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EEL RIVER RESTORATION AND CONSERVATION PLAN

Phase 1: Planning

The
Eel River
Watershed
RESTORATION AND
CONSERVATION
PROGRAM



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Front cover photo: South Fork Eel River

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Acronyms and Abbreviations

AEAM	Adaptive Environmental Assessment and Management
ANOVA	analysis of variance
ASP	Aquatic Survey Program
BLM	U.S. Bureau of Land Management
CalTrout	California Trout
CDFW	California Department of Fish and Wildlife
CESA	California Endangered Species Act
DPS	Distinct Population Segment
DWR	Department of Water Resources
EDT	Ecosystem, Diagnosis, and Treatment
ESA	Endangered Species Act
ESU	Evolutionary Significant Unit
FACA	Federal Advisory Committee Act
GIS	Geographic Information System
HARP	Habitat Assessment and Restoration Planning
HUC	hydrologic unit code
IFRMP	Integrated Fisheries Restoration and Monitoring Plan
IMW	intensively monitored watershed
LCM	life-cycle monitoring
MCDM	multi-criteria decision analysis
NGO	non-governmental organization
NHD	National Hydrography Dataset
NMFS	National Marine Fisheries Service
NRDC Coalition	Coalition of environmental NGOs led by Natural Resources Defense Council
PG&E	Pacific Gas and Electric Company
PIT	passive integrated transponder

Potter Valley Project Plan	Potter Valley Hydroelectric Project
Planning Team	Eel River Restoration and Conservation Plan
Program	Team Responsible for the Preparation of the Eel River Restoration and Conservation Plan
QA/QC	Eel River Watershed Restoration and Conservation Program
Reclamation	quality assurance/quality control
RFP	U.S. Bureau of Reclamation
SAB	request for proposal
SHaRP	Science Advisory Board
TAC	Salmonid Habitat Restoration Priorities
USFS	Technical Advisory Committee
USFWS	U.S. Forest Service
	U.S. Fish and Wildlife Service

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- Individuals on the Technical Advisory Committee (TAC), who participated in numerous meetings and workshops; reviewed interim products; and provided expert knowledge, data, and resources to support this effort (see Appendix A).
- Participants in Eel River Forum, including natural resources professionals and knowledgeable members of the public who provided valuable input on restoration planning during meetings where the aspects of the Plan were presented and discussed.
- Representatives of Native American Tribes who provided valuable input and perspective on Tribal priorities for restoration and conservation of the Eel River watershed through participation in the Eel River Forum, TAC, or focused meetings. To date, the Planning Team has received initial input from the Round Valley Indian Tribes, the Wiyot Tribe, and other Tribal entities, and is committed to further collaboration as the next phase of the Eel River Watershed Restoration and Conservation Program moves forward.

This Plan was funded by the California Department of Fish and Wildlife, from Governor Newsom’s Executive Order N-10-21, which directed the agency to immediately implement projects that respond to drought conditions through habitat restoration.

PREFACE

There is at present no question of greater concern to the people of this county demanding immediate attention worse than that of the preservation of salmon in the waters of Eel River.

– Ferndale Enterprise (3 Feb. 1893)



There's a mythical, mystical feeling that comes from seeing a river's waters boil and churn from a large school of salmon making their majestic migration from the ocean into the river on their way to spawn. Chinook Salmon are the largest of the Pacific salmon, and each fish weighs 20 to 30 pounds on average and larger fish measure 36 inches or more, and often up to 48 inches! These enormous, powerful fish, having navigated the open ocean for several years, are seemingly even bigger in schools of hundreds on their journey inland to fight their way through currents and turbid storm runoff, up and over riffles and cascades, to eventually mate, and then die.

Great runs of migratory fish, like Chinook Salmon, transcend and unite cultures across time. They represent the life and health of watersheds and the human communities that depend on them. Even today, across the Pacific Rim, the arrival of salmon, of small silvery Eulachon (*rru'mula'wi* in the Soulatluk language of the Wiyot Tribe), called *salvation fish* by the lower Columbia River Tribes (MacKinnon 2015), and of the ancient jawless Pacific Lamprey is awaited with anticipation, prayer, and constant hope by humans and other resident fish-eaters (whales, sea lions, bears, otters, and riparian trees). They bring us food, medicine, and nutrients. To many of us, they also bring meaning, purpose, and identity. People say you need to go to Alaska to truly experience these annual spawning runs in all their grandeur, where salmon runs numbering in the tens-of-thousands persist. But it doesn't have to be that way.

California is a salmon state and was once rich in salmon, steelhead, and anadromous fish abundance,¹ an abundance that has persisted for more than ten thousand years. The *State of the Salmonids II: Fish in Hot Water* (Moyle et al. 2017) stated: “Nowhere in the world is the diversity of salmonids...more evident than in California.” Yes, California is at the southern end of the distribution of Pacific salmon (see figure below), but even at this end of their range, California’s natural ecosystems once sustained populations of salmonids that ranked among the largest in the Pacific Northwest. At the top of that list were the incredibly abundant and diverse salmon and steelhead runs in the Central Valley’s Sacramento and San Joaquin rivers, and the huge Chinook Salmon runs in the Klamath/Trinity River system. And then there was the Eel River.

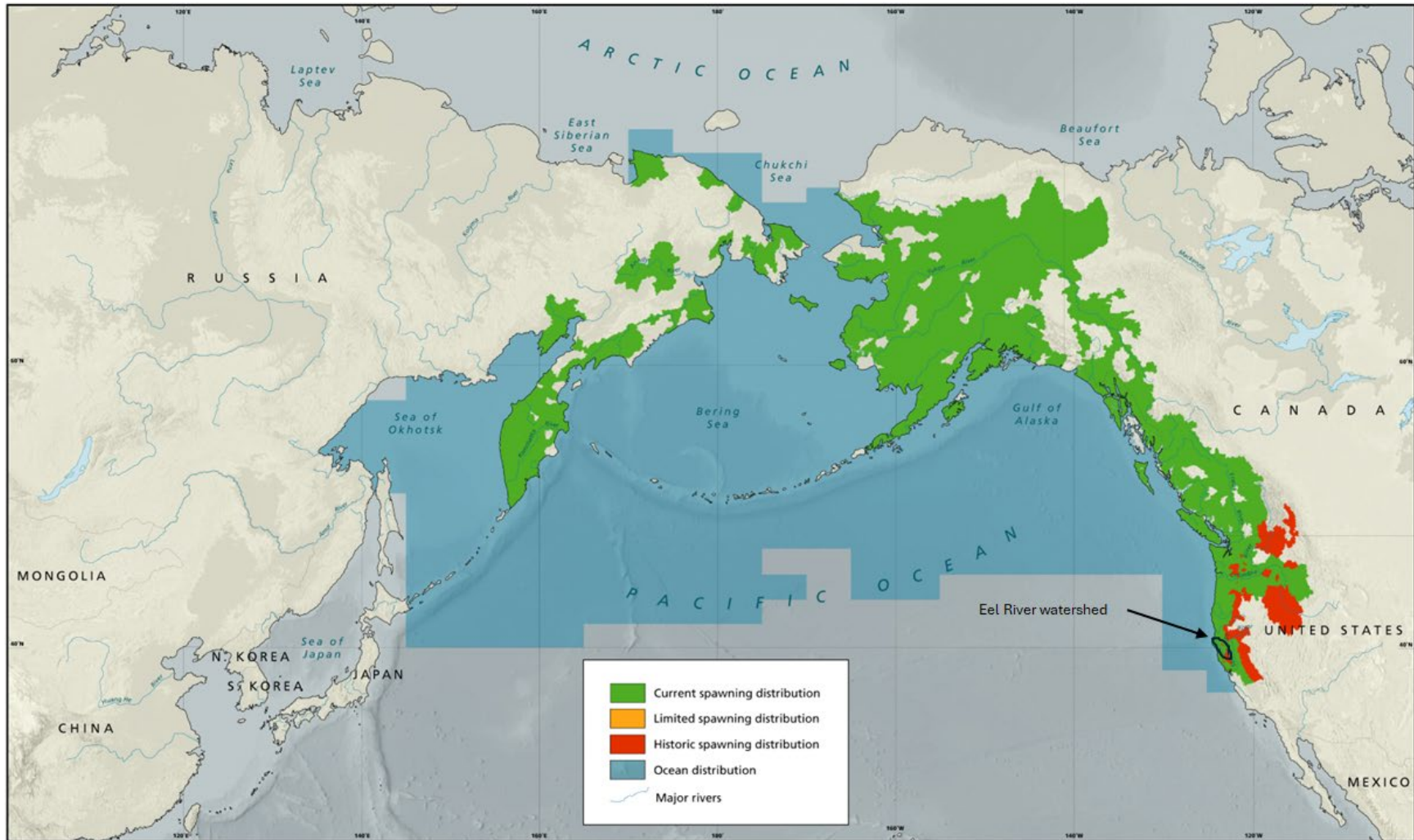
The Eel River epitomizes everything about salmon in California. Lying at the heart of California’s North Coast region, the Eel River spans five northern counties and 9,538 square kilometers and is ranked as the third largest watershed in California. The Eel River was misnamed by the first explorers who mistook Pacific Lamprey as “eel” and called it the *Eel River* (Elliot 1881), yet the river has been known as *Wiyat* by the Wiyot people since time immemorial.

The river has also been known as *The River of Abundance*, due to its highly productive fishery. In addition to copious runs of Pacific Lamprey, never estimated but surely numbering in the hundreds of thousands, the Eel River historically supported the third largest runs of salmon and steelhead in California, exceeded only by the Sacramento-San Joaquin and the Klamath rivers (CDFW 1972, as cited in Yoshiyama and Moyle 2010). In a 2010 study commissioned by California Trout, UC Davis scientists estimated the historical run sizes from the early cannery records and concluded that combined runs of Chinook Salmon, Coho Salmon, and steelhead likely totaled more than a million adult fish annually in good years, of which there were likely many.

The Eel River basin once possessed significant populations of at least five distinct kinds of anadromous salmonids, including fall-run Chinook salmon, coho salmon, winter and summer steelhead, and coastal cutthroat trout. In addition, there were small populations of chum and pink salmon and possibly spring Chinook salmon. It is likely that an even greater number of seasonal runs or life-history variants within some species previously co-existed in the Eel River system.

– Yoshiyama and Moyle 2010

¹ The term *salmon* being used here refers to anadromous salmonids, the numerous species of salmon, steelhead, and trout.



Chinook Salmon distribution across the Pacific rim. The Eel River remains a Chinook Salmon stronghold, near the southern end of their range but at the heart of salmon country. (Map used with permission from the Wild Salmon Center)

Chinook Salmon were easily the most numerous of the Eel River's runs, given they don't require the whole freshwater capacity of the watershed year-round, but only reside in its ample mainstems and tributaries for half the year—the winter and spring seasons, and its estuary in the summer (Cannata and Hassler 1995), as they migrate out to sea as sub-yearlings (i.e., less than one year-old). According to Yoshiyama and Moyle (2010), Chinook Salmon likely numbered in the many hundreds of thousands, even up to 800,000 adult Chinook Salmon in a single spawning season. Early cannery records “were converted into whole-fish equivalents (SEC 1998); the resulting catch estimates averaged 93,000 fish per year for the 35 years of record (1857–1921) with a peak number of 585,000 fish processed in 1877.” Averages aren't entirely revealing; the peak numbers are more awe inspiring, and those numbers only represent the fish that were actually caught, not those that “escaped” into the river to spawn. By 1854, immediately following the arrival of the first settlers to the Eel River in 1850, salmon were being packed in salt barrels and shipped throughout California and by 1857 were shipped as far as New York and China (Van Kirk 1996). Recorded harvests sometimes exceeded 16,000 fish in a single day, caught with gill nets in the estuary! Several times over the following decades (1860s and 1870s), the Eel River's cannery output exceeded those of the Columbia River (Van Kirk 1996).

Similar data were used to estimate the two other dominant Eel River anadromous salmonid species—Coho Salmon and steelhead. For Coho Salmon, historical numbers of spawning adults were probably in the 50,000–100,000 fish per year range; winter and summer steelhead were likely 100,000–150,000 adults per year (combined). Indeed, the Eel River was nature's fish factory. Historically, the Eel River was remarkable for its complete dominance by anadromous fishes. Other native anadromous fishes in the Eel River included Coastal Cutthroat Trout, Pacific Lamprey, Green Sturgeon, Longfin Smelt, and the occasional anadromous Three-spine Stickleback. This incredible abundance of anadromous fish not only provided nutritious sustenance for indigenous peoples of the Eel River and early Euro-American settlers but also linked the freshwater ecosystem to a huge surplus of marine-derived nutrients imported inland in the form of salmon carcasses, salmon eggs, and even pelagic (planktonic) larvae—described as tiny protein snacks floating in deep, isotonic estuarine waters. Abundant runs of anadromous fish subsidize marine-derived nutrients into multiple trophic levels of riverine ecosystems, in which nutrients from salmon excrement, eggs, and carcasses can directly feed local scavengers, decompose to support bottom-up food webs, and enrich soils to fuel riparian vegetation. For example, Reimchen et al. (2003) showed that wood samples extracted from cores of ancient trees contained detectable levels of marine-derived nitrogen, and that marine-derived nitrogen levels in wood of trees were proportional to the numbers of salmon entering the streams. Kline et al. (1990) demonstrated that nearly 25% of nitrogen in the foliage of riparian vegetation in a southeastern Alaska stream is derived from marine sources.

But there was even more to what makes the Eel River abundance special. The Eel River has the highest recorded suspended sediment yield per drainage area of any river of its size or larger in the contiguous United States (1,720 ton per square kilometer per year according to Brown and Ritter 1971). The Eel River also has an enormous annual water yield: the mean annual discharge for the Eel River (i.e., the average volume of water flowing out of the Eel River watershed in a year) is approximately 5.8 million acre-feet. This enormous annual water yield places the Eel River among the highest water yield rivers in the state. The Eel River also boasts more Wild and Scenic River miles than any other river system in the West, with 398 designated miles on the mainstem, its three forks, and the Van Duzen River. Further, it hosts the largest surviving contiguous stand of old-growth redwoods in the world: the 10,000-acre Rockefeller Forest spanning the lower South Fork Eel River and the lower Bull Creek watershed has some of the tallest trees in the world, some of which are thousands of years old. Finally, the Eel River delta and estuary is the third largest estuary in California (CDFG 2010), covering approximately

33,000 acres; the estuary is designated as critical habitat for salmon and steelhead under the federal Endangered Species Act (ESA).

The bounty of the Eel River could not, however, withstand the onslaught of European-American settlers who migrated into the watershed beginning in 1850. And so, as with so many other rivers and salmon populations throughout California, in little more than 40 years humans had pushed these iconic species to the brink of extirpation. By 1893 the Eel River's abundance was nearly completely wiped out. A prescient letter published in the Ferndale Enterprise stated:

*There is no mystery in the cause of the decline of the salmon. The fish have been mercilessly hunted, and the Cutting Packing Co.'s superintendent, Mr. Wetherbee, says there is no stream on the Pacific Coast that is fished as closely as Eel River. **He thinks that the salmon run for the Eel River is a thing of the past.** Salmon canning factories multiplied as long as there was a good profit in the business, but when the scarcity was first felt, instead of leading the fishermen to take measures to protect the fish, these factories only encouraged more strenuous efforts to take all that could be caught, and now there are none to catch.*

*The laws we have to protect the salmon are entirely inadequate when enforced, and are by no means enforced. **Whether anything can be done for California streams or not is doubtful.***

– Ferndale Enterprise (27 Jan. 1893)
Letter from Lower Island, Cannery Section, Ed. Enterprise

More than 130 years later, this great concern persists. Despite these concerns, the Eel River salmon did come back, somewhat, eventually. Fish counts conducted at Benbow Dam on the South of the Fork Eel River from 1938 to 1975, the only solid fish abundance estimates from anywhere in the Eel River, documented adult Chinook Salmon, Coho Salmon, and steelhead runs averaging 11,000 to 17,000 fish annually before 1955, and in the 1960s Chinook Salmon were estimated to have averaged 56,000 spawners annually in the entire Eel River watershed (Moyle et al. 2017). But these runs crashed again in the mid-twentieth century following the advent of mechanized logging and the historical floods of 1955 and 1964 that caused extensive sedimentation and degradation throughout the Eel River watershed.

Overall, the current abundance of adult salmonid populations in the Eel River is now hovering in the 2.5% to 5% range of historical abundance (14,000–18,000 Chinook Salmon, 500–5,000 Coho Salmon) (Loomis 2021, South Fork Eel River SHaRP Collaborative 2021). This historical decline has generally been linked to various causes. The *State of the Salmonids II: Fish in Hot Water* lists 15 factors that cumulatively contributed to the decline in anadromous fish: fire, logging, recreation, instream mining, hatcheries, major dams, agriculture, grazing, mining, estuary alteration, residential development, urbanization, harvest, alien species introductions, and transportation (Moyle et al. 2017). Nearly all these factors apply in some way to the decline of the Eel River's salmonid populations, some of them greatly so, especially historical commercial salmon harvest, logging, two Pacific Gas and Electric Company (PG&E) dams that block migratory access, extensive estuary alteration for dairy and cattle ranching, and the introduction of non-native fish species, most notably the Sacramento pikeminnow.

This story of rapid settlement, degradation, and salmon population crash has now been well documented, not just on the North Coast and the Eel River (NMFS 2014, 2016), but across California (Moyle et al. 2017) and the Pacific Northwest (e.g., Lichatowich 1999). The Eel River was no exception and did not escape the devastation of major extractive industries and rapid and extensive land use changes.

All Eel River anadromous fish are at risk. According to Moyle et al. (2017), the California Coast Chinook Salmon population is rated at *High* risk of extinction in the next 50–100 years; the Southern Oregon and Northern California Coast Coho Salmon is rated at *Critical* risk; the Northern California winter steelhead is rated at *Moderate* risk, but the Northern California summer steelhead is rated at *Critical* risk; and the Coastal cutthroat trout population is rated at *High* risk (Moyle et al. 2017). Widespread anecdotal information suggests that Pacific Lamprey and Green Sturgeon populations are also fractions of their historical levels. The State of California lists Pacific Lamprey and Green Sturgeon (Northern Distinct Population Segment [DPS]) as Species of Special Concern with Moderate and High levels of concern, respectively (Moyle et al. 2015).

We are thus at a major crisis in our certainty about these species' present and future persistence. These threats should not be ignored—there are broad implications for coastal communities and indigenous peoples who depended and continue to depend on these resources for sustenance and cultural food sovereignty.

Add to these alarming threats the contemporary disruption from a changing planet, already leaving its imprint throughout the Eel River and California, both in the form of natural disasters as well as in resource management responses:

- *Wildfire*: From 2015 to 2019, 18,210 square kilometers (km²) burned in California, and in 2020 alone, another 17,000 km² were consumed by wildfire. Of this, nearly 5,000 km² were in the North Coast region, including parts of the August Complex Fire, the largest fire in California history. High-intensity wildfires threaten community health and safety, water quality, and biodiversity. In recent years, drought, pests, tree pathogens, and historical land management practices have made the region susceptible to large, intense fires.
- *Drought and Flood*: California has a typical Mediterranean climate with annual seasons with wet winters and dry summers. But recent rain and drought cycles have become much more extreme. The 2020–2022 drought was the driest 3-year period on record, breaking the old record set by the previous drought from 2013–2015. Following this epic drought period, winter rains, atmospheric rivers, and floods returned with a vengeance in 2022–2023 and 2023–2024, having swung the pendulum to the other extreme. Between October 2022 and April 2023, more than 30 atmospheric river storms battered California, in one of the wettest winters on record.
- *Commercial Fishing Closure*: In 2023, the California Department of Fish and Wildlife (CDFW) closed the 2023 salmon fishing season in California due to low population estimates. This was the second time in recent decades that commercial and recreational fishing was entirely halted. This closure was extended through the 2024 season.

So, where do we go from here?

There are fundamentally important reasons for protecting these fish and for bringing them back to abundance. First, salmon support coastal livelihoods, feed forests and streams, and occupy a high position on our mantle of iconic Pacific Northwestern species, alongside the grizzly bear and California condor. Second, and no less importantly, these fish are intimately adapted to the cold,

clean waters of our rivers and streams and, thus, represent the health of those aquatic ecosystems. Polluted and degraded rivers and watersheds undermine the health and well-being of salmonid *and* human populations. In other words, if salmon can thrive in abundance, it's *because* their rivers and watersheds are healthy ecosystems. Wherever available, salmon have also been a highly accessible and nutritious source of food—throughout history for indigenous people, as well as for our modern diets.

But there's a deeper and more resonant meaning to these fish—important socio-cultural contributions of salmon to the well-being of people who depend on them. The Eel River is the ancestral home of numerous indigenous peoples, including the Wiyot, Yuki, and Eel River Athapaskan peoples, and is also now the home of other Native American Tribes that were forcibly moved to the area in the early twentieth century, mainly composing the Round Valley Indian Tribes. Justin and Black (2019) noted: “Salmon give reason and meaning to life in a very foundational sense, and teach children how to view the world from the lens of their cultural values.” The Wiyot people speak of “eco-cultural restoration” and do not make a distinction between *ecological* and *cultural* when referring to the need to restore the Eel River. In short, scientists, planners, regulators, and salmon-loving citizens must ensure a more equitable and sustainable salmon future for the Eel River and for the entire state of California.

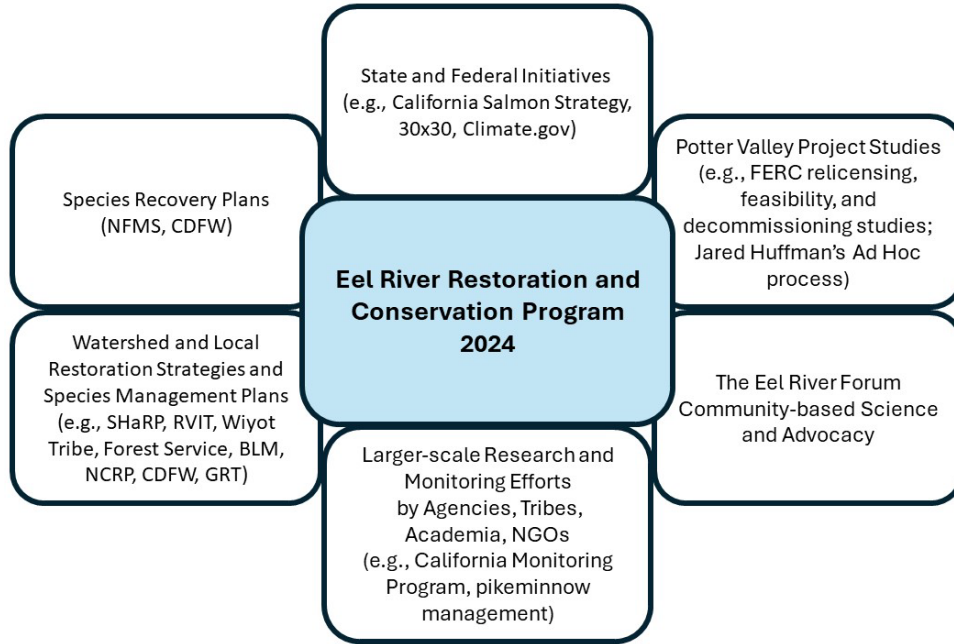
Remarkably, these fish are still coming back! The 2023–2024 Chinook Salmon count, recorded through the use of four underwater sonar cameras, may exceed 18,000 adult Chinook Salmon basin-wide, the largest return in perhaps a decade. Recovery is still possible. After an era of intensive, unregulated resource use, laws enacted beginning in the 1970s—the 1972 Clean Water Act, the federal ESA and Forest Practice Act of 1973, and subsequent stringent reforms by the California Board of Forestry under the Anadromous Salmonid Protection Rules passed in 2009, and regulation of fishing including the Magnuson–Stevens Act of 1976, have all enabled populations to at least stabilize in recent decades, albeit at very low levels.

Fortunately, the Eel River watershed retains substantial potential for recovery.

- While the proportion of private property ownership in the Eel River is high, most of the watershed is undeveloped. Here, the human population has grown at a very modest pace in the last several decades, but overall, the Eel River watershed has relatively low human population density. The North Coast region is projected to continue to grow (NCRP 2020); however, slower population growth rates are expected in the northern part of the region (including the Eel River watershed) due to its geographic isolation.
- The Eel River's salmon and steelhead are wild fish, not hatchery raised, making the Eel River the largest wild fish watershed in California.
- The Eel River watershed still shows signs of impairment from past logging practices and the floods of 1955 and 1964, but it has had 50–60 years to recover. Tributary watersheds have had time to reforest, and logging is now better regulated. Overall, the watershed recovery trajectory is positive.
- Importantly, the Eel River restoration community has made enormous progress in restoring this watershed. Some “game-changing” restoration projects have been implemented in the last decade, and several more are slated for the next few years: the Salt River Ecosystem Restoration Project; the Eel River Wildlife Area—Ocean Ranch Unit Restoration Project; fish barrier removal projects on Bridge Creek, Woodman Creek, Cedar Creek, Fish Creek, and Benbow Dam; the Eel River Estuary Preserve and Cannibal Island tidal habitat restoration projects, which are permitted and shovel ready; and Native American Tribes and scientists now taking up the challenge of managing the non-native pikeminnow population in the Eel River. Not to mention the countless other small and large restoration

projects that have been tackled by the Eel River’s numerous Native American Tribes, non-profit organizations, and grass-roots recovery groups (see following figure).

- PG&E’s Potter Valley Hydroelectric Project, located at the head waters of the Eel River, is now slated for decommissioning in the coming decade, potentially beginning as early as 2028 (PG&E 2023). PG&E’s surrender of its project license, issued by Federal Energy Regulatory Commission, after 100 years of operation, and the proposed decommissioning, marks an opportunity to remove the only two dams—Scott Dam and Cape Horn Dam—on the Eel River, improve fish passage conditions, and restore salmonid migratory access to the Eel River’s headwaters and an estimated 288 miles of high-quality spawning and rearing habitat.
- The Eel River is almost entirely free flowing, and with the decommissioning of the Potter Valley Hydroelectric Project proposed for 2028, the watershed will soon be entirely free of large dams, making the Eel the longest free-flowing river in the state.
- The decommissioning of PG&E’s Potter Valley Hydroelectric Project also serves as an important catalyst for developing a watershed-wide restoration program and plan that can prioritize restoration and conservation actions and locations and for identifying and allocating financial and human resources (i.e., this Plan).
- Chinook Salmon (California Coastal Evolutionary Significant Unit [ESU]), Coho Salmon (Southern Oregon/Northern California Coast ESU), and steelhead (Northern California Coast DPS) populations in the Eel River are listed as Threatened under the federal ESA (NMFS 2014, 2016; Section 3.1). These listings provide important protections for these species and have led to the development of recovery plans and status reviews, which highlight the critical importance of the Eel River populations for recovery of these species across the larger ESUs and DPS and leverages funding toward achieving recovery.
- Finally, California’s state agencies are committed to salmon recovery in the Eel River watershed and throughout the state. The California Fish and Game Commission listed Coho Salmon under the California Endangered Species Act (CESA), and CDFW developed a state recovery strategy for the species in 2004 (CDFG 2004). The California Fish and Game Commission listed summer-run steelhead, including Eel River populations, as Endangered under the CESA in 2022 (California Fish and Game Commission 2022). Most recently, the state released the California Salmon Strategy for a Hotter, Drier Future, which outlines actions state agencies are already taking to stabilize and recover salmon populations and additional or intensified actions needed in coming years (Office of the Governor of California 2024).”



Proposed Eel River Watershed Restoration and Conservation Program. The Program is positioned to be at the center of salmonid and other anadromous fish recovery efforts that are ongoing since the 1997–2000 federal and state Endangered Species Act salmonid listings, including guiding planning, implementation, science and monitoring, and basin-wide coordination.²

The decline in salmonid populations in response to the historical, contemporary, and ongoing stressors in the Eel River highlights the need for a holistic Eel River salmon restoration program. In short, our generation will decide the fate of salmonid abundance in the Eel River. We have an opportunity to act now and plan for restoration, conservation, and resilience to future change.

We must act now, in a holistic way, to restore these iconic anadromous fish populations in the Eel River and protect this enormously important watershed, before it's too late. Our hope is for this Plan to set us on the path to recovering the River of Abundance.

² Acronyms are defined in the list of acronyms and abbreviations in the front matter of this Plan.

EXECUTIVE SUMMARY

Aquatic and riparian habitats in the Eel River watershed have been significantly impaired by past and recent land and water use practices. Fish populations within the Eel River watershed, whose historical salmon and steelhead abundance reached nearly a million adults, have substantially declined in response to these past and recent practices. The drastic reduction in salmonid abundance has impacted all communities in the Eel River watershed: rural communities, indigenous peoples, sport and commercial fishers, recreational users, and others. Despite these drastic reductions in salmonid abundance, there is substantial reason for optimism and opportunity. For example, the decommissioning of the Potter Valley Hydroelectric Project will restore anadromous fish access to hundreds of miles of headwater streams in the upper Eel River, federal and state recovery plans and watershed assessments have been developed, and substantial restoration activities have been underway.

This Eel River Restoration and Conservation Plan (Plan) will build on these opportunities to guide substantial, collaborative, and long-term restoration and conservation actions to revitalize the Eel River and restore its fisheries. In addition, the Plan has been prepared to expand and coordinate efforts among those who are working on restoration and conservation efforts in the basin to have the greatest effect toward recovery of native anadromous fish populations. The Plan proposes a holistic approach to restoring and conserving the Eel River watershed, with a particular focus on the river corridor. The proposed Vision Statement is:

A restored Eel River watershed that is composed of diverse and resilient habitats from headwaters to sea, self-sustaining and harvestable native fish, and healthy local communities.

The Plan does not propose returning the Eel River watershed to historic unimpaired conditions; rather, a rehabilitation of the Eel River watershed to increase fish productivity, abundance, diversity, and resilience for the benefit of future generations. The Plan also adopts a strategy of preserving fish productivity strongholds (conservation) to avoid the need for future restoration in these higher quality, highly productive areas. This Plan is the first of three phases (see figure below) to implement an Eel River Watershed Restoration and Conservation Program (or Program).

After introducing the Program Vision, Goals, and Objectives, this Plan begins with overviews of the watershed (Section 1), the spatial organization proposed by the Plan (Section 2), and the focal fish species driving restoration and conservation actions of the Plan (Section 3). The Plan then transitions to a summary of restoration and conservation actions (Section 4) and proposes a prioritization framework for those actions (Section 5) that builds from existing restoration planning efforts (e.g., Salmonid Habitat Restoration Priorities [SHaRP], CDFW watershed assessments and California Monitoring Program, and National Marine Fisheries Service [NMFS] recovery plans). Next, the Plan proposes a management framework for a new Eel River Watershed Restoration and Conservation Program to be developed in Phase 2 (Section 6) and develops a monitoring and assessment framework for the new Program (Section 7). The Plan concludes with a summary of recommendations and next steps as the Program transitions to Phase 2 (Section 8). An overview of Sections 2 through 8 is provided below.



Section 2: Spatial Organization

The large size and physical and biological diversity of the Eel River watershed (greater than 3,600 mi², or greater than 9,300 km²) require restoration planning that allows it to be partitioned into units that match the scale of the process or action of interest. Therefore, the Plan proposes a hierarchy of planning scales that enables organization and assessment of potential restoration and conservation actions at smaller spatial scales, and then enables the potential actions to be reconnected and assessed across the entire watershed. The levels of spatial organization, generally from large to small, follow:

1. The entire Eel River watershed (~3,600 mi²; 9,300 km²);
2. The seven sub-watersheds, consisting of the Lower Main Eel River, Van Duzen River, Middle Main Eel River, North Fork Eel River, Middle Fork Eel River, South Fork Eel River, and Upper Main Eel River (~500–1,000 mi²; 1,300–2,600 km²);
3. Smaller sub-basins within Hydrologic Unit Code 12, which are approximately 20 mi² (50 km²) as defined by the U.S. Geological Survey’s National Hydrography Dataset;
4. Channel segments, 1 mile (1.6 km) in length or less; and
5. County parcels, which vary in size.

The Plan uses a watershed-wide system of characterization of channel segments, called “channel archetypes,” that represent groupings of distinct habitat types for fish use, and for potential restoration and conservation actions. Channel archetypes are categories of similar river channel

segments based on primary physical and environmental attributes that reflect physical processes and disturbance mechanisms that work to maintain channel morphology over time (e.g., channel segments that have steep gradient). These archetypes help (1) predict how fish use these channel segments and (2) identify opportunities and constraints for restoration and conservation actions. Channel archetypes are proposed within the restoration and conservation action prioritization framework to assist in identifying stream reaches that may host a higher diversity of focal fish species life-history strategies and provide opportunities for restoration actions.

Section 3: Focal Fish Species

A primary goal of the Program is to conserve and recover native anadromous fish populations, and the Plan includes the following as focal fish species for restoration and conservation: fall-run Chinook Salmon, Coho Salmon, steelhead (summer- and winter-run), Pacific Lamprey, and Green Sturgeon. These focal species collectively exhibit “life-history strategies” that use diverse aquatic habitats across the Eel River watershed to successfully complete their life cycles. Protecting and restoring the diverse habitats and ecological processes needed by these focal fish species will improve habitat conditions and help recover other native species in the Eel River watershed.

The Plan also adopts a strategy of restoring diversity to the life-history strategies used by the focal fish species as a primary mechanism for improving abundance and resiliency to fish populations. Similar to a diverse financial portfolio, having a diverse portfolio of life-history strategies in a fish population spreads the risk of mortality and reaps the benefits of surplus across time and space, contributing to resilience and reducing risk of extinction. Native fish species evolved to use the various river segments, habitats, and seasonal timing to maximize their chance of successfully completing their life cycle. For this reason, recovering life-history diversity of native fishes is an integral part of recovering abundance and resilience of their populations.

This Plan includes species conceptual models for each focal species to (1) help identify the potential suite of adult and juvenile life-history strategies that have the potential to occur in the Eel River watershed, and (2) visualize how different life-history strategies use different parts of the watershed across space and time. A conceptual model is simply a descriptive illustration of the fish’s life cycle, and how it uses different habitats to successfully complete its life cycle. The species conceptual models were used to identify a preliminary list of stressors for each species, which was supported by a careful review of existing information on focal fish species, including agency recovery plans, CDFW watershed assessments, and recent restoration planning efforts (e.g., SHaRP). The species conceptual models also allowed identification of several key themes and strategies for restoration and conservation that will support the recovery of focal fish species. The species conceptual models and the associated key outcomes will inform the ranking and development of criteria for prioritizing restoration and conservation actions in Phase 2 of Program development.

Section 4: Restoration and Conservation Actions

Given the large size of the Eel River watershed, numerous potential restoration and conservation actions could be implemented. Therefore, the Plan identified and organized potential restoration and conservation actions that build from the Program Vision and Goals described in Section 1.2.1 via tiered sub-goals and objectives described in Section 4.2, along with inputs from the focal species conceptual models (Section 3), and a careful review of existing assessments and plans that identify key restoration and conservation actions (e.g., NMFS and CDFW recovery plans, South Fork Eel River SHaRP). For each of the goals, the Plan developed increasingly specific sub-goals, objectives, and sub-objectives for restoration and conservation to provide a resolution that is appropriate for linking with specific actions. For example, by having a system of tiered

goals and objectives, the Plan can transition from a very broad goal of “Achieve naturally self-sustaining and harvestable native anadromous fish populations” down to an objective that can be specifically achieved, such as “reduce mortality of juvenile salmonids from non-native pikeminnow in a particular restoration reach.” The outcome of this process is a series of tiered goals and objectives tables and the resulting series of action tables (Appendix D and E, respectively).

Ultimately, restoration and conservation actions identified in this Plan will be used as inputs to the Phase 2 restoration and conservation action prioritization process, which will identify actions expected to be most effective at resolving stressors that are limiting fish population recovery, and thereby having the greatest ability to achieve Program goals.

Section 5: Prioritization Framework

An effective approach to prioritize restoration and conservation actions identified in Section 4 includes a systematic, replicable, and transparent process for estimating the efficacy of restoration and conservation actions. First, the Plan identified a prioritization framework that enables both broad and specific actions to be identified and prioritized. The Plan then reviewed several action prioritization approaches developed by other restoration programs, and developed a prioritization framework for the Eel River that would result in prioritizing (1) restoration actions that will best recover native fish populations, and (2) strategic locations for conservation that will protect fish populations and foster watershed resiliency into the future.

The Plan develops a prioritization framework for Phase 2 that uses a combination of quantitative spatial assessments and multi-criteria decision analyses to develop the first set of priority restoration and conservation actions. More specifically, the process would use Geographic Information System (GIS) analyses for different spatial scales of the watershed (Section 2) to identify land areas that meet several prioritization criteria, to identify high-priority lands (parcels) for restoration and conservation. The Plan recommends that spatial analyses be performed in parallel with a multi-criteria decision analysis, which uses a relatively simple scoring system (5 to 20 criteria) to rank potential restoration and conservation actions. Prioritization criteria should include the following: ability of restoration and conservation actions to recovery life-history diversity of focal fish species, benefits and impacts on multiple focal fish species, feasibility of actions, opportunities and constraints, and others. Participants in the ranking process to be conducted in Phase 2 will include technical representatives of Native American Tribes, federal and state agencies, conservation groups, restoration practitioners, research scientists, and others with local knowledge and expertise in the Eel River watershed. The results of prioritization analyses (quantitative spatial analyses and ranking analyses) will be synthesized in Phase 2 to develop a comprehensive Action Plan for the Eel River watershed, which will include guidance for each of the seven sub-watersheds.

Section 6: Program Management Framework

Successful implementation of an Eel River Restoration and Conservation Plan that achieves significant improvement to native fish abundance in the Eel River watershed will require forming a new program. Section 6 provides a summary of core components of a generic ecosystem management framework, reviews other comparable large-scale ecosystem restoration program management framework approaches, then recommends a future program management framework for an Eel River Watershed Restoration and Conservation Program that would be formed in Phase 2. The Plan does not recommend replacing existing restoration planning and implementation activities currently occurring within the Eel River basin, but rather recommends a future program management framework that builds from the existing work being done in different sub-watersheds (e.g., South Fork Eel River SHaRP Collaborative 2021), and provides a structure for

organizing and guiding restoration efforts for the entire watershed. In addition, the recommended program management framework would also include support for watershed-wide monitoring and assessment, to build from existing monitoring and assessment efforts.

Section 7: Monitoring and Assessment Framework

Monitoring and assessment of restoration and conservation actions are fundamental to determining whether, and to what extent, these actions are having the intended effect on improving habitat conditions for focal fish species and, more broadly, whether implementation is achieving desired species recovery goals and objectives. The three goals of the monitoring and assessment framework are to:

1. Evaluate whether restoration and conservation actions are working to meet the Vision Statement, goals, and objectives for native anadromous fish recovery;
2. Use focal fish species' populations and habitat metrics to adapt, refine, and/or reprioritize restoration and conservation actions, as needed; and
3. Share the recovery trajectory of anadromous fishes in the Eel River watershed with the public in accessible ways that inform and engage the community.

The core components of the monitoring and assessment framework are monitoring program oversight and coordination among partners (Section 7.2); monitoring and assessment process (Section 7.3); data management structure (Section 7.4); and adaptive management opportunities (Section 7.5).

A key concept recommended in the monitoring and assessment framework is to organize the different types and scales of monitoring between “program-level” monitoring and “project-level” monitoring. Program-level monitoring uses status, trend, and validation monitoring to determine whether the program is on a trajectory toward achieving its goals over large spatial and temporal scales (e.g., anadromous fish population recovery for the South Fork Eel River), while project-level monitoring uses baseline and post-implementation monitoring to determine whether individual restoration and or conservation actions are achieving their intended project-specific effect (e.g., increasing quantity of juvenile rearing habitat at a specific restoration site).

The monitoring and assessment framework includes a process that uses structured hypothesis testing, data visualization, and/or narrative interpretation to determine if the restoration program is meeting its goals—both at program-level and project-level scales. Specifically, the monitoring and assessment framework recommends constant challenging of assumptions and paradigms between restoration actions and predicted outcomes to ensure that restoration and conservation actions occur that are ecologically meaningful, cost-effective, and can evolve in a timely manner based on new scientific understanding. The recommended program management framework (Section 6) is fashioned to facilitate communication between Program monitoring staff and restoration implementation practitioners to ensure that data being collected to evaluate restoration actions are also used to adapt, refine, or reprioritize restoration actions. Like the recommended program management framework in Section 6, the recommended monitoring and assessment framework is meant to support, expand, and integrate existing monitoring efforts within the various Eel River sub-watersheds, and not replace these existing efforts. Finally, the monitoring and assessment framework emphasizes integration between monitoring partners (federal, state, Tribal, and conservation organizations), discusses tradeoffs in the scale of fisheries monitoring activities, discusses opportunities for conducting adaptive management (Section 7.5), and recommends an approach to implement a successful Eel River monitoring and assessment framework (Section 7.7).

