 Where is a tributary habitat limitation affecting life stages?

The CVPIA Science Integration Team developed decision-support models to optimize habitat-restoration actions among the Sacramento River, San Joaquin River, and associated tributaries (Peterson and Duarte 2021). Potential habitat-restoration actions included additions of spawning habitat, perennially inundated rearing habitat (i.e., channels), and seasonally inundated rearing habitat (i.e., floodplain), which were assumed to be inundated two months per year, with annual inundation probability of 0.67. Decision analyses showed that restoration of either spawning or in-channel rearing habitat was optimal under most evaluated conditions. Furthermore, the optimal restoration activities consistently included juvenile habitat restoration, either on the mainstem Sacramento River or Clear Creek, suggesting that habitat limitation more strongly affects salmon production in these systems. In the decision-support models, rearing habitat quantity determined juvenile carrying capacity; if carrying capacity is exceeded in a given tributary, then all remaining juveniles are assumed to migrate downstream, with some corresponding migratory mortality.

Estimates of habitat availability in the decision-support models were developed using Flow Incremental Methodology and floodplain hydraulic-modeling studies to relate flows to corresponding suitable area relationships (e.g., Matella and Merenlender 2015).

The table below shows priority actions identified by the CVPIA program to address limiting factors in Central Valley watersheds with a focus on watersheds with Central Valley Project facilities.

Near-Term Restoration-Strategy Action	Chinook Runs Primarily Benefiting
Action 1: Juvenile habitat restoration in mainstem Sacramento River above the American River confluence	All
Action 2: Ephemeral nonnatal tributaries reconnection below Keswick Dam to the mainstem Sacramento River	Winter
Action 3: Juvenile habitat restoration in Battle Creek in winter-run juvenile rearing locations	Winter
Action 4: Juvenile habitat restoration in American River	Fall
Action 5: Juvenile habitat restoration in the Stanislaus River, downstream through the San Joaquin River at Vernalis	Fall
Action 6: Juvenile habitat restoration in Clear Creek	Spring, Fall
Action 7: Survival improvement in Butte Creek in downstream areas	Spring, Fall
Action 8: Juvenile habitat restoration in the lower Feather River, below the confluence of the Yuba River	Fall, Spring

Near-Term Restoration-Strategy Action	Chinook Runs Primarily Benefiting
Action 9: Maintaining existing spawning habitats in Upper Sacramento, American, and Stanislaus Rivers and Clear and Butte Creeks	All

4.2 Does habitat restoration increase primary and secondary productivity and improve growth?

If habitat restoration includes construction of seasonally inundated floodplain habitat, then restoration can increase primary and secondary productivity and improve growth based on studies of growth rates in floodplain and in-channel habitats (Jeffres et al. 2008). Estimated juvenile growth in seasonal floodplain habitat can be twice that observed in perennial habitat (Sommer et al. 2001).

The effects of perennially inundated habitat restoration on productivity and growth are less clear. The Upper Sacramento River Anadromous Fish Habitat Restoration Project conducts habitat restoration for spawners and rearing juveniles in the Upper Sacramento River and monitors conditions after restoration (Banet et al. 2021). Monitoring of several side-channel restoration projects observed no clear differences in growth rates among restoration and control of side channels. However, Chinook salmon sampled from restoration sites tended to exhibit greater fork lengths than seen at mainstem sites, which could suggest either increased growth rates or differential habitat use by different size classes. More recent side-channel monitoring observed higher macroinvertebrate abundance in restored side channels than seen in baseline channel habitats (Banet et al. 2022). Monitoring of a side-channel restoration project in the Lower Mokelumne River observed rapid colonization of newly created habitat by macroinvertebrates and habitat use by juvenile steelhead and Chinook salmon, but did not compare fish or invertebrate densities to control sites (Heady and Merz 2007). Comparison of growth rates among multiple rearing habitats in the lower San Joaquin River revealed lower growth rates in main-channel habitat and suggested that enhancements in habitat productivity may be necessary in these regions (Zeug et al. 2019). Spawning-habitat restoration via gravel augmentation also can increase observed macroinvertebrate biomass, but effects on growth are less clear (Merz and Chan 2005).

4.3 Does habitat restoration provide refuge habitat and improve survival?

The scientific literature suggests that fish response to restoration varies greatly, depending on the watershed template, location, and characteristics of the habitat restoration and the life history of and limiting factors for a species, thus adequately determining whether changes in fish abundance observed in a restored area are due to increased movement or survival, or whether the amount of restoration will require detailed monitoring of these factors simultaneously (Roni 2018).

Results obtained from monitoring-habitat projects in the Upper Sacramento River (Keswick to Red Bluff area) Anadromous Fish Habitat Restoration Project from 2015–2021 show that the work effectively produced additional high-quality juvenile salmonid habitat that supports greater numbers of fish (Banet et al. 2022). The effects of restoration on fish size and condition varied between runs when looking at limited seining data. Higher abundance of macroinvertebrates (determined by sampling rate) observed in restored side channels, as compared to baseline channels, suggests that restoration may have a positive effect on food availability, although biomass and diet information were unavailable (Banet et al. 2022).

