Southwest Fisheries Science Center Decadal Strategy for Pacific Salmon Recovery Science

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Introduction

The Southwest Fisheries Science Center (SWFSC) has a broad research and service portfolio shaped to meet its obligations under the Magnuson-Stevens Fisheries Conservation Act (MSA), the US Endangered Species Act (ESA), other federal laws and international treaties. We actively engage with fishery and related resource managers through our support of the Pacific Fishery Management Council, including their Salmon Technical Team, and in conservation through our support of the NMFS West Coast Regional Office and other comanagers, including state agencies (e.g., California's Departments of Fish and Wildlife, Water Resources; State Water Resources Control Board), federal agencies (e.g., US Bureau of Reclamation, US Fish and Wildlife Service) and tribal groups (e.g., Yurok, Hoopa, Karuk, and Winnemem Wintu tribes). We aim to produce information and scientific tools that will be useful to resource managers and other interested parties and to advance NOAA's conservation and sustainability goals.

The SWFSC has a comprehensive strategic planning and implementation process that aligns SWFSC science with direction from the Department of Commerce, NOAA, and NMFS, and the needs of its customers. DOC, NOAA, NMFS and the SWFSC produce periodically-updated strategic plans and annual documents that outline high-priority research needs across the SWFSC's diverse study areas. This document aims to offer more specific guidance to scientists at the SWFSC working in the area of salmon recovery.

Pacific salmon[1] and steelhead are important species for tribal, commercial, and recreational fisheries; are of high interest to the general public due to their iconic status; and play important roles in freshwater, estuarine and marine ecosystems. The history and current status of salmon in California is complex: a litany of loss interspersed with examples of resilience. The future of salmon in California is in doubt, but one certainty is that their recovery and sustainability will depend on the effectiveness of conservation actions taken in the face of an increasingly variable and rapidly warming climate and changing ocean.

Ten species (as defined under the ESA) of salmon that spawn and rear in California are listed as threatened or endangered. Since the first listings of salmon species in the 1980s and 1990s, salmon conservation has received significant attention. Investments in restoration, management, and science have successfully averted extinction of the most vulnerable listed species, and conservation actions have improved the status of some populations, but overall progress towards recovery has been slow and the status of no species has improved enough to warrant removal from the list of endangered species. There are numerous reasons for this slow progress, but it does raise the question of how our investments in salmon science can be best prioritized to help accelerate progress towards recovery.

The purpose of this plan is to develop a more detailed science strategy for Pacific salmon than is possible within the SWFSC strategic plan. The timing is right because NMFS has received a temporary but significant budget increase from Congress (Inflation Reduction Act of

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[1] For the sake of brevity, we include steelhead (*Oncorhynchus mykiss*) in Pacific salmon, which also include Chinook salmon (*O. tshawytscha*) and coho salmon (*O. kisutch*) in California and southern Oregon.

2022) that included funding to "*support transformative modeling and scientific efforts for Pacific salmon to identify and prioritize high-impact restoration and reintroduction strategies to secure climate-resilient ecosystem function and salmon abundance improvements at watershed and population scales*."

SWFSC scientists have been working diligently on these issues for the past decade or more, during a period of flat or declining budgets. In spite of this challenging fiscal climate, we have greatly expanded our capacity to address salmon conservation issues through partnerships with extramural funders (including US Bureau of Reclamation, California Departments of Water Resources and Fish and Wildlife, US Army Corps of Engineers, State Water Board) and collaborators (including agency, tribal and academic researchers). The challenge facing us now is how to best use the temporary but significant funding increase to build upon our existing capabilities and achieve near-term conservation gains and continued, sustainable progress after the temporary funding has expired. The goal of this document is to lay out such a plan.

Mission and Vision

The SWFSC's mission is "*to generate and communicate the scientific information necessary for the conservation and management of the region's marine life*." We seek to achieve this mission by "*conducting scientific research to ensure that the region's marine and anadromous fish, marine mammal, marine turtle and invertebrate populations remain at healthy and sustainable levels, as functioning parts of their ecosystems and continue to enhance the quality of life for the public*."