Section 8: Recommendations and Next Steps

Lastly, the Plan compiles and summarizes recommendations and next steps from the preceding sections that (1) summarize recommendations from this Phase 1 planning effort and (2) identify next steps to facilitate Phase 2 implementation (Program Formation and Prioritization).

Categories of recommendations follow:

- Program management framework (Section 8.1.1.1);
- Funding strategies (Section 8.1.1.2);
- Restoration and conservation priorities (Section 8.1.2); and
- Monitoring, assessment, and research priorities (Section 8.1.3).

The recommendation categories above outline the fundamental components for creating and implementing a successful watershed-wide restoration and conservation program for the Eel River (Phase 1). The overall next step will be to implement Phase 2: Program Formation and Prioritization. The recommendations in this Plan are intended to guide the Phase 2 effort, and participation by agencies, Native American Tribes, conservation groups, and the public will be critical to improving the recommendations in this Plan and implementing Phase 2. The Plan then summarizes the next steps that will need to be achieved in the Phase 2 process, assuming funding can be obtained to implement it, including:

- *Phase 1 Plan Distribution and Outreach:* Continue conducting outreach of the Plan to community members or organizations (particularly those that have not been exposed to the Plan development process) to provide opportunities to provide input into the Phase 2 effort. The Phase 1 Plan will be published on the California Trout website and released via local media outlets to ensure broad distribution across the Eel River community.
- *Entity Formation, Board of Directors, and Staff:* Building on Section 6, a Program entity would be formed so it can begin to execute the strategies being formulated in this Plan. A working group should be formed to help develop the details of entity composition, roles and responsibilities, administration, and funding.
- *Financing and Budget:* Phase 2 of the Program development will require additional funding to implement, including financial requirements for developing the entity, startup costs (office space, supplies, legal costs, licenses), staff salaries, executing the restoration and conservation action prioritization process (Section 5), and conducting initial monitoring needs (Section 7).
- *Prioritize Restoration and Conservation Actions:* Once the Program is formed, one of the first tasks would be to implement the prioritization framework (Section 5), including advancing the highest priority analyses and syntheses that will be used as inputs to the prioritization process. Completing the restoration and conservation action prioritization process should not preclude implementing restoration or conservation actions that are already in the design and permitting process, and completing the prioritization process should be a high priority once the Program is formed to quickly inform the implementation process.
- *Baseline Monitoring:* Continuation and expansion of the baseline monitoring of juvenile and adult salmonids being conducted in the Eel River watershed is imperative. The Plan illustrates multiple purposes of baseline monitoring. First, it will help establish the current fish population status, making future changes to fish population status clearer as cumulative restoration actions are completed (Program-level monitoring). Second, baseline monitoring will be the foundation for hypothesis testing and site-specific effectiveness evaluation (project-level monitoring). Lastly, baseline monitoring and research will help fill existing priority data gaps and identify additional data needs.

1 INTRODUCTION

The history of the Eel River, as described in the *Preface*, demonstrates a clear need for immediate action and development of a holistic watershed-wide restoration and conservation strategy that identifies and advances the most-needed salmon recovery actions. The upcoming decommissioning of Pacific Gas and Electric Company's (PG&E's) Potter Valley Hydroelectric Project (Potter Valley Project), a milestone for restoration and conservation in the Eel River watershed, represents a catalyst for watershed-wide restoration. Aquatic habitats have been significantly impaired by past and recent intensive land use practices that have contributed to substantial declines in the abundance of native anadromous fish populations. These population declines have, in turn, resulted in state and federal listings to protect and facilitate recovery of these populations (Table 1-1) (CDFW 2014; NMFS 2014, 2016; Eel River Forum 2016). Given the current circumstances in the Eel River and its history, it is clear that the time is now to develop an Eel River Watershed Restoration and Conservation Program (or Program) and ensure the ecosystem provides for generations to come. The first step in developing such a program is the planning phase. In this case, the outcome of the initial planning phase is this document—the Eel River Restoration and Conservation Plan (or Plan). The following subsections provide an overview of the Plan (Section 1.1), Program (Section 1.2), and the Eel River watershed setting (Section 1.3).

1.1 Eel River Restoration and Conservation Plan

An initial fisheries restoration framework for the Eel River watershed was developed by Stillwater Sciences and McBain Associates (2021) to build on the potentially transformational habitat and fish passage improvements anticipated by relicensing or decommissioning of the Potter Valley Project.³ The 2021 framework has been refined herein to include three phases: (1) Planning, (2) Program Formation and Prioritization, and (3) Implementation, Monitoring, and Assessment (Figure 1-1). Leveraging this framework, California Trout (CalTrout) led development of Phase 1: Planning—the outcome of Phase 1 is this document, the Eel River Restoration and Conservation Plan, which is intended to lead to the execution of Phase 2 and Phase 3. In Phase 2, an Eel River Watershed Restoration and Conservation Program entity will be formed, including hiring Program directors, administrators, and staff. Phase 2 will also include implementing the restoration and conservation action prioritization process that will determine the areas and actions needed to effectively and efficiently restore and conserve the Eel River. In Phase 3, Program actions will be implemented and paralleled by a robust monitoring program to assess effectiveness of the Program (Figure 1-1). The Program's three phases are not necessarily meant to be implemented sequentially, rather they can move in parallel and be complementary to each other. For example, implementation and monitoring of projects requires prioritization to be complete (Phase 2 and Phase 3), rather these phases can happen simultaneously to demonstrate potential effectiveness.

The Plan describes the planning and development of the key Program components. This Plan was developed by a Planning Team that includes professionals from CalTrout; Stillwater Sciences;

³ At the time of the 2021 fisheries restoration framework development, the Potter Valley Project was still being relicensed by PG&E. Soon after the framework was completed, PG&E announced the abandonment of the Potter Valley Project. Approximately a year later, when no viable parties were able to take over the Potter Valley Project, PG&E initiated the decommission phase and is in its current state today.

Applied River Sciences; and University of California, Berkeley. The Planning Team is supported by members from the Round Valley Indian Tribes, the Wiyot Tribe, and a Technical Advisory Committee (TAC), composed of regional experts from state and federal agencies, universities, and Native American Tribes (see Appendix A for more information about the Planning Team and the TAC).



Figure 1-1. Conceptual diagram of phases needed to establish the Eel River Watershed Restoration and Conservation Program. Phase 1: Planning describes the work that went into developing this Plan document.

The goal of the Plan and of Phase 1 of the Program is to develop products (e.g., data, presentations, documents) that build the groundwork and make recommendations to create a successful Program (Section 1.2). Building from the restoration framework (Stillwater Sciences and McBain Associates 2021), the Plan moves through each task, develops products, and reviews them with a TAC and the Eel River Forum. This peer-reviewed approach was selected because the success of the Program depends on support from state/federal agencies, non-profit organizations, Native American Tribes, and all community members of the Eel River watershed.

The Plan takes a holistic approach to restoring and conserving the Eel River watershed with a focus on the river corridor (including the riparian corridor) and recovery of native, anadromous fish species with commercial, recreational, or Tribal cultural value. Accordingly, the Plan includes Chinook Salmon (*Oncorhynchus tshawytscha*), Coho Salmon (*Oncorhynchus kisutch*),

steelhead (*Oncorhynchus mykiss*), Pacific Lamprey (*Entosphenus tridentatus*) and Green Sturgeon (*Acipenser medirostris*) as focal species for the Plan. The Plan approaches recovery of the focal species with a focus on life-history diversity or the diverse set of choices that fish can make throughout their life cycle in freshwater, as a means of recovering abundance and building resilience. The spatial focus of the Plan is the river corridor, but it will not ignore the interconnectedness of ecosystems across the watershed and relationships with upslope processes. In addition, the Plan must also address the continuous and ongoing threat of climate change to the Eel River and develop strategies for climate resilience. Finally, the Plan must also partner with, and be invested in, community members across the watershed and incorporate the ecosystems services that support those community members, such as recreational access, access to clean water, economic benefits, and robust and harvestable fisheries.

The Plan includes the following steps:

1. Define Program vision and goals (Section 1.2.1)
2. Synthesize background information and spatial analysis framework (Section 2)
3. Develop species conceptual life-cycle models to identify potential limiting factors (Section 3)
4. Identify and categorize restoration and conservation objectives and actions (Section 4)
5. Develop a prioritization framework and approach (Section 5)
6. Develop a management and administrative framework and funding strategy (Section 6)
7. Develop a monitoring and adaptive management framework (Section 7)

Herein, the Planning Team summarizes the outcomes, frameworks, and recommendations from the preceding list of tasks. The first task was to develop the vision and goals of the Program, which are considered fundamental to its success and to gather support from the watershed community. The Planning Team investigated and compiled existing data on anadromous fish life-history needs, riparian area, land cover, and vegetation, among other data specific to the Eel River watershed. During this process, the Planning Team built a spatial framework and a data set of “Channel Archetypes” to characterize the riverscape into reaches that are likely to give rise to distinct habitat types used by fish and maybe appropriate for similar restoration actions. The Planning Team also compiled a list of data gaps that can be addressed during future phases of the Program. Next, the Planning Team built a broad list of potential restoration and conservation actions and framed these in a tiered objectives framework grouped by the following categories: Fish Populations, Habitats, Landscapes, and Conservation. These actions were further defined and categorized within the numbered Channel Archetypes to directly relate the actions to fish life-cycle history needs where appropriate. A prioritization framework was built to outline options for deciding on which sub-basins at the Hydrologic Unit Code (HUC) 12 level of granularity have the highest priority for restoration and conservation implementation. Finally, the Planning Team developed and then integrated the frameworks for implementing, monitoring, managing, and funding actions, which work in concert to ensure actions are accomplishing restoration and conservation goals and thus, resilience in the Eel River watershed. Each of these tasks was done with information sharing and feedback meetings with the TAC and the Eel River Forum.

1.2 Eel River Watershed Restoration and Conservation Program

This section introduces the Proposed Eel River Watershed Restoration and Conservation Program, which is discussed further in Section 6. The Program is intended to guide and implement a substantial, collaborative, long-term restoration and conservation approach that revitalizes the Eel River watershed and restores its fisheries. The Program is proposed to be more

than a document or an informal group; rather, the Program is intended to serve as an administrative entity that will guide and coordinate prioritization, implementation, and monitoring of restoration and conservation efforts across the Eel River watershed for the foreseeable future.

The Program will not and cannot do this work alone. It will coordinate and collaborate with existing efforts being led or pursued by state and federal agencies and local entities, including Native American Tribes, municipalities, and non-governmental organizations (NGOs), that are aligned with the vision of a restored Eel River watershed (see Vision Statement in Section 1.2.1.1). The Program structure will include full time staff that can lead, direct funds, and coordinate restoration and conservation efforts from agencies and local entities in the Eel River in perpetuity (Section 6). The leadership and stability will not replace any existing organization, but instead will be a central organizing entity to coordinate watershed-wide restoration.

A successful restoration and conservation program across the entire watershed will integrate existing information gathered by agencies and local entities. This approach is critical because the Eel River is a large and relatively data-limited watershed. Specifically, the Plan and the Program will rely heavily on existing information from federal recovery plans for salmonid species (NMFS 2014, 2016), species management and regional implementation plans for Pacific Lamprey (Wiyot Tribe Natural Resources Department and Stillwater Sciences 2016, Boyce et al. 2022), restoration plans (Eel River Forum 2016, McBain Associates 2017, South Fork Eel River SHaRP Collaborative 2021), watershed assessments (Downie and Lucey 2005; CDFG 2010, 2012; CDFW 2014), and other existing documents with information on the Eel River watershed.

In summary, the Program will include several components that do not currently exist, or are not coordinated by a single entity, at the watershed scale, including (1) a central organizing entity for watershed-wide restoration, (2) identification and prioritization of land conservation actions (in addition to habitat restoration actions), (3) a prioritization process that integrates the needs of multiple species and emphasizes life-history diversity, and (4) an integrated monitoring program intended to evaluate success of the Program and inform periodic refinement of restoration priorities.

1.2.1 Program Vision and Goals

The primary objective of Phase 1 was to develop a framework for a successful Program and define its key components (Section 6). A clear vision statement and supporting goals are critical components of a successful long-term restoration program (Beechie et al. 2008). Therefore, the Planning Team developed the Program's vision and goals. The vision statement and goals will provide The Program guidance and strategies into the future and ensure the vision and goals continue to align with the community's values and intended outcomes for the Eel River. In crafting the Program's vision statement, the Planning Team combined the technical understanding of the ecosystem, community values, and the connections between the focal species and the habitat to support it. The vision statement and goals were reviewed by the TAC, and the Planning Team held community meetings (Eel River Forum) to review the vision and goals with regional experts and community members. The Planning Team also looked to restoration programs with successful results throughout the western United States to develop a vision statement that would be realistic, achievable, and inspire creative solutions to the issues in the Eel River.

1.2.1.1 Program's Vision Statement

A restored Eel River watershed that is composed of diverse and resilient habitats from headwaters to sea, self-sustaining and harvestable native fish, and healthy local communities.

The terms used in the vision statement and the rationale for their inclusion follow:

Restored Eel River Watershed:	<i>Definition:</i>	A restored Eel River watershed that remains healthy over time despite stressors from climate, land use, and natural disturbance. The term <i>restored</i> does not necessarily imply a return to unimpaired conditions, but a significantly improved condition that is informed by the state and function of unimpaired conditions.
	<i>Rationale:</i>	Restoration provides desired watershed benefits (described in the vision statement) over the long term for future generations.
Diverse Habitats:	<i>Definition:</i>	Habitats that vary across the watershed and differ in features (e.g., flood plain versus estuary) and function (e.g., food and fish production).
	<i>Rationale:</i>	Diverse habitats create numerous pathways for native fish to successfully complete their natural life cycle and are important for maintaining productive and resilient populations.
Resilient Habitats:	<i>Definition:</i>	Habitats that remain healthy over time and across the watershed, despite stressors from climate, land use, and natural disturbance.
	<i>Rationale:</i>	Resiliency provides desired habitat benefits over the long term and resists watershed productivity limitations across the watershed in response to natural and human-induced stressors.
Headwaters to Sea:	<i>Definition:</i>	Headwaters to sea encompasses the spatial extent of the Program, including estuarine habitats to the high-elevation headwater habitats.
	<i>Rationale:</i>	Achieving and sustaining significant watershed improvements requires integrated restoration and conservation actions over a wide range of habitat types and sub-watersheds throughout the Eel River, including headwaters, mainstems, and estuarine habitats. The term also refers to the connections needed for migratory fish to pass through the watershed and complete their life cycle.
Self-sustaining and Harvestable Native Fish:	<i>Definition:</i>	Self-sustaining native fish populations that are robust enough for harvest by recreational, commercial, and Tribal communities through time without requiring long-term hatchery supplementation or management intervention. Harvestable native fish include populations of Chinook Salmon, Coho Salmon, steelhead, Pacific Lamprey, and Green Sturgeon, and other species that exceed minimum adult escapement levels in the Eel River needed to produce numbers of juvenile fish that lead to successive harvestable adults.
	<i>Rationale:</i>	The ability to sustainably harvest native fish is important for healthy local communities as a food source, as well as recreational, commercial, traditional, and ceremonial uses.
Healthy Local Communities:	<i>Definition:</i>	Healthy communities that support all basic human needs, are socially connected, culturally vibrant, safe, environmentally sustainable, and economically secure.
	<i>Rationale:</i>	Local communities and Native American Tribes are integrally tied to the Eel River watershed, and thus, restoration and conservation actions support the sustainable resource use and human access to Eel River resources that also support healthy local communities.

1.2.1.2 Program Goals

Watershed restoration programs, including the Program proposed in this Plan (Section 6), depend on goals to guide program actions and evaluate the effectiveness of those actions. It is usually implicit that the purpose of watershed restoration is to achieve a state of ecosystem condition or health, but that condition is difficult to define by broad goals alone, such as population abundance or habitat area. Attributes such as *restored*, *resilient*, *diverse*, and *productive* can be quantified (e.g., with units) in some contexts. But these attributes also imply a qualitative meaning that emerges from shared understanding within the human community present in the system. Within any human community, there will be differences of opinion on the goals and desired outcomes of watershed restoration. However, collaboration, clear communication, and knowledge sharing (as occurred with the TAC for this Plan) can lead to elements of a shared ethos or understanding, which is a powerful mechanism for guiding restoration and conservation priorities. This Plan uses a tiered list of goals and objectives in Section 4 that transitions from broad, qualitative goals (e.g., restored, resilient, and diverse) to more specific, quantifiable objectives and sub-objectives that define specific attributes of a desired ecological condition (e.g., increase number of returning adults). These tiered goals and objectives were informed by TAC input and by via feedback from the Eel River Forum (a forum of Eel River community members that have an open dialogue about conservation issues).

The following two categories of Program goals are the result of that process and support the vision statement above and will guide development of the program management framework described in Section 6.

The following *outcome goals* describe components of the Program that are needed to successfully restore and conserve the Eel River:

1. *Restore*: Restore variable ecological and geomorphic processes that support diverse life-history strategies of native fish to increase population size and resilience.
2. *Protect*: Protect and conserve landscape connections between important riparian and upland habitats.
3. *Incorporate Ecological and Geomorphic Processes*: Embrace the variability in dynamic ecological and geomorphic processes at the sub-watershed scale and integrate across the sub-watersheds to create an interconnected mosaic of habitats that support the various life-history stages and strategies of focal species.
4. *Support Socio-economic Values*: Support local community and Tribal resource needs, economics, ecosystem services, and recreational values of the watershed.
5. *Recommend Meaningful Actions*: Recommend restoration and conservation actions that are implementable on a timescale, magnitude, and trajectory that will achieve efficient and meaningful improvements.
6. *Prioritize*: Implement a restoration and conservation action prioritization process that integrates watershed attributes with the needs of native fish and the habitats they rely on.
7. *Monitor and Assess*: Include a robust monitoring, assessment, and active management process that allows evaluation of measurable goals and restoration targets, and refinement of the Program.

The following *process goals* describe principles and strategies for developing the Program:

8. *Coordinate with Local Entities*: Coordinate with Native American Tribes, agencies, and local communities to build support for restoration goals and strategies.

9. *Integrate Best Available Information*: Incorporate the best available information in the Eel River watershed by synthesizing existing data, input from experts, and species management plans within the watershed.
10. *Build in Lessons Learned*: Incorporate lessons learned from ongoing and past restoration/recovery efforts in the Eel River watershed, and from other similar basin-wide programs.
11. *Include Traditional Ecological Knowledge*: Collaborate with Tribal leaders to bring Traditional Ecological Knowledge and its understanding of historical ecology to inform and develop restoration and conservation strategies, and the action prioritization process.

Developing the Program vision and goals was a fundamental first step of Phase 1. After the Planning Team developed the vision statement and goals, it received input and feedback from the TAC at coordination meetings, and from Native American Tribes and community members during both virtual and in-person Eel River Forum meetings. The intent of this input and feedback process was to ensure that the fundamental direction of the Program was supported and reviewed by not only technical scientists and experts, but also the watershed community who will benefit the most from successful implementation of the Program.

1.2.2 Defining Restoration and Conservation

For the purposes of the Plan, the Planning Team uses the definition of *restoration* developed by the Society of Ecological Restoration⁴ as the process of assisting or accelerating the recovery of an ecosystem that has been degraded, damaged, or destroyed. Restoration is distinct from conservation in that restoration attempts to retroactively repair already damaged ecosystems rather than take preventative and protective measures to avoid future damage to an ecosystem. Restoration does not imply that the ecosystem can be returned to an unimpaired historic condition; rather, it attempts to change the trajectory of a degraded ecosystem towards one that results in a significantly improved condition. While rehabilitation may be a more accurate description, the Planning Team and TAC agreed that restoration is more commonly understood and would be a better term for public outreach.

Similarly, *conservation* is defined for the purposes of this Plan as the preservation and management of landscapes, biodiversity, and natural resources that are currently in a highly functional ecological state and would benefit from protection from future impairments. This definition of conservation does not imply that restoration cannot occur within conserved lands. Conservation intends to protect ecosystems from future damage, preventing the need for future restoration, which is less expensive and impactful to the ecosystem (an ounce of prevention is worth a pound of cure).

1.3 Watershed Setting

The Eel River watershed is a large and diverse watershed; it receives snowpack in the headwaters and heavy rains in the coastal areas, there are tributaries in old growth redwoods along the coast and dry conifer forests further inland (Figure 1-2). The Eel River is inhabited by a diverse spectrum of fish and other aquatic species that have successfully adapted to the physical and hydrologic diversity that the watershed provides. This section provides an overview of the Eel River watershed, its environmental setting, and a brief description of its diversity.

⁴ Available at: <https://ser-rrc.org/what-is-ecological-restoration/>.

1.3.1 Climate, Hydrology, and Geography

The Eel River is the third largest watershed in California, with a drainage area of more than 9,538 square kilometers (km²). The watershed occurs in California's rugged northern Coast Range within Humboldt, Mendocino, Trinity, Glenn, and Lake counties. The watershed is composed of seven primary sub-watersheds: Lower Eel, Van Duzen, Middle Main Eel, North Fork Eel, South Fork Eel, Middle Fork Eel, and Upper Main Eel. The nearly 200-mile-long mainstem Eel River flows northwest from the high inner Coast Range (peak elevation 6,782 feet) to the Pacific Ocean near Ferndale.

Most of the Eel River watershed is characterized by a Mediterranean climate with cool, wet winters and warm, dry summers. Between October and April, precipitation typically falls as rain at lower elevations and as snowfall at the higher elevations of the inner Coast Range. The strong gradient in average annual precipitation from west to east across the watershed ranges from about 40 inches in the lower, western portions of the watershed to about 80 inches in the higher, eastern portions of the watershed. Precipitation varies significantly within a calendar year and across water years.

The Eel River annually discharges an average of 5.8 million acre-feet of water, making it one of the largest rivers in California (CDFG 2010). At the lower Eel River U.S. Geological Survey Scotia gage, the Eel River can range from a maximum daily average discharge of 648,000 cubic feet per second to a low of about 20 cubic feet per second. The Coastal Watershed Planning and Assessment Program provides a more detailed summary of the Eel River hydrologic and climatic characteristics (CDFG 2010).

A complex gradient of aquatic habitat conditions occurs across the seven primary sub-watersheds, ranging from cold and wet to hot and dry. The South Fork Eel River and its tributaries in the western portion of the basin, for example, are predominantly cold-wet tributaries that occur at lower elevation and are cooled by the Pacific Ocean. Tributaries in the Upper Eel River watershed and the Middle Fork Eel River watershed occur at the opposite end of the spectrum compared to the South Fork, experiencing more arid climates and intermittent streamflow fed by snowmelt. The Eel River delta and estuary occupies nearly 33,000 acres near the river's outlet to the Pacific Ocean, historically providing critical habitat for aquatic species and life-history diversity.

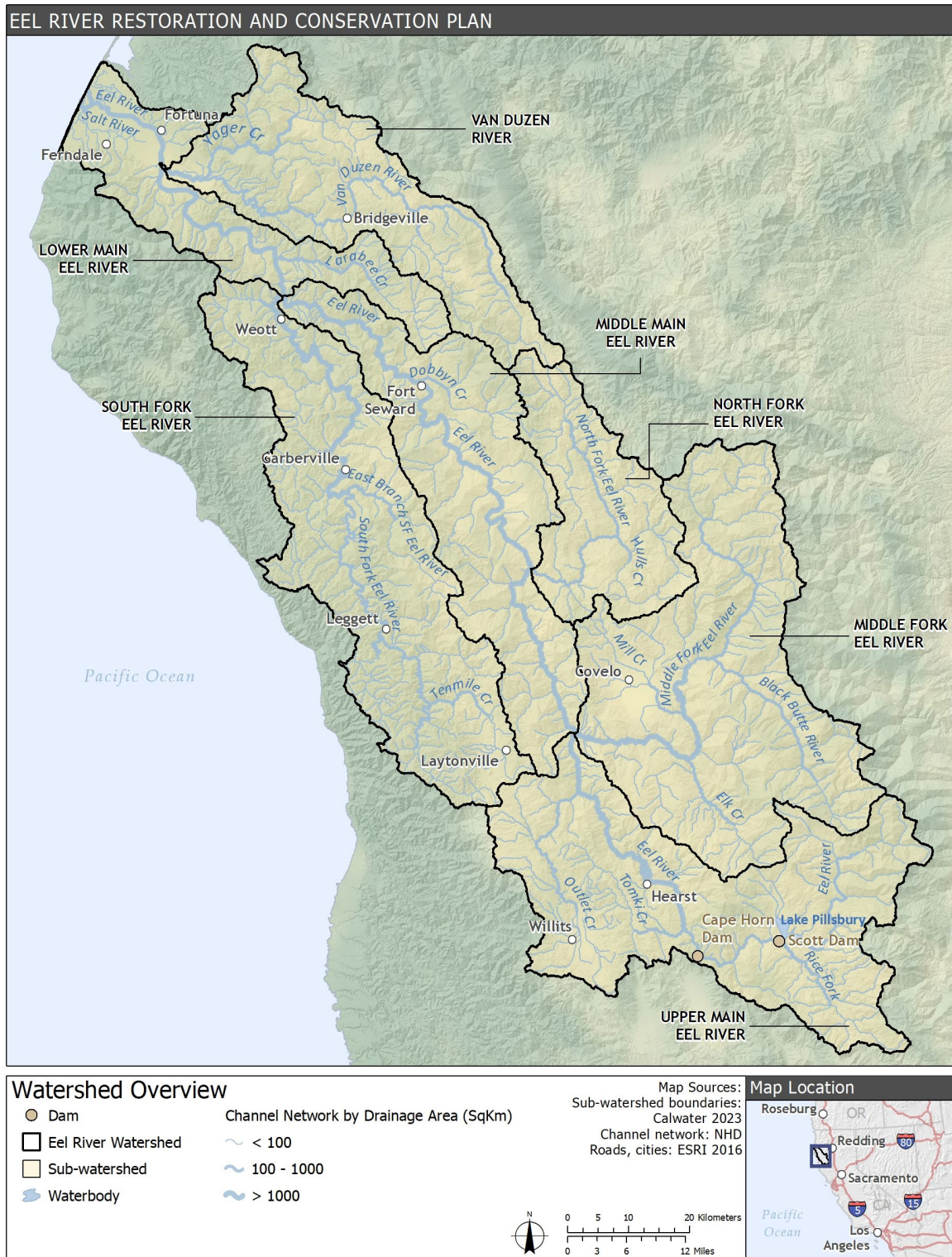


Figure 1-2. Overview of the Eel River watershed.

1.3.2 Geologic and Geomorphic Controls on Aquatic and Riparian Ecosystems

Geology is one of the most important overarching factors in determining physical habitat diversity and, in turn, salmonid life-history diversity in the Eel River watershed. Different geologic terranes exhibit distinctively different *landforms* (e.g., hillslope, valley bottom, and channel), *surface processes* (e.g., production and transport of water, wood, and sediment that influence channel form), and *hydrologic responses* (i.e., surface water and groundwater interactions that influence functional flows). These geology-driven differences play a fundamental role in determining spatial and seasonal differences in fish habitat suitability, as well as suitability of a given location for implementing restoration and conservation actions.

The Eel River watershed occurs within the northern part of the Coast Range Geomorphic Province, where migration of the Mendocino triple junction and evolution of the San Andreas transform boundary imprinted a strong northwest trend in the drainage network. The watershed is predominantly composed of the Franciscan Complex, a deformed accretionary prism of sedimentary, metamorphic, and igneous rocks that were assembled in a subduction zone and accreted to the continental margin between the Late Jurassic and Miocene (Jayko et al. 1989, Ohlin et al. 2010, McLaughlin et al. 2018). The Franciscan Complex primarily consists of three structural belts that decrease in age from east to west: the Eastern, Central, and Coastal belts (Jayko et al. 1989) (Figure 1-3). The Eastern belt, the earliest of the three Franciscan belts, is composed of less disrupted rocks that have undergone more uniform regional metamorphism than in the Central and Coastal belts to the west (McLaughlin et al. 2018, Blake et al. 1967). Much of the mainstem Eel River downstream of approximately Cape Horn Dam drains the Central belt. The Central belt consists of a Late Jurassic to Middle Cretaceous *mélange* matrix enclosing large blocks and slabs of more resistant rocks (McLaughlin et al. 2000, 2018). The western-most portion of the basin is predominantly underlain by rocks of the Coastal belt Franciscan Complex and Yager Terrane. These rocks are predominantly fine-grained marine sandstone, argillite, and conglomerate of Pliocene to Late Cretaceous age (McLaughlin et al. 1994).

The three belts of the Franciscan Complex exhibit contrasting hillslope geomorphology and erosion processes. Hillslope geomorphology in the Eel River watershed can be generally characterized as “hard” or “soft” based on topography, morphology, and surface processes (Kelsey 1980, Muhs et al. 1987, Mackey and Roering 2011). The higher rock-strength in Coastal belt rocks in the western portion of the basin typically leads to “hard” hillslope geomorphology with steep, ridge-and-valley topography and well-organized drainage networks where erosion is dominated by debris slides, debris flows, and fluvial incision (Kelsey 1980, Kelsey et al. 1995, Stock and Dietrich 2006). Conversely, the weaker and finer-grained *mélange* of the Central belt typically forms “soft” hillslope geomorphology where large earthflow complexes and gullies result in hummocky topography with longer, low-gradient slopes and poorly organized drainage networks. More competent blocks within the *mélange* persist as erosion-resistant topographic highs (Mackey and Roering 2011, Roering et al. 2015).

Naturally high erosion and sediment transport rates in the basin are attributed to active tectonics, erosive geology, high seasonal rainfall, and intense winter storm events. Sediment delivery rates generally increase from upstream to downstream and from east to west within the watershed (Stillwater Sciences 2021; Mackey and Roering 2011; USEPA 1999a, 1999b, 2002, 2003, 2004, 2007). Widespread anthropogenic disturbance over the last 150 years has increased erosion and sediment delivery from hillslopes and unimproved road networks to stream channels, impairing instream habitat conditions throughout basin.

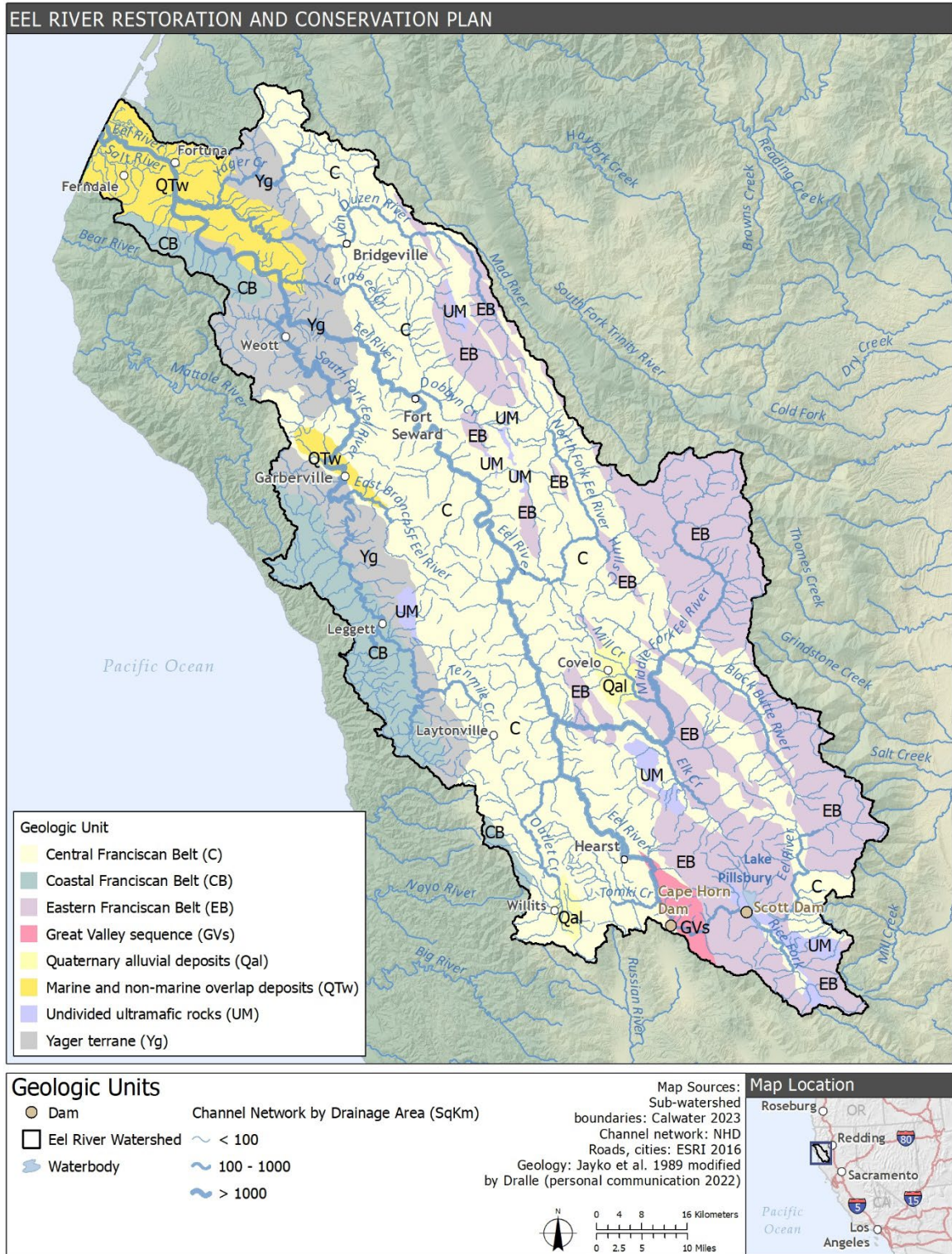


Figure 1-3. Simplified geologic map of Eel River watershed (Jayko et al. 1989, as modified by Dralle pers. comm. 2022).

Differences in bedrock geology and geomorphology across the three contrasting belts of the Franciscan Complex also result in distinctively different critical zone structure. The critical zone is Earth's near-surface layer from the tops of trees to the depth of fresh bedrock. Importantly, the critical zone is where chemical and physical weathering transform fresh bedrock, generating porosity, soil, and rock fractures capable of retaining and releasing water. Geologically mediated differences critical zone structure across the three belts of the Franciscan Complex result in distinct hillslope groundwater and root-zone storage dynamics (i.e., recharge, water storage capacity, and discharge) that strongly affect streamflow, plant water availability, stream water temperature, and stream energetic regimes; with important consequences for aquatic and riparian ecosystem functions (Dralle et al. 2023) (Figure 1-4). Geology, geomorphology, sediment dynamics, plant communities, and hillslope groundwater dynamics are therefore important factors in stratifying the Eel River watershed into sub-watersheds and channel archetypes that reflect key controls on fish life history, establishing restoration and conservation objectives, and developing decision support tools for prioritizing actions.

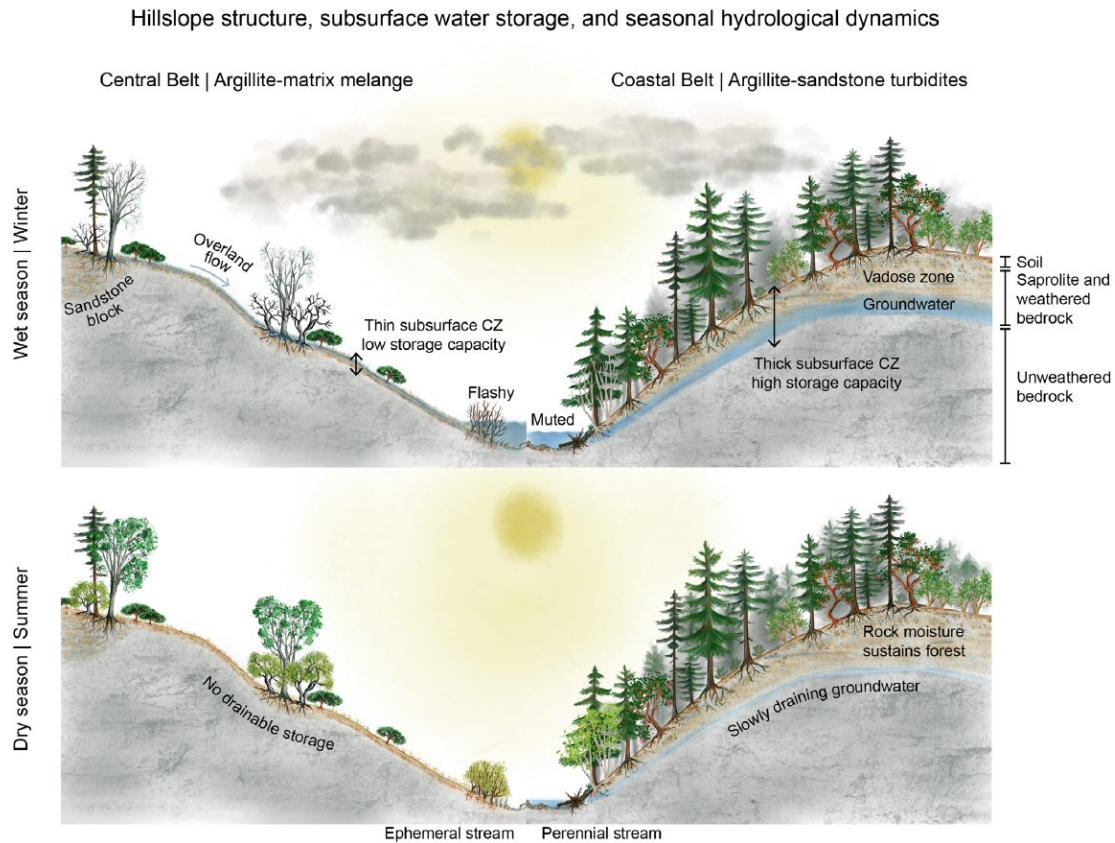


Figure 1-4. Relative comparison of hillslope structure, subsurface water storage, and seasonal hydrology between central belt (left) and coastal belt for wet season (top) and dry season (bottom) (used from Dralle et al. 2023 with permission).

1.3.3 Biodiversity and Ecological Setting

The watershed's physical diversity creates a template for a diverse and productive ecosystem. The canopy and vegetation of the Eel River is largely driven by underlying geology and lithology, and maritime influence. The coastal, foggy portion of the watershed is characterized by dense ferns and historically by tall conifers and redwoods. Some inland regions in the Central Belt receive

upwards of 2,000 mm (nearly 80 inches) of mean annual rainfall (enough to support dense temperate forest), yet small subsurface water storage capacity in the critical zone is only able to support less-productive (yet highly biodiverse) oak savanna. Further inland, drier portions of the watershed are characterized instead by grassland savannas and oak woodlands.

Historically, the watershed supported at least four species of anadromous salmonids: fall-run Chinook Salmon, Coho Salmon, winter and summer run steelhead, and Coastal Cutthroat Trout (*Oncorhynchus clarkia clarkia*) (Yoshiyama and Moyle 2010). Within these species, there were likely many forms of diversity in habitat use and age structure across the watershed that are not currently observed (Section 3). Additionally, at least sporadic runs of Pink Salmon (*Oncorhynchus gorbuscha*), Chum Salmon (*Oncorhynchus keta*), and Eulachon (*Thaleichthys pacificus*) were likely present (Yoshiyama and Moyle 2010). Pacific Lamprey provided the namesake for the river and was historically abundant, along with Green Sturgeon. Various other native fish species occupy the Eel River, including Sacramento Sucker (*Catostomus occidentalis*), Western Brook Lamprey (*Lampetra richardsoni*), Three-spined Stickleback (*Gasterosteus aculeatus*), sculpin species (*Cottus* spp.), and occasionally, White Sturgeon (*Acipenser transmontanus*) (CDFG 2010). Introduced species include the widely distributed and abundant Northern Coastal Roach (*Hesperoleucus venustus navarroensis*), Sacramento Pikeminnow (*Ptychocheilus grandis*), as well as generally less common and less widely distributed species such as Largemouth Bass (*Micropterus salmoides*), American Shad (*Alosa sapidissima*), Striped Bass (*Morone saxatilis*), Brown Bullhead (*Ameiurus nebulosus*), Speckled Dace (*Rhinichthys osculus*) and sunfish species (*Lepomis* spp.).

The diversity of fish species and life histories are supported by a complex food web of aquatic plants and invertebrates. The composition and relative abundance of the food web members differ greatly between small, nitrogen-limited shaded tributaries and large, sunlight-rich mainstem rivers. In general, food webs become longer and more complex with increasing drainage area (Sabo et al. 2010), including in the Eel River (Power et al. 2013). In the sunny, mainstem rivers, the primary producer trophic level is dominated by the green, stringy mats of *Cladophora glomerata*, a filamentous green algal species (Power et al. 2008). *Cladophora* provide structure for other primary producers, including nutrient-rich, epiphytic diatoms like *Epithemia* that fuel invertebrate production and native fishes. *Epithemia*, which are not nitrogen fixers, become more common in drainages greater than 100 km², where there is also often a stepwise increase in nitrogen availability in the Eel River (Power et al. 2009). The inter-annual variability in composition and abundance of primary producers in the summer months interacts with the magnitude and duration of wintertime flow events. For example, in years when winter floods scour out and suppress the numbers of the armored caddisfly grazer, *Dicosmoecus*, filamentous algae can be more productive (Power et al. 2008). Alternatively, when winters with bed-scouring flows are followed by summers with extreme drought conditions and flow stagnate, *Cladophora* tend to rot earlier, to be replaced with toxic cyanobacteria (Power et al. 2015). Cyanobacteria do not provide the same structure for nutritious diatoms, creating a less productive food web for fish species, and in some cases providing a public health concern from the release of microcystins (Power et al. 2015, Bouma-Gregson et al. 2017).