4.4 How does habitat restoration affect operations for flood conveyance, water supply, water quality, and/or hydropower?

Habitat restoration is constrained by flood conveyance, water supply, water quality, and hydropower and can contribute to increasing the flexibility of each factor. For example, the flood-conveyance baseline continually changes as river beds downgrade from sediment movement without replacement. The downgraded condition becomes the new baseline for subsequent habitat projects, which limits the scope of the project. When habitat projects can expand flood conveyance laterally, they can increase habitat, while maintaining and potentially increasing conveyance capacity. These same projects can increase the amount of time water remains on streamside areas, which increases groundwater storage for the future.

Habitat projects can be designed to provide suitable habitats at flow regimes with less variability than the historic habitats experienced. Downcutting of river mainstems has disconnected off-channel habitat, such as side channels and floodplains. New habitats can be developed to inundate in lower-flow conditions and result in a reduced need for water to maintain suitable habitats.

Habitat restoration can improve water quality by providing backwater areas for suspended sediment to settle out, resulting in cleaner water and fertile soils for establishment of riparian vegetation. Habitat restoration in the form of assisting fish passage to previously inaccessible cool-water areas can reduce the need for power bypasses at times when cooler water is needed to keep below-dam fish alive. Allowing fish to live in native habitats can free up water downstream from dams that would otherwise be needed to provide habitat in those areas.

4.5 Can connectivity be restored to provide fish access to suitable habitats and reduce potential habitat restoration needs downstream?

High water temperature is a factor that habitat restoration downstream of dams has not yet been able to ameliorate. If fish are not able to reproduce successfully in warm water, then habitat-restoration projects will not be able to successfully perpetuate the species. Therefore, fishery agencies and tribes are studying how native salmonids will survive with assisted migration to and from areas currently inaccessible to the fish. First year results show successful egg incubation in streamside incubators, even under high turbidity conditions, and successful migration to downstream reservoirs. Options for capturing fish are being tested, and a portion of the fish surviving have been assisted in their migration to the lower reaches of the river. Initial results are promising and, as studies continue, processes can likely be improved, such that, particularly in dry years, these upstream areas can maintain the populations without the use of additional hatchery facilities and fuel-intensive water coolers to keep species alive.

Preliminary analyses that Reclamation conducted compared estimates of expected temperature-dependent mortality for winter-run Chinook salmon eggs and alevins among four regions in the Upper Sacramento River and nearby tributaries: (1) below Keswick Dam–Above Clear Creek site; (2) in Battle Creek–Above Digger Creek site; (3) above the Shasta Reservoir–Box Canyon site; and (4) in the McCloud River–approximately 5 miles downstream of McCloud Dam. The last three regions represent areas for salmon introduction above currently impassable barriers to migration. This analysis can inform expected survival of incubating eggs and embryos as a function of region-specific water temperatures. Analyses compared stage-independent temperature-dependent mortality (i.e., Martin et al. 2017) for one critical (2014) and one below normal (2016) water year type, assuming identical run timing among all regions based on aerial redd surveys below Keswick Dam and using default model parameters from SacPAS. Analysis results show that spawning regions in the McCloud River and above Shasta Reservoir have historical temperature profiles that are expected to produce similar or lower temperature-dependent mortality than those in Battle Creek or below Keswick Dam (Table 1). Greater summer temperatures in Battle Creek produced the highest estimates of temperature-dependent mortality in both years. Although temperatures below Keswick Dam are intensively managed to stay below set thresholds to protect winter-run Chinook salmon, no such management occurs in the other regions. Past results show successful migration of larger juveniles through reservoirs and power systems and survival to the ocean under high-flow conditions (Plumb et al 2019).

Table 1. Estimated temperature-dependent mortality for winter-run Chinook salmon, expressed as a proportion, in 2014 (N=127 surveyed redds) and 2016 (N=18 redds) for current spawning habitat below Keswick Dam and three potential reintroduction sites.

Site	2014 Estimate of TDM	2016 Estimate of TDM
Below Keswick	0.914	0.008
Battle Creek	0.976	0.964
Above Shasta	0.236	0.343
McCloud River	0.093	0.040

TDM = temperature-dependent mortality.

5. Conclusions

- Decision analyses suggest that tributary habitat-restoration actions, primarily focused on the addition of spawning or perennial rearing habitat in the mainstem Sacramento River and Clear Creek, can address habitat limitations and improve population productivity in these watersheds.
- Restoration of floodplain rearing habitat can result in increased prey resources and greater fish growth, compared to perennially inundated habitat, during periods of flooding. Restoration of perennially inundated habitat, including side-channel habitat, can provide similar prey abundances and fish growth rates to neighboring side channels and mainstem habitat and increase the total amount of suitable habitat available.
- Direct effects of tributary habitat restoration on rearing and migratory survival are poorly understood. However, high densities of fish in restored habitat sites suggest that restored habitat can provide quality rearing habitat for juvenile salmon and steelhead. Furthermore, increasing rearing habitat availability may decrease negative density-dependent effects on growth and outmigration timing.
- Habitat restoration projects that are designed to expand flood conveyance laterally and flood at lower-flow conditions can reduce the river flow required to inundate floodplains, maintain or increase flood conveyance, increase groundwater storage, and potentially increase settling of sediments and riparian vegetation recruitment.
- Expected effects of providing fish access to habitats upstream of existing barriers on reducing the need for downstream habitat restoration are unknown. Preliminary incubation and spawner translocation efforts have been conducted in Battle Creek and upstream of Shasta Reservoir. Temperature conditions for survival of eggs and alevins appear suitable above Shasta and in the McCloud River, but may be too high in Battle Creek.

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