With respect to Pacific salmon, and for this strategy, the term "recovery" embodies NOAA's goals for both Protected Species and Sustainable Fisheries. Actions we take for recovery of ESA listed species are intended to create a trajectory for them to be healthy and harvestable. It is also crucial that we conserve unlisted species to prevent additional listings and to provide sustainable fisheries while working toward delisting of ESA-listed species.

Our approach is organized with a life cycle perspective– a necessity given the complex life history and habitat usage of Pacific salmon and the myriad ways human activities affect salmon and their habitats. We blend field and laboratory studies with theoretical and empirical modeling to create information and tools that enable natural resource managers and other interested parties to make the most informed decisions possible about how to conserve and recover Pacific salmon.

Context

Conserving and recovering salmon is one of the most challenging problems in natural resource management. Partly this is because of the nature of salmon themselves. Salmon have complex life cycles and utilize a variety of freshwater, estuarine and marine habitats across space and time. Within each habitat they are impacted directly in multiple ways, and impacts in one habitat can carry over to others, resulting in mortality or reduced reproductive capacity later on and somewhere else. Recovering salmon populations and ESUs requires meaningfully addressing enough of the impacts to achieve a desired level of viability[2]. Various management scenarios might achieve the same effect for salmon, but each would impose different costs on different human interests, thus highlighting the need for evaluating tradeoffs among sets of recovery strategies to identify those that are most accepted in terms of their social, cultural, and economic impacts.

While these problems are challenging anywhere salmon are found, they are perhaps most challenging in California, where the southernmost Chinook salmon, coho salmon, and steelhead populations spawn. In spite of the southerly latitude and Mediterranean climate, salmon can thrive in California because of the typically subarctic character of the California Current and seasonal upwelling of cold ocean water. The interaction of winter storms with mountainous terrain, and the cooling effect of the ocean near the coasts, creates complex mosaics of habitats that support a surprising diversity of salmonid species and life histories. Unfortunately for salmon, intensive development over the past 170 years has disconnected and degraded many of these habitats, and a large and growing human population depends on this development. Without consideration of the needs of people, salmon recovery would not be complicated (but might nonetheless take a long time). In reality, however, there are limited opportunities to reverse impacts of development, and the challenge is to identify the best opportunities for restoration and protection that are compatible with continued human occupation and utilization of the landscapes upon which salmon depend.

This challenge is exacerbated by California's rapidly changing climate. In general, rivers, estuaries, and the ocean are warming. Precipitation is becoming more variable, with fewer near-average years and more very dry and very wet years. The proportion of precipitation falling as snow is declining, resulting in flashier hydrographs and earlier timing of peak runoff. The ocean environment is not only warming, but is also becoming more variable, with marine heatwaves, harmful algal blooms and other climate-related impacts becoming both more frequent and more impactful. To cope with this kind of variability, salmon need a variety of habitats, including seasonally-inundated floodplains and high-elevation, spring-fed or snow-fed streams that remain cool in summer. Unfortunately, hydrological and other development (e.g., impassable dams, levees, and altered flow regimes) has strongly restricted access to these habitats, making salmon more vulnerable to climate fluctuations. California has relied ever more heavily on salmon hatcheries to mitigate these problems (particularly for Chinook salmon in the Central Valley), but hatchery production creates its own challenges to viability through simplification of life history variation, domestication selection, and increased fishery impacts on naturally-spawning populations. Recovering salmon will require reversing or mitigating these trends.

The future of salmon in California depends on restoring and reconnecting functional habitat networks in a sufficient number of locations to support productive salmon populations, as defined in NMFS recovery plans and supporting documents. For conservation actions to be effective and efficient, a number of questions need to be addressed. These include, but are not limited to:

- Where will habitat conditions (freshwater and marine) support salmon in the future?
- What restoration and protection actions are needed to create and sustain needed functional and climate-resilient salmon habitat?

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[2] Viable populations are at low risk of extinction. Viability is related to abundance, productivity, spatial structure, and diversity.