In shaded tributaries, the primary producers are a thin biofilm of diatoms and filamentous algae, which is often not visible to the naked eye due to suppression by armored invertebrate grazers (McNeely et al 2007). These often-invisible primary producers provide the “hidden carbon” that fuels the food web, along with influx of terrestrial carbon. In tributaries, drifting invertebrates are seasonally abundant and fuel the growth of rearing salmonids (Rossi et al. 2022). Rearing salmonids in small tributaries can also be fueled by the dispersal of aquatic invertebrates from the mainstem that provide a dense seasonal subsidy (Uno and Power 2015). The frequency and

seasonality of the mainstem-tributary linkages are understudied throughout the watershed but may provide a missing food source in salmon-producing tributaries.

One theme that holds true throughout tributaries and mainstems in the watershed is the high inter-annual variability in ecological interactions and processes. In Mediterranean-climate riverine systems like the Eel River, the only predictable feature is unpredictability, and there is meaningful variability among years in the frequency and magnitude of winter flows and the severity of dry conditions the following summer (Gasith and Resh 1999). For aquatic species, the timing of hydrologic events relative to the progression of their life cycle largely determines their success and abundance (Resh et al. 1988). As a result, the variability of the Mediterranean seasonality influences energy fluxes up the food web, from primary producers to invertebrates and fishes, and across space, between larger and smaller channels and their upland slopes (Power et al. 2013). This inter-annual and spatial diversity likely created a mosaic of habitats that fostered the persistence of a diverse and productive fishery in the Eel River.

1.3.4 Watershed History

Historical anadromous salmon and steelhead populations in the Eel River likely exceeded a million returning adults in good years but have been reduced to about 15,000 fish in recent years (Yoshiyama and Moyle 2010, Moyle et al. 2017, Metheny 2020, Loomis 2021, Kajtaniak and Roberts 2022, Smith 2022). A decline of salmonid populations and other species (e.g., Pacific Lamprey and Green Sturgeon) in the Eel River has been linked to various causes, such as historical logging practices, catastrophic flooding and sediment loading from historical logging practice, and salmonid over-harvesting (Yoshiyama and Moyle 2010).

From before the arrival of colonial settlers through to today, the Eel River watershed has been inhabited by several Native American Tribes. These Tribes have deep cultural and spiritual connections to the river, which has provided them with sustenance, transportation, and a source of cultural identity since time immemorial. The Eel River is not only a vital resource for food and water but also plays a central role in their cultural practices and ceremonies, highlighting the deep relationship between the Native American Tribes and the river ecosystem.

Since the colonial settlement beginning in the 1850s, the dynamic balance of the Eel River has been disrupted by numerous stressors. Starting in the late 1800s and early 1900s, salmon fishing supplied the local canneries; to meet the demand and fuel profits, the fishing pressure unfortunately was excessive and nearly ended the fishery. During the same period, clearcutting of the watershed's timber was happening; to support the timber industry, roads and railroads were cut into the landscape. The newly cleared areas, once hit with the catastrophic floods, resulted in excessive runoff and sedimentation. Ultimately, these issues of increased sediment supply, channel aggradation and simplification, loss of riparian vegetation, and reduced large wood recruitment, increased water temperatures, and altered hydrology. In addition to these widespread watershed impacts, the construction of the Potter Valley Project in the early 1900s blocked access to the upper Eel River to spawning and rearing salmonids, introduced non-native Sacramento Pikeminnow, and diverted water from an already low-flow system into the Russian River (Cooper et al. 2020, Fitzgerald et al. 2022). Sacramento Pikeminnow consume and compete with juvenile salmonids and are thought to be a major challenge for salmonid recovery in the upper Eel River. (Brown and Moyle 1997, Reese and Harvey 2002, Nakamoto and Harvey 2003, PG&E 2017, Stillwater Sciences and Wiyot Tribe Natural Resources Department. 2020). These historical stressors over the last 150 years have resulted in many ecological consequences, perhaps most impactful, are the loss and degradation of fish habitat and introduction of non-native species.

As the twenty-first century arrived, a set of new stressors presented themselves to the Eel River and compounded with those already present. Like many areas of California and the western United States, climate change has resulted in warmer air temperatures and more intense/frequent periods of drought (Dai 2013, Dettinger et al. 2015). The effects of climate are already being observed as drought, and the Eel River watershed is experiencing low streamflow and more intense and larger wildfires.

The Eel River watershed has also long been a hotspot for cannabis cultivation in Northern California (Bauer et al. 2015) with many farms illegally diverting water to support the thirsty plants. While each farm individually does not extract significant amounts of water, the cumulative impacts of cannabis cultivation can result substantially lower summer and fall flows that can disrupt the Eel River's food webs (Power et al. 2015). Taken comprehensively, the Eel River is now a difficult place for self-sustaining fisheries. However, as discussed in the *Preface*, it does not have to be this way. The Eel River and the species that use it are resilient and can be recovered with the right set of restoration and conservation actions.

1.3.5 Present-Day Land Management and Conservation

The Eel River's land management and conservation status is as diverse as its habitats. The Northern California Coastal Mountain Range is a remote and rugged area, but much of the watershed is privately owned by timber companies and individual landowners. Other large tracts of land in the watershed are under federal control by the U.S. Forest Service (USFS) and the U.S. Bureau of Land Management (BLM) or under state or local control by the California Department of Fish and Wildlife (CDFW) or California Department of Parks and Recreation, or the counties, municipalities, and NGOs. Native American reservation lands are also present throughout the watershed; the largest is for the Round Valley Indian Tribes and the Wiyot Tribe. The complexity of landownership will present challenges to the Program. Overall, the Eel River watershed is 57% private and 43% public lands. Protected areas make up 20%, and non-protected natural areas and working forests make up 19%, indicating there is potential for conservation action on lands throughout the watershed that are in a somewhat natural state, but not yet protected (CNRA 2023) (Table 1-1, Figure 1-5).

Table 1-1. Land management calculated square kilometers and square miles within the Eel River watershed boundary.

Land Management in the Eel River watershed	Square kilometers	Square miles	% of watershed
Private	5,397	2,088	57
Non-private and public (merged)	4,138	1,598	43
Eel River watershed total	9,535	3,686	100
<i>Breakdown of Non-Private and Public Lands</i>			
U.S. Forest Service	2,858	1,103	30
Other state and federal (California Department of Parks and Recreation, Natural Resources Conservation Service, Department of Natural Resources, and others)	467	180	5
U.S. Bureau of Land Management	427	165	5
Non-governmental organizations	288	111	3
Native American Tribes	97	38	1
Other (city and county)	2	0.8	0.02
<i>Breakdown of Protected Lands and Non-Protected Natural Areas</i>			
Protected lands and easements (Gap Analysis Project 1 + 2, CNRA 2023) ¹	1,939	749	20
Non-protected natural areas and working forests (Gap Analysis Project 3 + 4, CNRA 2023) ¹	1,850	714	19

¹ Gap Analysis Project 1+2 refers to existing protected areas with a management plan in place. Gap Analysis Project 3+4 refers to other natural areas, working lands, and forests that have state or federal management in place but are not protected as conservation lands (CNRA 2023). Other land management data were derived from CalFire Land Ownership data 2022. All data were analyzed for the Eel River watershed by CalTrout in 2024.

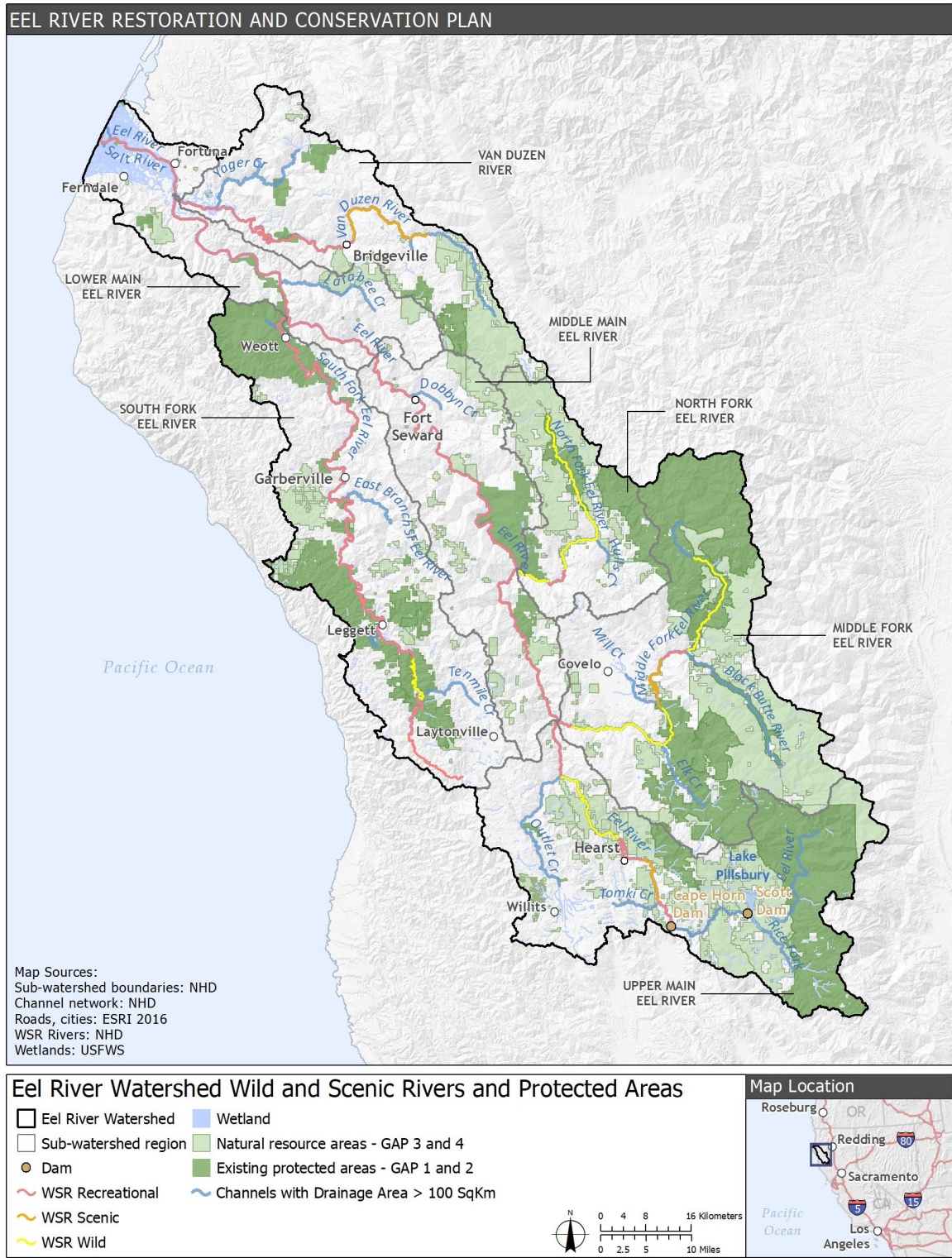


Figure 1-5. Wild and Scenic Rivers showing Recreation, Scenic, and Wild categories. Only parts of the Scenic and Wild designated areas have management plans, as described in Table 1-2.

A total of 431 linear miles of river corridors is designated as *Wild and Scenic*, specifically the Middle Fork Eel, North Fork Eel, and portions of the Van Duzen, Black Butte, South Fork Eel, and Upper Main Eel sub-watersheds (Figure 1-5). While protections under the Wild and Scenic River Act are beneficial, they are limited without a comprehensive protection effort to ensure resilience. At the time of this report, less than 14% of the Wild and Scenic segments in the Eel River watershed have a management plan. The current management plans for the Eel River Wild and Scenic Rivers are Scenic and Wild segments under USFS management. However, the buffer for the USFS segments of the Wild and Scenic River is derived from the center line, thus limiting the extent of the total area of the Wild and Scenic River, which is typically analyzed from the high-water mark on either side of the river. Additionally, with the decommissioning of the Potter Valley Project, there is an opportunity to classify many river miles of the upper mainstem Eel River as Wild and Scenic River segments. Opportunities for improving the Wild and Scenic River system management are (1) establishing management plans for those areas lacking plans and (2) allocating new Wild and Scenic River segments (Table 1-2).

Table 1-2. Wild and Scenic River miles in the Eel River watershed separated by category and percent of total miles per category without a management plan.

Category	Linear miles	Percent of total	Miles without a management plan	Percent without a management plan
Recreation	283	66	283	100
Scenic	36	8	32	88
Wild	112	26	57	51
Total	431	-	372	86

Opportunities exist for improving the protected area with strategic conservation planning in the Eel River watershed. The opportunity described in this Plan combined with the intent of California's 30x30 initiative to protect 30% of lands supportive of biodiversity and climate resilience by 2030, point to the Eel River region as a target area for conservation that will restore the river's fisheries and build climate resilience at the landscape scale as intended by the 30x30 initiative.

2 SPATIAL ORGANIZATION FOR PLANNING

Restoration planning is best conducted at the watershed scale to incorporate linkages between biological and physical processes across spatial scales, from the hillslope to the channel, and from upstream to downstream (Wohl et al. 2005). All watersheds encompass variation in physical and biological characteristics, so, in restoration planning, there is a need to divide watersheds into units that match the scale of the process or structure of interest, and then piece it back together. The Eel River, as a very large and diverse (5,794 km²) watershed, is no exception. The Planning Team has developed a hierarchy of planning scales that enables organization and assessment of problems at smaller spatial scales, and then for the pieces to be reconnected and assessed the entire watershed. Here, the hierarchy of planning scales to be used in the Plan and in future prioritization activities (Section 5.2) is discussed in Section 2.1. The channel archetype scale, which is the smallest spatial scale that will be considered and was developed specifically for the Eel River, is then discussed in detail in Section 2.2.

2.1 Hierarchy of Planning Scales

Watersheds and channel networks are inherently nested in space, from riffle-pool sequences, to stream reaches and sub-watersheds. The ecology and geomorphic form of a river at the smallest scale is affected by its position longitudinally in the watershed and the larger climatic and geologic setting (Vannote et al. 1980, Polvi et al. 2020). Additionally, while the day-to-day ecology of a fish depends on the habitat conditions in its current reach, many fish species, especially anadromous species, use habitats throughout the watershed over the course of their life cycle. In places where restoration objectives include restoring ecosystem processes and the species that rely on them, river restoration planning is much more likely to be successful if undertaken at the scale of an entire watershed (Wohl et al. 2005). However, there is a need to develop data inputs and analyses that address smaller scales as part of the planning process. A hierarchy of spatial scales in the Plan will allow for the integration of datasets and analyses at different scales for prioritization.

Nested spatial scales will be used to organize data inputs, analyses, and planning efforts for this Plan and are proposed for the Program when it is implemented (Figure 2-1). From large to small, the spatial organization moves from the whole watershed to seven primary sub-watersheds to HUC-12 sub-basins (large tributary basins, as defined by the U.S. Geological Survey's National Hydrography Dataset (NHD)), to the river segments (or reaches). Some analyses will also consider data inputs at the parcel level, which are typically smaller than the HUC-12 sub-basins. Underlying the spatial scales for planning are the geologic drivers of landscape processes described in Section 2.2. As such, geology is not a planning scale, but rather a structural organizational element that needs to be considered in concert with the nested planning scales. In addition to physical organizational elements such as geology, biological organizational elements will also need to be considered, including the three levels of organization used by the National Marine Fisheries Service (NMFS) for Endangered Species Act (ESA)-listed salmonid populations in recovery planning (i.e., populations, diversity strata, and Evolutionary Significant Unit [ESU] or Distinct Population Segment [DPS]).

The seven primary sub-watersheds are the Lower Main Eel, Van Duzen, Middle Main Eel, North Fork Eel, Middle Fork Eel, South Fork Eel, and Upper Main Eel sub-watersheds (Figure 2-1). This scale of representation is relevant for larger landscape processes such as dominant underlying geology, total annual precipitation, and maritime influence. As a result, these seven

sub-watersheds differ in the (1) presence/absence of fish species (most numerous in the Lower Main Eel sub-watershed due to the inclusion of the estuarine environment); (2) unusual life-history strategies (e.g., presence of summer run steelhead in the Middle Fork Eel and Van Duzen sub-watersheds due to snowmelt hydrologic components); and (3) land use and resource management history.

Within the seven primary sub-watersheds, there are 113 HUC-12 sub-basins in the Eel River watershed. HUC-12 sub-basins are approximately 50 km² (range 26–104 km²). The Plan considers HUC-12 sub-basins to be “ecological neighborhoods” because most include a collection of tributaries and mainstem river reaches that juvenile rearing salmonids could feasibly move between. HUC-12 sub-basins within a sub-watershed can differ in the geomorphic form of channels, temperature characteristics, and flow regimes. The HUC-12 sub-basins within a sub-watershed will be characterized for the potential need for restoration during the prioritization process in Phase 2 (Section 5.2).

The next smallest scale of spatial organization in the Plan is county parcels. County parcels will be considered primarily for conservation planning, where landownership is a driving variable. There are 44,642 county parcels in the Eel River watershed, spanning five counties and ranging significantly in size, from 0.000005 km² to 14 km² (Figure 2-1). Parcel-level planning and prioritization is needed to connect high-quality habitat or core parcels, integrate landowner support by initiating new or improved conservation easements on private land, and coordinate with agencies for conservation opportunities on public lands.

The final spatial scale of consideration in the Plan is channel segments, which are 1 km or less in length and are defined by the NHD and in some cases further divided (following FitzGerald et al. 2022). These channel segments are relatively uniform in geomorphic form, temperature, and flow regimes. Ecologically important features within these segments may be missed in this watershed-wide Plan (e.g., unique deep pools, or thermal refugia at tributary confluences). Understanding geographic variation in channel segments at a level of detail at <1 km will be left to local practitioners who develop site-specific restoration and conservation actions. In developing the spatial structure for the Plan, the Planning Team identified a need to characterize commonalities between channel segments, which results in a set of “channel archetypes.” This clustering analysis was novel for the Eel River, and the goals and process are described below in detail (Section 2.2).

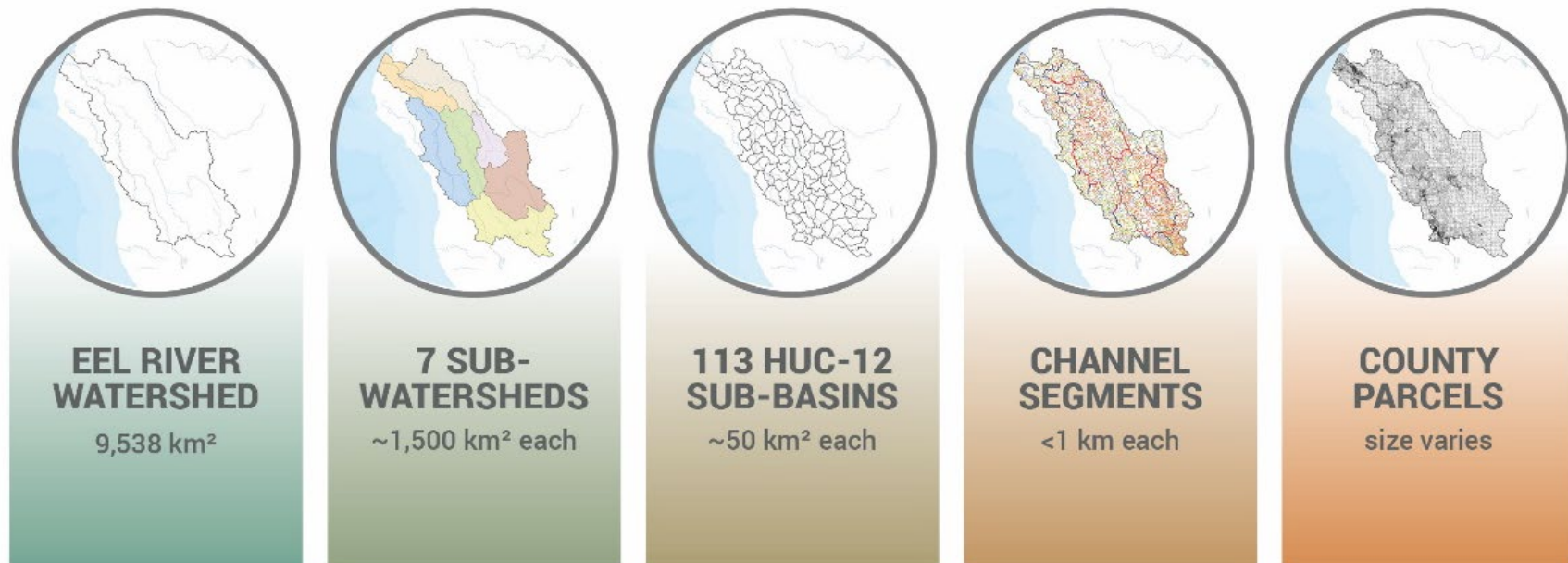


Figure 2-1. Planning scales used for restoration and conservation in the Eel River watershed. Eel River watershed boundary (n=1), primary sub-watersheds (n=7), HUC-12 sub-basins (n=113), channel archetype stream segments (n=10,541), county parcels (n=44,642).

2.2 Channel Archetypes

Habitat diversity within watersheds creates life-history diversity of fish species (Beechie et al. 2006, Lisi et al. 2013). A mosaic of diverse habitats allows fish to move between them, even if some habitats are seasonally unsuitable, and increases opportunities for growth and survival (Armstrong et al. 2023) (Figure 2-2). Because of the importance of life-history diversity for the stability and resiliency of fish populations (Hilborn et al. 2003, Section 3.2.2), the Planning Team sought to characterize channel diversity within the Eel River watershed as a way of predicting how many and what life-history strategies may have been historically present across the landscape. The channel archetype analysis is a grouping analysis that seeks to categorize habitat diversity for fish as driven by underlying geology (Section 2.3) for use in predicting fish use and designing restoration actions.

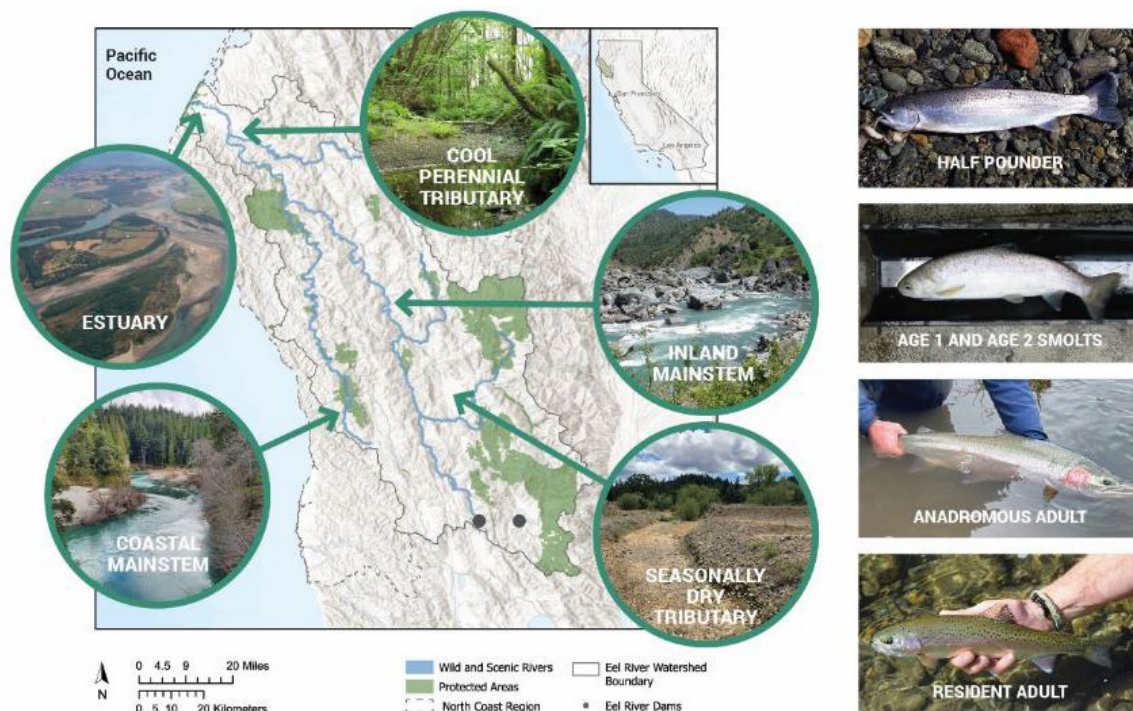


Figure 2-2. Diversity in stream channel characteristics, from cool tributaries to inland mainstems, provide a mosaic of habitats that differ in timing and extent of ecological productivity. This habitat diversity likely gave rise to life-history diversity, such as variation in the age at outmigration to the ocean or return to freshwater, within the native anadromous fishes of the Eel River. Categories of diverse habitat types, or *channel archetypes*, were developed for use in the Plan.

Channel archetypes were developed to categorize similar river channel segments across the watershed at the reach-scale (approximately 1 km) based on primary physical and environmental attributes that reflect physical processes and disturbance mechanisms that work to maintain channel morphology over time. These attributes influence (1) how fish use these channel segments and (2) the opportunities and constraints for restoration and conservation actions. The archetypes were designed to be a tool to help predict, in a spatially explicit manner, which streams throughout the watershed would support which life-history strategies for the focal species. Predictions of life-history diversity can then be linked to which restoration actions will

be most appropriate and effective within the same river channel segments. The combination of predictions for potential life-history diversity value and restoration actions at the channel level will be used in the prioritization process described in Section 5.2.

Channel archetypes were developed using a hierarchical categorization of readily available, watershed-wide datasets on drainage area, channel slope, and stream thermal regime. See Appendix B for a more detailed overview of this process and the data inputs. These datasets represent many geomorphic categories that are likely to influence fish use and restoration potential. Drainage area and channel slope were calculated by FitzGerald et al. (2022) from NHD Plus. Mean monthly water temperatures were also predicted by FitzGerald et al. (2022) using a large-scale, empirically based statistical interpolation method named the Stream Spatial Network. The channel archetype analysis resulted in 14 groupings organized around drainage area, channel slope, and stream thermal regimes (water temperatures) (Table 2-1).

Table 2-1. Channel archetypes and the encompassing drainage area, slope, and thermal groups. The range of mean May and August water temperatures is shown to highlight that cool and warm channel archetypes can be seasonally suitable, and even more optimal, for salmonid growth.

Channel archetype	Code	Drainage area category	Channel slope category	Stream thermal category	Mean August water temperature range (°C)	Mean May water temperature range (°C)
Small tributary	0	Small tributary (<2 km ²)	All	Cold, cool, warm	8.3–23.3	6.5–21.2
Low-gradient, cold tributary	1.1-cold	Tributary (2–100 km ²)	<2%	Cold	11.5–17.0	8.9–15.4
Low-gradient, cool tributary	1.1-cool			Cool	17.0–20.0	9.7–16.4
Low-gradient, warm tributary	1.1-warm			Warm	20.0–23.3	11.4–16.5
Mid-gradient, cold tributary	1.2-cold		2–7%	Cold	11.6–17.0	7.4–15.3
Mid-gradient, cool tributary	1.2-cool			Cool	17.0–20.0	9.3–16.6
Mid-gradient, warm tributary	1.2-warm			Warm	20.0–22.3	12.3–15.3
High-gradient, cold tributary	1.3-cold		7–12%	Cold	10.4–17.0	7.5–15.2
High-gradient, cool tributary	1.3-cool			Cool, warm	17.0–21.8	10.5–15.5
Very high gradient tributary	1.4		>12%	Cold, cool, warm	8.3–20.9	6.8–14.9
Cool mainstem	2-cool		Mainstem (100–1,000 km ²)	<2%, 2–7%	Cool	14.7–20
Warm mainstem	2-warm	<2%, 2–7%		Warm	20–23.8	10.6–16.6
Large mainstem	3	Large mainstem (>1,000 km ²)	<2%	Cold, Cool, Warm, Hot	16.2–24.6	12.4–16.1
Estuary	4	Estuary	<1%	-	-	-

Notes: °C = degrees Celsius
km² = square kilometers

The channel archetypes have several limitations due to the methods and data used to develop the groupings. Some of the archetypes encompass a diversity of channel features and habitat types. For example, the estuaries encompass many different habitat types (e.g., Simenstad et al. 2011) that are not addressed in this Plan. Additionally, with any grouping analysis, outliers are lumped rather than highlighted. These outliers may be of outsized ecological importance (e.g., the large mainstem channels that are cold are not identified as a separate group due to their rarity). A separate analysis to identify unique habitats/channels may be warranted in the prioritization process, particularly if they have high ecological relevance (e.g., a biological hotspot).

Additionally, the archetype datasets likely do not encompass the true complexity of each variable due to their scale. For example, slope is calculated over 1 km segments, which is not suitable for identifying knickpoints or shorter low-gradient features within those segments. Similarly, the water temperature model does not predict thermal complexities of the river (e.g., stratified deep pools, or tributary confluence plumes), so potentially unique/anomalous locations within the river continuum will not be captured. Any recommended restoration and conservation actions linked to these channel archetypes are considered general guidelines. A necessary next step before undertaking a restoration project within a channel archetype would be to ground-truth the channel to determine project location and site suitability.

In summary, the hierarchy of planning scales described in this section, ranging in size from small channel segments and parcels to the entire watershed, will allow for nimble assessment of structure and processes across spatial scales. These spatial scales can be used to describe the nested habitat diversity that gives rise to fish life-history diversity, which is a critical component of the Plan (Section 3.2.2).

3 FOCAL FISH SPECIES CHARACTERIZATION

This section describes the rationale for using focal fish species as a foundation of restoration and conservation in the Eel River watershed; summarizes the approach applied to characterize each species and their potential life-history diversity through conceptual models (Appendix C); and outlines how the conceptual models can be used to inform restoration and conservation actions (Section 4) and aid in development and implementation of informed prioritization (Section 5) and monitoring frameworks (Section 7).

3.1 Rationale for Focal Species

A principal goal of the Program is to protect and aid in the recovery of native, anadromous fish species with commercial, recreational, or Tribal cultural value, as well as those with state or federal special-status designations (Section 1.2.1.2). Accordingly, the Planning Team selected fall-run Chinook Salmon, Coho Salmon, steelhead (summer- and winter-run), Pacific Lamprey, and Green Sturgeon as focal species for restoration and conservation (Table 3-1, Figure 3-1). Each of these species are high priorities for population recovery and management in the Eel River watershed (CDFW 2004; NMFS 2014, 2016; Moyle et al. 2015; Eel River Forum 2016; McBain Associates 2017; Wiyot Tribe Natural Resources Department and Stillwater Sciences 2016; Stillwater Sciences and Wiyot Tribe Natural Resources Department 2017; South Fork Eel River SHaRP Collaborative 2021).

Table 3-1. Focal fish species for the Eel River Watershed Restoration and Conservation Program and their special-status designations.

Common name <i>Scientific Name</i>	Federal and State status ¹	Rationale for inclusion
Chinook Salmon California Coastal ESU (fall-run) <i>Oncorhynchus tshawytscha</i>	FT, SSC ²	Federal listing; Tribal importance; commercial and recreational fisheries; primary marine subsidy and ecosystem structuring species, represent large river and estuarine habitats
Coho Salmon Southern Oregon/Northern California Coast ESU <i>Oncorhynchus kisutch</i>	FT, ST	Federal listing; Tribal importance; historical commercial and recreational fisheries; represent cool and low-gradient streams, off-channel, and estuarine habitats
Steelhead (summer, fall, and winter runs) Northern California Coast DPS <i>Oncorhynchus mykiss</i>	FT, SE ³ , SSC ²	Federal and state listing; recreational fishery; Tribal importance; wide distribution across diverse coastal and inland habitats
Pacific Lamprey <i>Entosphenus tridentatus</i>	SSC, BLM, USFS	Tribal importance; unique ecological roles; important marine subsidy, wide distribution and long freshwater and ocean residence periods
Green Sturgeon (Northern DPS) <i>Acipenser medirostris</i>	FSC ⁴ , SSC	Tribal importance; historical recreational fishery; represent large river and estuarine habitats

¹ Status designations are from Moyle et al. (2015) and CNDBB (2024). FT = Listed as Threatened under the federal Endangered Species Act; FSC = Federal Species of Concern; ST = Listed as Threatened under the California Endangered Species Act; SE = Listed as Endangered under the California Endangered Species Act; SSC = CDFW Species of Special Concern; BLM = Listed as U.S. Bureau of Land Management Sensitive Species; USFS = Listed as U.S. Forest Service Sensitive Species in Region 5.

² Moyle et al. (2015) lists the population as an SSC, but CNDBB (2024) does not.

³ SE designation applies to summer-run steelhead only.

⁴ FSC designation from NMFS (2006).



Figure 3-1. Focal fish species for the Eel River Watershed Restoration and Conservation Program.

Importantly, the focal species collectively exhibit life-history strategies that use diverse aquatic habitats across the Eel River watershed. Restoring and conserving these habitats, as well as the physical and ecological processes needed by the focal species across their life cycles, effectively provides an umbrella of restoration and protection for other native aquatic and riparian species in the Eel River watershed (Lambeck 1997). For example, focusing on Chinook Salmon and Green Sturgeon requires understanding, restoring, and conserving habitats along the mainstem Eel River corridor, larger tributaries, and the estuary. A focus on steelhead and the wide range of adult and juvenile life histories displayed by the species ensures that channels in inland, higher elevation, and steeper parts of the watershed, as well as coastal-oriented and estuarine areas, are considered in planning and prioritization.

Other ecologically important aquatic species would also benefit from more focused attention, and their inclusion could contribute to more holistic watershed restoration planning; however, selecting too many focal species can defeat the purpose of a focal species approach by overcomplicating prioritization or spreading limited resources too thin. Still, additional focused assessments of important fish and aquatic wildlife species such as Longfin Smelt, Coastal Cutthroat Trout (whose southern distribution terminates at the Eel River), and Foothill Yellow-legged Frog, would be valuable to understand whether habitat needs for these species are not covered under the umbrella of the selected focal species. Information from these assessments could be integrated into future restoration planning, prioritization, and monitoring decisions.

3.2 Species Descriptions and Life-history Conceptual Models

This section explains the purpose of focal fish species descriptions and life-history conceptual models (Section 3.2.1), discusses the importance of life history and habitat diversity to fish population recovery (3.2.2), describes the approach used for developing life-history conceptual models for focal species (Section 3.2.3), and summarizes key outcomes of the conceptual models (Section 3.2.4).

3.2.1 Purpose

Identifying and prioritizing restoration and conservation actions that address the root causes of decline and most directly contribute to the recovery of focal species populations requires a thorough understanding of their distribution, life-history timing, habitat needs, ecological interactions, and, most importantly, the factors driving their population dynamics. As described in Section 3.2.2, a fundamental component of anadromous fish abundance and resilience to environmental change is life-history diversity, or variation in how animals balance trade-offs among survival, growth, and reproduction (Roff 1992, Schindler et al. 2010, Braun et al. 2016). This Plan emphasizes one aspect of life-history diversity: the variation of movement patterns and habitat and resource use across time and space that individuals can exhibit over their life cycle. Accordingly, for each focal species, the Planning Team (1) reviewed and synthesized available information on each life stage and (2) developed life-history conceptual models to help identify and describe the suite of life-history pathways, their potential to exist in the Eel River watershed, and factors limiting their prevalence. The primary objectives of these efforts and their nexus with other parts of the Plan are listed in Table 3-2 and described in more detail in the sections that follow. The outcomes of these efforts for each species are provided in Appendix C.

Table 3-2. Primary objectives of focal fish species characterization and life-history conceptual models.

Objective	Restoration planning nexus
Describe population status, known current and historical distribution, ecology, life-history timing, and habitat needs for each life stage	Reference for all planning tasks
Identify and describe life-history strategies currently and intrinsically supported by the watershed and the factors limiting their expression ¹	Restoration and conservation actions (Section 4) Prioritization framework (Section 5) Monitoring and assessment framework (Section 7)
Systematically identify key stressors that limit population abundance and resilience by impairing habitat capacity, growth, survival, and life-history diversity	Restoration and conservation actions (Section 4) Prioritization framework (Section 5)
Identify important data gaps and generate testable hypotheses for factors limiting life-history expression and abundance for each species	Monitoring and assessment framework (Section 7)
Provide input and guidance on prioritization decisions	Prioritization framework (Section 5)
Develop basis and parameters for quantitative life-cycle models or other future models	Potential future quantitative tools to support prioritization

¹ In this Plan, the term *life-history strategy* refers to fundamentally unique life-history types within a species' life stage. For juveniles, strategies are generally defined based on length of time spent rearing in natal streams (e.g., natal rearing, spring fry emigrant, fall parr emigrant). The term *life-history pathway* is used to refer to the variation in movement patterns across time and space that can occur within a strategy. For example, within the spring fry life-history strategy of juvenile Coho Salmon, there are different pathways that rear for varying amounts of time in some combination of mainstem corridors, non-natal tributaries, and the stream-estuary ecotone.

3.2.2 Importance of Life-history Diversity and Habitat Diversity

Within a population of fish, especially highly migratory species, different individuals can exhibit different patterns of movement across space and time during their life cycle. The diversity of pathways that can occur from the time of birth in spawning streams until fish enter the ocean and ultimately return to spawn in fresh water is commonly known as life-history diversity. Like a diverse financial portfolio, having a diverse portfolio of life-history strategies in a fish population spreads the risk of mortality across time and space, contributing to resilience and reducing risk of extinction (Hilborn et al. 2003, Schindler et al. 2010, Moore et al. 2010, Carlson and Satterthwaite 2011). A diverse portfolio of life-history strategies is especially important in changing landscapes, where it is unknown which strategies will succeed in the face of watershed disturbances and environmental and climatic changes. Because only a fraction of the thousands of eggs laid by a female salmon, lamprey, or sturgeon will survive to return as adults, having a diversity of life-history strategies in the population increases the chances that, each year, at least some individuals will experience suitable conditions and survive to continue the next generation, increasing population stability and resilience (Hilborn et al. 2003, Schindler et al. 2010).

As introduced in Section 2.2, a mosaic of connected habitats distributed across space and time provides the potential for the expression of diverse fish life-history strategies, which both increases population resilience and results in greater overall abundance (Moore et al. 2014, Atlas et al. 2023, Cordoleani et al. 2024, Rossi et al. 2024). The limited area of habitat in natal streams limits their carrying capacity. Thus, when juvenile fish can spread out across the watershed and use diverse, non-natal habitats (including habitats that are only seasonally suitable), the watershed's overall rearing habitat area and associated carrying capacity increases, thereby increasing population abundance. Furthermore, by spreading out individuals across the landscape, some strategies will inherently be more successful than others as environmental impacts in different habitats shift, and asynchrony in success across the landscape provides resilience through time. The critical need for diverse habitats underscores the importance of a basin-wide restoration and conservation strategy that addresses habitat impairments across a diversity of habitat types.

Despite the increasing recognition of the fundamental role life-history diversity plays in abundance, persistence, and stability of anadromous fish populations, management and restoration strategies tend to focus on widely recognized life-history strategies that are currently present on the landscape, often overlooking strategies that may have contributed significantly to the great historical abundance of Eel River fish populations but are less common now. Specifically, restoration planning and implementation efforts in the Eel River have been weighted heavily toward protection and restoration of physical habitat in cold, low-gradient tributaries that support juvenile natal stream rearing life-history strategies (those that spend a year or more in their natal streams before emigrating to the ocean) for Coho Salmon and steelhead (NMFS 2014, 2016; South Fork Eel River SHaRP Collaborative 2021). Continued focus on protecting and restoring these cold natal streams is justified because they are salmon strongholds, and under current conditions, natal life-history strategies likely contribute to a large fraction of fish populations in many streams during most years. However, even when fully restored, the juvenile habitat capacity of natal streams is likely insufficient to produce the great abundance of returning adults that historically occurred in the Eel River. It follows that other life-history strategies, such as early emigrants that rear along mainstem corridors, in the stream-estuary ecotone, or in non-natal tributaries, must have contributed substantially to the historical abundance, and likely still contribute to abundance and resilience of current population to some degree. For example, in the Central Valley of California, late-emigrating juveniles were critical to sustaining Chinook Salmon populations during drought and ocean heatwaves (Cordoleani et al. 2021). More importantly,

recovery of the Eel River’s anadromous fish population will depend on recovering life histories that are currently depressed or rare, rather than increasing the abundance of life histories that are common today. For this reason, understanding, protecting, and restoring non-natal juvenile life-history strategies—as well as less commonly recognized adult life-history strategies—are fundamental to recovering native fish populations and are a core focus of the Plan. As described below, the life-history conceptual models were developed to help identify and describe the suite of life-history strategies with potential to exist in the watershed (including those that have been extirpated), determine that factors that may be limiting their expression, and outline strategies for restoring them.

3.2.3 Life-history Conceptual Model Approach

Understanding the factors that control the abundance and persistence of returning adult anadromous fish is an extremely complex undertaking, particularly for a large watershed like the Eel River. Developing a life-history conceptual model for each species provides a framework to (1) organize the available information, (2) identify data gaps and testable hypotheses, (3) identify factors potentially limiting production of each life stage and life-history strategy, and (4) inform efforts to identify and prioritize restoration strategies that are most likely to increase population size and resilience.

The Planning Team synthesized information on status, current and historical distribution, ecology, life-history timing, and habitat needs of each life stage for each focal species in the Eel River watershed (Appendix C). Building on this review and drawing on information from other watersheds in the region, the Planning Team developed diagrams to help (1) identify the potential suite of adult and juvenile life-history strategies (and variation within each) with the potential to occur in the Eel River watershed and (2) visualize how different strategies use different parts of the watershed across space and time. Figure 3-2 shows an example of a life-history diagram developed for Coho Salmon. In this example, primary juvenile life-history strategies are shown in different colors. Within each strategy, the suite of more specific life-history pathways with the potential to occur in the Eel River are shown. For instance, after leaving natal streams in the fall, individuals in the “fall parr emigrant” strategy have the potential to spend the wet season rearing in mainstems, non-natal streams, or the stream-estuary ecotone.

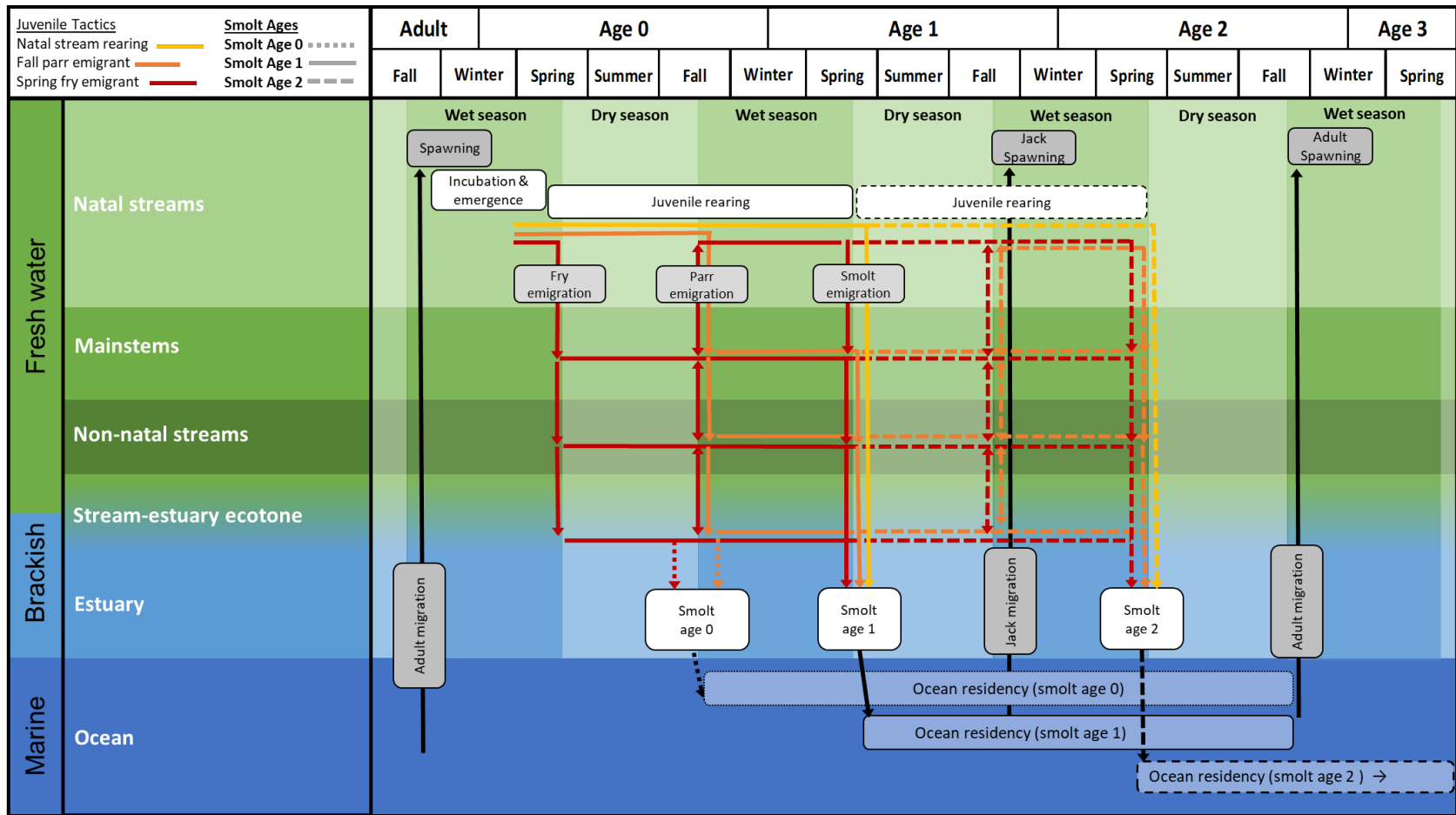


Figure 3-2. Example of a life-history conceptual diagram for Coho Salmon in the Eel River. The diagram shows potential movement pathways across time (X-axis) and space (Y-axis) for primary juvenile life-history strategies, which are represented by yellow, orange, and red lines. Each line represents a potential pathway within a strategy. The direction of the arrows represents the directions of movement between primary portions of the watershed. Refer to Appendix C for further description of these diagrams and the associated species conceptual models.

After creating life-history conceptual diagrams, the Planning Team developed accompanying narratives to describe primary juvenile and adult life-history strategies for each focal species. Depending on species, these narratives generally include discussion of the following:

- Overall behavior, ecological interactions, and time frames spent in natal and non-natal habitats (for juveniles);
- Potential variations (pathways) within each strategy and evidence for their current and historical distribution and prevalence in the Eel River watershed;
- Natal and non-natal stream conditions and channel archetypes (Section 2.2) that support each life-history strategy and example streams with these conditions;
- Influence of annual variation in hydrological patterns on expression and survival of each strategy;
- Primary factors affecting survival and prevalence of each strategy, including factors occurring within rearing and spawning habitats, and factors influencing survival during transitions between habitats; and
- Key data gaps and level of certainty in knowledge about life-history diversity and stressors of each species.

These species conceptual models should be viewed as iterative and will be refined as additional information is compiled during the action prioritization process and new data from ongoing and future research and monitoring efforts become available.

3.2.4 Key Outcomes

The information compiled and understanding gained from focal fish species descriptions and life-history conceptual models was used to:

- Identify a draft list of likely stressors for each species (Section 3.2.4.1);
- Identify and describe key themes and strategies for restoration and conservation (3.2.4.2); and
- Catalog important data gaps (Section 3.2.4.3) to help identify research and monitoring activities needed to address them.

This section provides a higher-level synthesis of these outcomes across all focal species. More detailed lists of stressors, restoration strategies, and data gaps for each species are provided in Appendix C. Importantly, as described in Section 5, the species' conceptual models will also be used in the proposed action prioritization process as a tool to determine the most impactful stressors for each species and to help identify the priority restoration and conservation actions for addressing them.

3.2.4.1 Identified stressors to focal species

Table 3-3 lists the stressors with potential to contribute to loss of population productivity and resilience for one or more of the focal species in the Eel River watershed. The table also includes preliminary ratings of the level of certainty that each stressor has a significant impact on each species. Herein, stressors are defined as:

Physical, environmental, or biotic factors driven by anthropogenic impacts that can significantly impair natural watershed or ecological processes and negatively impact habitat capacity, growth, survival, and diversity of focal species in the Eel River, contributing to less abundant and resilient populations.

The list of stressors was generated from the species conceptual models (Appendix C), along with existing recovery plans and species assessments (e.g., NMFS 2014, 2016; Stillwater Sciences 2014; Stillwater Sciences and Wiyot Tribe Natural Resources Department 2017, Boyce et al. 2022). While each stressor listed in Table 3-3 has the potential to adversely affect one or more life stages of each of the focal species, some stressors are expected to be more important than others in terms of limiting population productivity or expression of life-history diversity for certain species. Appendix C includes more in-depth discussion about the factors hypothesized to have the greatest influence on abundance and resilience of each species. As described in Section 5, this information will be an important input into the process for prioritizing restoration and conservation objectives during Phase 2 of the Program. Section 4 provides a suite of restoration and conservation actions that address likely stressors to focal fish species. This action list—which was also informed by existing recovery plans, species assessments, and a hierarchical process to identify tiered goals and objectives—will serve as the starting point for selecting actions that most directly address priority restoration objectives identified in Phase 2 of the Program (Section 5.2.2).

Table 3-3. Stressors identified through species conceptual models, existing species assessments, and recovery plans with potential to contribute to less abundant and resilient populations of focal species in the Eel River watershed.¹

Stressor category	Stressor	Chinook Salmon	Coho Salmon	Steelhead	Pacific Lamprey	Green Sturgeon
Fish passage barriers	Anthropogenic physical barriers to movement	K	K	K	K	U
	Flow or sediment related barriers to seasonal movement	K	K	K	L	U
	Reduced passage through mainstem due to introduced predatory fishes and warming temperatures	K	K	K	U	U
	Reduced connectivity with estuarine habitats	K	K	K	L	K

Stressor category	Stressor	Chinook Salmon	Coho Salmon	Steelhead	Pacific Lamprey	Green Sturgeon
Physical aquatic habitat	Reduced area of low-velocity instream winter rearing habitats	U	K	K	L	U
	Impaired connectivity with and loss of floodplain rearing habitats	K	K	K	K	U
	Alteration of estuarine habitat quantity and quality	K	K	K	K	K
	Loss of complex habitat that provides refuge from predators	K	K	K	K	K
	Reduced pool frequency and depth in mainstems and tributaries, loss of thermally stratified pools	K	K	K	L	K
	Channel bed and redd scour	L	L	L	L	U
	Fine sediment infiltration of spawning substrates and redds	L	K	K	K	K
Instream flows	Impaired dry-season stream flows	K	K	K	K	K
	Impaired fall pulse flows	K	U	L	U	U
	Delayed winter storm events and flows	K	L	K	U	U
	Reduced spring recession flows	K	L	K	K	L
	Loss of snowmelt component of spring recession	K	U	K	L	L
Water quality	Increased water temperatures	K	K	K	K	K
	Reduced area of and access to coldwater habitats and refugia	K	K	K	L	L
	Low dissolved oxygen concentrations	U	U	U	U	U
	Exposure to toxins from urban and agricultural run-off	U	U	U	U	U
	Elevated nutrient inputs from agricultural run-off	U	U	U	U	U
	Elevated turbidity levels beyond reference state levels	L	L	L	U	U
Species interactions and food webs	Loss of beneficial species interactions	L	L	L	L	L
	Increased prevalence of disease and parasites	U	U	L	U	U
	Introduced predators and anthropogenic factors that increase vulnerability to them	K	K	K	K	L
	Introduced competitors and anthropogenic factors that increase vulnerability to them	K	K	K	U	L
	Loss of marine-derived subsidies and nutrients	K	K	K	K	K
	Alteration of benthic algal and cyanobacteria communities, with influences on higher level food resources like macroinvertebrates	K	K	K	L	L
	Alterations to the timing, magnitude, and availability of macroinvertebrate food resources	K	K	K	L	L
Harvest	Ocean harvest or bycatch	K	L	L	U	U
	Poaching	L	L	L	U	L

¹ K = known stressor; L = likely stressor; U = unknown but potential stressor

3.2.4.2 Important themes informing restoration and conservation priorities

During the development of life-history conceptual models and identification of key stressors—and during various internal and TAC discussions—the Planning Team identified the following

central themes and focus points related to recovery of focal fish species in the Eel River watershed.

Coldwater habitats

Identifying, protecting, restoring, and improving access to coldwater habitats across the watershed is essential for protecting and restoring the strongholds of focal species in the face of climate change. At the watershed-scale, these habitats include important coldwater tributaries, headwater streams, and estuarine habitats that can support focal species through the summer during drought years. Restoring anadromous fish access to and improving habitat within the coldwater habitats upstream of Scott Dam is a high priority. At smaller, within-reach scales, these habitats include thermal refugia within thermally-stratified pools, coldwater plumes associated with tributaries and springs, coldwater reaches associated with upstream hyporheic or sub-surface flows, and other anomalously cold habitats in otherwise warm reaches. Restoration planning efforts should emphasize restoring habitat at tributary confluences and improving connectivity between mainstems and the lower reaches of tributaries, which provide refugia from both high temperatures in the summer and, as described below, high stream flows in the winter.

Habitat heterogeneity and non-natal rearing habitats

Extensive, annually variable and, sometimes, large-scale movements of focal species between diverse habitat types suggest a system-wide approach to habitat restoration is needed to maximize production and resilience of focal fish species. Continued efforts in the protection and restoration of salmonid stronghold streams—low-gradient, coldwater tributaries that support year-round juvenile rearing by natal life-history strategies—are crucial to the persistence and recovery of focal fish populations. However, as discussed previously, even complete restoration of natal streams will be insufficient to return focal fish populations to historical abundance. The life-history conceptual models illuminate the pressing need to expand efforts to protect and restore a mosaic of non-natal rearing habitats that provide variable conditions within and between years for early emigrant strategies (i.e., individuals that leave the natal streams in the spring as fry or in the fall as parr).

Specifically, restoring a mosaic of non-natal habitat features between natal streams and the ocean, which can be used across variable conditions within and between years, is a critical component to fostering juvenile fish life-history diversity. Non-natal habitats with potential to provide seasonally productive rearing conditions and increased carrying capacity for focal species include (1) mainstem habitats; (2) off-channel ponds, beaver ponds, and wetlands along mainstem corridors (Petersen 1982, Soto et al. 2016); (3) perennial tributaries (Skeesick 1970, Stillwater Sciences 2023); (4) small, intermittent tributaries (Ebersole et al. 2006, Wiginton et al. 2006); (5) large unconfined valleys, such as Little Lake Valley, that historically provided extensive winter rearing habitat (NMFS 2014); (6) estuarine habitats such as tidal wetlands and sloughs (Miller and Sadro 2003, Koski 2009, Jones et al. 2014, Rebenack et al. 2015, Wallace et al. 2015); and (7) tributaries near the estuarine habitats that may provide temporary refugia for estuary-rearing juveniles during winter high flows (Hayes et al. 2011).

Both natal and non-natal streams that are too warm to support salmonids through the summer have largely been overlooked in efforts to restore fish populations in the Eel River, but these streams have potential to provide high-quality rearing habitats during the wet season that can substantially contribute to overall population abundance and resilience. Even small streams that become intermittent in the summer can provide excellent non-natal rearing and winter refuge habitat during the wet season (Skeesick 1970, Ebersole et al. 2006, Wiginton et al. 2006). For

example, Ebersole et al. (2006) found high Coho Salmon overwinter survival and growth rates in a small tributary relative to adjacent mainstem reaches. In addition to providing winter rearing habitats, drier or intermittent streams (associated with Central Belt *mélange*) can provide better conditions for rapid fry and juvenile growth during the spring relative to cold perennial streams (associated with Coastal Belt turbidites) because of their quicker rate of flow recession and warmer water temperatures during that season, which are driven by differences in underlying geology (Figure 3-3, Dralle et al. 2023). In some sub-watersheds, like the Middle Fork of the Eel River, the majority of habitat is within intermittent tributaries, and writing off these habitats significantly reduces the total habitat capacity in that sub-watershed. Finally, stream reaches that are not habitable during warmer, drier portions of the year can still drive food production, fish growth and life-history diversity during cooler, wetter portions of the year (Armstrong et al. 2021).

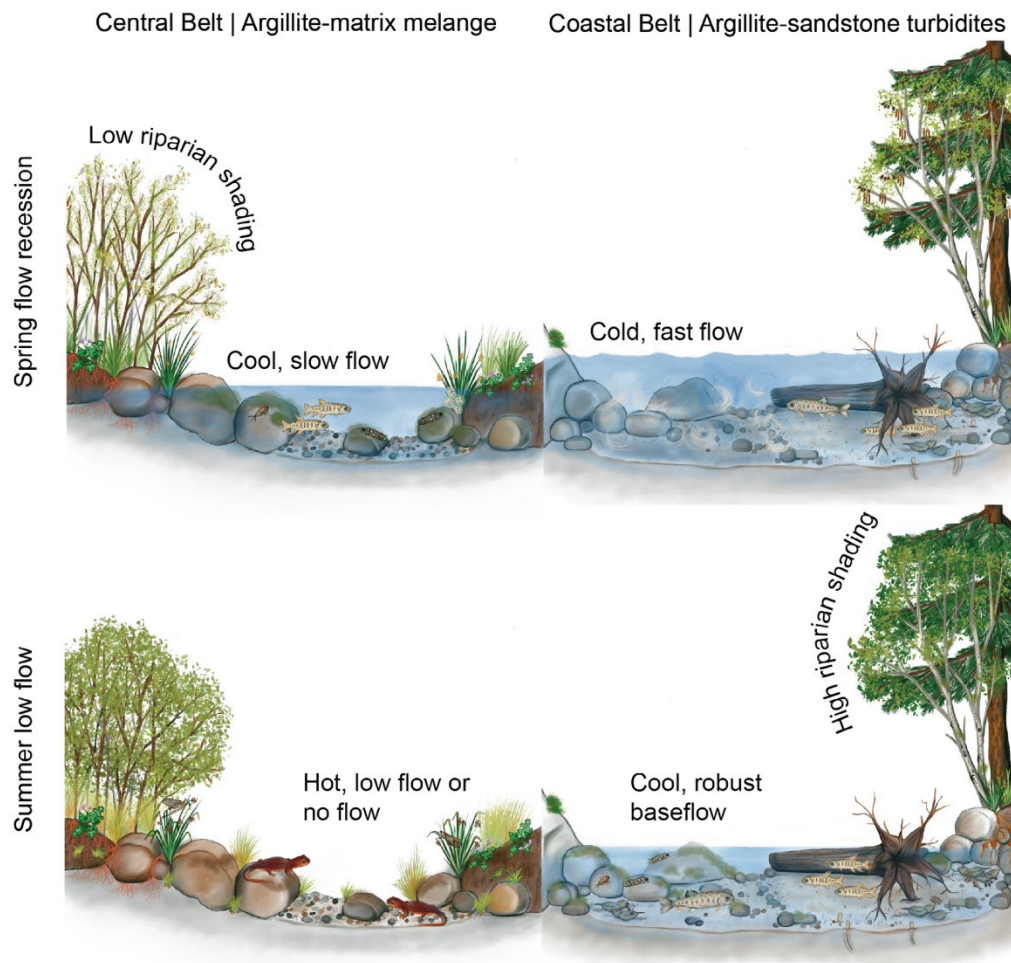


Figure 3-3. Typical progression of stream conditions between the Central Belt *mélange* (left) and Coastal Belt turbidites (right) following the last significant rainfall event of the wet season. The top row illustrates conditions in the spring/early summer when air temperatures have begun to increase, and streamflow is beginning its long seasonal recession. The bottom row depicts late summer low-flow conditions when air temperatures are high and water availability in the stream is approaching its annual minimum. (Figure and caption used from Dralle et al. (2023) with permission).

In addition, restoring the high-value non-natal habitat described above, another important strategy for restoring life-history diversity is to identify and restore other unique habitats across a range of scales in the watershed. One important example of such unique habitats are the large valleys that are present in more inland portions of the watershed. These valleys include Little Lake Valley (Outlook Creek drainage in the Upper Main Eel sub-watershed), Round Valley (Mill Creek drainage in the Middle Fork Eel sub-watershed), upper Tenmile Creek (near Laytonville in the South Fork Eel sub-watershed), and Gravelly Valley (mostly under Lake Pillsbury in the Upper Main Eel sub-watershed, Figure 3-4). Prior to widespread habitat degradation and hydrological alteration associated with European settlement, agricultural and urban development, and resource extraction; the low-gradient, unconfined channels found in these valleys likely provided extensive, complex, and high-quality spawning and rearing habitats that contributed to the diversity and resilience of focal species populations.



Figure 3-4. Gravelly Valley and the upper mainstem Eel River in the winter of 1910, looking north toward the Salmon Creek and Smokehouse Creek drainages and Hull Mountain. Note the complex network of streams and side channels running through the large valley (Source: California Historical Society Collection 1860–1960).

Other examples of unique habitats that warrant additional restoration and conservation planning attention include (1) locally unconfined mainstem channel segments with high potential for floodplain connectivity in otherwise confined reaches and (2) very low-gradient channels that are highly connected to floodplain areas across a range of stream flows. The latter habitat, sometimes referred to as “swampy meadow units,” often occur in upper basin areas where channels are underfit to the relatively large valleys where they occur, typically due to a reduction in former drainage area caused by stream capture. These channels, which share many of the characteristics of “stage zero” channels described by Cluer and Thorne (2014), are often braided and contain

deep sediment deposits, accumulated organic material, and wetland vegetation such as sedges (Figure 3-5). In addition to likely providing high-quality summer rearing habitat for salmonids, these headwater reaches provide excellent winter refuge habitat due to their relatively low flows and seamless connectivity with the floodplain that attenuates flood peaks. These unique channel types also provide different stream insect assemblages than adjacent reaches with rocky substrates (M. Power, UC Berkeley, pers. comm. 2024). Examples of this habitat type can be found in various tributaries along the western edge of the South Fork Eel River watershed, such as Redwood Creek (tributary to upper South Fork Eel River), upper Anderson Creek (tributary to Indian Creek), and tributaries to Hollow Tree Creek (Figure 3-5).



Figure 3-5. Example of unique low-gradient headwater habitat in a tributary to Hollow Tree Creek in the South Fork Eel River sub-watershed.

Stream-estuary ecotone and estuary

Historically, the stream-estuary ecotone and estuary likely provided the most productive and vast non-natal rearing habitats in the Eel River watershed. Widespread degradation and disconnection of lower mainstem and estuarine winter habitats due to diking, tide gates, and agricultural conversion have diminished their habitat capacity and quality, and along with them, life-history diversity. Approximately 60% of the estuary has been lost due to construction of levees and dikes (CDFG 2010). For this reason, restoring these habitats is fundamental to meeting restoration goals.

An ecotone is an area of transition between two biological communities that is often richer in species and biomass than the surrounding communities (Koski 2009). The stream-estuary ecotone, which encompasses the lower reaches of coastal watersheds where streams transition into estuaries, is particularly valuable for habitat restoration and recovery of anadromous fish (Jones et al. 2014, Wallace et al. 2015, Flitcroft et al. 2016). In addition to providing unique and highly productive habitats that promote life-history diversity, the stream-estuary ecotone and estuary can play an outsized role in influencing growth, survival, and population dynamics of anadromous species because entire populations must pass through them, first as juveniles and then as adults (Bottom et al. 2005, Bond et al. 2008, Hayes et al. 2008, Koski 2009, Jones et al. 2014, Bennett et al. 2015, Wallace et al. 2015).

Numerous studies have shown that favorable growth conditions in estuaries can enable juvenile salmonids to recruit disproportionately to the adult population compared with fish that rear in

upstream habitats because larger individuals typically have higher ocean survival rates (Miller and Sadro 2003, Bond et al. 2008, Koski 2009, Jones et al. 2014). Moreover, restoration of estuaries has been shown to increase salmonid life-history diversity. For example, extensive restoration of estuarine tidal wetlands in the Salmon River in Oregon increased variation in both Chinook Salmon and Coho Salmon juvenile rearing strategies, enhancing the species' overall life-history diversity and resilience in the watershed (Bottom et al. 2005, Flitcroft et al. 2016). The estuary and lower mainstem Eel River are also essential habitats for adult salmonids, Pacific Lamprey, and Green Sturgeon, which often stage there at the onset of, and during, their spawning runs. Additionally, estuaries are known to be feeding habitats for both juvenile and adult Green Sturgeon (Allen et al. 2009, Nakamoto et al. 1995, Lindley et al. 2011).

Seasonal habitat capacity of natal streams may become limited during extreme climatic events such as droughts and floods. During these periods, the relative importance of the estuary, lower mainstem Eel River corridor, and adjacent tributaries increases. During extreme drought years when many tributaries become too dry or hot to support summer rearing or their habitat capacity decreases, the importance of the lower mainstem Eel River and estuarine habitats for the population is expected to increase. Likewise, during wet winters with high-magnitude flood events, greater downstream displacement of juvenile fish places greater importance on winter rearing habitats in the lower Eel River watershed and stream-estuary ecotone. Given the recent predictions of increased frequency of extreme climatic events in the region (Swain et al. 2018), these dynamics highlight the importance of the recent and ongoing habitat restoration (e.g., Salt River, Cannibal Island, Cock Robin Island, and Ocean Ranch), conservation (e.g., Eel River Estuary Preserve), and planning (e.g., lower Eel River Salmonid Habitat Restoration Priorities [SHaRP]) efforts being conducted in lower portions of the watershed and estuary.

Lower watershed mainstem corridors

Restoring and protecting the lower reaches of the mainstem Eel, South Fork Eel, and Van Duzen rivers—along with adjacent off-channel habitats and the lower reaches of their tributaries—are also critically important for the recovery of focal species. As with the estuary, a large portion of the watershed's anadromous fish populations must pass through or rear in these reaches. In addition to providing habitat for migrating adults and out-migrating juveniles, these reaches have potential to provide large areas of excellent non-natal rearing habitat. Along mainstem river corridors, low-velocity winter rearing habitats may occur in floodplain channels with ponded features or off-channel ponds connected to the mainstem by small channels (Soto et al. 2016). Such features are often associated with small tributaries, which can (1) help maintain connectivity with the mainstem; (2) improve water quality in off-channel habitats during drier winter periods; and (3) provide clearwater feeding habitats during high flows when high turbidity levels in adjacent mainstems can cause negative physiological effects, impair feeding, and prompt juvenile salmon to seek refuge habitats (Bisson and Bilby 1982, Sedell et al. 1990, Soto et al. 2016). Low-gradient tributaries entering the lower mainstems of the Eel, South Fork Eel, Van Duzen rivers (e.g., Price, Strongs, and Barber creeks) are expected to have particularly high potential to provide valuable non-natal rearing habitats for early emigrant life-history strategies during both the dry and wet seasons. For this reason, assessing and restoring habitat in and connectivity to these streams is important for increasing the prevalence of early emigrant strategies.

Highway and levee construction and sediment deposition from logging and large floods have altered much of the lower mainstems of the Eel, South Fork, and Van Duzen rivers, as well as the lower reaches of their tributaries, resulting in degraded or disconnected off-channel features within the watershed. Such changes are expected to have lowered the survival and prevalence of the early juvenile emigrants. Filling of deep pools in the mainstem and loss of mainstem habitat

complexity, including a reduced supply of large wood, have also likely resulted in decreased survival of early emigrants during their movements from natal to non-natal habitats and during smolt emigration. These habitat alterations, along with the introduction of non-native Sacramento Pikeminnow, have further diminished the prevalence of these life histories. By reducing the quantity and quality of adult holding habitats and limiting connectivity between them, channel aggradation and other habitat alterations in the lower mainstem Eel River also negatively influence early-migrating adult salmonids during their spawning runs, particularly Chinook Salmon and in years with lower stream flows during the fall.

Beaver-assisted habitat restoration

The North American Beaver (*Castor canadensis*) is a keystone species and ecosystem engineer that supports numerous other species by altering stream geomorphology and hydrology and creating and maintaining high-quality and diverse aquatic and riparian habitats (Naiman et al. 1988; Pollock et al. 2003, 2004, 2007, 2014; Dewey et al. 2022). Beaver dams and associated ponds, bank lodges, side channels, and burrows can create large areas of prime summer and winter rearing habitat for juvenile salmonids and other fish (Swales et al. 1986, Pollock et al. 2004, Parish 2016). For example, during the winter, juvenile Coho Salmon rearing within side channels created by beaver dams occur at higher densities and have higher growth and survival rates than individuals rearing within side channels without beaver dams (Bustard and Narver 1975, Swales et al. 1986). Beaver dams can also reduce water velocities during high-flow events, providing winter refuge habitat for Coho Salmon and other species (Pollock et al. 2003, Lundquist and Dolman 2020). By slowing and spreading out stream flows, beaver dams also create wetlands and promote groundwater recharge that can enhance summer base flows and fish habitats in downstream reaches (Lundquist and Dolman 2020, Dewey et al. 2022).

Although beaver appear to be reestablishing in parts of their historical range (Lundquist et al. 2013), their abundance and distribution in the Eel River watershed and California are greatly depressed from historical levels, largely due to intensive trapping and habitat modification (Lundquist et al. 2013, Lundquist and Dolman 2020). Because of the ecological benefits described above and the diminished presence of beaver on the landscape, beaver-assisted restoration through reintroduction of the species into suitable areas and the restoration of habitat and ecological processes through simulated beaver dams (beaver dam analogs) have potential to be core actions for recovering focal fish species in the Eel River watershed, warranting additional attention under the Program. Beaver-assisted habitat restoration is expected to be more cost effective than many active restoration methods because beavers (rather than heavy machinery) create the habitat and, importantly, sustain it. Beaver reintroduction may be particularly well suited for the remote and inaccessible (yet still degraded) portions of the watershed where active restoration can be logistically infeasible or cost prohibitive. Initially, focused assessments of present-day distribution and the potential for beaver reintroduction in the watershed are needed.

In addition to directly addressing the Program goals of (1) restoring abundance and resilience of native fish populations and (2) incorporating ecological processes into restoration, beaver-assisted restoration is expected to be an effective, low-cost strategy for increasing resilience to climate change–induced drought and wildfire in the Eel River watershed (Lundquist and Dolman 2020, Fairfax and Whittle 2020, Dewey et al. 2022). Moreover, focused efforts to evaluate and implement beaver-assisted restoration opportunities in the Eel River watershed are aligned with CDFW’s recently established Beaver Restoration Program, which aims to “...implement beaver-assisted restoration projects to support ecosystem conservation, habitat restoration, species conservation, and improve climate change, drought, and wildfire resilience throughout California.”

Foodscales

The importance of physical habitat heterogeneity and non-natal habitat use is described above; however, the success of juvenile anadromous fish in these dynamic environments depends on their ability to grow, which is also a function of biotic conditions, including the abundance, quality, and accessibility of prey (Rossi et al. 2024). The dynamic changes in food abundance, food accessibility, and consumer energetics that contribute to spatial and temporal variation of fish growth in rivers is termed *foodscales* (Rossi et al. 2024). Historically, food sources for anadromous fishes in the Eel River watershed included a combination of instream prey resources, terrestrial invertebrates, and marine-derived nutrients from tissue and eggs delivered by anadromous fish. In a healthy watershed, fluxes of these resources vary through time and may occur as pulses that, while short in duration, can be dominant sources of annual energy intake for any population of focal species. Such food resources can control the abundance of fish populations as much as habitat quality. However, impairments to the Eel River watershed such as levees that cut off floodplains, channel aggradation from floods and logging activities, the introduction of invasive pikeminnow, and the decline of marine-derived subsidies affect the production of food and the ability of native fish to track and exploit food resources. For these reasons, foodscales in the Eel River warrant further consideration in restoration planning and design of restoration actions. Rossi et al. (2024) define the central question of foodscape restoration as: How have patterns and processes affecting food abundance, food accessibility, and physiological growth potential been degraded and how can they be recovered? More focused questions follow from this question and include: Have important trophic pathways, which could help re-establish critical consumer populations and life histories if restored, been impaired? How might consumers track resources across the landscape (or riverscape) if the foodscape was healthy? These questions should be applied to help prioritize and guide restoration actions in the Eel River.

Riverscape connectivity

In an idealized world, funding and capacity would exist to restore the entire watershed, including all aspects of habitat heterogeneity to support non-natal rearing (see above). However, there are often trade-offs, and not all components of the historical habitat mosaic will be returned to maximum ecological function. One strategy to compensate for the loss of habitat heterogeneity throughout the watershed is to ensure connectivity throughout the riverscape between currently functioning and productive habitats (Torgersen et al. 2022). Improving passage conditions in the mainstem reaches throughout the year will create a corridor for passage into and between tributaries. During the dry season, connectivity planning could include restoration and/or protection of “stop-over” habitats or local refugia from warming temperatures and predators. One such strategy would be to focus on restoring habitat at tributary confluences. During the wet season, ensuring connectivity could occur through a pearl string of off-channel, low-velocity habitats or easily accessible tributaries. For adults that migrate in and hold in lower flows (e.g., summer-run steelhead, fall-run Chinook), ensuring connectivity between suitable holding habitats is critical. Restoration actions that improve long segments of the mainstem that are seasonally inhospitable could improve connectivity between currently functioning habitats, increasing the total habitat capacity for focal species.

Survival of juvenile emigrants

Survival of salmonid fry and parr, larval lamprey, and juvenile sturgeon as they move between natal streams and non-natal habitats—as well as survival of smolt (or juvenile lamprey and sturgeon) during outmigration to the ocean—is likely key in driving the abundance of returning adults, warranting more research and attention. For example, during a 5-year study in the

Sacramento River, Michel (2019) found that survival during Chinook Salmon outmigration to the ocean ranged from 3–17%, while marine survival ranged from 4–23%. A related analysis of 20 years of survival data by the author suggests that smolt-to-adult survival was primarily driven by survival during outmigration to the ocean, except in years of low marine productivity. Preliminary results from an ongoing acoustic telemetry study evaluating survival of Coho Salmon smolt emigrating from natal streams through the mainstem South Fork Eel River during the spring found average survival (across tag groups from different streams) was about 20% in one year of study (G. Rossi, U.C. Berkeley pers. comm., 2024). Because of the importance of survival during this life stage, further research is needed to (1) describe inter- and intra-annual differences in survival of out-migrating salmonids, lamprey, and sturgeon in the Eel River and (2) identify and address the mechanisms of mortality.

Sacramento Pikeminnow

One likely important source of mortality for both out-migrating smolt and rearing juveniles is predation by non-native Sacramento Pikeminnow, a large piscivorous cyprinid that was introduced into Lake Pillsbury in the upper mainstem Eel River around 1979 and has since expanded its distribution across the watershed (Brown and Moyle 1997, Kinziger et al. 2014). Pikeminnow occur at very high densities in many parts of the watershed (e.g., White and Harvey 2001, Higgins 2020, PG&E 2020, Georgakakos 2020, Stillwater Sciences and Wiyot Tribe Natural Resources Department 2020) and therefore have potential to fundamentally alter the aquatic ecosystem and negatively impact native species—particularly, anadromous species, which must migrate from headwater streams through the mainstem to reach the estuary and ocean. Numerous studies indicate that pikeminnow compete with, prey on, or alter the behavior of juvenile salmonids, lampreys, and other native fishes in the watershed (e.g., Brown and Moyle 1997, White and Harvey 2001, Reese and Harvey 2002, Nakamoto and Harvey 2003, Georgakakos 2020). The presence of pikeminnow has likely selected against important life-history strategies that may have been historically abundant, such as mainstem rearing in the spring and summer by juvenile salmonids. The presence of pikeminnow may also favor earlier emigrating individuals that move rapidly through the mainstem corridor to the ocean, potentially selecting against individuals that spend more time feeding and growing in the mainstem and stream-estuary ecotone through the spring and early summer.

3.2.4.3 Key data gaps

The species descriptions and conceptual models developed herein are meant to capture the current state of knowledge of focal species and to be used as a reference for making informed decisions about restoration and conservation priorities (Section 5). Importantly, the conceptual models are also intended to (1) systematically identify and highlight uncertainties and gaps in the understanding of these species and the factors limiting their abundance and (2) help generate hypotheses that can be tested through targeted research (Section 7.3.3.1). For this reason, these models should be viewed as iterative and periodically refined as the state of knowledge improves in response to research and monitoring designed to fill these data gaps (Section 7). Table 3-4 lists the key data gaps identified for one or more of the focal species. Notably, the extent to which each item is a data gap varies by species and location. In general, data gaps with potential to constrain effective species management or limit informed prioritization and implementation of restoration and conservation actions are listed. Appendix C provides a more comprehensive list and discussion of key data gaps for each species. As described in Section 5.2.2.2, additional key data gaps will be identified during the action prioritization process proposed for Phase 2.

Table 3-4. Key data gaps that may impair effective species management or limit informed prioritization and implementation of restoration and conservation actions. ¹

Life stage	Key data gap	Focal species				
		Chinook Salmon	Coho Salmon	Steelhead	Pacific Lamprey	Green Sturgeon
Adult holding and migration	Adult population size and trends by sub-watershed	O	O	X	X	X
	Distribution of holding adults and preferred adult holding habitats.	O	O	O	X	X
	Prevalence, distribution, and genetic relatedness of distinct adult run ecotypes	O	--	O	X	--
	Historical prevalence and distribution of adult life-history strategies	X	O	X	X	X
	Adult survival in fresh water (pre-spawning mortality) and factors affecting it	O	X	X	X	X
	Locations and extent of anthropogenic barriers to migration	O	O	X	X	X
Spawning and incubation	Spawning distribution	O	--	O	X	X
	Survival from spawning until fry/larval emergence	X	X	X	X	X
	Quantity and quality of suitable spawning habitat. Changes in spawning habitat conditions and recovery trajectory from alteration of sediment dynamics by floods, logging, and other anthropogenic disturbances.	X	X	X	X	X
Juvenile or larval rearing and movement	Seasonal distribution (not just in the summer)	X	X	X	X	X
	Current prevalence and distribution of early emigrant life-history strategies in non-natal rearing habitats within and between years with variable environmental conditions—including in mainstems, adjacent off-channel habitats, warm and cool non-natal tributaries, and the estuary.	X	X	X	X	X
	Historical prevalence and distribution of juvenile life-history strategies	X	X	X	X	X
	Timing of movements between natal streams and non-natal rearing habitats and survival during these movements.	X	X	X	X	X
	Fry-to-smolt survival (or larval to juvenile survival for lamprey and sturgeon). Spatial and temporal variation in juvenile survival.	X	X	X	X	X
	Locations, habitat characteristics, and use of thermal refugia within mainstems and larger tributaries.	X	X	X	X	X
	Spatial, seasonal, and interannual variation in in-situ food resources, across rearing habitats.	X	O	X	X	X
	Existence of, and spatial, seasonal, and interannual variation in, food subsidies (e.g., from fish eggs or terrestrial invertebrates) that provide growth opportunities. How subsidies have been altered and how they can be restored.	X	X	X	X	X
Spatial, seasonal, and interannual variation in physiological growth potential (bioenergetics) and prey accessibility. Influence of restoration on these factors.	X	X	X	X	X	

Life stage	Key data gap	Focal species				
		Chinook Salmon	Coho Salmon	Steelhead	Pacific Lamprey	Green Sturgeon
Juvenile emigration to ocean	Salmonid smolt or juvenile lamprey and sturgeon production from important spawning streams.	X	X	X	X	X
	Survival of emigrating smolt or juveniles between natal streams and the ocean across time and space. Where are the mortality hotspots and why?	X	X	X	X	X
Ocean residence	Ocean survival and influences of ocean conditions, prey composition and abundance, harvest management practices, and bycatch from other fisheries.	X	X	X	X	X
	Prevalence of Thiamine Deficiency Complex due to changes in ocean diet and associated mortality of offspring during the embryo and fry stages	X	X	X	X	X
Other	Impacts of pikeminnow predation, presence, and competition on native focal species and how these impacts vary spatially and temporally	X	X	X	X	X
	Influence of other non-native aquatic predators and competitors such as Largemouth Bass and Brown Bullhead	X	X	X	X	X
	Water temperatures from fall through spring (not just summer)	X	X	X	X	X
	Prevalence and distribution of fish diseases and factors influencing them	X	X	X	X	X

¹ X = significant data gap; O = moderate data gap; "--" = not considered a data gap for species.

4 RESTORATION AND CONSERVATION ACTIONS

Section 1.2.2 defines the terms *restoration* and *conservation* for this Plan. This section describes the process for and outcomes of identifying a suite of actions that will help achieve the Program restoration and conservation goals (Section 1.2.1) and address the stressors to focal fish species (Section 3.2.4.1). Section 4.1 describes the approach for identifying and organizing actions, then Section 4.2 summarizes the tiered goals and objectives that were used to help identify actions, and finally Section 4.3 lists and describes identified action categories. Appendix D provides more detailed tables of tiered goals and objectives, and Appendix E provides more detail on restoration and conservation actions. The restoration and conservation actions identified herein are not an exhaustive list, but rather an initial working compilation of actions that will help achieve Program goals and alleviate one or more of the stressors identified for focal species (Section 3).

Ultimately, restoration and conservation actions identified here will be used as inputs to the Phase 2 prioritization process, which will be designed to identify priority actions expected to be most effective at achieving Program goals and that will most directly address stressors that are limiting fish population recovery.