    - What locations simultaneously offer high social and bio/physical potential for these restoration actions?
    - To what extent can restoration actions “make room” for salmon to persist in the face of future climate extremes (like the recent 2012-2016 and 2020-2022 hot droughts) and directional climate change?
    - Will salmon be able to access these habitats, or will something need to be done to allow that?
- Which salmon populations will be able to thrive in the future, and where?
- What are the physiological and evolutionary limits of adaptation in California salmon? To what extent is their adaptive capacity linked to their genetics, ecotype, and historical and current habitat uses?
- How can we reconcile fishery management and hatchery management with conservation of naturally reproducing populations to ensure viability and sustainability of salmon species and tribal, commercial and recreational fisheries?
- How can California’s infrastructure be designed and operated to balance water supply reliability, flood protection, and salmon conservation, along with other competing interests?
- Are there habitat management actions (including land and water management) that can deliver socially viable climate-buffering salmon conservation benefits? If so, what and where are they?
- What challenges do a changing and variable California Current pose to salmon conservation, and can they be mitigated?

Research Themes

A research program that addresses the questions above can be organized into five interrelated themes. Jointly, the research program seeks to identify recovery strategies that can succeed in a changing climate and reduce critical uncertainty in the science underlying these strategies so they can be applied with reasonable confidence. This overall goal is captured in the Recovery Strategy Evaluation theme. It will rely on the information and tools developed under the other four themes to identify focused portfolios of management actions that can achieve recovery goals while illuminating ecological and socioeconomic tradeoffs. This will help our partners to prioritize and sequence their salmon management and recovery actions, and understand potential consequences for other aspects of the coupled social-ecological systems within which salmon are embedded.

1. Climate resilience and adaptive capacity

The Climate Resilience and Adaptive Capacity theme seeks to quantify current and potential future habitat conditions across freshwater, estuarine and coastal areas, and the adaptive capacity of salmon to exploit them. The habitat information will inform where restoration actions may be most efficient in light of different climate change scenarios, and identify salmon populations that may have what it takes to use these future habitats. Jointly, the information will inform barrier removal and reintroduction strategies, including the potential need for facilitated migration and selective breeding.

Key questions:

- Where are habitat conditions (freshwater, estuarine, marine and connections among them) likely to support salmon in the future?
- Which populations are likely to thrive or survive in the future, and where?
- What are the physiological and evolutionary limits of adaptation in California salmon and steelhead? To what extent is their adaptive capacity linked to their genetics, ecotype, and (historical and current) habitat use?

Potential Methods:

- Systematic evaluation of habitat quality and connectivity under current conditions and a representative variety of future climate and socioeconomic conditions using climate and habitat models.
- Application of landscape genomics to assess the relationship between adaptive genetic variation and habitat conditions of salmon populations across their North American range.
- Common garden/laboratory experiments.

Outcomes:

- A database detailing current conditions, potential restoration opportunities, and possible future value of watersheds for salmon recovery.
- Identification of salmon populations likely to be able to persist in face of climate change in currently or potentially available habitats.
- A long-term plan for moving or allowing salmon to move from existing habitats to habitats not currently used by or available to them.

2. Restoration and reintroduction techniques

Habitat restoration and reintroduction to currently inaccessible habitats or areas where salmon have been extirpated are some of the main strategies identified in recovery plans. While there is a strong expectation that such actions would be qualitatively beneficial, it is currently difficult to predict quantitatively the impacts of such actions and therefore benefit-cost analysis is challenging. It is widely assumed (but not assured) that habitat restoration will provide not just more space (capacity) but improve population-level productivity, abundance, distribution and diversity (via refuge from predation, increased growth leading to less size-dependent mortality within the habitat or later in life, and increased habitat complexity that gives rise to a more diverse salmon production system). Similarly, reintroduction may involve various management actions with positive or negative effects, and data on these effects are also limited but needed.

Key questions:

- How do restoration actions affect the capacity, productivity, diversity and distribution of habitats?
- What are the survival rates (or expected lifetime reproductive output) of fish reintroduced to habitats at different life stages, accounting for losses in their capture and transport?

- Which source populations are best suited for reintroduction efforts?
- What are the demographic and genetic outcomes of reintroductions, and how might these responses change over time with differing levels of effort?

Potential Methods:

- Application of adaptive management techniques to large-scale restoration projects and reintroductions (e.g., by measuring key demographic rates affected by the action).
- Meta-analysis of published studies on these effects.
- Analyze tissues and data collected during ongoing monitoring by agency partners in key watersheds (e.g., parentage or pedigree analysis to assess survival).

Outcomes:

- Ability to quantitatively predict benefits of specific restoration and reintroduction actions.
- Identification of most efficient portfolios of recovery actions.