4.1 Approach for Identifying and Organizing Actions

Restoration and conservation actions were identified based on tiered goals and objectives, along with inputs from the species conceptual models (Section 3.2) and existing assessments and plans that identify key restoration and conservation actions (e.g., recovery plans, SHaRP) (Figure 4-1).

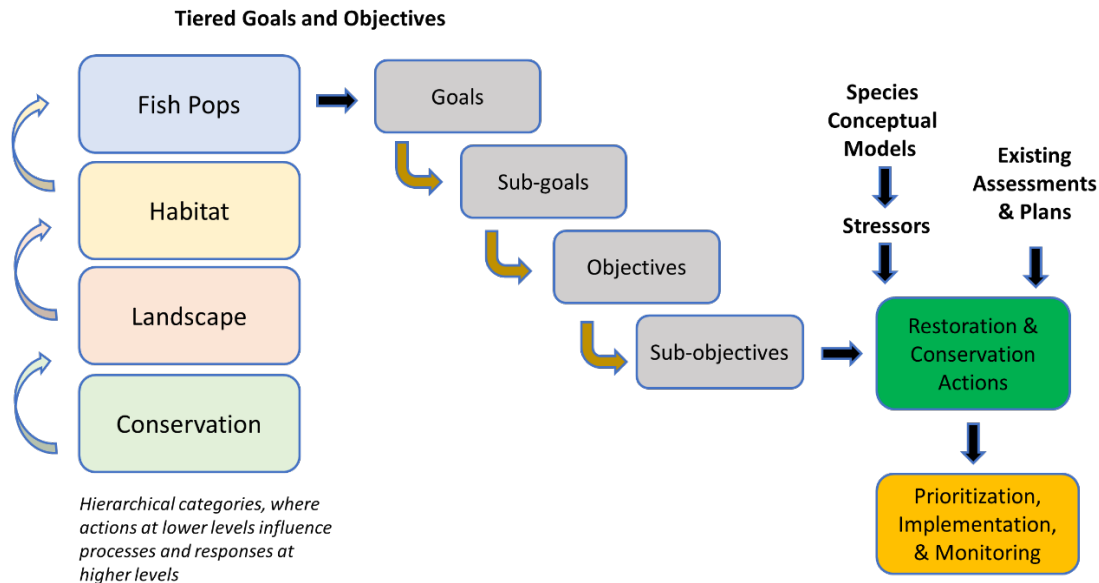


Figure 4-1. Process for identifying restoration and conservation actions. Increasingly specific goals and objectives (goals, sub-goals, objectives, and sub-objectives) were developed for each of the hierarchical categories of influence (conservation, landscape, habitat, and fish populations).

The tiered goals and objectives approach initially involved identifying broad goals for the following hierarchical categories of watershed influence: *Conservation, Landscape, Habitat, Fish Populations*. These broad goals are consistent and encompass important elements of the Program goals listed in Section 1.2.1, including *Restore, Protect, Incorporate Ecological and Geomorphic Processes, and Recommend Actions*.

For the broad goals developed for each hierarchical category, the Planning Team developed increasingly specific sub-goals, objectives, and sub-objectives for restoration and conservation. Sub-objectives were identified at a resolution that is more appropriate for linking with specific restoration and conservation actions. The outcome of this process is shown in a series of tiered goals and objectives tables organized by the hierarchical categories (*Fish Populations, Habitat, Landscape, and Conservation*) that are presented in Appendix D (Tables D-1 through D-4). This tiered goals and objectives approach is similar in concept to the tiered objectives approach developed for the Trinity River Integrated Assessment Plan (TRRP and ESSA 2009).

An example of the tiered goals and objectives identified for the Fish Populations category follows:

- **Goal:** Achieve naturally self-sustaining and harvestable native anadromous fish populations
 - **Sub-goal:** Increase freshwater productivity of anadromous species (e.g., population growth rate, smolts per adult, adults per adult)
 - **Objective:** Fry-to-smolt survival—Increase survival rates through juvenile life stages by inducing favorable changes to stream habitat and competition
 - **Sub-objective:** Reduce mortality due to predation.

After developing the tiered goals and objectives tables, specific restoration and conservation actions were identified, categorized, and included in a series of action tables. Actions were identified in three ways: (1) through the tiered goals and objectives process described above, (2) by identifying those expected to address stressors to focal fish species, and (3) from reviewing actions listed in existing Eel River plans (e.g., South Fork Eel River SHaRP Collaborative 2021; NMFS 2014, 2016; Boyce et al. 2022). As described in Section 3, species conceptual models were used to identify stressors with potential to limit population productivity and resilience of focal fish species. Actions thought to address the root causes, or drivers, of those stressors were also identified and included in the action tables. The outcome of this process is a series of action tables that are presented in Appendix E (Tables E-1 through E-12).

Where appropriate, actions were linked to the channel archetypes where they are most appropriate to be applied. For example, large wood additions to improve habitat complexity are generally most effective in channels with bankfull widths of about 2 to 12 meters and channel slopes from about 0.5% to 4%. These attributes correspond to a subset of channels in the low gradient and mid-gradient tributary (cold, cool, and warm) channel archetypes. Additional spatial analyses will be conducted as part of Phase 2 prioritization process to help determine where within the watershed high priority restoration and conservation actions are most appropriate and expected to have the greatest benefit to focal species (Section 5.2).

4.2 Tiered Goals and Objectives Summary

As described above (Section 4.1, Figure 4-1), the tiered restoration and conservation goals and objectives approach uses a hierarchical structure intended to provide flexibility to expand as the Program evolves and prioritization of restoration and conservation actions progresses. Table 4-1 lists the broad goals and more specific sub-goals for each hierarchical category of influence. Appendix D includes more specific objectives for each sub-goal, and more specific sub-objectives for each objective. As one gets into more specific objectives and sub-objectives, the ability to quantify, monitor, and assess those objectives increases.

4.3 Restoration and Conservation Actions Summary

Categories of restoration and conservation actions that have been identified by this Plan are summarized in Table 4-2, and more detailed actions are presented in the Appendix E action tables. The action tables (Appendix E) are intended to be a working document that will be refined and expanded with Program Formation and Prioritization in Phase 2.

Within the prioritization process, restoration and conservation actions will be identified as either *broad* or *specific* (Section 5.2). *Broad actions* are general types of projects that could be applied in multiple locations such as large wood additions to promote habitat complexity. *Specific actions* are projects associated with a specific location such as a culvert that is a complete barrier to upstream fish passage at a specific road-stream crossing. The majority of restoration and conservation actions identified in the action tables (Appendix E) are *broad actions* that will require additional investigation to determine where (e.g., sub-basin, channel archetype) implementation of the action would be most beneficial, as well as considering the relative benefit of the action during the prioritization process, and ultimately whether it is identified as a high priority action for implementation.

Table 4-1. Tiered Goals for habitat and ecological restoration.

Category	Goals	Sub-goals
Fish Populations	Achieve naturally self-sustaining and harvestable native anadromous fish populations	Increase species population sizes
		Increase freshwater productivity of anadromous species (e.g., population growth rate, smolts per adult, adults per adult)
		Restore species distributions to historical extents
		Maintain and increase diversity of life-history strategies
Habitats	Improve quantity, complexity, and diversity of habitats within the stream corridor	Increase quantity of suitable habitat for focal species and life stages
		Increase complexity and quality of key habitats
		Restore connectivity between habitats
		Foster productive riverine food webs that support growth of native fishes
		Increase and improve estuarine habitat
Landscapes	Protect, enhance, and restore intrinsic physical watershed processes (e.g., hydrologic, geomorphic, and riparian) that create and maintain complex channel morphology and regulate habitat connectivity.	Protect, enhance, and restore functional flow components
		Protect, enhance, and restore geomorphic processes to healthy ranges
		Promote riparian corridor processes that support and sustain complex aquatic habitats
		Improve water quantity and quality
Conservation	Protect the Eel River's natural resources through land conservation actions that promote habitat connectivity and resiliency	Increase amount of conserved and protected land
		Establish and maintain connectivity and heterogeneity of conserved areas
		Use climate refugia strategy for planning conservation areas
		Protect ecosystem services
		Priority habitat data integration
		Protect species diversity and persistence
		Develop regional partnerships

The conservation actions were developed using a strategic planning approach to first identify conservation needs in the entire Eel River watershed. The conservation actions do not specifically crosswalk to fish habitat stressors and channel archetypes for instream habitat. Instead, conservation actions are focused on the landscape surrounding the Eel River (i.e., the riparian corridor). The initial strategic planning was focused in each of the seven primary sub-watersheds, and in specific focal areas identified as important for aquatic species, such as riparian corridors, estuaries, and mainstem rivers. Core upland habitat adjacent to riparian corridors and existing protected areas was also considered. Potential representativeness, effectiveness, and connectivity of existing protected areas were used as indicators to view where there may be gaps in habitat protection across the watershed and at different scales.

In addition to the action categories presented in Table 4-2, monitoring infrastructure will be critical for informing and understanding conditions and evaluating project-level and program-level performance (Section 7).

Table 4-2. Restoration and conservation action categories and descriptions.

Restoration and conservation action categories	Description
Fish passage improvement	Actions that improve aquatic habitat connectivity by improving volitional upstream and/or downstream movement of fish and aquatic species, particularly at man-made or otherwise anthropogenic barriers and obstacles such as road-stream crossings.
Instream habitat restoration (physical habitat)	Actions that increase or improve physical habitat conditions within the active stream channel and adjacent floodplain to support greater abundance and/or life-history diversity for focal fish species.
Off-channel habitat restoration and habitat connectivity	Actions that increase or improve physical habitat conditions outside the active stream channel but within the riparian/floodplain corridor that have at least seasonal connectivity (e.g., during high flow periods) to support greater abundance and/or life-history diversity.
Estuary habitat restoration	Actions that increase or improve physical habitat conditions or habitat connectivity within the estuary, floodplain, and stream-estuary ecotone.
Instream flow protection and improvement	Actions that increase, improve, or protect water supply and aquifers or conditions that maintain surface and groundwater that contribute to supporting instream flows for fish and other aquatic species and the ecosystems they depend on (e.g., riparian corridor ecosystem).
Water quality improvement (including water temperature)	Actions that improve water quality conditions for fish and other aquatic species and support the ecosystem on which they depend include water temperature, water chemistry, fine sediment, and pollution.
Riparian and wetland habitat restoration	Actions that increase, improve, or protect riparian and wetland habitat conditions that influence channel form and geomorphic processes (e.g., large wood supply), aquatic habitat conditions (e.g., stream shading, water quality), and ecology (e.g., allochthonous inputs).
Invasive species management	Actions that reduce the impact of invasive species on focal fish species, particularly predation by non-native fish (e.g., Sacramento Pikeminnow). Invasive vegetation (e.g., <i>Arundo donax</i>), aquatic mollusks, and terrestrial wildlife species are also considered.
Active species management	Actions that improve habitat conditions or productivity of focal fish species through active species management (e.g., beaver reintroductions; hatchery or hatch box program).

Restoration and conservation action categories	Description
Upslope sediment control/management (including streambank erosion)	Actions that decrease sediment delivery rates to streams particularly increased sediment supply caused by man-made infrastructure (e.g., roads), land management activities (e.g., timber harvest), or other anthropogenic disturbance (recreation, increased wildfire activity).
Land conservation and protection	Actions that protect or conserve lands with unique, important, and/or intact habitats to maintain or improve river corridor habitat, preserve natural processes, and/or improve habitat connectivity over 10s-100s year time scale.
Biodiversity protection	Establish conservation targets for state listed species of concern and other important habitats by integrating available data to biodiversity metrics.
Ecosystem services	Protect landscapes that deliver multiple ecosystem services are resilient and likely to persist under future climate conditions.
Upland forest to riparian corridor connectivity	In land adjacent to and or impacting riparian corridors, avoid conversion and advance durable protection measures, such as acquisition, voluntary easements, and less near forested areas. Retain and manage forests to preserve carbon storage value, reduce sediment loads in rivers, cool air temperatures, and support habitat connectivity and diversity.
Wetland conservation	Connect wetlands to riparian areas, prioritize those with dense vegetation values. Where vegetation values are low, prioritize revegetation, restoration, and connect to riparian corridors between existing protected areas and other core habitat.
Conservation policy	Increase the extent of Wild and Scenic Rivers. Rank potential riparian climate resilience within the Wild and Scenic River areas of the watershed to promote the protection of those areas. Work with management agencies to develop management plans for existing and new Wild and Scenic Rivers. Assess opportunities for Outstanding National Resource Waters designation.
Conservation for climate mitigation	Focus prioritizations to protect remnant and/or parcels connected to existing protected areas that have low solar radiation values, lower temperatures, and heat mitigating landscape features, especially in Disadvantaged Community Areas. Strategize and engage with local forestry managers to support restoration action in these areas. Recommend revegetation where upland habitat connects to riparian corridors, incorporate USFS data from recently burned areas, updated vegetation maps post-fire impacts. Partner with community groups and agencies to recommend priority parcels for flood mitigation acquisition.
Other potential restoration, conservation, and protection strategies	Community outreach/education: Eel River watershed natural history publications. Regulatory: Wild and Scenic Rivers, river and ocean fisheries management, instream flow policy. Improve biotic conditions through nutrient additions and disease monitoring and management.

Note: USFS = U.S. Forest Service

5 PRIORITIZATION FRAMEWORK

Numerous potential restoration and conservation actions could be implemented in the Eel River watershed. Some are expected to be more effective for achieving Program goals than others. A prioritization process is needed to synthesize existing information and reports to identify the most important actions and target locations for implementation.

An effective approach to prioritize restoration and conservation actions includes a systematic, replicable, and transparent process for making decisions about the efficacy of actions (Beechie et al. 2008, ESSA 2019). A prioritization framework provides structure to complex decision-making in a way that can be easily understood by community members, funders, and restoration practitioners and can integrate new information throughout the process and result in a more effective and meaningful restoration. Additionally, prioritization frameworks should not start from scratch, but build from existing knowledge in a watershed, including species recovery plans, restoration plans, watershed assessments, and local and Tribal knowledge about ecosystem processes and function.

Prioritizing, or ranking, potential actions can incorporate immediate restoration needs in response to disturbances (e.g., wildfires), or they can consider opportunistic projects that require large-scale collaboration among different groups and agencies (e.g., Potter Valley Project decommissioning). As immediate needs are met, priorities will change. Additionally, implementation of actions and ongoing hypothesis-based monitoring will inform adjustments to established priorities depending on how well initial priority actions are performing. In summary, the priority of actions and projects should be revisited regularly.

The prioritization framework described in this Plan defines a process for identifying and ranking critical restoration needs and conservation opportunities (actions). The desired outcome of prioritization for the Program is to provide guidance on the relative predicted importance of (1) restoration actions that will recover fish populations and (2) strategic locations for conservation that will protect fish populations into the future. Within this framework, there are separate, yet complementary, processes for restoration and conservation action prioritization. The results of the prioritization analyses will be synthesized to develop a comprehensive Action Plan for the Eel River watershed, and specific to each of the seven sub-watersheds. The Action Plan will be developed in the next phase of Program development.

Arriving at the outcome of the prioritization process requires several steps in a complex and diverse, yet data-poor, watershed like the Eel River. Four steps for successfully prioritizing restoration actions have been outlined by Beechie et al. (2008): (1) identify restoration goals, (2) select a prioritization approach, (3) use watershed assessments to identify needed actions, and (4) prioritize actions based on criteria that reflect restoration goals. The Planning Team has developed a list of restoration goals that would be beneficial for the Eel River (Section 1.2.1). The next steps are to select and develop a prioritization approach; integrate existing watershed assessments, recovery plans, and restoration plans; and identify and rank needed actions. The Planning Team sought to develop an approach for prioritizing actions that can efficiently help inform the following two questions:

- *What* restoration actions should be taken, and
- *Where* will restoration actions be most effective at recovering fish population abundance and resilience?

Additionally, the Planning Team sought to develop a prioritization approach that would integrate conservation action opportunities. The Plan defines conservation as the development of protection measures for areas important for the focal species and goals of the Program. Land use, landownership, landowner needs and interests, and parcel size and condition will dictate conservation opportunities, while conservation goals (e.g., potential to host biodiversity or provide climate refugia) define conservation priorities among parcels. In this way, prioritization of conservation actions will primarily ask the question:

- *Where* are conservation actions needed to protect ecological productivity, biodiversity, and cultural resources, and provide climate change resilience to support recovery of focal fish species.

The framework guides how Eel River restoration and conservation action prioritization should occur in the next phase of Program development. This section outlines the fundamental concepts of prioritization, including the goals, the types of frameworks that exist, and the scale and resolution of prioritization in the Eel River. The Planning Team reviewed approaches that have been applied to other watersheds, their relevance to the planning scale hierarchy (Section 2), and their feasibility given data limitations and watershed size of the Eel River. The Planning Team also developed a vision for how action prioritization might be evaluated and revisited in a well-funded program with ongoing monitoring and active management (Section 7). In summary, this section discusses the following fundamental aspects of an action prioritization framework:

- Spatial planning tools, quantitative population models, and multi-criteria decision analysis (MCDA) approaches;
- Approaches for:
 - Identifying conservation opportunities and locations,
 - Ranking restoration objectives and developing corresponding actions, and
 - Integrating restoration and conservation actions in an Action Plan;
- Data availability and needs; and
- Hypothesis testing within prioritization.

5.1 Review of Approaches for Ranking Restoration and Conservation Actions

The Planning Team considered several different approaches to identify and rank restoration and conservation actions at the watershed scale, three of which are discussed here: (1) quantitative spatial planning tools, (2) quantitative fish population models, and (3) data-informed MCDA. These approaches and examples are briefly described below. All tools and processes use available data to inform action prioritization but require thoughtful and systematic synthesis to recommend high-priority actions and locations. The pros and cons of each approach, along with the suitability of their use for the Eel River watershed due to timing and data availability, informed the Planning Team's proposed approach for prioritization.

5.1.1 Quantitative Spatial Planning Tools

Spatial planning is a key component of restoration and conservation planning because it brings together multiple factors to show how they are connected and highlights similarities and differences across a landscape. The most informative spatial analyses consider multiple scales of data inputs and landscape processes to help meet restoration and conservation goals (Figure 5-1)

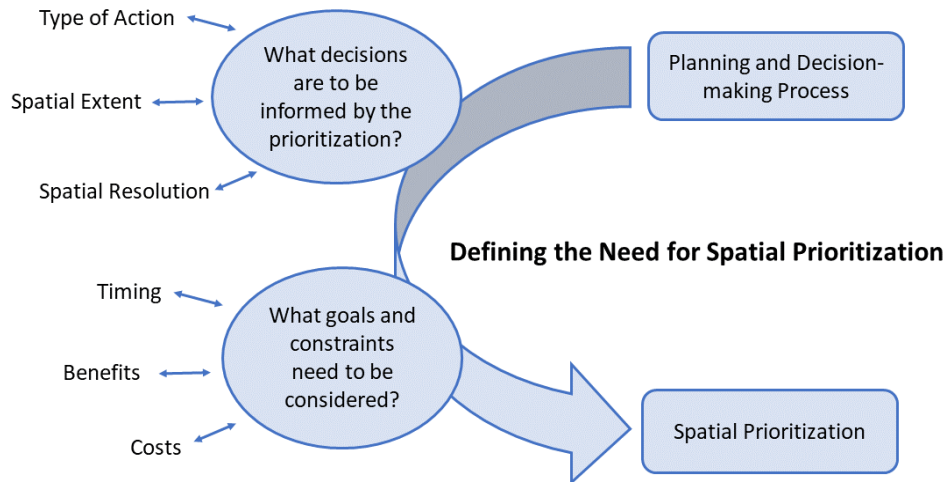


Figure 5-1. Defining the need for spatial data analysis in a restoration and conservation action prioritization process. The process for choosing spatial data and how they will be used for restoration and conservation prioritization. (Adapted from Moilanen et al. 2009)

Spatial analyses help highlight important areas for both restoration and conservation actions within a watershed. Spatial planning tools are best suited to answer the question:

- *Where* are actions most needed?

For conservation planning, it is important to answer this question first so that opportunities on strategic and available lands that can meet the Program’s goals can be identified (Section 1.2.1). For restoration planning, answering this question may come second, after understanding what factors are most likely limiting fish populations. The same spatial planning tool, with different inputs and rankings, may help with planning for restoration and conservation actions. The Planning Team identified several quantitative spatial planning tools that have previously been used to rank and assess restoration and conservation actions. These tools are briefly reviewed below.

Marxan is a GIS-based software that can be used to identify land areas that meet several criteria, such as forest cover, urban areas, and biodiversity, that are ranked by the user (Ball et al. 2009, Margules and Pressey 2000). Marxan identifies many land areas that fit the criteria that are set to achieve a project’s goals. The solutions do not provide a definitive answer for the best land areas but, instead, provide several highly ranked land areas that the user can consider. At the watershed level, Marxan has been used in several applications to support management objectives of ecological connectivity, metapopulation persistence and resilience, and biodiversity protection (Daigle et al. 2020). Marxan has been used by EcoTrust and the USFS to develop a regional prioritization mapping tool for watersheds in the Pacific Northwest, based on watershed condition, species use, and climate change vulnerability (EcoTrust and USFS 2010). The Nature Conservancy applied Marxan to identify sub-watersheds that protect habitat for deer, salmon, and karst features on the Prince of Wales Island in Alaska (Albert et al. 2008).

Marxan Connect is a GIS-based software in the Marxan family of planning tools, which in addition to analyzing spatial data with conservation targets, can integrate the connectivity needs defined by the user for the planning area. While useful in concept, there are other connectivity planning adjustments that can be made using the basic Marxan software. With Marxan Connect, the connectivity elements are integrated into the algorithm, while with the regular Marxan

software, the user has more control to adjust these connectivity calibrations manually (Daigle et al. 2020).

Other strategic spatial planning tools such as Miradi,⁵ which is an open-source tool that helps conservation practitioners design, manage, monitor, and learn from their projects, were used by the Planning Team to initially define the variables and landscape impacts to the focal anadromous species, providing a framework to consider how to make restoration and conservation targets that can later be used as quantitative inputs to algorithm-based planning software such as Marxan (Carwardine et al. 2009, 2010; Doherty et al. 2018). For example, the Planning Team used Miradi to decide on the granularity of planning processes that would be useful in a large landscape such as the Eel River watershed but did not explicitly set those target percentages for restoration actions in this Plan. A precursor to the Miradi method was used when developing federal recovery plans for the ESA-listed Coho Salmon, Chinook Salmon, and steelhead in the Eel River basin (NMFS 2014, 2016). The Miradi method is one of several planning tools that can be used by experts in Phase 2: Prioritization to help decide on quantitative targets for restoration and conservation planning.

5.1.2 Quantitative Fish Population Models

Fish population modeling is another approach that can inform action prioritization. These models rely on watershed-wide fish-focused models to make predictions about the types of actions that will provide the greatest benefit to fish recovery. Many of these models require some form of life-cycle modeling, where species survival from one life stage to the next is predicted based on a suite of input data and parameters. Among the various modeling tools, two were considered in more detail for the Program because they have been implemented in other recently completed restoration plans: Ecosystem, Diagnosis, and Treatment (EDT) and Habitat Assessment and Restoration Planning (HARP).

EDT is a river flow and habitat modeling tool designed to help managers weigh the effects of different scenarios on fish population performance (Lestelle et al. 2004, Blair et al. 2009). The EDT model assumes pre-developed relationships between species survival and productivity and the spatial/temporal variation in habitat quality. The model relies on a Beverton-Holt production function, where productivity declines with density dependence, and maximum productivity rate is a function of the environment. One unique aspect of the EDT software is that it explicitly models life-history diversity via “trajectories,” or pathways through the environment. EDT can be used to estimate the number of spawners, intrinsic productivity, and life-history diversity of a population under different restoration scenarios. EDT is a proprietary software (currently owned by ICF International) that has been applied to many watersheds, including streams in the Columbia River Valley, Washington; Puget Sound, Washington; Central Valley, California; and the Scott River watershed, California.

HARP is a similar framework for identifying habitat change and restoration potential in a watershed (Beechie et al. 2021). The HARP model is divided into three steps: (1) a spatial analysis that translates spatial data into habitat conditions, (2) a habitat analysis that creates habitat scenarios under current, historical, or future conditions, and (3) a life-cycle model. Similar to EDT, the HARP model implements life-cycle models that are based on life stage capacities and productivity within a Beverton-Holt curve that assumes density dependence. Sub-basins are modeled as sub-populations within HARP, allowing for a spatially explicit understanding of the

⁵ Available at: <https://www.miradishare.org/ux/home>.

effect of restoration on basin-wide populations. HARP has been applied in the Chehalis River basin, Washington; and in the Snohomish and Stillaguamish rivers, Washington.

These two fish population models are similar in their need for spatially explicit data that describe habitat condition throughout a watershed. Additionally, they both require professional opinions or predictions about how restoration actions influence habitat quality and quantity, in a way that then directly impacts productivity and survival of salmonids at each life stage. These assumptions are foundational to how the models perform and predict which restoration actions will be most beneficial for restoring salmonids. For example, if it is assumed that large wood has a large impact on habitat improvement or a strong linkage to salmonid success, it will be ranked higher as an action. Both fish models also require a set of pre-determined scenarios for evaluation. Additionally, most fish population models focus on just one species, and neither has been developed for the non-salmonid species focal species, Pacific Lamprey or Green Sturgeon.

Other quantitative fish population models have been used to assess the potential benefit of particular restoration actions (e.g., inSalmo [Railsback et al. 2021], the Stream Salmonid Simulator (S3) [Perry et al. 2018], and the RIPPLE model [Dietrich and Ligon 2008]). For brevity, these models are not reviewed in this Plan because they share the same need for watershed specific fisheries and/or habitat data and the lack of inclusion of non-salmonids. Additionally, some of these fish models cover a much smaller spatial scale than is suitable for watershed-wide planning.

After reviewing the function and inputs to quantitative fish population models, the Planning Team developed a general list of pros and cons about this type of model. The list was developed to inform the decision about whether these fish population models should be incorporated into Phase 2: Prioritization for the Program (Table 5-1). In weighing the pros and cons of quantitative fish population models, the Planning Team does not recommend including them in the prioritization approach in the current phase of the Program. The data limitations in the Eel River watershed make developing the models impractical. Additionally, one of the goals of the Program defined in this plan is to “coordinate with local entities” (Section 1.2.1), and developing a quantitative model as a primary component of prioritization framework would make engagement and coordination with diverse and interested parties challenging.

Table 5-1. Pros and cons of using a large-scale quantitative fish population model for prioritizing restoration actions.

Pros	Cons
Provides quantitative predictions for the relative efficacy of restoration actions	Requires data-intensive life-cycle models, ideally with basin-specific survival parameters between life stages
Provides spatial explicit information about where restoration actions can improve salmonid populations, if the model is set up to test that question	Requires data-intensive predictions on habitat quality throughout the basin
Evaluates complex emergent properties of restoration actions on species’ life histories and abundances	Requires assumptions and professional judgement on relationships between habitat characteristics and salmonid survival/productivity
Synthesizes the effects of restoration on a large spatial scale (e.g., a very large watershed, integrating across smaller sub-watersheds)	May require years to parameterize, develop scenarios, and run models

Pros	Cons
Allows sensitivity analyses with respect to restoration scenarios, which can quantitatively highlight uncertainties	Requires decisions early on about the spatial scale/units of the model, with little flexibility
--	Is difficult to communicate the method and to engage the public and other interested parties in model development, leading to a lack of understanding how the model works, e.g., it may be perceived as a “black box,” with little buy-in outside the core technical team
--	Is costly in terms of time and funds to develop and would delay prioritization and implementation of priority actions

5.1.3 Multi-Criteria Decision Analysis

MCDA approaches rank decisions based on multiple criteria using simple scoring (Roni et al. 2013). The scoring, which is often done by a group of experts, can incorporate a variety of data inputs to rank limiting factors for focal species, specific actions, action types, watershed-wide stressors, or important sub-watersheds and locations. This “scoresheet” approach can be a powerful decision support system that provides transparency and flexibility and incorporates the knowledge of a range of people with different experience in the subject watershed (Beechie et al. 2008, Roni et al. 2013). Recent restoration plans that rely on MCDA approaches in the Pacific Northwest include the SHaRP approach (e.g., South Fork Eel River SHaRP Collaborative 2021), the Integrated Fisheries Restoration and Monitoring Plan (IFRMP) in the Klamath River watershed (ESSA and Klamath Basin Working Groups 2023), and the Atlas framework (Roni et al. 2023). These examples are discussed below.

The SHaRP process was developed by NMFS and CDFW to facilitate implementation of actions in state and federal recovery plans. The first step in SHaRP is to identify those focus areas within a larger watershed with the highest potential for recovery of the focal species. Next, those individuals with knowledge and experience of that focus area were invited to join an expert panel, which considered all available information about the habitat condition and fish distribution to first individually rank the habitat-related problems in that area (the limiting factors). The expert panel was then invited to a second workshop to collectively identify the restoration solutions for those problems. The result of the South Fork Eel River SHaRP process is an action plan for each sub-watershed that identifies high-priority treatments and actions along with the reaches and streams for which the treatments would be appropriate.

The IFRMP is a large-scale restoration plan for the Klamath River watershed led by ESSA (2023). The IFRMP created a ranking system to evaluate restoration project concepts that were based on number of affected species, the need to improve core performance indicators (ecosystem processes and fish habitat metrics), scale of benefit, and potential for implementation. In a multi-day workshop, IFRMP restoration practitioners, which included members of agencies, Native American Tribes, and watershed councils, brainstormed projects that would be evaluated within each sub-watershed of the Klamath River. Projects were then ranked based on the previously defined criteria. The criteria include species affected, watershed condition, stressors addressed for focal species, scale of benefit, and implementability. The relative importance of each criterion for the final score can be altered in real time by the public on an interactive website to visualize how changes to the criterion would affect ranking of restoration projects.

The Atlas framework was developed to rank sub-watersheds, reaches, and restoration projects for tributaries to the Columbia River in a consistent and transparent manner that involved local restoration researchers and practitioners (Tetra Tech 2017). The Atlas approach synthesizes available empirical data, watershed assessments, and models to inform criteria and rankings (Roni et al. 2018). Each restoration action is rated for its ability to address limiting habitat factors, impact focal species, lessen climate change, and restore watershed processes (Roni et al. 2018). Restoration opportunities are then mapped throughout the watershed and prioritized. Atlas has been implemented in several tributaries to the Columbia River and in the Grande Ronde watershed, a tributary to the Snake River (Roni et al. 2023). The time to complete and robustness of the framework depends on available data and participation of local experts (Roni et al. 2023, 2018).

MCDA approaches, such as the SHaRP, IFRMP, and Atlas examples, are flexible decision-support tools that can rank a range of restoration objectives and include various data inputs and criteria in the scoring process. These approaches allow for many people to have a voice, which can improve support of the end results. Depending on the scope of the restoration planning effort, expert ranking can be used to prioritize broad actions (as in the SHaRP process and Atlas framework) or more specific project concepts (as with the IFRMP). They are not reliant on proprietary software and can be adjusted and refined relatively easily as projects are completed and lessons about efficacy and cost are learned. The results depend on the experts who are responsible for the ranking and the extent of expertise in the basin. Careful planning is advised so that an appropriate group of diverse experts representing the range of experience and knowledge present in the basin are invited to the ranking process. However, engaging interested parties in the prioritization process and plan production has strong, positive emergent benefits. When the restoration community has a voice in the production of the plan and strategy, adoption of the final plan is much more likely. Given these strong benefits, the Planning Team recommends adopting a MCDA approach for this phase of prioritization, as described in Section 5.2.2 in further detail. The full list of pros and cons of using an expert ranking approach are outlined in Table 5-2.

Table 5-2. Pros and cons of using expert ranking approaches for prioritization in restoration planning.

Pros	Cons
Data inputs are tailored to specific watershed or sub-watershed of interest.	Ranking process and results may be considered subjective and likely depend on the composition of the group doing the ranking.
The ranking process is easy to understand and communicate to many interested parties.	--
Interested parties can participate and/or observe in the ranking process, increasing the credibility of the product and the likelihood of actions being funded and implemented.	Rankings are based on expert understanding, without the ability to game/model how actions might play out.
The process can be conducted over a shorter time frame and is much less expensive than a quantitative population model.	People with various levels and types of training, experience, and knowledge may participate, which could influence the perceived legitimacy of the results.
Spatial scale can be refined through iterative ranking exercises (starting at larger watersheds, moving to smaller sub-watersheds and reaches).	Differences in opinion of the importance of criteria or limiting factors can be difficult to manage in a group setting.
There is flexibility in the scale of the ranking, which can be of actions or projects, depending on available information and scale of planning.	--

Pros	Cons
Best available information is included by considering different forms of knowledge and observations beyond formal scientific data.	--
Criteria can be weighted in the ranking process.	--

5.2 Proposed Approach to Prioritizing Restoration and Conservation Actions

After reviewing several sets of tools, the Planning Team recommends a prioritization approach that includes a quantitative spatial planning tool (Marxan) and an MCDA approach. Marxan would be used to synthesize spatial data sets to inform which lands and sub-watersheds rank highly for restoration and conservation actions. An MCDA approach would be used to rank and develop restoration actions. Quantitative fish population models are not recommended at this time due to the relatively higher need for watershed-specific fisheries data to parameterize such a model and the time required to collect the data. Additionally, results from a quantitative fish population model could be integrated into an MCDA prioritization approach at a later stage (Roni et al. 2018). This combined approach of quantitative spatial planning tools and ranking would allow prioritization to occur without waiting to collect the necessary data to adequately parameterize a quantitative fish population model.

In the proposed approach, the steps for how Marxan and MCDA will work together differ for restoration and conservation actions and locations. The conservation prioritization will use Marxan and expert-informed conservation targets for the data inputs to the tool (Section 5.2.2). Restoration prioritization requires several steps and will include multiple workshops that will be supplemented by spatial data and planning analyses, including Marxan (Section 5.2.3). After prioritizing restoration and conservation actions in parallel, there will be a need for informed synthesis for both types of actions to develop an Action Plan (Section 5.2.4).

The multi-pronged approach proposed here considers constraints, such as extensive data gaps in a geologically and biologically diverse watershed and the need for strategic, rapid action to recover and protect imperiled fish populations. The set of tools identified here will be applied to help achieve the desired outcome of ranked restoration and conservation actions and locations. The steps outlined below provide an initial framework for prioritization, but the exact steps will likely change upon refinement at the onset of Phase 2. Before conducting prioritization and gathering additional key input data sets, various aspects of the proposed approach will need to be refined and expanded, including the specific criteria for ranking objectives, order and workflow of steps and analyses, and composition of experts and community members involved in each step.

5.2.1 Coordination with Agencies and Local Entities and Integration of Existing Plans

Two of the process goals of the Program are to “coordinate with local entities” and “integrate best available information” (Section 1.2.1). A prioritization process that coordinates with federal agencies, state, and Tribal governments and local entities to integrate existing plans, data, and local knowledge will result in more effective and informative ranking of restoration and conservation actions. Many plans have been developed throughout the watershed by local entities, and consideration and integration of these existing plans will be very important to (1) ensure that the best available information is used, (2) improve the restoration and conservation action prioritization process, and (3) bring about the best outcomes for native fish and healthy local communities.

Coordination with local entities and government agencies will provide unique benefits to the prioritization process. In this Plan, references to *local entities* include non-profit organizations, restoration practitioners, counties and municipalities, and other knowledgeable people. Coordination with local entities will infuse local knowledge to ensure that opportunities discussed during the prioritization process are aligned with the needs relevant to each portion of the watershed and will foster local understanding and encourage support of the outcomes. Engagement with and inclusion of government agencies in developing and implementing the prioritization process are also critical to successful planning. This engagement will ensure effective integration of available information and priorities from existing plans along with the extensive body of knowledge held by agency staff. It will also lead to prioritized actions that have a greater chance of being supported with agency funds.

During the action prioritization phase of the Program (Phase 2), the approach to prioritization will be refined and then implemented. Involvement of local entities and agency staff will be integral in many steps of Phase 2 prioritization. Specifically, when planning where restoration and conservation actions should occur, local entities and agency staff will advise on which data sources to include and rank their relative importance (Sections 5.2.2–5.2.4). Additionally, during prioritization of restoration actions, local entities and agency staff will be involved in ranking restoration objectives, refining restoration actions, and ultimately ranking actions with criteria that represent goals for fisheries recovery and perceived implementability and efficacy (Section 5.2.4). At the onset of Phase 2, the Planning Team plans to coordinate closely with local entities and agency staff in a way that is inclusive of, and also compatible with, the need to move restoration and conservation action prioritization forward in a timely manner. This effort will also include coordinating with other planning efforts in the watershed (e.g., the Great Redwood Trail Master Plan and the Lower Eel River SHaRP), so data and planning products can be shared to increase efficiency and efficacy of all efforts. To this end, during scoping for Phase 2, the Planning Team will coordinate closely with local entities and agency staff to understand capacity to engage in planning efforts, identify needs and mechanisms to support participation, and seek funding to support those needs.

In a relatively data-limited watershed like the Eel River, prioritization requires synthesizing existing information to inform criteria for and rankings of restoration and conservation actions. In this Plan, the development of the species conceptual models (Section 3, Appendix C) and identification of restoration and conservation actions (Section 4) drew from existing information in federal recovery plans for listed salmonids (NMFS 2014, 2016), restoration plans (Eel River Forum 2016, South Fork Eel River SHaRP Collaborative 2021, McBain Associates 2017), species management and regional implementation plans for Pacific Lamprey (Wiyot Tribe Natural Resources Department and Stillwater Sciences 2016, Boyce et al. 2022), watershed assessments (Downie and Lucey 2005; CDFG 2010, 2012; CDFW 2014), and other existing plans and reports with information on the Eel River watershed. Sections 5.2.2 and 5.2.3 describe how these existing plans will be integrated into prioritization, including as data inputs into the restoration and conservation spatial analyses, to inform the relative importance of restoration objectives, provide restoration actions that can be further refined, and inform the final ranking of restoration actions.

Federal recovery plans identify restoration priorities for populations of Chinook Salmon, Coho Salmon, and steelhead across the Eel River watershed, but they do not integrate priorities for multiple species (NMFS 2014, 2016). Existing restoration plans and watershed assessments provide valuable characterizations of watershed conditions and restoration priorities with a focus on ESA-listed anadromous salmonids (a subset of focal species) and cover only certain portions

of the watershed—mainly the South Fork Eel River, Lower Eel River, and Van Duzen sub-watersheds (Downie and Lucey 2005; CDFG 2010, 2012; CDFW 2014; South Fork Eel River SHaRP Collaborative 2021). The Eel River Action Plan provides a summary of issues considered to be primary factors impairing salmonid recovery and ecological health of the Eel River watershed but is not meant to provide a comprehensive, in-depth plan for restoration and conservation (Eel River Forum 2016). An important contribution of the Program and prioritization under Phase 2 will be to synthesize the information and recommendations provided by each of these recovery planning efforts—along with new data and analyses—to develop a watershed-wide planning process that identifies priorities for the recovery of all five focal fish species, emphasizing the protection and restoration of life-history diversity. Inherently, this means considering the entire watershed, including how each sub-watershed and fish population may contribute to supporting diverse life-history strategies of each focal species through time. This comprehensive approach to restoration and conservation planning for five focal species across the entire Eel River watershed will draw from these many important building blocks.

Overall, including local entities and agency staff in the prioritization process and integrating the information provided in existing plans and reports—along with new data and analyses—will ensure use of the best available information and increase integration and efficiency with other planning efforts in the watershed.

5.2.2 Conservation Prioritization Approach

A program goal (Section 1.2.1) is to “protect and conserve landscape connections between important riparian and upland habitats.” In many cases, an ad hoc approach to conservation, where land is set aside for protection based on logistical reasons or ad-hoc opportunities, is the normal practice. For example, conserved areas are located where land is cheap or away from populated areas, regardless of biodiversity or landscape connectivity. Conducting formal spatial planning that integrates various desired characteristics of the land, such as biodiversity, presence of focal species, vegetation health indices, presence of wetlands, possibility to provide climate refugia, cultural resources, and connectivity to other conserved lands, can greatly improve the efficacy of conserved lands to support species in a changing world (Jones et al. 2016, Wohl et al. 2021).

To protect important, yet representative, habitats, the Planning Team proposes to use spatial analyses to define core areas for conservation and associated upland areas that currently provide productive habitats for focal fish species. However, species distributions will likely shift across the watershed as the climate shifts (Krosby et al. 2015). Therefore, habitats that species will need to use as climate changes must also be identified and protected with a strategic process (Heller et al. 2015, Lawler et al. 2015).

To meet the Program goal to *protect and conserve*, as described above, the Planning Team developed an approach for conservation planning that leans heavily on quantitative analyses, and expert opinion. Core conservation areas will be identified with a quantitative spatial planning tool—Marxan. The approach, which is a multi-criterion, conservation target and structural connectivity systematic assessment strategy, or Resilience Strategy, is described in detail below:

- Identify desired characteristics for conserved lands,
- Conduct a spatial analysis using Marxan to identify locations that have desired characteristics,
- Convene experts to review and adjust the conservation targets and rerun Marxan as needed,

- Conduct corridor/network planning, (Donald and Evans 2006, Fremier et al. 2015, Haddad et al. 2015); and
- Share results with the public and Eel River community to increase public and community engagement and support (Chan et al. 2006).

5.2.2.1 Desired Characteristics for Conserved Lands

The conservation approach was built on a set of guiding principles for effective climate resilient conservation planning. In this approach, lands that are conserved will have characteristics that will:

- Protect biodiversity (Eken et al. 2004);
- Adequately represent diverse habitat types in the newly protected areas (Geldmann et al. 2013);
- Provide riparian climate refugia (Dunn and Angermeier 2019, Krosby et al. 2018);
- Provide thermal refugia for aquatic species in the future; and
- Promote protection of lands with multiple benefits (e.g., climate resilience, biodiversity, and cultural resources).

5.2.2.2 Implementing Marxan

The steps developed to use Marxan for prioritization of conserved areas in Phase 2 prioritization are depicted in Figure 5-2, and are described in detail here.

Landscape, habitat and species data are first integrated into the conservation strategy as spatial data. Each spatial dataset will first go through a thorough review of adequacy and completeness. The data are mapped across the planning area and used as conservation features for defining focal areas for conservation. After the key data variables for the quantitative analysis are decided on, a group of experts decides on the percent of each variable that will be used to derive the conservation solution.

Conservation targets are set within each of the habitat and landscape data variables. For example, conservation targets recommended by the Convention on Biological Diversity are set at percentages based on international expert opinion and scientific reports. Often these target percentages are used as guidelines for local and regional planning. The recommendations outlined by the California Natural Resources Association (CNRA 2022), follow the Convention on Biological Diversity parameters for protecting 30% of California by the year 2030. This recommendation is locally referred to as the California 30x30 initiative. However, simply protecting 30% of California lands and oceans will not meet ensure that conserved lands contain the desired characteristics, as described in above (Section 5.2.1.1). Thus, conservation targets are defined by a group of subject experts to inform the quantitative prioritization process and guide the establishment of a recommended protected area network across the watershed.

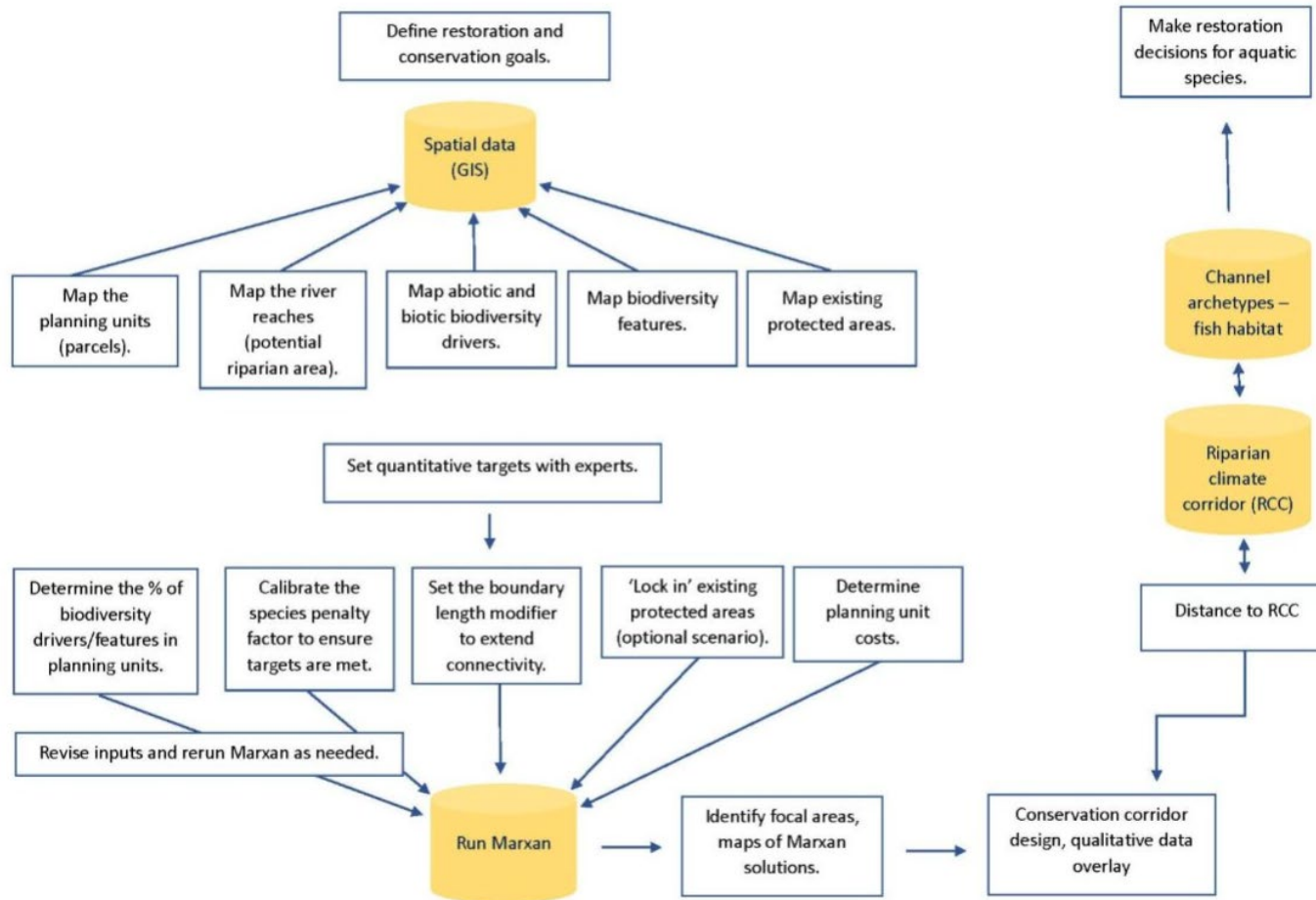


Figure 5-2. Workflow for combining the conservation prioritization strategy with other Eel River data products. The diagram shows the relationship between data inputs, Marxan algorithm model outputs, corridor design, and other data overlay options.

After datasets are integrated and targets are set, Marxan is used to define maps of spatial solutions that meet the restoration and conservation targets for the watershed area.

A review of the Marxan mapped spatial area results will be necessary to ensure the solutions meet the goals of the Program (Serra et al. 2020). The review, conducted by an expert panel in Phase 2 of the Program, will examine the effectiveness and efficiency of the solutions.

- *Effectiveness*: How well the results meet the achievement of the defined analysis goals and targets. To do this, Marxan must be calibrated to adjust the outcome to ensure the targets are met at 100% for the best solutions (Possingham et al. 2000).
- *Efficiency*: How efficient the solutions are at meeting conservation goals within a minimal cost range and with an efficient clumping of sites for land management. To ensure this efficiency of cost and area, the boundary length modifier tool within the Marxan software can be calibrated (Serra et al. 2020).

The result from this first step of implementing Marxan will be a set parcels that are highly ranked due to their characteristics that meet conservation guiding principles.

5.2.2.3 Riparian corridor network planning

A corridor is a general term for a conduit or connecting group of features in the landscape. Connected landscapes are considered as the best strategy for building climate resilience (Zavaleta 2009). To be effective as a habitat corridor, a corridor must be strategically selected for its connective attributes at the watershed scale. These attributes are size >1 km elevation gradients, degree of fragmentation, availability of habitat per species (many plants cannot disperse at <20% habitat), predicted rate of climate shifts, species dispersal capacity, and habitat preferences (Groves et al. 2012, Tallis et al. 2021). Corridors must also include prioritized sites for habitat restoration and conservation which incorporate species needs and landscape processes (Anderson et al. 2014, Metzger and Brancalion 2013). Riparian areas provide a natural framework to build connected networks (Salviano et al. 2021, Steidl 2009).

Planning conservation networks around riparian corridors is a natural fit as over time, there has been a preference in land management for preserving riparian forests over more valuable, farmable, or timber harvestable land (Krosby et al. 2018, Pressey and Bottrill 2009, Soule and Terborgh 1999). A simple method to refine corridor design with the goal of improving freshwater protection in a planning area is to extend the protection of rivers to the full length of their flow. This also addresses the need for protecting environmental gradients in the planning area (Nel et al. 2009). The first step to build the connected corridor network is to spatially define, name and number riparian corridors and connective blocks of land between protected areas and riparian corridors.

Marxan is a quantitative planning tool that can provide spatial data-informed connectivity solutions, but it cannot build corridors. To expand on the conservation solutions derived from the Marxan, the Planning Team recommends establishing a conservation corridor network in Phase 2 of the Program, to ensure that basin-wide processes for connectivity are built into the conservation strategy (Davis 2020, Rouget et al. 2006).

To build a representative, conservation corridor network, the Planning Team will consider connectivity elements, such as proximity to existing protected areas, riparian buffers, riparian corridors, connectivity corridors, and climate corridors. To create structural connectivity within the framework, the team will include the connectivity needs of many species and overlaid these

with important biodiversity areas and representative landscape resiliency data for environmental gradients known to assist species persistence during climate change.

5.2.2.4 Integration of Marxan solutions and corridor development

Results from conservation planning at the parcel scale will be overlaid with results from the corridor analysis, along with other analyses within the Program, including restoration prioritization at the HUC-12 sub-basin scale (Section 5.2.2) and the channel archetypes (Section 2.2). Additionally, the final step of planning will integrate other spatial planning datasets and analyses such as riparian climate refugia corridor data and block polygons from the California Essential Habitat Connectivity project (Spencer et al. 2010). Additionally, there will be a need to overlay mapped potential riparian area polygons to establish real-world boundaries for the riparian area in the network. This synthesis step will inform the final recommendations for high priority lands and parcels to be conserved and protected.

The results from Marxan prioritization and associated spatial planning in Phase 2 will be used to establish core climate resilient habitat areas of the corridor network. The results will be analyzed by the Planning Team to assess how the prioritized areas meet the Program goal *Protect* defined in Section 1.2.1.2:

- Increase the size of core habitat areas to establish a buffer zone around the core areas;
- Identify potential areas for corridor network expansion into locations of upland habitat;

5.2.2.5 Maps for public engagement in conservation

Maps and visual aids that engage private landowners are integral in sharing the results of the conservation prioritization and providing resources and links for conservation acquisition, easements, and future landowner incentive programs in the watershed. Thus, a final but key task of the conservation prioritization approach in Phase 2 will be to build and maintain a web map and ArcGIS StoryMap with the analysis outcomes clearly described and accessible to interested parties. The mapped conservation parcel prioritization results will have short- and long-term outcomes in the watershed:

- *Short-term Outcome:* An online resource of digitized, dynamic, and interactive maps showing lands (HUC-12 sub-basins) that score highly for climate resilience, biodiversity, and cultural resources as permission from landowners and information providers allow.
- *Long-term Outcome:* Strengthened partnerships between community organizations, participation from Native American Tribes, expanded capacity for community members and Native American Tribes to add to and validate information about climate resiliency, ecosystem services, and cultural resources that would benefit from protected habitat across a connective watershed riparian climate corridor.

5.2.3 Restoration Prioritization Approach

A guiding principle for the restoration prioritization approach is to identify actions that meet the Program goal of *restoring life-history diversity* of each species, as a means of recovering fish populations (Section 1.2.1 and Section 3). The prioritization process will consider that focal fish species require the entire watershed, including areas that are not traditionally considered such as warm mainstems and seasonal tributaries, to develop diverse life-history strategies that provide population resilience across different water year types. Therefore, in Phase 2, prioritizing restoration actions should begin with a watershed-wide perspective and ask what needs to be done, with the greatest benefit for many species and life-history strategies, before focusing on

smaller HUC-12 sub-basins or reaches where those actions will be most suitable. Identifying the *what* before the *where* will guide the restoration planning to consider watershed-wide needs for each focal species as they move through the watershed in their life cycle. In line with this workflow, the Planning Team suggests identifying the restoration objectives and associated actions (Section 4.2) that are predicted to be most beneficial for focal species, and then conducting the spatial planning of associated locations for each high priority action. One component of this spatial planning will be to identify strongholds, or relatively intact habitats that host focal species and key life-history strategies (Beechie et al. 2008), including key diversity stratum identified by NMFS recovery plans (NMFS 2014, 2016). The final step will be to rank the combination of actions and their most-suitable associated locations, along with their predicted scale of response, implementability, and efficacy.

Within this context, the recommended approach for prioritizing restoration actions requires several steps to arrive at (1) recommended restoration goals and actions and (2) HUC-12 sub-basins and channel archetypes that will benefit most from those restoration actions. Together, these steps will answer *what* restoration actions should be prioritized and *where* should they be done. The recommended restoration prioritization framework includes expert-based rankings and quantitative spatial planning tools. A multi-step, logic-based ranking conducted by watershed experts and informed by the best available data and species conceptual models (Section 3) will be used to identify high-priority restoration actions (Phase 2). The results of expert ranking will be combined with spatial planning tools to inform where restoration actions should be conducted. This multi-pronged approach will enable efficient prioritization and will use collective understanding to characterize habitat conditions and fish populations in much of the Eel River watershed. This approach should be considered a starting point and does not preclude developing quantitative population models and/or watershed assessments to guide future restoration actions.

5.2.3.1 Broad and Specific Restoration Actions

Before describing the restoration action prioritization steps in detail, it is important to understand the proposed scale of recommended restoration actions for the Action Plan that will be developed in Phase 2. Two levels of resolution should be prioritized, each with slightly different steps: *broad actions* and *specific actions* (Figure 5-3).

- *Broad actions* are beneficial for focal species and life histories in many locations throughout the watershed. One example is the addition of large wood to create habitat complexity. For broad actions, there is a need to prioritize not only *what* actions are most likely to achieve restoration goals but also *where* each action will be most beneficial in terms of benefits to focal species and life histories. Following the spatial structure (Section 2), broad actions will be associated with certain channel archetypes and HUC-12 sub-basins. Many of the broad actions that will be ranked have been previously identified by NMFS recovery plans (NMFS 2014, 2016), restoration plans (Eel River Forum 2016, South Fork Eel River SHaRP Collaborative 2021), and watershed assessments (Downie and Lucey 2005; CDFG 2010, 2012; CDFW 2014). This plan will build on the previous body of work to rank actions for their perceived benefits to multiple species and for restoring life-history diversity within focal species. The identification of where these broad actions would likely have the greatest benefit will occur with spatial analyses (Section 5.2.3.2). Local landowners, restoration practitioners, Native American Tribes, and watershed restoration groups can use these broad actions and locations as a starting point to develop specific projects. The Plan does not intend to propose projects associated with broad actions; rather, restoration practitioners should determine the exact site and actions given their knowledge of the area. This scale of planning allows for and depends upon the creativity and engagement of local entities and community members.

- *Specific actions* are those that are inherently associated with a geographic location and are anticipated to have an outsized benefit on the watershed’s ecological and geomorphic function. For example, future dam decommissioning in the upper Eel River watershed is anticipated to have long-term benefits for downstream hydrology and geomorphology and to restore access to headwater habitat for spawning and rearing. Another example may be addressing a known major source of fine sediment from a landslide or road failure that is degrading water quality and downstream habitat (choking spawning gravels or filling in deep pools).

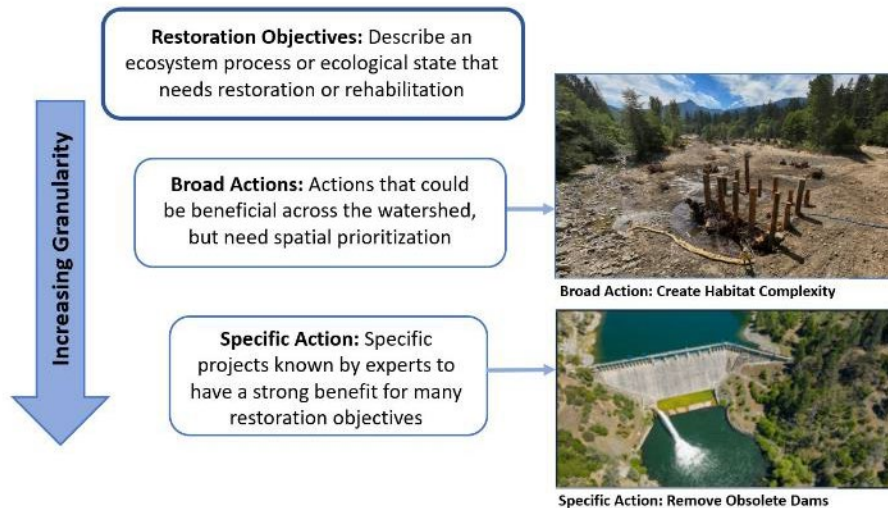


Figure 5-3. Conceptualization of how broad and specific restorations address restoration objectives. *Broad* and *specific* actions will be considered separately in restoration action prioritization.

5.2.3.2 Steps of the Restoration Prioritization Approach

The following steps are proposed for prioritizing restoration actions (both broad and specific actions) and locations (Phase 2) during a series of workshops and analyses:

- Rank habitat and landscape restoration objectives for their ability to achieve fish population and life-history diversity goals (Section 4.2);
- Identify broad restoration actions that will address objectives;
- Solicit professional opinion to identify specific restoration actions that will meet objectives;
- Conduct spatial analyses to determine where broad restoration actions are most needed and most appropriate (Planning Team); and
- Rank broad and specific restoration actions (separately) for their predicted ability to recover fish populations, based on predicted feasibility and ability to address underlying stressors and reestablish natural watershed processes. At this stage, all restoration actions (broad and specific) will be associated with locations where they are predicted to be most beneficial and suitable, and that information will be part of the ranking.

These steps are depicted in relation to conservation prioritization in Figure 5-4 and are described in further detail in the following sections.

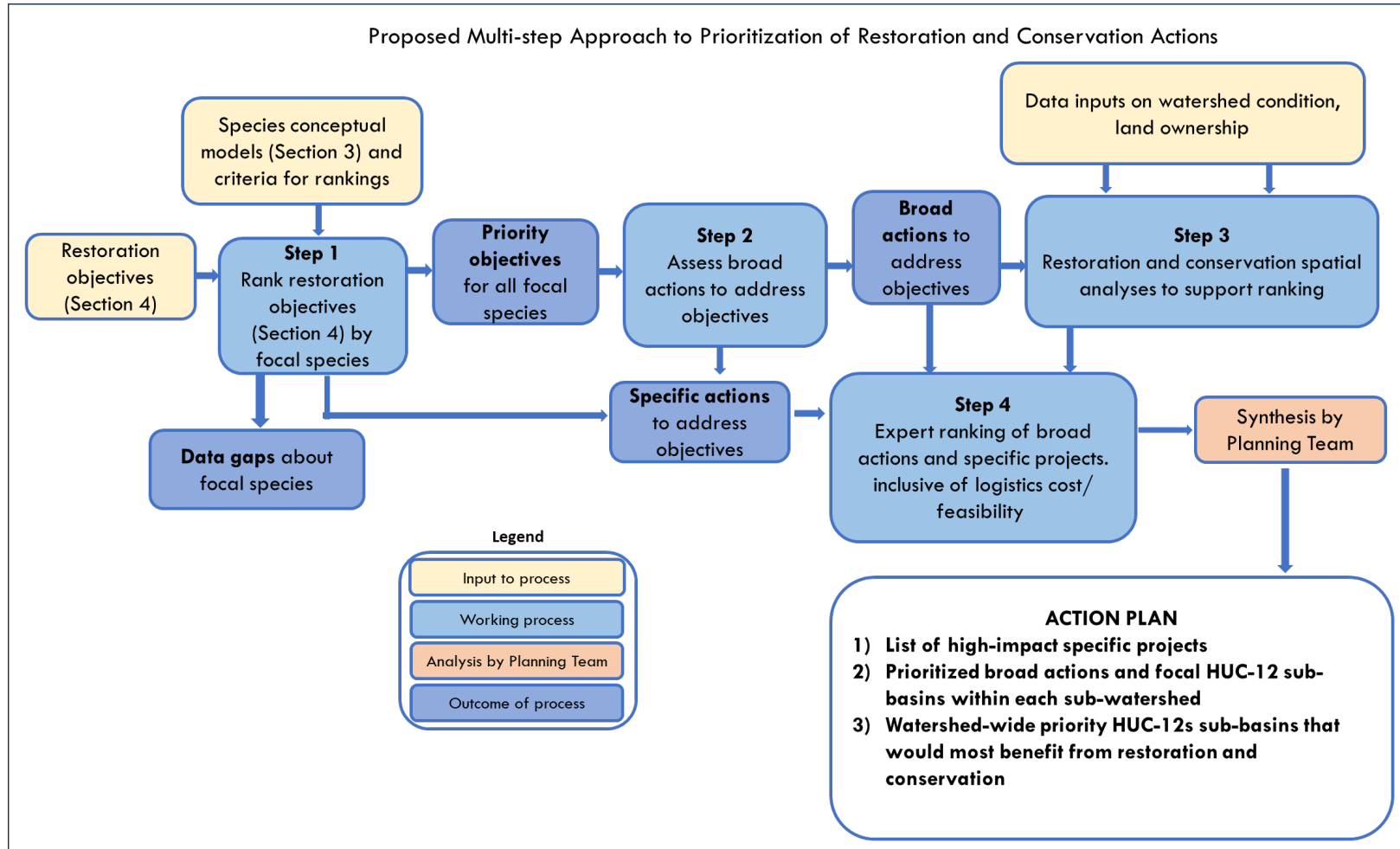


Figure 5-4. Proposed restoration and conservation action prioritization framework that integrates both expert ranking and spatial planning tools. The outcome for this multi-pronged approach is an Action Plan with guidance on how to proceed with restoration and conservation. The outcomes of the Action Plan need to be revisited with ongoing lessons learned from implementation and monitoring.

Step 1: Rank restoration objectives and identify specific restoration actions

- *Goal:* The goal of the first working step is to rank habitat and landscape objectives (Section 4) based on their importance for recovering abundance and resilience of each focal species. The discussion in this set of workshops should focus on the *need* for restoration and perceived importance of objectives. Feasibility of associated restoration actions will come later in the final ranking step.
- *Restoration Community Involvement:* People with an on-the-ground understanding of fish populations in the Eel River, including agency scientists, Tribal biologists and members, local citizen scientists, knowledgeable community members, academic scientists, and watershed council members. Participants plus facilitators (n=15 to 20).
- *Process:* Ranking restoration objectives will occur in a series of workshops for each sub-watershed. The life cycle and life-history strategies of focal species will be used as the basis for discussion. Species conceptual models and channel archetypes will be used to construct scenarios that the group walks through to discuss limiting factors and data gaps for each focal species. The group will walk through 3–5 scenarios for each species (total of 20–25 scenarios). Each scenario will be developed by beginning at one type of natal stream (channel archetype, Section 2.2). The group will then discuss the life-history strategies that arise from fish that are born in that archetype, guided by species conceptual models (Section 3) and various needs throughout the life cycle, including rearing, juvenile and adult holding, passage, and spawning. The discussion will focus on key stressors that limit habitat capacity and condition in the various habitats that are encountered for life-history strategies originating from that archetype. While the species' life cycle will begin in a natal stream in each sub-watershed, habitat needs in other sub-watersheds will be discussed and ranked. For example, restoration actions in the estuary will be considered in the workshop for each sub-watershed, given that all anadromous salmonids move through the estuary. As the discussion progresses, data gaps, such as whether a certain life-history strategy exists or whether a habitat type is impaired, will be noted. In addition, opportunities will arise to note specific high-impact restoration actions that are identified in discussion of life history strategies.

After discussion of the species' life-history strategies and factors limiting the recovery of each strategy, each expert panel member will rank the habitat and landscape objectives (Section 4, Appendix D) by predicted level of importance for recovering life-history diversity and overall abundance. Their rankings will be guided by pre-developed criteria and informed by the previous in-depth discussion. After ranking is conducted, Planning Team members compile and summarize ranking results. At the end of the workshop, participants will have an opportunity to discuss the rankings to understand if and why there are outliers in the rankings.

- *Outcomes:*
 - Top 3–5 most important (priority) restoration objectives for each species.
 - Top 3–5 most important (priority) restoration objectives for all species together.
 - List of specific high-impact specific restoration actions.

Step 2: Identify broad actions to meet priority objectives

- *Goal:* The goal of the second set of workshops is to identify broad restoration actions that will address the priority objectives identified during the first step. Specific restoration actions will also be noted. This workshop will reference other actions plans in the Eel

River watershed (e.g., SHaRP and the Eel River Action Plan) to ensure that their recommended restoration actions are integrated with the ones of the Program.

- *Restoration Community Involvement:* Restoration practitioners, restoration design engineers, fish and riparian biologists, knowledgeable community members and citizen scientists, Tribal members and staff. This group will need to have a strong understanding of real-world implementation of restoration actions that work to meet certain restoration objectives. The composition will be slightly different from the first set of workshops due to the need for expertise in restoration implementation and design. Experts plus facilitators (n=15 to 20).
- *Process:* Participants will identify broad restoration actions deemed most likely to achieve each prioritized restoration objective identified previously. The broad restoration actions described in Section 4 and listed in Appendix E will be used as a starting point, but participants can identify additional actions. Each broad restoration action will also be categorized by whether it is needed to restore watershed processes, restore habitat structure, or both. That information will be used as criteria for the final ranking of broad actions. Approximate relative feasibility will be estimated for restoration actions for each objective. Each restoration action will also be associated with the appropriate channel archetypes for implementation. While the focus of this set of workshops is to identify broad restoration actions that address priority objectives, spatially explicit high-impact actions identified by participants will be added to the list of specific actions developed during previous working groups.
- *Outcomes:* Actions that address each high-priority restoration objective.

Step 3: Conduct spatial analyses to identify priority locations for broad restoration actions

- *Goal:* The goal of spatial analyses is to identify *where* broad restoration actions should occur within the Eel River watershed, given that there are likely many locations that would benefit from restoration actions. The spatial analyses will identify the HUC-12 sub-basins that would provide the greatest benefit from broad restoration actions based on (1) the potential to benefit a high number of species, key diversity stratum, and life-history strategies or an unusual but important life-history strategy, (2) historical land use and the estimated current state of habitat degradation, and (3) other factors influencing where priority broad actions are most appropriate to implement.
- *Process:* Spatial analyses will be conducted by members of the Planning Team in consultation with local entities. The first component will be to use the prioritization planning tool Marxan to identify high priority HUC-12 sub-basins throughout the entire Eel River watershed. The second component will be to layer additional suitable spatial datasets or analytical products onto the Marxan outputs that provide context to inform where each broad restoration action should be implemented. For example, if beaver reintroduction is a highly ranked broad restoration action, then an output from a beaver intrinsic potential model would be highly informative for identifying the most suitable HUC-12 sub-basins and reaches for beaver reintroduction. The outcome of the ranking of the broad restoration actions in Workshops 1 and 2 will dictate which datasets should be considered for additional spatial analyses in this step of the process.

The processes for running Marxan to inform where restoration actions are most needed follows:

1. Identify and gather appropriate data input layers (Table 5-3).
2. Develop a weighting/importance ranking for data layers for use in Marxan.

3. Use Marxan to establish multiple priority outcome sets of HUC-12 sub-basin solutions using different percentage targets for all focal species. These targets should be initially set at 10% for all focal fish species and then modified up to <100% after each scenario is developed. HUC-12 sub-basins selected in all Marxan processing will be considered a high priority location that would provide the greatest benefit from restoration actions. Watersheds selected in fewer runs will have a lower priority.
4. Watersheds with potential restored conditions that are less conducive to focal species habitat are scored as a lower priority for restoration and conservation actions. For example, these watersheds may have poor relative condition, high relative climate change vulnerability, lower overall species richness, and less likely to support a diversity of life-history strategies of focal species (Section 3).
5. After all scenarios are created, resulting data layers will be merged and combined to rank the sum of the number of times any given sub-basin is selected for all model runs and used to create categories of the degree of relative prioritization.
6. Finally, use a decision table to view and categorize the results of the iterative Marxan analysis. For example, Table 5-3 shows the representation of the number of times a watershed is selected, along with the associated category of relative importance defined at approximately 20% per category.

Table 5-3. Example relative importance ranking for Marxan prioritization analysis results for the 113 HUC-12 sub-basins in the Eel River watershed.

Number of times a planning unit (HUC-12 sub-basin) is selected	Relative importance ranking
1–25	Low priority
26–50	Medium low priority
51–75	Medium priority
76–100	Medium–high priority
101–113	High priority

- *Outcomes:* A list of HUC-12 sub-basins that are most suitable for each high-priority broad restoration action (developed in Workshop 2). There will likely be an overlap in the highly ranked HUC-12 sub-basins among the restoration actions.

Step 4: Rank broad and specific restoration actions

- *Goal:* The goal of the final working step is to quantify expert opinion to rank broad and specific restoration actions based on criteria related to impacts on fish populations, as well as perceived feasibility and efficacy. This ranking will be based on the synthesis of the previous steps and the spatial analyses (HUC-12 sub-basin rankings using Marxan).
- *Restoration Community Involvement:* Participants from all previous workshops will be invited to rank broad and specific restoration actions. (n=25 to 30 experts plus facilitators)
- *Process:* The ranking will occur in a series of workshops. Each priority restoration action will be discussed for potential impact to fish populations and implementation feasibility and costs. Participants will be given a score sheet to rank broad and specific restoration actions (separately). The final score/ranking of each restoration action will be an average of all the scores.

- *Outcomes:*
 - A ranked list of broad actions and the high priority HUC-12 sub-basins that are associated with each action, as identified from spatial analyses.
 - A ranked list of specific restoration actions.

5.2.4 Developing a Phase 2 Action Plan for Restoration and Conservation Actions

The workshops and spatial analyses will produce a ranked list of high-priority broad and specific restoration actions and a ranked list of high-priority conservation actions. To develop the Phase 2 Action Plan, the rankings will need to be synthesized and a cross-comparison of restoration and conservation priorities will need to be developed. If there is a sequence that would provide the greatest benefit for restoration and conservation actions, that order will be identified. For example, for some watersheds, it may make sense to remove a significant fish passage barrier before conducting habitat restoration upstream. For each HUC-12 sub-basin, a list of priority broad actions will be synthesized based on the species presence, composition of channel archetypes present, and other characteristics of the HUC-12 sub-basin. At this step, there will also be a need to cross-reference other restoration plans in the Eel River watershed. For example, specific actions developed by the SHaRP should be considered and referenced. The Planning Team expects that the Action Plan will contain other components beyond the priority recommended restoration and conservation actions. In total, the components that may be included in the Action Plan include the following:

- A ranked list of high-priority broad restoration actions and HUC-12 sub-basins and channel archetypes where they will be most effective at helping achieve restoration goals,
- A ranked list of specific “grand slam” restoration actions for the Eel River watershed,
- A ranked list of conservation actions for the Eel River watershed,
- Recommendations for the next phase of prioritization by the Program,
- Recommendations for the development of broad restoration actions into site-specific projects, and
- Recommendations for continuing coordination with monitoring and assessment in the Program.

5.3 Data Availability and Needs

The proposed restoration and conservation action prioritization framework will require many data layers to inform spatial planning and ranking analyses. Table 5-4 summarizes data layers gathered and expected to be included in the spatial planning. Table 5-5 summarizes additional datasets used to refine the spatial planning interpretation. Some of the layers and datasets may also be presented to workshop participants to inform ranking and development of actions. The compilation of data layers to date focused on data available at an appropriate scale.⁶ Some data inputs will be refined for use in the framework. The data presented at the parcel scale will be used mainly for conservation spatial planning. Additionally, spatial planning will lean toward using fewer, more informative layers, at the top of the table, for the quantitative Marxan runs, with the outcomes being informed by additional layers. Data layers at the parcel scale will primarily inform conservation. In the absence of a formal watershed assessment, some data layers will broadly inform watershed condition (e.g., land use history will inform the likelihood impaired sediment transport and altered canopy cover). Data layers listed as “additional data” will likely

⁶ Currently available data layers can be viewed at: <https://caltrout.org/eel-river-watershed-program/data>.

not be used in quantitative Marxan runs but may be used to inform outputs or for planning of restoration actions.

Table 5-4. Data layers and analyses that may be included in spatial planning for restoration and conservation and their availability at corresponding spatial scales.

Analysis scale	Spatial data and analyses
Watershed (HUC-12 sub-basin)	Land use type
	Land use history
	Contemporary canopy cover/vegetation condition
	Fire risk
	Biodiversity of terrestrial and aquatic species
	Priority of diversity strata (NMFS 2014, 2016)
Parcel	Riparian thermal refugia
	Land ownership type
	Protected area status
	Vegetation density
	Connectivity—proximity to existing protected areas
	Biodiversity—terrestrial and aquatic
	Resilient lands index (TNC)
	Low solar radiation
Channel	Fish species distribution
	Life-history diversity potential
	Channel archetypes
	Floodplain connectivity
	Riparian buffer area
	Migration barriers
	Water temperature regime
	Flow impairment/diversions

Table 5-5. Additional datasets that may be layered on top of the spatial planning analyses to inform the ranking and sequence of restoration and conservation actions.

Social/Political Data	Disadvantaged communities
	Social and recreational potential
	Existing restoration projects
	Tribal lands
	Tribal and cultural resources
	Privately owned lands
Physical and Ecological Data	Geology and Lithology
	Streamflow regime
	Geomorphic outliers, such as wide, low-gradient floodplains
	Wetland presence and area
	Channel confinement
	Pikeminnow presence/absence
	Beaver presence and potential
	Sediment wasting events
	Proxies for food productivity
	Large wood density
EPA healthy watersheds data	

5.4 Hypothesis Testing within Prioritization

The prioritization process that will unfold as described above will reflect the current understanding of the Eel River watershed. The process integrates multiple information sources, including a historical understanding of the watershed (e.g., fish populations, impairment levels, land use), the contemporary understanding of focal species' life-history diversity (those which are expressed or are no longer expressed) and leverages the collective knowledge of watershed experts to make prioritized recommendations of what restoration and conservation actions are most likely to recover the watershed and meet the Program Goals (Section 1.2.1) and restoration objectives (Section 4). Thus, the prioritization process described above will imply a series of hypotheses about the ecological response to environmental change that will create the largest directional change toward the Program goals. For example, the Planning Team's current understanding suggests that non-native predators are very detrimental to the survival and life-history expression of juvenile salmonids. Preliminary results from pikeminnow suppression and associated studies in the South Fork Eel River suggest low mainstem survival of migrating juvenile salmonids between April and June, with mortality higher in certain reaches compared to others. However, more work is needed to understand the mechanisms of mortality (direct predation or habitat mediated impacts), the impacts to life-history diversity, and the most effective mechanisms to reduce these pressures on juvenile salmonid survival. Because of the limited information around restoration actions in the Eel River watershed, the prioritized actions will be presented as hypotheses that are grounded in the current understanding of the ecosystem. In the scientific method, after hypotheses are developed, they should be tested experimentally or with data collection. The restoration prioritization approach that is for Phase 2 should be treated similarly by integrating closely with validation monitoring.

The prioritization approach can be tested through both data collection and experimental designs at different scales in the watershed. The hypothesis testing can be evaluated at two scales: (1) project-level and (2) program-level (population response). At each scale, the prioritization process will interact with the Program monitoring and assessment (Section 7). At the project-level, data can be collected at a project site before and after implementation to collect basic variables around fish presence or absence, water temperature, predator presence, invertebrate productivity, or focal species survival (or any other specific mechanism the project is intended to address). Hypothesis testing around individual projects answers how effective actions can be at a local scale. However, because the Program goals are to recover focal species at the population level and thus demands evaluation at the larger program-level. To test the hypotheses of the prioritization at the watershed scale, the Program should lean on program-level monitoring (Section 7) to determine whether the culmination of multiple actions across the watershed are effective.

Over time, the Program should use this hypothesis framework to (1) determine whether the prioritization process was effective; (2) update the prioritization process with additional information and data; and (3) update the process to determine new actions or locations where restoration and conservation could be most effective. The prioritization process described here or the suggested actions or locations should not be treated as static or fixed, rather it is a dynamic process that interacts with the understanding of the watershed and should be updated as hypotheses are tested, and data are collected. Adoption of the hypothesis testing approach in a large and complex system such as the Eel River will improve the likelihood of recovery and long-term resilience and provide vital information for other restoration and conservation programs.

5.5 Next Steps and Future Refinement of Restoration and Conservation Action Priorities

Additional preparation will be needed to implement the proposed process for prioritizing restoration and conservation actions process. The next steps for each workshop in the planning process follow:

- Refine order, agenda, and number of workshops,
- Write and test guided questions,
- Refine datasets that will be presented to workshop participants as background,
- Develop criteria for ranking restoration actions and objectives, and
- Create and invite a list of attendees.

Some next steps for the spatial planning analyses include the following:

- Refine input data layers,
- Develop missing, critical data layers,
- Develop quantitative target percentages for ranking the data layers in Marxan,
- Map the riparian corridors using the potential riparian area data set, and
- Prioritize among the riparian corridor segments to highlight sections for proposed restoration and conservation actions.

The proposed multi-pronged restoration and conservation action prioritization framework developed by the Planning Team is meant to be a first iteration that can proceed quickly to inform rapid and strategic restoration and conservation actions. Quantitative population models have been very helpful in providing mechanistic predictions for the efficacy of restoration actions in other watersheds if the data is available to support these models. As monitoring data in the Eel River continues to be generated, it may become feasible to develop a quantitative fish population model for the Eel River watershed. The Planning Team supports working toward using a quantitative fish population model and suggests that the feasibility of applying such a model be revisited in 3 to 5 years and periodically thereafter as information is gathered. Additionally, because future monitoring (Section 7) will inform the efficacy of restoration and conservation action types in the Eel River, the monitoring and assessment results should be regularly reviewed, tied back into a fish population model, and used to update priority restoration and conservation actions priorities in an iterative feedback loop.

6 PROGRAM MANAGEMENT FRAMEWORK CONSIDERATIONS

Because of its size, geographic diversity, and disproportionate amount of private landownership, the Eel River lacks a central entity or agency to oversee and coordinate resource management and restoration activities across the watershed. Without centralized coordination, the numerous agencies, Native American Tribes, and non-profit organizations working throughout the watershed to restore the Eel River ecosystem and its native fish populations often focus on their own individual mandates and objectives and miss opportunities to integrate, prioritize, and focus available resources to achieve a collective vision and goals. The purpose of the Program is to implement restoration and conservation actions that achieve the Program’s vision and goals (described in Section 1.2.1). To achieve this purpose, a program management framework needs to be developed and implemented. In this section, based on experience in other programs with similar vision and goals, the Planning Team recommends a governing and administrative organization (i.e., a management framework) along with a Program Management body that can successfully implement the Program.

A management framework can range from simple, well-defined efforts (e.g., led by one person), to large, complex organizations for large-scale efforts, such as the San Joaquin River Restoration Program (SJRRP 2007) and Trinity River Restoration Program (USFWS et al. 2000). The larger and more complex the ecological restoration effort (including diversity of participants), the larger and more complex the management framework will likely need to be. Larger management frameworks will also require stable and substantial funding to operate successfully. To address the unique characteristics and needs of the Eel River watershed, and to succeed in the long-term, the appropriate scale and organizational structure needs to be defined at the start, be embraced by the various entities who will participate in the Program’s development and implementation and be flexible to adapt and evolve as needed. Recommending a management framework for the Program is a critical step and is dependent on assumptions about the scale and stability of future funding sources.

The Planning Team considered a range of potential management frameworks based on other large-scale restoration programs in the western United States and recommends a management framework based on the current understanding of management needs and potential future funding strategies that may become available, at least to initiate the Program. For this section, “management framework” is defined as initial ideas on how the Eel River restoration framework would be structured and implemented, including funding options, Program structure, roles and responsibilities of participants, topical extent, spatial extent, and linkages to Section 7, *Monitoring and Assessment Framework*, and Section 7.3, *Monitoring and Assessment Process*. Given the scale and complexity of the Eel River watershed, the Planning Team assumes that the future Program Management body will require a robust management structure that is commensurate with other large-scale restoration programs (such as those for the Trinity River and the San Joaquin River). Therefore, this section focuses on a potential management framework for implementing larger-scale ecological management framework considerations (Section 6.1) and assumes that a longer-term and stable funding source can be developed to support this type of ecological management framework for the Eel River (Section 6.2).

6.1 Components of an Ecosystem Management Framework

A large-scale ecosystem management entity should include the following core functions:

- Governance
- Program Management
- Science
- Planning
- Implementation
- External Review

Most large-scale restoration Program Management entities have similar structures and components as shown in Figure 6-1. Similar to a well-functioning government, the structure and function of a restoration program should be developed to provide a transparent decision-making process, have checks and balances to ensure transparency, make informed decisions, allow the Program to adapt based on learning and changing conditions (i.e., improve effectiveness), and share information with interested participants. External review and public outreach are key components of a successful program, and while external review and public outreach are often features of large-scale restoration programs, they are the exception rather than the norm. The Program should also be as simple as possible to meet its needs and be flexible and adaptable over time as participants change, the scientific understanding improves, and implementation approaches evolve. Finally, to best achieve its goals, the Program also needs to be implemented as efficiently and cost-effectively as possible and maintain participant and public support over time.