3. Ocean ecology

A better understanding of the ocean's role in regulating salmon populations is needed for two reasons. First, the success of management actions in freshwater and estuaries is influenced by ocean climate and ecosystem variation and change, and periods of good or bad ocean conditions can obscure signals of change in other habitats. We need ways to control for this variation when assessing the effectiveness of recovery actions. Second, people have many goals for our oceans, including sustainable fisheries, wind energy development, and conservation of various species, some of which interact in important ways (e.g., marine mammal predation on salmon). Of particular interest is how or whether our many goals for different parts of the marine ecosystem can be achieved, given likely conflicts among them. Models that can evaluate the degree to which management strategies can achieve these goals require a better understanding of how salmon interact with predators, prey, and fishers; how experiences in their early life in freshwater or the estuary affect them in the ocean; and how their experience in the ocean affects their reproductive success (so-called carry-over effects).

Our salmon ocean ecology research will also need to be forward-looking to evaluate the impacts of future climate/ocean change scenarios on California salmon. We will have opportunities to connect these efforts with the ongoing Future Seas project and the nascent Climate, Ecosystems, and Fisheries Initiative.

Key Questions:

- Are there indicators that can be used to characterize ocean conditions and control for ocean climate variation effects in status assessments and restoration effectiveness evaluation?
- What impact do various predators, including those protected by conservation laws, have on the productivity of salmon populations, and can those impacts be mitigated by restoration or other management efforts in freshwater systems?
- How do changing ocean conditions affect the performance of models used in fishery management, and can these models be improved by including ocean climate and ecosystem information?
- What are the mechanisms and magnitude of carry-over effects?

- How might future ocean warming, changes in the distribution of both predators and prey, acidification, and declines in dissolved oxygen impact California salmon ocean ecology and the success of different salmon recovery actions?

Potential Methods:

- Identification and evaluation of ocean ecosystem and climate indicators and ways they can be used to make management more responsive to the changing environment.
- Development of salmon stock assessment tools that account for ocean climate and ecosystem variation (including increasing predator populations) and better account for uncertainty.
- Special studies on carry-over effects (appropriate methods depend on the mechanism, but could include demographic analysis, tagging, ‘omics, and microchemistry of otoliths and eye lenses).
- Development of salmon ocean ecology models and related decision-support models for evaluating the outcomes of different management actions under future climate/ocean scenarios.

Outcomes:

- Ecosystem indicators for use in management.
- Improved models for managing salmon fisheries.
- Identification of carry-over effect mechanisms and possible strategies to mitigate or take advantage of them, depending on their sign.

4. Integrated model development

Integrated modeling is needed to provide a framework for bringing together the information generated in the previously mentioned themes, to evaluate complex suites of management actions and strategies under future scenarios, and to support adaptive management. Integrated models include salmon life cycle models (LCMs), as well as supporting physical, biological, and socioeconomic models necessary to characterize the major factors impacting salmon populations and predict how human actions will influence salmon population viability in a changing environment. We have a well-developed modeling system for Sacramento River winter-run Chinook salmon, but require similar or analogous models for other species. The development of models for additional species will allow for the evaluation of interactions and cumulative benefits of various management actions under historical and future climate conditions.

Major products:

- LCMs for CV spring- and fall-run Chinook salmon and steelhead, building on existing models for these ESUs and winter-run Chinook. Focus on hydrosystem effects, habitat restoration, reintroduction, hatchery-fishery interactions, and ocean ecosystem and climate effects. These models can be used to evaluate causes for salmon population responses to past and future drivers (climate-driven and human-driven changes in freshwater, estuary, and ocean conditions, hatchery and harvest practices, etc.)
- LCM for CCC Coho, with a focus on metapopulation and freshwater/estuarine habitat dynamics, habitat restoration, reintroduction, and hatchery supplementation

- LCM for Klamath salmon, using the framework developed for CV salmon.
- LCM for coastal steelhead populations, with focus on how flow management, aquifer management, habitat restoration and assisted migration can interact to improve anadromous life-history expression.

Outcomes:
- Improved tools for more rapid and accurate evaluation of management actions.
- Improved ability to analyze trade-offs among competing management objectives.
- Improved understanding of the ocean's changing productivity and carrying capacity for California salmon and steelhead.