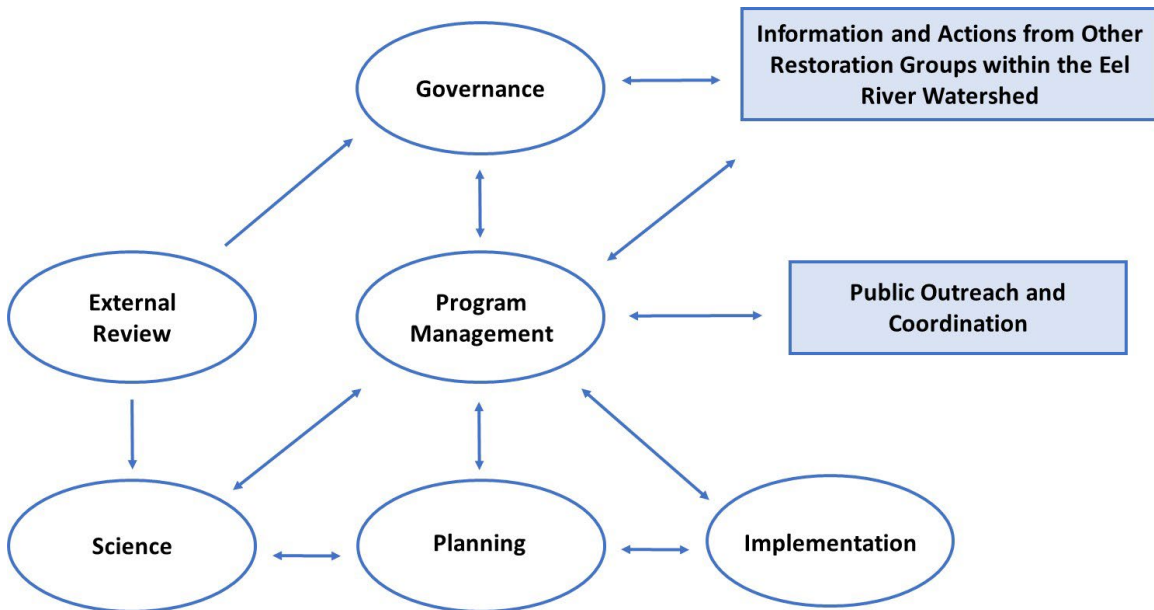


Figure 6-1. Core components of a successful large-scale restoration program.

The components shown in Figure 6-1 are discussed in the sections below using the following organizational structure:

- General overview of role and function of the management framework component;
- Lessons learned from other large-scale restoration programs that should be considered for the management framework; and,
- Recommendations of role and function of that component specifically for the management framework.

Within this management framework, different “bodies” perform specific roles within the components of the framework (e.g., Governance body). The initial recommendations for the Program organizational chart are summarized in Section 6.2.

6.1.1 Governance

The role of Governance is primarily programmatic-level decision-making and strategic planning. Decisions include administrative decisions (e.g., funding and staffing) and implementation decisions (e.g., approving conservation and/or restoration projects and monitoring efforts) that involve allocating staff or funding. Strategic planning decisions include coordination with other agencies and groups, project prioritization and sequencing, staff/resource allocation and prioritization, and other large-scale planning efforts. The participating individuals in the Governance body should have the knowledge and authority to make decisions on behalf of their organization, otherwise the Governance role will be less efficient and less effective if those decisions need to be approved by higher-level supervisors. To build confidence and trust in Program Governance among partners, agencies, and the public, decisions should be transparent and informed by the best possible information. Providing this information to the Governance body is a critical function of Program Management body (described below). Strategic planning and management action decisions made by the Governance body can then be delegated to the Program Management body for implementation.

Several of the authors of this Plan have participated in large-scale restoration programs that are useful examples to consider for assessing strengths and weaknesses in developing a management framework (Table 6-1).

Table 6-1. Select comparable large-scale restoration programs in the western United States that can inform a potential management framework.

Program	Governance and management structure	Notes
Trinity River Restoration Program	Governance conducted by the Trinity Management Council, consisting of eight county, state, federal, and Tribal representatives. Program Management conducted by agency staff, and some tasks conducted by agency staff, but most tasks contracted to agencies and Native American Tribes.	<ul style="list-style-type: none"> • Members of the Trinity Management Council are compensated by the organization they represent, and administrative funding is also provided to several of Trinity Management Council entities. • Governance does not include members of the public or NGOs. • A citizen’s advisory group (now disbanded) governed by the FACA provided input to the Trinity Management Council but had no Governance responsibilities. • Agency staff is responsible for Program Management, and personnel issues are often hampered because of the lack of timely resolutions to problems. • Agency and Tribal contracting discouraged periodic changes to monitoring and program implementation, limiting quick responses and the initiation of new work to lessons learned. • A SAB periodically advises the Trinity River Restoration Program, and several programmatic reviews of Governance and Program Management have been conducted. • Very few competitive RFPs have been released due to annual budget inflexibility. • Although adaptive management was intended to be a key component of the program, it has received limited application.
San Joaquin River Restoration Program	Governance conducted by implementing agencies (Reclamation, USFWS, NMFS, CDFW, and DWR), with implementation advised by a Restoration Administrator and a TAC hired by settling parties (Friant Water Users and NRDC coalition). Program Management is conducted by agency staff, and nearly all program tasks are conducted by agencies.	<ul style="list-style-type: none"> • Implementing agencies are compensated as part of normal salary and congressionally authorized funding. • Governance does not include members of the public or NGOs (no citizen’s advisory group governed by the FACA). • Program Management is conducted by agency staff, and personnel problems have been limited. • No SAB is included in an advisory role, although the Restoration Administrator and TAC perform some aspects of the advisory role to Governance, Program Management, and Science. • Agency staff conducting work has often resulted in high costs and long delays that cannot be corrected by program staff. • The program has some opportunity for adaptive management, but little structured adaptive management experiments have been conducted to date.

Program	Governance and management structure	Notes
Platt River Recovery Implementation Program	Governance Committee consists of state and federal agencies and water users. Program Management is contracted to consultant, and many tasks are subcontracted through competitive bids.	<ul style="list-style-type: none"> • Governance Committee members are compensated as part of normal salary. • Governance Committee does not include members of the public or NGOs. • Program Management by consultant enables rapid corrections by Governance Committee. • Governance Committee and Project Management contractor staff can facilitate rapid correction of consultant work as warranted. • The program has a strong focus on adaptive management.
Klamath River Renewal Corporation	Non-profit corporation is governed by a board of directors consisting of up to 15 members from California, Oregon, Yurok Tribe, Karuk Tribe, Klamath Tribe, and NGOs. Program Management is conducted by six staff members from the Klamath River Renewal Corporation, and most tasks are subcontracted through competitive bids or Tribal agreements.	<ul style="list-style-type: none"> • Board members are compensated by corporation. • Strong participation in Governance includes Native American Tribes, states, and NGOs. • Because Program Management is staffed by the Klamath River Renewal Corporation, the board of directors can facilitate rapid correction as warranted. • Board of directors and Klamath River Renewal Corporation staff can facilitate rapid correction of contractor work. • Advisory committees engage as needed.

Notes: CDFW = California Department of Fish and Wildlife
DWR = Department of Water Resources
FACA = Federal Advisory Committee Act
NGO = non-governmental organization
NMFS = National Marine Fisheries Service
NRDC Coalition = Coalition of environmental NGOs led by Natural Resources Defense Council
Reclamation = U.S. Bureau of Reclamation
RFP = request for proposal
SAB = Science Advisory Board
TAC = Technical Advisory Committee
USFWS = U.S. Fish and Wildlife Service

Based on the Planning Team’s experiences with the large-scale restoration programs listed in Table 6-1, the Planning Team recommends the formation of a non-profit corporation to govern and implement the Program similar to the model provided by the Klamath River Renewal Corporation. While the purpose of the Klamath River Renewal Corporation is focused on dam removal and its longevity is limited to the time required to fulfill its purpose (dam removal and associated post-removal obligations), it nonetheless provides many desirable functions that would likely function well for the proposed Program, including the following:

- Incorporation of high-level management and governance decisions by a board of Directors that includes major constituencies and local entities (local buy in);
- Ability by the board of directors to delegate most of the routine management and operational responsibilities to an executive director;
- Rapid and smooth Program staff performance corrections because staff are supervised by the executive director and serve at the direction of the board of directors to facilitate;

- Minimal number of Program staff to facilitate efficient management and implementation actions and use of subcontracts with Native American Tribes, NGOs, and contractors, as needed, to provide services in a timely and cost-effective manner;
- Significant agency coordination and collaboration on their resource management and regulatory responsibilities;
- Greater transparency in decision-making and disclosure of financial information (thus facilitating the public trust);
- Ability to actively pursue funding for Program implementation from both public and private funding sources and efficient and effective dispersal of funds;
- More effective and efficient responsiveness to management and implementation based on lessons learned;
- More flexibility to pursue real estate transactions, such as conservation easements, land purchases, and Tribal land-back programs;
- Greater ability to incorporate public input into decision making (does not require a FACA-chartered citizen's advisory group); and
- More control in addressing performance challenges with staff and contractors.

In addition to the organizational structure components of the Klamath River Renewal Corporation, Planning Team recommends the following for the Eel River Watershed Restoration and Conservation Program:

- Adding a Science staff to help coordinate monitoring and research efforts throughout the basin, manage a spatial database, support sampling design and monitoring implementation for both program-level and project-level scales, assess monitoring and research results and convey learning to future restoration and conservation actions, and develop and manage adaptive management experiments (it is anticipated that agencies, Native American Tribes, academic institutions, NGOs, and others will continue to perform nearly all of the monitoring efforts);
- Adding external review bodies for both the Science and Implementation components, as well as the Program Management and Governance components, to ensure timely, effective, and efficient implementation of the Program; and
- Avoiding setting an end date of the Eel River Watershed Restoration and Conservation Program because restoration and conservation actions are expected to continue indefinitely into the future.

One of the primary challenges with a non-profit corporation, rather than an agency-led Governance structure, is how state and federal agencies can best interact with a non-agency entity when confronted with regulatory requirements, monitoring and assessment coordination, and resource management issues. This interaction could be accomplished via regular coordination (quarterly meetings) between an executive director for the Program and agency managers on policy issues, followed by regular coordination with agencies within the Science and Implementation bodies for resource management and regulatory issues. In summary, initial recommendations for the Governance body are as follows (Figure 6-2):

- Form a non-profit corporation to govern and manage the Program similar to the Klamath River Renewal Corporation structure.
- Empower the new non-profit corporation to hire a small group of staff (approximately 7 to 10 initially) to manage the Program, discussed further in Section 6.1.2.

- Establish a board of directors, of up to 7 members, to govern the Program. The board directors likely cannot include staff from state and federal agencies, but it could include members of Native American Tribes and representatives from counties, NGOs, and the local watershed. The board of directors would be responsible for guiding and approving the following:
 - Program implementation priorities;
 - Annual program budgets;
 - Requests for proposals (RFPs) and contracts;
 - Staffing decisions, such as recruiting and hiring an executive director and Program staff; and
 - Periodic delegation to subcommittees to address specific governance issues, as needed, and report back to the board of directors for discussion and decision-making.

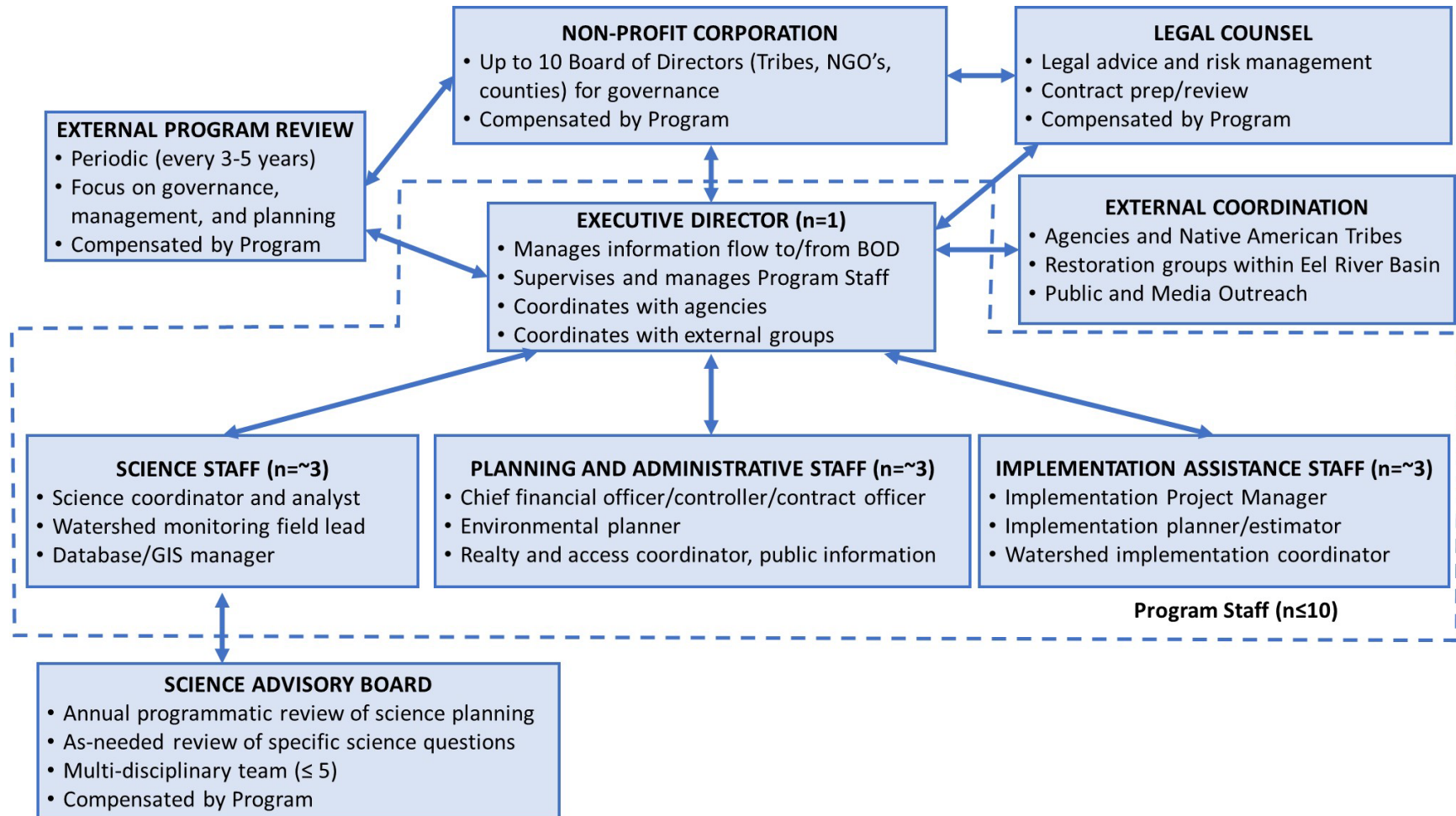


Figure 6-2. Recommended organizational structure (based on a non-profit corporate structure) for the Eel River Watershed Restoration and Conservation Program.

6.1.2 Program Management

The role of the Program Management body is to implement the decisions made by the Governance body and conduct the day-to-day Program operations, including tasks associated with administering the Program, hiring and managing Program staff, coordinating with partners, overseeing project design, implementing and monitoring projects, overseeing Science and research, conducting public outreach and education, coordinating external review of Program Science and management actions, and providing information to the Governance body for discussion and decision-making. The role of individuals within the Program Management body is to provide efficient implementation of the directives of the Governance body and to provide objective science and management information to the Governance body to enable well-informed decision-making.

Common challenges with Program Management include the ability to make timely staffing changes and adjustments to Program actions when needed. A non-profit corporation can be structured to ensure nimble responses can be made when changes to staffing and Program actions are needed. The Planning Team recommends hiring an executive director to oversee implementation of the Program, execute policy, and make management decisions. As the primary conduit of information between the board of directors and Program staff, the executive director would also be responsible for the following:

- Recruiting and making hiring recommendations for Program staff;
- Coordinating with external entities, disseminating information, and conducting public outreach;
- Coordinating with a Science Advisory Board (SAB) and conducting external review;
- Overseeing and submitting annual budgets to the board of directors for review and approval;
- In coordination with the Public Information Officer and Tribal Liaison, reporting on progress made toward reaching Program goals to the board of directors, regulatory agencies, Native American Tribes, media, and the public; and
- Assisting the board of directors with fundraising and pursuing grants.

Lastly, within the Program Management body, the Science, Planning, and Implementation bodies are key components to a successful Program, as discussed further below.

6.1.3 Science

The key role of a Science body within a large-scale restoration program is to provide decision-makers with the best possible information to inform their decisions in a way to achieve program goals in a timely and cost-effective manner. Effective science for a large-scale restoration program must balance several challenging influences:

- Policy provided by the Governance body provides guidance to the Science body based on program goals and objectives but does not define the actual science being conducted by the Science body.
- Likewise, the science conducted by the Science body must be focused, strategic and applied to the key management uncertainties to best inform the decision-makers in the Governance body. Research for the sake of research that does not address priority uncertainties that inform management improvements must be avoided. Therefore, the Science body needs to be strategically managed via prioritization of uncertainties, ensuring

that key cause-and-effect relationships can be made, and that key trend monitoring can assess performance and effectiveness.

- The Science body must include both monitoring and assessment responsibilities, as described in Section 7. Collecting monitoring data without assessment and linking the data back to management actions and priority uncertainties wastes time and resources.
- Data management and access are common challenges to effective assessment and data availability; consequently, a specific focus on data management and accessibility is critical to the Science body.

Based on these challenges, the Planning Team recommends structuring the Program Management body in a way that efficiently develops, oversees, and manages the science conducted under the Program, which can be done with a relatively small Science staff. The Planning Team recommends that Science staff do not conduct the field-based science activities; instead, qualified Native American Tribes, agencies, NGOs, academic institutions, and/or contractors should conduct the field components of the Science program under the direction of a science coordinator. Analysis could be shared between Program staff and contractors, depending on the experience level of the participants. Data management should be conducted by Program staff to provide consistency, accessibility, and quality assurance/quality control (QA/QC).

Importantly, one of the first tasks for the Science body should be to review, refine, and use the prioritized specific and broad restoration and conservation actions in Section 5. A second task that the Science body should complete is to refine and adopt the priority monitoring and assessment needs identified in Section 7 that will inform the understanding of the ecological responses to management actions (cause-and-effect, trend, and adaptive management), as well as research needs to fill priority information gaps needed to improve management actions. Accordingly, the Planning Team recommends inclusion of the following staff within the Science body (Figure 6-2):

- *Science Coordinator and Lead Analyst*: Responsible for developing, coordinating, and implementing science priorities for the Program. This coordination role will include coordination with scientists and technical staff within and outside the Program (e.g., Native American Tribe and agency technical staff and the SAB) and contractors / agencies / Native American Tribes hired to conduct Program Science. The science coordinator should develop annual science work plans and budgets (with the chief financial officer), maintain and update priority information needs based on monitoring and assessment results, update conceptual models and scientific hypotheses, and develop adaptive management experiments where warranted. The science coordinator will also likely be the technical representative for outside science contracts. Accordingly, the science coordinator should be able to integrate across disciplines that are expected to be important for the Eel River (e.g., fisheries, ecology, water quality, fluvial geomorphology, riparian ecology). In addition, the science coordinator would be responsible for developing or advising study plans and preparing RFPs for science, monitoring, and assessment projects approved by the board of directors. These study plans should be developed cooperatively with the implementing entities (agencies, Native American Tribes, NGOs, academic institutions) and focus on ensuring that the study plan can address the priority question with a reasonable cost and time effectiveness and provide sufficient statistical power to reduce uncertainty to a desired level. The science coordinator must be able to advise across the range from project-level to program-level monitoring and assessment as described in Section 7. The science coordinator may conduct some modeling and analysis of data collected by others but more likely will provide guidance (if needed) to entities hired to conduct Program science. Accordingly, this sampling and data analyst should have

expertise in statistical analysis, ecological modeling, field work, environmental variability across different disciplines, and science budgeting and possess the ability to convey/translate complex scientific information to decision-makers.

- *Watershed Monitoring Field Lead*: Responsible for field monitoring assistance and coordination with agencies, Native American Tribes, NGOs, and academic institutions to ensure quality field data collection, field method consistency, field techniques training and sharing, and field data collection coordination amongst partners. This lead would coordinate field efforts between partners and science coordinator, sampling and data analyst, and database/GIS manager.
- *Sampling and Data Analyst*:
- *Database/GIS Manager*: Responsible for managing and sharing field and spatial data for the Program as described in Section 7.4. Responsibilities would likely include developing or advising study plans for field data and spatial data management, guiding QA/QC processes for entities collecting data, providing a user-friendly method for outside access to spatial and Program data, and facilitating public education by sharing data and analytical results.

6.1.4 Planning

The key Planning role in a large-scale restoration program is to ensure that the restoration, conservation, and monitoring activities directed by the Governance body can be implemented in a timely and lawful manner. Planning activities depend on the types of restoration, conservation, and monitoring activities being undertaken and often include administrative and financial specialists, environmental planners, engineers, realty specialists, surveyors, regulatory compliance specialists, and project managers. Cost-effective and timely restoration implementation requires good planning and the appropriate level of administrative support.

Given that the Program is likely to include a combination of monitoring, restoration, and conservation actions as described in Sections 5 and 7, the Planning Team recommends hiring staff to conduct administrative/financial duties, project planning and contracting duties, regulatory compliance, and realty/access actions (rights-of-way, conservation easements, land purchases). Accordingly, the Planning Team recommends inclusion of the following (Figure 6-2):

- *Chief Financial Officer, Controller, and Contracting Officer*: Responsible for the financial management of the non-profit corporation and as the primary contracting officer for monitoring and restoration projects. Members of the Science and Implementation bodies would assist the contracting officer as a technical representative for monitoring and restoration contracts.
- *Environmental Planner*: Responsible for developing regulatory compliance strategies for program-led monitoring, restoration, and conservation projects to facilitate cost-effective and timely implementation. Depending on the funding source, duties could include developing strategies for programmatic regulatory compliance, complying with the California Environmental Quality Act, and permitting (either leading the effort or supporting partners conducting the compliance). The regulatory compliance coordinator should continuously seek assistance and advice from regulators to facilitate more efficient project implementation and regulatory compliance. The regulatory compliance coordinator would also work closely with Implementation staff and other entities to ensure that permit requirements are followed for monitoring, restoration, and conservation actions. Responsible for working closely with the Implementation body to plan and manage implementation projects and coordinating with the Science and Implementation bodies to

integrate their activities (e.g., prioritized projects described in Section 5). The environmental planner would also work closely with the Implementation body and chief financial officer on budget planning and cost estimation

- *Realty and Access Coordinator, Public Information Officer*: Responsible for obtaining land and right-of-way access when conducting monitoring and restoration activities and for overseeing realty/property boundary activities associated with conservation easements and land purchases. Given the coordination role of the realty and access coordinator, this person could also assist the executive director with public questions and interactions associated with Program activities. Responsible for working with Program staff to develop and disseminate information generated by the Program to the public, agencies, and Native American Tribes. This public information officer would assist the executive director by preparing briefing documents, conducting interviews, preparing press releases, and coordinating with Native American Tribes in the Eel River watershed.

6.1.5 Implementation

The key role in implementation of a large-scale restoration program is to ensure that the restoration implementation and conservation activities that are directed by the Governance body can be achieved in a timely and lawful manner. In some programs (e.g., San Joaquin River Restoration Program), restoration designs are developed by program staff or technical agency teams; in other programs (e.g., Trinity River Restoration Program and Platte River Recovery Implementation Program), program staff provide guidance on designs and contract with Native American Tribes, agencies, or NGOs to develop the final designs and bid documents. Program staff then conduct construction inspections and review as-built surveys/documentation to ensure that the project was constructed per design. Close coordination with the Science body is required to ensure that the pre-project and as-built surveys are compatible with the need of any project-level monitoring and assessment. Staffing needs for the Implementation body will depend on the role of the Program in how implementation is conducted (funding versus design versus level of involvement in implementation) and can include design engineers, cost estimators, environmental planners, realty specialists, surveyors, and project managers.

For the Program framework, Section 4 distinguishes between two general categories of actions: ecological restoration and watershed conservation. These two interrelated categories of actions involve unique program-level implementation steps and workflow with different roles and responsibilities, coordination, and integration among Program staff and participants. Key steps involved in implementing ecological restoration projects typically include planning (e.g., identifying the problem and establishing goals and objectives), project design (e.g., conducting site investigations, developing and analyzing alternatives, and creating construction-ready design plans and specifications), permitting and regulatory compliance, contracting, construction, and implementation monitoring.

Based on the restoration and conservation priorities developed in Section 5, Implementation staff would develop design guidelines and other technical products that support planning, design, implementation activities that range from watershed to site-specific scales. As part of these efforts, project phasing and synchronization activities may be identified to ensure that spatial and temporal dependencies (e.g., potential benefits to species, life stages, life-history strategies; potential short or long-term negative impacts of a project on other locations) that Implementation staff will need to consider in the planning of restoration and conservation projects. The Planning Team envisions that two types of restoration solicitation strategies will be required, consistent with the categories described in Section 5:

- *Specific (Program-directed) Actions*: Actions that enable the Program to direct a significant portion of resources to spatially explicit critical actions and/or projects that are high priorities identified by the Program and are expected to result in the most meaningful and substantial restoration and conservation outcomes; and
- *Broad (non-Program-directed) Actions*: Actions that are more generically defined priorities in sub-basins and/or channel archetypes and that are amenable to implementation by numerous entities (Native American Tribes, agencies, NGOs, contractors) to propose, design, and implement through competitive funding programs, based on the unique objectives, priorities, expertise, and geographic influence of their individual organizations.

These two categories ensure known, high-priority projects get designed and implemented under the Program and also allow other entities to be innovative in identifying and developing projects opportunistically, assuming they are consistent with the Program’s general priorities as described in Section 5.

To keep the Implementation body staffing requirements as low as possible to efficiently fulfill their responsibilities, the Planning Team recommends that the Program (1) conducts the planning and advisory role for restoration design and implementation for Program-directed projects described above and (2) rely on partner entities (contractors, Native American Tribes, NGOs) to develop the restoration designs and conduct restoration implementation. Program staff should engage in developing conceptual designs for the priority restoration projects, develop planning-level cost estimates, prepare RFPs for Program-directed implementation entities, review proposals for non-Program-directed restoration or conservation projects, then provide technical assistance (as needed) to the implementation entities to collect pre-project data, finalize and document designs, implement the project, and conduct as-built surveys and prepare documentation. This staffing approach results in the following Implementation staff that would work closely with Planning and Science staff (Figure 6-2):

- *Implementation Project Manager*: Responsible for working closely with the Science and Planning teams to ensure that the prioritized projects are pursued in a logical sequence, coordinated and integrated within the Program, and designed/implemented as intended. Working in concert with the implementation planner/estimator, the implementation project manager may work with Science and Planning staff to develop conceptual designs, develop preliminary cost estimates, develop RFPs for Program-directed projects, develop RFPs for non-Program-directed projects, develop annual budgets with the CEO, and develop strategic plans and yearly planning budgets for the Implementation staff.
- *Implementation Planner/Estimator*: Responsible for working closely with the implementation project manager to help plan and budget restoration and conservation implementation projects. The implementation planner/estimator may also serve as a technical representative for implementation contracts funded by the Program, conduct site inspections, facilitate pre-project and as-built data collection efforts, assist the implementation project manager in developing RFPs, and estimate restoration and conservation project implementation costs for budgeting and strategic planning.
- *Watershed Implementation Coordinator*: Responsible for assisting agencies, Native American Tribes, and NGO partners on implementation throughout the watershed and coordinating with the Implementation project manager and Implementation planner/estimator. These coordinators would assist partners on technical issues and design consistency on watershed restoration projects.

6.1.6 External Review

An External Review body is a critical component of a well-functioning large-scale restoration program, if done strategically and efficiently. External review of the Science body (e.g., TACs or SABs) is common in large restoration programs, whereas external review is less commonly applied to the Governance body and Program Management bodies. However, because the Governance body and Program Management bodies are responsible for decision-making and implementation (rather than the Science body), it is important that external review of both the Science and decision-making/implementation functions of the Program occurs with some frequency. To facilitate transparency and trust, external review should be performed by topical experts who are familiar with the goals, objectives, strategies, and actions of the program but have no policy or financial motivations for their participation (i.e., independent).

External review of Science is best done by a TAC or SAB that is composed of independent topical experts that cover the range of applied science topics. The external SAB should be a small (approximately 5 individuals), interdisciplinary staff with extensive experience in applied science and implementation. They should be innovative problem-solvers, who are experts in their field. The role of the SAB should focus on big-picture science and implementation questions, such as advising the program with priority scientific uncertainties, conceptual models, interpretation of key research results, prioritization of restoration and conservation actions, and other higher-level Science needs. The time step for this type of advising should be on the order of yearly review so that the SAB remains at arms-length and does not become part of the Program staff. The SAB can also provide review of specific Science reports (e.g., monitoring results), but it should only review a small number of key reports, but not all the reports, so that it maintains independence from the Program. Review of Science reports by the SAB should be conducted by the entire group to avoid individual members from reviewing reports in isolation from the rest of the group.

External review of the Governance body and Program Management bodies should also be conducted, but often by a different group of topical experts whose expertise is focused on Program Management rather than strictly Science. This external review could be performed by engineers, administrators, program managers, attorneys, financial experts, and other experts. These experts may not necessarily need to be associated with ecosystem restoration programs, but they should have experience in managing and implementing large multidisciplinary programs. The time step for Governance and Program Management review should be longer than the Science review due to the lag time between management decisions, implementation, and outcomes, likely on a 3- to 5-year time step. Institutionalizing this review of Governance and Program Management is usually more difficult to achieve because the Governance body may not want to be exposed to potentially critical external review; however, given the challenges and scientific uncertainties associated with large-scale ecological restoration programs, the External Review body is extremely important to improve decision-making and Program implementation and build trust with the public.

6.1.7 Summary

The organizational chart lists recommended Program staff within the dashed box, and external (non-employees) outside the dashed box (Figure 6-2). The proposed organizational chart is intended to keep the staff numbers as small as possible (less than or equal to 10 full-time employees), but sufficient to accomplish the tasks needed to successfully run and implement the Program. For comparison, the Klamath River Renewal Corporation has 6 employees; the actual number of employees needed for the Program will need further scoping and discussion during the next phase of Program development. As an initial estimate, assuming an average cost of \$170,000

per employee for fully burdened cost (salary, benefits, taxes), annual staff costs for 10 full-time staff would be approximately \$1.7 million. Additional program structures that have similar desirable attributes should also be considered in the Phase 2 Program Formation to further refine and improve the recommendations here, including the Grande Ronde Model Watershed (GRMW), the Klamath Basin Restoration Agreement (KBRA, never passed by Congress), the California Fish Passage Forum, and others.

6.2 Potential Funding Strategies

As mentioned at the beginning of Section 6, the program management framework assumes that a large-scale, centralized restoration and conservation program is needed for the Eel River. This framework will require stable funding for the following reasons:

- Employing and recruiting highly qualified staff shown in Figure 6-2 (e.g., unstable or uncertain funding will discourage applicants);
- Ensuring continuity of planning, design, and implementation tasks to facilitate timely and cost-effective implementation; and
- Reducing the time and effort that Program staff and partners need to spend pursuing funding, allowing them to spend more of their time on Program implementation rather than fundraising.

Ideally, a large capital endowment (e.g., similar to the Headwaters Fund) could be obtained where interest revenue generated by the endowment would be sufficient to fund all Program administration and operational costs in perpetuity, and ideally a portion of annual restoration and conservation action implementation costs. At this point, there is no large capital endowment in place, although several potential sources are being explored. Even with an endowment, a portfolio of potential funding and in-kind support sources will likely be needed to fully implement the Program, as conceptualized in Figure 6-3. A primary role of the board of directors and executive director will be to strategize and obtain funds and in-kind support necessary to fully implement the Program and minimize interruptions to the funding stream that would delay implementation of restoration and conservation actions.

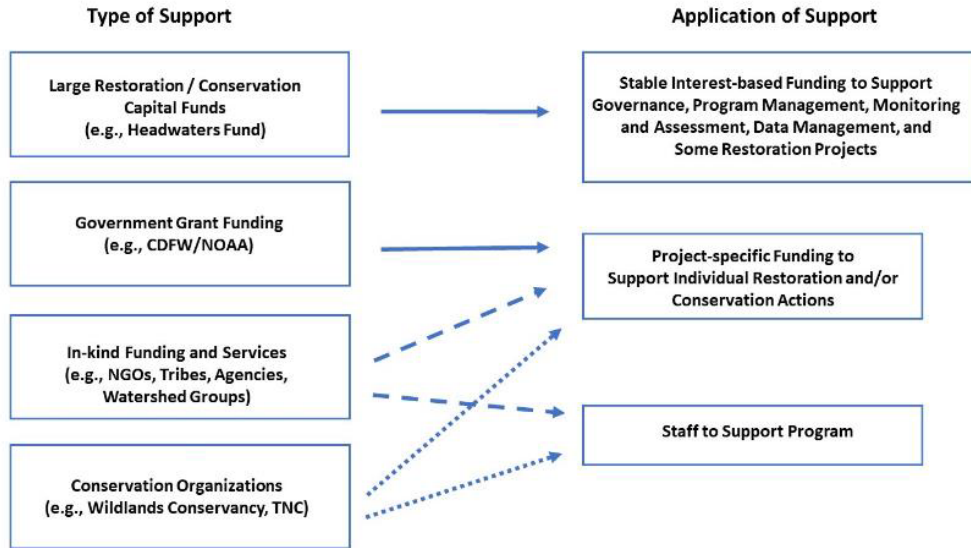


Figure 6-3. Potential funding and in-kind service support for the Eel River Watershed Restoration and Conservation Program and how that support could be used by the Program.

6.2.1 Potential Funding Allocation Processes

As mentioned above, the Planning Team recommends two processes for allocating restoration or conservation implementation project funding: (1) Program-directed funding for targeted projects, and (2) non-program-directed funding to enable implementation entities to identify potential high priority projects that meet broad Program goals and priority action types in sub-basins and/or channel archetypes identified by the Program.

For Program-directed funding, the Implementation body (Figure 6-2) could develop conceptual designs for a high-priority project, a planning-level cost estimate, and an RFP for outside services to design and implement the project in either a competitive or non-competitive manner. This strategy would enable more rapid design and implementation of priority projects, and cost controls would be in place via cost estimating and close coordination by the Implementation body with potential design and implementation entities. A proportion of the total annual implementation budget could be assigned for these directed actions.

For non-program-directed funding, the Science, Planning, and Implementation bodies could prepare a general RFP to solicit proposals for restoration or conservation projects in prioritized geographic areas or channel archetypes (i.e., not site-specific), and encourage watershed groups, NGOs, Native American Tribes, and others to solicit cost proposals for planning and design for specific sites that they recommend as priority sites based on the guidelines provided by the Program in the RFP. This broader RFP process would allow local watershed groups, NGOs, Native American Tribes, and others that may have much more specific knowledge about potential restoration or conservation projects than Program staff to develop funding proposals to plan and design those projects. In other words, this funding strategy would enable innovation and creativity and inclusion by these local watershed groups, NGOs, Native American Tribes, and others in project identification, planning, design, and implementation. A proportion of the total annual implementation budget could also be assigned for these non-directed actions. Program staff would then review the proposals, rank them based on priorities and funding availability, and award funds to plan, design, and implement the project.

7 MONITORING AND ASSESSMENT FRAMEWORK

A scientific framework for monitoring is necessary to track progress toward the Program’s vision and goals (Section 1.2.1), ensure that restoration actions are designed to evaluate and improve hypotheses about focal species recovery (Sections 3 and 4), and reassess the prioritization of restoration and conservation actions (Section 5) as data gaps are filled and fish demographics change through time. In addition, monitoring provides the raw information needed to inform and engage the community about the fish population recovery in the Eel River watershed, which is a key part of the Program’s vision. In short, implementation (Section 6.1.5), along with monitoring and assessment (Section 7), are the core enterprises of the Program (Section 6). Achieving the Program’s vision for recovery depends on robust execution of, and interaction between, these core enterprises.

The basic challenge of monitoring to guide recovery of anadromous fish populations was summarized by Reeves et al. (1991) and paraphrased by Bilby et al. (2024):

Habitat and fish population measurements must be collected in a manner that enables habitat changes due to restoration to be linked to demographic changes in salmon.

To address this challenge, the monitoring and assessment framework (monitoring framework) must identify which metrics and sampling scales (spatial/temporal) are “necessary, feasible, and practical to measure” (Botkin et al. 2000). The program must also nimbly and effectively synthesize monitoring data into clear guidance for restoration practitioners and/or information for the public (Botkin et al. 2000). The monitoring framework must address how and where the Program can integrate ongoing monitoring efforts within the basin, particularly fish demographics monitoring conducted by the State of California, NMFS, Native American Tribes, and NGO partners, and in addition, where new monitoring will be needed to address critical information gaps and decision feedback loops. Finally, this framework must describe how the monitoring component relates to and interacts with the broader Program. This section describes the scientific framework for monitoring anadromous fish habitat and population responses to restoration and conservation actions in the Eel River watershed. While anadromous fish habitat and populations are the focus of much of the monitoring described in this section, the overarching goal of the Program is to improve the river corridor ecosystems that support these native fish populations. Conservation strategies and actions are a critical component of an overall recovery strategy and will be considered within the monitoring program at multiple spatial and temporal scales.

7.1 Goals and Objectives

The purpose of the monitoring framework is to define the overarching goals of a future Eel River monitoring program, identify the key components of the monitoring program, and describe the utility and merits of each component and how each integrates with the monitoring program as well as the broader Program.

The goals for a future Eel River monitoring program are as follows:

1. Evaluate whether restoration and conservation actions are working to meet the Program's vision and goals for native anadromous fish recovery;
2. Use key focal species populations and habitat metrics to adapt, refine, and/or reprioritize restoration and conservation actions, as needed; and
3. Share the recovery trajectory of anadromous fish in the Eel River watershed with the public in accessible ways that inform and engage the community.

The monitoring framework described in this section establishes the necessary components of a monitoring program and discusses tradeoffs between monitoring designs, but it does not dictate the specific methods, sites, and statistical designs that will make up a final monitoring plan nor does it provide specific details about operating such a monitoring program (e.g., equipment, staffing). The monitoring plan will be developed during Phase 2 and implemented during Phase 3.

This monitoring framework focuses on monitoring and assessment and identifies opportunities for conducting adaptive management when and where it makes sense (Section 7.5). Adaptive management is a structured approach to decision-making that uses new information as it becomes available to inform and adjust hypotheses and approaches to achieving restoration and conservation goals and objectives. This structured process is intended to reduce scientific uncertainty in evaluating the effectiveness of restoration and/or conservation actions over time. This monitoring framework also describes other feedback loops such as focused iterative hypothesis testing (hypothetico-deductive approach) and less formal collaborations with program partners that are intended to generate knowledge, inform performance and the potential need to adjust restoration and conservation actions, and increase the pace of fish population recovery.

The following five key components/concepts have been identified to describe the recommended structure and integral processes of the monitoring framework:

1. Monitoring program oversight and coordination among partners (Section 7.2)
2. Monitoring and assessment process (Section 7.3)
3. Data management structure (Section 7.4)
4. Adaptive management structure (Section 7.5)
5. Program linkages (Section 7.6)

Descriptions of these five key components/concepts are presented in the following subsections (Sections 7.2–7.6) and provide the scientific basis and supporting rationale for an effective monitoring program. They also comprise the primary objectives required to achieve the stated goals of the monitoring program. Section 7 concludes with a discussion of additional considerations regarding the monitoring framework and the necessary steps required to develop a monitoring plan during Phase 2 (Section 7.7).

7.2 Monitoring Program Coordination among Partners

Because of the large size of the Eel River watershed and the numerous entities currently involved in conducting and recommending monitoring in the basin, the Planning Team anticipates that the monitoring program will be most effective if Program staff serve in an oversight role to coordinate and guide monitoring rather than being the primary conductors of monitoring activities. Most of the field monitoring is expected to be performed by Program partners (e.g., state and federal agencies, Native American Tribes, contractors, and NGOs) with analysis and

assessment shared between partners and Program staff, this will provide the greatest benefit and effectiveness for assessing the extent to which the monitoring program objectives are being met.

Key elements of the monitoring program's role include the following:

- Collaborating with Program partners and science advisors to develop the monitoring plan and to organize the yearly implementation of monitoring tasks;
- Managing and synthesizing shared data;
- Providing a forum for practitioners to discuss monitoring strategies, methods, and results and any lessons-learned to inform future monitoring; and,
- Assisting with assessing whether monitoring program goals are being achieved.