5. Recovery Strategy Evaluation

Salmon recovery plans contain comprehensive lists of actions that, if taken, would support recovery. With better knowledge of the benefits and costs of recovery actions and the analytical framework provided by life cycle models and their associated physical, biological and socioeconomic models, we can identify the most efficient pathways to recovery, important sources of uncertainty, and effective methods for evaluating progress towards recovery goals. In many cases, this work will be most effective if it involves appropriate comanagers and interested parties in all stages.

Key questions:
- What suites of actions, including but not limited to those proposed in recovery plans, would likely achieve recovery under different future scenarios, and which are most feasible in light of socioeconomic considerations (e.g., cost, governance, legal)?
- Are some kinds of actions commonly found in efficient sets of actions, and others not?
- In what order should actions be taken?
- What kinds of trade-offs exist with other conservation goals such as recovery of marine mammals (Southern Resident killer whales, California sea lions), green sturgeon, Delta smelt and among the disparate goals we have for salmon and land and water use?

Potential Methods:
- Scenario development.
- Application of integrated models to scenarios.

Outcomes:
- Identification of recovery action portfolios that maximize benefits.
- Reduced uncertainty about whether recovery strategies will be successful and better understanding of the tradeoffs among competing objectives.
- A better understanding of past and present limiting factors for California's salmon, steelhead, and sturgeon populations.

Information dissemination and coordination

We must deliver the products of our research to NOAA Fisheries colleagues, comanagers and interested parties in ways that will enable their effective application. We will create and deploy web-based tools and utilize our relationships with existing stakeholder groups such as the Collaborative Science and Adaptive Management Team, the Sacramento River Science Partnership, and the Reorienting to Recovery project team. We will also seek opportunities to increase engagement with other groups interested in salmon recovery and the food-energy-water nexus, including Native American tribes. Major products could include a web portal for data, publications, and simplified user interfaces to model systems to enable model exploration and application by interested parties. The goal is to empower comanagers and better inform the public. We will coordinate closely and collaborate where possible with colleagues at the Northwest Fisheries Science Center, who face the same challenges.

Operational Goals and Strategies

Executing the strategy outlined in this document will be challenging in a variety of ways. We will need to manage long-term, complex, interdisciplinary research programs carefully to ensure they achieve their goals. The timeline is long enough that a portion of the people completing these programs will be hired along the way, and some who will be leading them at the beginning will have moved on before they are done. The work also depends critically on functional administrative support (e.g., grants management, contracting, purchasing, budgeting) and facilities and infrastructure, and facilities and other infrastructure requirements may change as scientific methods advance and hybrid work practices further develop. Success will depend on adequate funding. Without increased resources in the future, we will need to increasingly rely on partnerships with non-NOAA funders.

Over the next decade, there will be substantial turnover of staff at the SWFSC's Fishery Ecology Division as the cadre of scientists that joined the division in the late 1990s and early 2000s reach retirement eligibility. Furthermore, as scientific developments in remote sensing, 'omics, autonomous vehicles, and machine learning (among others) expand and accelerate, the expertise that we require will very likely change. Coping with these challenges will require careful consideration of how to integrate hiring, exploitation and development of expertise in partner institutions (e.g., NOAA cooperative institutes and their members such as UCSC and the Fisheries Collaborative Program), and contracting to maintain the right mix of skills.

The Northwest Fisheries Science Center has recently completed their own salmon science strategy document. While many of the specifics of challenges facing salmon in the Pacific Northwest differ from those in California, we share many of the same challenges and objectives, and our strategies are broadly similar. We intend to maintain and expand collaborations with NWFSC staff and leadership and will seek to join forces where appropriate.

Summary

SWFSC salmon scientists have been working for more than two decades on a variety of problems related to the conservation and recovery of Pacific salmon and have made highly significant discoveries that have had practical impacts on the management of salmon and their habitats. We expect that by taking stock of our research programs and achievements, and thinking about the remaining and newly emerging challenges facing salmon recovery, the recovery science strategy described here will further sharpen our focus on the highest priority problems and increase the strength of collaborations across disciplines within the SWFSC and with our partners, thereby accelerating the production of transformational research results that can be used by NMFS, comanagers and other interested parties to more effectively conserve and recover salmon in California and the US west coast.