To be most effective, the monitoring program needs to coordinate closely with Program partners to provide input on monitoring strategies and methods, allow information exchange between the monitoring program and partners, and acquire and use monitoring data for the assessment process.

Monitoring by Program staff should include the following collaborative efforts:

- Establishing a structure and staffing that allows for assessment to ensure monitoring is achieving Program goals;
- Prioritizing and coordinating monitoring activities, locations, and methods;
- Conducting specific monitoring activities that fill data gaps (Section 3.2.4.3) and answer specific questions; and
- Where appropriate, developing and implementing adaptive management experiments.

7.3 Monitoring and Assessment Processes

Monitoring and assessment are fundamental to determining whether, and to what extent, restoration and conservation actions are having the intended effect on improving habitat conditions for focal fish species and, more broadly, whether program implementation is achieving species recovery objectives. To meet these goals, a range of monitoring types and scales are necessary. A key concept used to organize the different types and scales of monitoring within the monitoring framework is differentiating between **program-level** monitoring and **project-level** monitoring. Program-level monitoring focuses on whether the program is on a trajectory toward achieving its goals over a large spatial and/or temporal scale (e.g., anadromous fish population recovery), while project-level monitoring focuses on whether restoration and or conservation actions are achieving their project-specific intended effect (e.g., increasing quantity of juvenile rearing habitat at a site).

There is frequent reference to various spatial scales in Section 7, with the generally hierarchical structure from large to small as follows: watershed (i.e., Eel River watershed [9,538 km²]), sub-watershed (i.e., the seven primary sub-watersheds [~1,500 km² (range 136–2,072 km²)]), sub-basin (e.g., the 113 HUC-12 sub-basins [~100 km² or less], reach (or segment) ~100s of meters, habitat (or site) ~10s of meters]). Additional discussion of spatial scales is provided in Section 2.1.

In their simplest form, program-level monitoring and project-level monitoring may be discrete categories; however, within this monitoring framework, these concepts are on a continuum of spatial and temporal scales with different levels of inference (Figure 7-1). Program-level

monitoring is generally conducted over larger spatial scales and over longer temporal scales compared with project-level monitoring. These differences in scale determine which methods are most appropriate for program- and project-level monitoring and assessment.

Both program-level and project-level monitoring will be designed to evaluate the success of prioritized restoration and conservation actions. The process for implementing both program- and project-level monitoring involves similar steps—but differs in the spatial scale, design, timeline, and scope of inference (Figure 7-1). The monitoring and assessment steps for both categories follow:

- Defining the specific objectives for each monitoring effort;
- Identifying hypotheses to be tested;
- Developing a monitoring design, including metrics to be measured, replications, and sampling methodology;
- Developing a data collection and data management workflow;
- Performing implementation monitoring;
- Performing assessment of monitoring data; and
- Performing knowledge integration, synthesis, and sharing to improve implementation effectiveness (e.g., increase ecological response, decrease effort/cost and time) inform (1) restoration implementation and (2) the public and managers about the trajectory of recovery toward the program’s ultimate objectives.

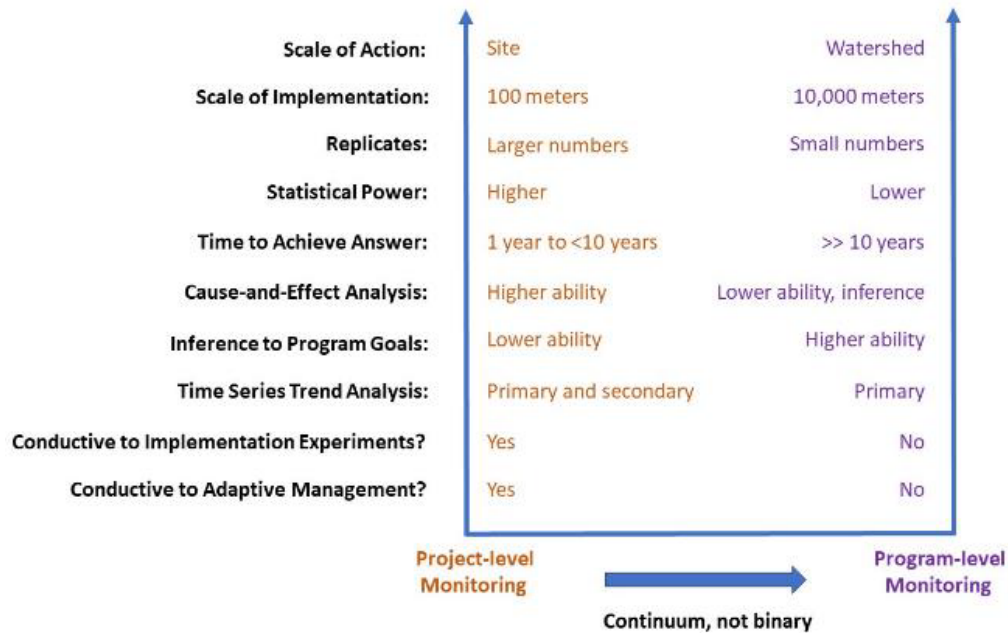


Figure 7-1. Conceptual framework for project-level monitoring and program-level monitoring.

While many of the monitoring materials and concepts described or referenced in this section are based on, or were developed for, anadromous salmonids, the monitoring strategies and approaches can be applied to other fish species including Green Sturgeon and Pacific Lamprey (focal species). In addition, while the Program and Plan emphasize native fish, the Program goals are largely ecosystem-based and include restoring physical habitat conditions and properly

functioning ecological processes that support the recovery of healthy riverine ecosystems throughout the Eel River watershed. Program- and project-level monitoring and assessment are described in more detail in Sections 7.3.1 and 7.3.2, respectively.

7.3.1 Program-level Monitoring and Assessment

Following from the general description of program-level monitoring and assessment in Section 7.3, this section provides additional information and detail regarding the potential scope and scale of program-level monitoring and assessment within the broader Eel River Watershed Restoration and Conservation Program (Figure 7-2). Program-level monitoring and assessment is intended to:

- Establish status and trend population data for focal fish species and life histories (Section 3) and evaluate the overall success of the Program at restoring native anadromous fish populations and ecological functions in the Eel River watershed;
- Identify and fill key data gaps (Section 3.2.4.3) that would inform refinements to restoration site planning and prioritization (Sections 4 and 5), and improve implementation processes and approaches once the program has begun; and,
- Evaluate and refine the hypotheses about the cause-and-effect relationships between restoration actions and ecological response using an experimental approach to restoration implementation (see Section 5.2.2). Iterative hypothesis testing, through monitoring of implementation projects, and communication between Science staff and Implementation staff, can generate institutional knowledge to increase the pace of recovery.

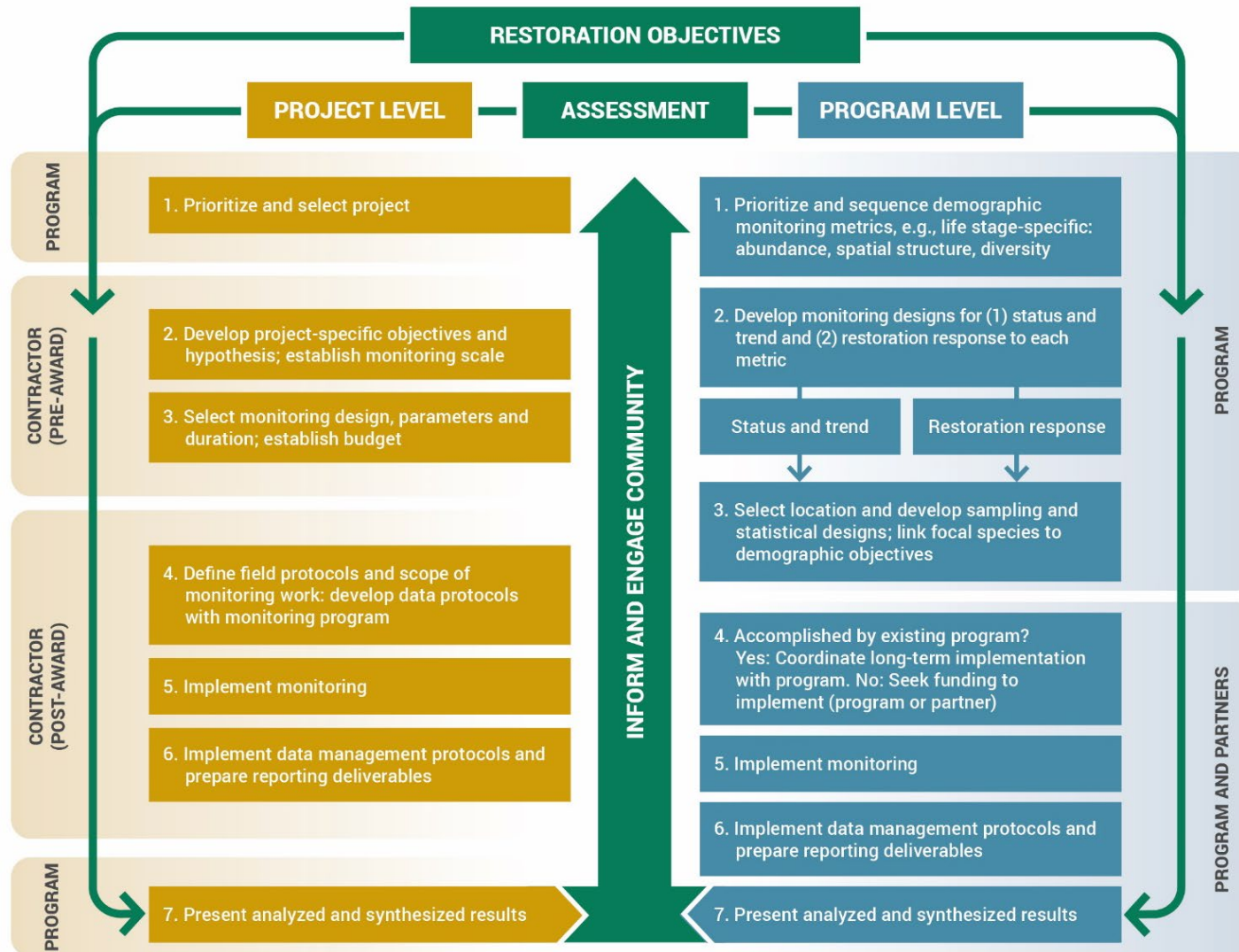


Figure 7-2. Basic process for project-level (left) and program-level (right) monitoring and assessment.

7.3.1.1 Monitoring Types

Program-level monitoring focuses on three primary types of monitoring—status, trend, and validation—and is intended to assess changes in demographic rates of the focal population, often over large spatial scales (e.g., the seven primary sub-watersheds).

- *Status and Trend Monitoring*: These types of monitoring can be applied to physical habitat, water quality, or fish population metrics to characterize the current conditions (status) and change through time (trend) of key habitat or population metrics. For fish, the metrics used (Table 7-1) and the spatial and temporal sampling regime will be designed to evaluate the recovery trajectory of the existing fish populations, as well as the occurrence of rare or imperiled sub-populations and life histories that were historically important but may not be commonly expressed in the current population.
- *Validation Monitoring*: This type of monitoring evaluates whether hypothesized cause-and-effect relationship between restoration and/or conservation action and response variables are realized.

At the program level, status and trend monitoring will focus on population abundance and life-history diversity of focal fish species and include metrics guided by the species conceptual models (Section 3) and agency recovery metrics such as NMFS's viable salmonid populations criteria: abundance, productivity, spatial structure/distribution, and diversity (McElaney et al. 2000). NMFS recovery plans also organize ESA-listed salmonid populations into three levels of biological organization (i.e., populations, diversity strata, and ESU/DPS) based on species' population genetics and spatial structure. These spatial groups will be considered within the program's structure and goals.

When possible, validation monitoring will be conducted in a “hypothetico-deductive” framework (Starfield and Bleloch 1986), where the monitoring program (1) starts with hypotheses (Sections 3.3.2 and 5.2.2); (2) constructs simple quantitative or conceptual models that make directional predictions about how the system will respond to restoration; and (3) develops monitoring designs to perform quick iteration between models (hypotheses), data tests (implementation and monitoring), and revised models to build knowledge. This approach would use restoration implementation efforts as experimental designs and knowledge integration would depend on assessment (Section 7.3.3)

Table 7-1. Common metrics used to evaluate anadromous fish population health within status, trend, and validation monitoring.

Population metrics	Methods	Spatial scale ¹	Temporal scale	Priority ²
Marine survival	LCM, Floy tags, ³ coded wire tags, smolt-to-adult ratios	Sub-watershed or sub-basin	Long term (4+ years)	3
Adult abundance	Sonar, LCM/IMW, weirs, creel and spawner surveys	Watershed, sub-watershed, sub-basin	Multiple time scales	2
Redd numbers	Spawner survey, drone video	Reach	Seasonal or event based	3
Egg-to-fry survival	Emergence traps, substrate bulk samples, permeability	Reach	Event based (weeks)	4
Juvenile or larval abundance	Snorkel survey, electrofishing, video	Habitat or reach	Season-specific	3
Juvenile density	Snorkel survey, electrofishing, seining	Habitat or reach	Daily	3
Juvenile survival (over-summer; over-winter)	Mark-Recapture	Habitat or reach	Season-specific	3
Juvenile growth	Mark-Recapture, length distribution analyses	Habitat or reach	Season-specific	3
Juvenile residence time	Mark-Recapture	Sub-basin or reach	Season-specific	4
Smolt production	Downstream migrant trapping, video	Watershed, sub-watershed, or sub-basin	Season-specific	2
Smolt migration survival	Acoustic telemetry, radio telemetry, PIT tagging	Sub-watershed or sub-basin	Monthly	2
Population spatial structure	Snorkel survey spatial design, spawning survey, sonar, telemetry	Sub-watershed or sub-basin	Annual	1
Life-history diversity	Combination of methods: Presence/absence (eDNA), isotope studies, mark-recapture, snorkeling, trapping, genetic analyses, modeling.	Sub-basin	Multiple time scales, more valuable in the long term	3

Notes: IMW = intensively monitoring watershed

LCM = life-cycle monitoring

eDNA = environmental DNA

PIT = passive integrated transponder

¹ Spatial scales from large to small include: watershed, sub-watershed, sub-basin, reach (or segment), and habitat (or site). Spatial scales are described in more detail in Section 2.1.

² Relative priority from 1 (higher) to 4 (lower).

³ External tags that are long, narrow, colored and coded. Also known as spaghetti tag. Typically inserted just underneath the dorsal fin.

7.3.1.2 Program-level Monitoring Design and Metrics

As discussed elsewhere, most of the descriptions and examples included in Section 7.3 pertain to anadromous fish populations, however, other important response variables such as sediment, water temperature, and stream flow will be considered for both program-level and project level monitoring.

Common metrics to evaluate the health of an anadromous fish populations and to be used in status, trend, and validation monitoring are shown in Table 7-1. A critical decision point in program-level monitoring is the spatial scale at which population monitoring takes place. In large watersheds across the Pacific Northwest, anadromous fish make use of almost the entire stream network (including small headwater streams to off-channel estuarine habitats) through complex and co-occurring life histories (e.g., Hilborn et al. 2003). This characteristic of anadromous fish, which provides resilience to their populations (e.g., Moore et al. 2014), also makes monitoring those populations inherently difficult. Thus, a fundamental tradeoff in population monitoring is between spatial (and population) scale and the resolution of monitoring data. Two program-level scales are as follows:

- *Watershed and Sub-watershed Scales:* At larger spatial scales (e.g., the size of the Eel River watershed [9,538 km²] or the seven primary sub-watersheds [~1,500 km²]), fish monitoring tends to focus on adult escapement (fish in) and smolt production (fish out), an approach used in the Washington State (Lando et al. 2013). Conducting this monitoring and assessment at large spatial scales provides long-term adult and juvenile fish population data, often for multiple subpopulations—an integrated view of the trajectory of population recovery. However, monitoring over these large spatial scales requires large investments in labor, materials, and time—especially to ensure an adequate recapture rate to estimate juvenile population abundance. In addition, monitoring at large spatial scales makes it difficult to draw inference between population data and restoration actions or to evaluate the recovery of fish life-history diversity (e.g., Section 1.2.1 and 3.2.3).
- *HUC-12 Subbasin or Smaller Scale:* At smaller spatial scales (e.g., the size of the 113 HUC-12 sub-basins [~100 km² or less]) monitoring can focus on understanding more complex relationships and employ higher-resolution sampling methods (also see Section 2 for a description of scales). The HUC-12 subbasin and smaller scales category includes the intensively monitored watershed (IMW) and life-cycle monitoring (LCM) station scale approaches to monitoring and assessment. In response to issues of scale, IMWs and LCM stations are often employed to track salmon demographic rates and determine fish and habitat responses to restoration actions (Table 7-1, NMFS 2014, Zimmerman et al. 2012, Adams et al. 2011). A basic premise of IMWs and LCMs is that complex relationships, which control a salmonid population's response to habitat conditions, can best be understood by conducting higher-resolution monitoring at smaller sub-basin scales. In an IMW or LCM, data can be collected on each life stage of focal species and related to habitat and environmental variables. An IMW differs from an LCM in that an IMW specifically includes experimental manipulation. While both IMWs and LCMs are relatively labor intensive and expensive to implement, they can provide a higher degree of confidence in estimating local demographic rates and in the relationships between habitat restoration and population response than coarser, large-scale population monitoring (i.e., they have stronger ability to detect cause-and-effect relationships). However, it is challenging to make strong inference between data collected at the IMW/LCM scale and the status and trends of the broader (e.g., watershed scale) population. In addition, depending on their size and location, IMWs and LCMs may miss key parts of the salmon life history (e.g., juvenile mainstem emigration, estuarine residence, and adult immigration). Juvenile mainstem emigration, estuarine residence, and adult immigration). LCM is specifically called out in the NMFS Coho Recovery Plan as a critical approach to track demographic rates of Coho Salmon in the South Fork Eel River (NMFS 2014, Table 5-41) and the NMFS Coastal Multispecies Recovery Plan (NMFS 2016), which recommends a minimum of one LCM station within each diversity stratum. For example, for Coho

Salmon, the Eel River is composed of two diversity strata: “Interior Eel” (which includes the South Fork, Mainstem, Middle Fork, and North Fork Eel River) and the “Lower Eel-Van Duzen” (Jording 2020). Neither have an LCM station.

A basic, non-exhaustive, introduction to common types of program-level monitoring, their objectives, common methodologies, and their application at the sub-watershed or smaller sub-basin scale (e.g., IMW/LCM) is presented below.

Fish in–Fish out Monitoring

- *Purpose:* Adult escapement or fish in (the total number of adult fish and early maturing males or “jacks” returning to a stream to spawn) and smolt production or fish out (the total number of smolts and pre-smolts emigrating from a stream toward the ocean) are perhaps the two most fundamental metrics of the health of an anadromous fishery (NMFS 2014, Zimmerman et al. 2012, Adams et al. 2011.). Adult escapement is the basis of federal listing (and delisting criteria) and smolt production represents the success (or lack thereof) of the freshwater phase of anadromous fishes life cycle. Adult abundance is called out as the highest priority in the NMFS Coastal Multispecies Recovery Plan, and juvenile abundance is the second highest priority (NMFS 2016, Table 25).
- *Methods:* Adult escapement can be estimated using fish counting weirs, mark recapture methods, hydro-acoustic methods (DIDSON and ARIS cameras), video, and redd counts. Smolt production can be estimated using downstream migrant traps (e.g., using fyke traps, rotary screw traps, and/or incline plane traps), weirs, video, and mark-recapture methods using passive integrated transponder (PIT) tags or acoustic tags. All these approaches require statistical models to estimate total counts and abundance (Adams et al. 2011).
- *Sampling Strategies:* Fish in–fish out monitoring would ideally be conducted at locations that (1) represent the trajectories of focal populations within the Eel River (Section 3); (2) represent the diversity of key channel archetypes (Section 2.2); and (3) reflect changes from restoration investment. Accomplishing all three of these objectives with a single monitoring location is not feasible; and thus, the cost and effort associated with fish in–fish out monitoring will necessitate difficult choices.
 - Sub-watershed scale: It would be ideal to monitor these demographic rates for the focal species in each of the Eel River’s seven primary sub-watersheds (Figure 2-1). If funding is limited, priority should be given to a paired watershed analysis, where the least impaired sub-watershed serves as a reference state (e.g., the South Fork Eel sub-watershed) and a sub-watershed that will receive major restoration alterations (e.g., dam removal in the Upper Main Eel sub-watershed) serves as an “impact” site.
 - HUC-12 subbasin and smaller scale: A suite of smaller, IMWs could serve as an “indicator” of the status and trends of fish in–fish out demographics in the Eel River. Installing IMWs across a range of key channel archetypes (Section 2.2), would allow researcher and managers to understand the relative recovery of different sub-populations and life histories and make better inference of recovery of the whole Eel River population.

Life Stage–specific Survival

- *Purpose:* Survival of anadromous fish at each life stage varies between years with environmental conditions and ecological interactions. Human alteration of a watershed often imposes survival bottlenecks that might not be apparent from fish in–fish out

monitoring but can be identified with a life stage–specific survival analysis. Quantitatively linking habitat change to life stage–specific parameters in a life-cycle model (Figure 7-3) greatly benefits the process of prioritizing restoration actions “by examining the extent to which each action potentially contributes to the biological response of populations” (Jorgenson et al. 2021). This is a key step in several prioritization frameworks (e.g., the HARP model, Jorgenson et al. 2021).

- *Methods*: Accurate estimates of egg-to-fry survival and fry-to-smolt survival (Figure 7-3) are challenging to determine in the field. Emergent-fry traps, capsules, and incubation-emergence boxes are used to estimate egg-to-fry survival (NOAA 2022); however, statistical approaches and literature values are often used in practice. Substrate size composition can be used as an indirect measure of egg-to-fry survival (Tappel and Bjornn 1983). Fry-to-smolt survival, including over-summering and over-wintering survival, can be evaluated using mark-recapture techniques, with numerous marking techniques available based on fish size (Zimmerman et al. 2012). Recent advances in acoustic and radio telemetry have greatly improved estimates of smolt survival during migration (Peterson et al. 2021). Smolt outmigrant survival can also be estimated using PIT tags and mark-recapture methods using antennas and/or downstream migrant traps such as rotatory screw traps or weirs (Volkhardt et al. 2007). Adult marine survival can be estimated using coded wire tags or Floy tags (Jefferts et al. 1963, Drenner et al. 2012). Adult abundance estimates, determined with sonar or weirs, can be used along with out-migrating smolt abundance to estimate smolt-to-adult return. These data are also necessary to determine population productivity, defined as *returns per spawner*, which is considered a high priority Viable Salmonid Population metric (NMFS 2016, and McElhany et al. 2000).
- *Sampling Strategies*:
 - Sub-watershed Scale: Acoustic telemetry in mainstem rivers and estuaries can provide critical information on the degree and locations of juvenile mortality and smolt during migration and estuarine residence (Peterson et al. 2021). In addition, studies on adult-holding habitat and adult survival during freshwater migration are best conducted at larger spatial scales (e.g., mainstem corridor).
 - HUC-12 Subbasin and Smaller Scale: Most other aspects of life stage–specific survival and LCM are best analyzed in IMWs or at a life cycle–monitoring station where the researchers can make spatially explicit estimates of survival parameters. A paired watershed design for IMW monitoring is also desirable for evaluating the effect of restoration actions on life stage-specific survival parameters (Zimmerman et al. 2012).

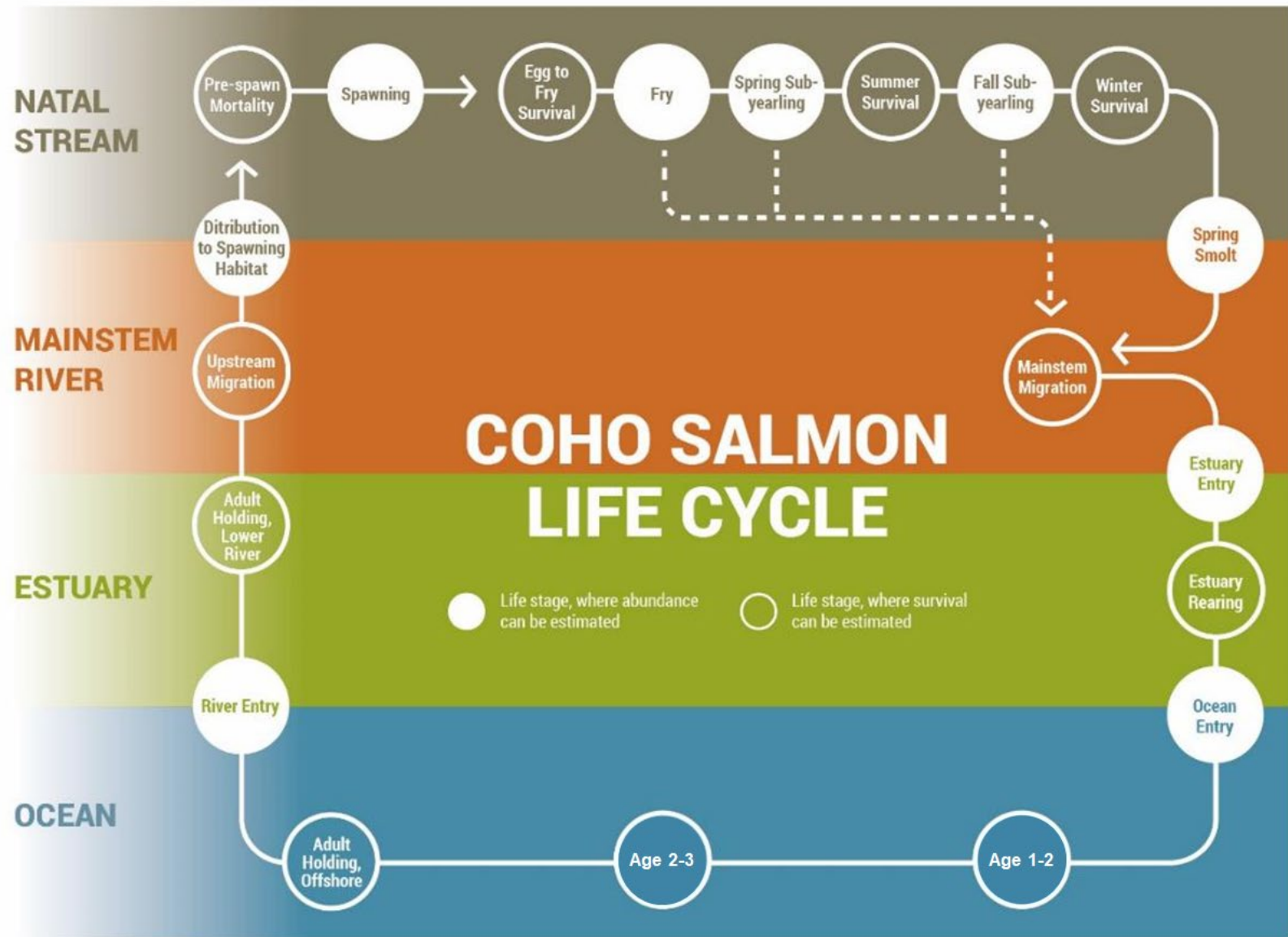


Figure 7-3. Example of a life stage-specific survival model for Coho Salmon. This type of life-cycle model is useful for identifying potentially limiting life stages and estimating life stage-specific production, which can assist with identifying where restoration should be focused and/or key data gaps filled.

Population Spatial Structure and Life-history Diversity

- *Purpose*: The geographic and ecological distribution of anadromous fish across the riverscape and the connectivity between populations of fish are important traits that “protect against the effects of catastrophic events and buffer extinction risk, particularly at low abundance” (Adams et al. 2011). In addition, this Plan makes hypotheses about the relationship between salmonid spatial structure, channel archetype, and life-history diversity (Section 2.3). Spatial structure is a key metric in NMFS’s viable salmonid population concept (McElhany et al. 2000) and considered a high priority in Coho Recovery Plan (Table 5-41) and in the NMFS Coastal Multispecies Recovery Plan (NMFS 2016, Table 25). Spatial structure sampling helps to both understand where key fish population distributions extend and evaluate the diversity of anadromous fish life histories (Section 3.2.2). This Plan emphasizes the different ways that animals move within watersheds to exploit patterns of growth potential and rearing capacity through time. The population structures and diversity strata used by NOAA in recovery plans (NMFS 2014, 2016) will be considered when designing program-level monitoring for population spatial structure and life-history diversity.
- *Methods*: Spatial structure is typically evaluated primarily using summer and fall juvenile salmonid snorkel surveys in reaches selected in a random, spatially balanced manner (Adams et al. 2011). Life-history diversity can also be evaluated using movement studies (telemetry), isoscape, and genetic analyses. Telemetry studies can be used to evaluate reach-specific survival of migrating juvenile salmonids. Isoscape analysis using strontium (e.g., Sturrock et al. 2015) or fatty acid profiles (e.g., Pilecky et al. 2022) can be used to reconstruct juvenile life histories and age at habitat transitions.
- *Sampling Strategies*:
 - *Sub-watershed Scale*: Spatial structure sampling is scalable; however, it is most applicable at the scale of the projected (or hypothesized) range of focal populations. In the Eel River, these are typically larger scales (e.g., sub-watershed or larger, see Section 3.2). Population-level spatial structure is a function of habitat variability and the movement of individuals across habitats. Surveying the larger spatial areas can be accomplished using a stratified sampling method. For example, a Generalized Random Tessellation Stratified sampling technique is often used to select sites that are then allocated into panels that receive rotating effort over the years (Adams et al. 2011).
 - *HUC-12 Subbasin and Smaller Scale*: At smaller scales, “within population” spatial structure is also informative and can provide higher resolution information on the factors that contribute to change in spatial structure. Similar methods are applied to “population level” spatial structure; however, higher resolution sampling is conducted (including higher temporal resolution) and more covariates can be explored.

7.3.2 Project-level Monitoring and Assessment

This section provides additional information and detail regarding the potential scope and scale of project-level monitoring and assessment within the Program. Most project-level monitoring is expected to be conducted by restoration practitioners or contractors, although monitoring program resources and monitoring program staff may assist and guide project-level monitoring (Section 6.1.3 and 6.1.5). Project-level monitoring data should be stored by the Program monitoring body and/or granting agency, and the program should have a database to store and maintain monitoring and other data (Section 6.1.3 and 7.4).

Project-level monitoring and assessment are intended to:

- Guide evaluation of the success of individual restoration and conservation projects in achieving their objectives.
- Evaluate and refine the hypotheses about the cause-and-effect relationships between restoration actions and ecological response.
 - Institutional knowledge can be generated through project-level monitoring and communication between program monitoring staff and restoration practitioners can increase the pace of recovery.
 - Where possible, an experimental approach to restoration implementation should be applied using iterative hypothesis testing approach or adaptive management.

7.3.2.1 Monitoring types

Project-level monitoring generally focuses on two types of monitoring—baseline and effectiveness—and is intended to assess changes over relatively small spatial scales (typically the segment [reach] or site scale).

- *Baseline monitoring* characterizes physical, chemical, and/or biological conditions existing prior to implementation of a restoration or conservation action and provides a basis for planning and future comparisons.
- *Effectiveness monitoring* determines whether restoration and/or conservation actions have the desired effect on physical, chemical, and/or biological conditions.

Both baseline and effectiveness monitoring would be evaluated on the primary restoration and conservation action types described in Section 4: instream habitat restoration (physical habitat); off-channel habitat restoration and connectivity; estuarine restoration; riparian habitat restoration; fish passage improvement; stream flow protection and enhancement; water quality; and species management. However, the metrics and statistical design of monitoring will vary depending on site setting, restoration action, and hypothesis to be tested.

7.3.2.2 Project-level monitoring design and metrics

Each restoration action (Section 4) to be implemented and monitored will be based on a specific objective that is geared toward achieving the broader Program’s watershed recovery goals (Section 1). To determine the effectiveness of the restoration action, metrics that can indicate a project’s success must be selected, and these metrics must be measured with adequate temporal and spatial distribution to statistically evaluate the project’s effectiveness. Table 7-2 provides a family of metrics that are associated with specific stream restoration project types and broadly grouped into the restoration actions described in Section 4.

Monitoring design for project-level monitoring will vary depending on the project objectives, scale, and hypotheses to be tested. The monitoring design should select the best metrics (e.g., Table 7-2), and a sampling design should have adequate spatial and temporal replication so that it is possible to evaluate the hypotheses that are being tested. In addition, monitoring needs should also include effectiveness monitoring to assess whether the project is achieving its objectives. A comprehensive discussion of sampling design for project-level monitoring is described in Roni et al. (2013). An example of this process is provided in Table 7-3.

Table 7-2. Project-level monitoring actions and potential metrics to assess.

Restoration action groups (from Section 4.4)	Project-level action types	Potential metrics to assess
Riparian restoration	Active and passive revegetation	Seedling recruitment, plant survival (years), canopy cover, riparian composition, riparian plant health, and invasive plants
Instream habitat restoration	Fluvial geomorphology	Pool and riffle frequency, sinuosity, channel geometry, active channel width, bankfull width, and residual pool depths
	Longitudinal connectivity	Thalweg profiles, longitudinal depth profiles, and riffle crest thalweg depths
	Instream habitat quantity and quality—physical	Channel geometry and habitat composition (pools, riffles, and runs), large wood abundance, cover, substrate embeddedness, composition, grain size, grain size diversity, percent fines in spawning habitat, and Fredle index
	Instream habitat quantity and quality—biological	Habitat area (species-specific), species presence, abundance, behavior, residence time, growth, and survival
	Primary and/or secondary production	Primary: light penetration index, direct measurement of benthic gross primary production, and stream metabolism modeling. Secondary: invertebrate drift, benthic productions, infall, taxa diversity, and seasonal timing
Streamflow protection and enhancement	Instream flow	Degree of surface flow alteration, risk assessment, days of disconnectivity, fish passage, hydraulic thresholds, bioenergetic assessment, frequency of bench floodplain inundation, seasonal changes in flow magnitude (e.g., summer baseflow), water quality
	Groundwater	Degree of alteration to background dynamic shallow groundwater storage, alteration to infiltration capacity, and groundwater pollution
Invasive species management	Active removal/suppression of Sacramento Pikeminnow	Pikeminnow density, age-structure, and spatial distribution Juvenile salmonid densities and survival
Water quality	All types	Seasonal changes in dissolved oxygen, water temperature, total dissolved solids, turbidity, conductivity, pH, nitrogen, and phosphorous
Off-channel habitat restoration	Floodplain connectivity	Residual pool elevation, bankfull elevation, inundation flow recurrence, proportion of inundation per discharge, flood prone width, and assessment of flood control structures (levees, dykes, and tide gates)
	Secondary channels	Number, length, and habitat quality/quantity of secondary channels in geomorphically appropriate reaches
	Floodplain habitat quality	Side channel complexity, canopy density, structural diversity, buffer width, woody debris, emergent vegetation, and sediment and soil composition and distribution Biological indicators: presence/abundance/habitat quality for invertebrates, amphibians, birds, and fish

Restoration action groups (from Section 4.4)	Project-level action types	Potential metrics to assess
Estuarine restoration	Saltmarsh restoration	Hydraulic: connectivity, well water depth, pore water salinity, and sedimentation Vegetation: biomass, density, composition, and macrobenthic density Organismal: fish utilization and invertebrate density and assemblage
	Ecotone	Area or volume of isotonic water under different flow conditions + see <i>Organismal</i> for saltmarsh above
	Estuarine connectivity	Degree of tidal inundation on landscape

Table 7-3. Example for project-level monitoring design and replication selection process using the impact of elevated fine sediment on egg-to-fry survival. The example steps through the process of developing a monitoring design for a specific impact.

Step in Process	Description of Monitoring Step
Identify Impact	Increased fine sediment loads due to road construction and other watershed disturbance decreases egg-to-fry survival.
Implement Restoration Action	A contractor is hired to construct bioswales below logging roads and disturbed areas at prioritized locations within a HUC-12 sub-basin. Lead-off ditches were also constructed, and riparian planting was conducted to trap sediment and minimize discharge into the stream channel.
Identify Monitoring Objective	Determine the degree to which the implemented actions reduce fine sediment deposition in the target reach during critical salmonid spawning and egg incubation periods. Estimate whether reductions were sufficient to protect egg incubation and reduce the effect of fine sediment on egg-to-fry mortality.
Develop Monitoring Hypotheses	This bioswale and riparian re-vegetation scheme are an effective method to reduce fine sediment entrainment during critical salmonid spawning and egg incubation periods.
Identify Parameters to be Measured	Percent of fine sediment (<2 millimeter) in each sample, Fredle index, embeddedness.
Develop Sampling Design	Before-after-control-impact (BACI) study design was selected, where both a control and treatment (impact) are monitored before and after restoration (Underwood 1992).
Conduct Temporal and Spatial Replication	Ideally, a power analysis will be used to determine the number of replicates. In the absence of data for a power analysis, as many replicates as possible will be obtained during each sampling event (e.g., before x control, after x control, before x impact, after x impact).
Develop Sampling Methodology	Gravel samples will be taken with a McNeil sampler at index sites and selected salmon redds to determine the Fredle index and percent fines <2 millimeter. Samples will be taken in a control reach (control), with limited fine sediment impairment, and in the project reach (impact), during the season before construction (before) and for two seasons after construction (after).

7.3.3 Assessment Strategies

A monitoring program will be ineffective if assessment of the monitoring data is not conducted. Assessment strategies discussed here address both program-level and project-level monitoring. Assessment is the process of evaluating the collected monitoring data to (1) evaluate whether restoration and conservation actions are working to meet the Program’s vision and goals for native anadromous fish recovery; (2) use key focal species populations and habitat metrics to

adapt, refine, and/or reprioritize restoration and conservation actions, as needed; and (3) share the recovery trajectory of anadromous fish in the Eel River watershed with the public (Section 7.1). Assessment includes hypothesis testing, data visualization, and/or narrative interpretation. A critical element of assessment is ensuring communication between Program monitoring staff and restoration implementation practitioners to ensure that data being collected to evaluate restoration actions are also used to adapt, refine, or reprioritize restoration actions. Finally, assessment also includes formal reporting on the Program's progress toward recovery goals.

7.3.3.1 Hypothesis testing

Testing to evaluate restoration hypothesis and outcomes involves both quantitative (statistical, graphical) and qualitative (logical, hypothesis-generating) analyses. Quantitative hypotheses testing depends on the sampling design, the distribution of the monitoring data, and the degree of spatial and temporal replication. For project-level assessment, projects without temporal replication and where the data are well described by a bell-shaped (normal) distribution, simple statistical analyses such as t-tests, analysis of variance (ANOVA), or correlation analyses may be adequate to statistically evaluate project-level hypotheses (Roni et al. 2013). For more complex designs with replication in time and space, linear mixed effects models, ANOVA and Akaike information criterion analyses are more appropriate. For program-level assessment, time series data, trend analyses, and indices of life-history diversity can reveal whether the focal fish populations are heading toward or away from the overall Program goals.

Qualitative hypothesis testing seeks to understand, explore, or describe the outcome of the project, develop logical and narrative descriptions of what was learned, and translate those into new hypotheses that iteratively move toward more effective restoration implementation. Qualitative assessment is particularly useful for the hypothetico-deductive approach and for communication between monitoring staff and implementation staff.

7.3.3.2 Data visualization and narrative interpretation

Data visualization allows monitoring program staff to share complex monitoring information in simple ways that communicate with decision-makers and support public outreach. Data visualization includes charts, graphs, pictures, videos and maps. Dynamic web-based visualization tools, such as ArcGIS StoryMaps,⁷ can combine data visualization with spatial tools and storytelling to effectively communicate the status and trends of restoration implementation and monitoring data. Well-established and effective salmonid monitoring programs, such as the State of Alaska Salmon and People Project⁸ and Salmon Status in Washington⁹ rely heavily on dynamic web-based data visualization platforms to communicate the status and trends of focal species and populations.

7.3.3.3 Communication between monitoring and implementation

Monitoring and assessment are inseparable from restoration implementation in this framework, and the feedback loop is vital to the success of the Program (Section 7). Monitoring is designed specifically to evaluate the effectiveness of restoration implementation both at a project-level (Section 7.3.2) and program-level (Section 7.3.1). In turn, restoration practitioners will have valuable insights to inform when, where, and how monitoring can be improved on the landscape.

⁷ Available at: <http://storymaps.arcgis.com>.

⁸ Available at: <https://knb.ecoinformatics.org/portals/SASAP/data>.

⁹ Available at: <https://stateofsalmon.wa.gov/executive-summary/salmon-status/>.

One tool to accomplish this feedback loop is a formal knowledge integration workshop, held annually, where Program monitoring partners share information from program- and project-level monitoring directly with restoration practitioners. The workshop should facilitate knowledge integration by encouraging future implementation solicitations to incorporate information from the Program's monitoring partnership into Implementation projects. Program Science staff will also receive feedback from Implementation staff on if and how to adapt monitoring designs to effectively measure implementation project outcomes.

In addition to annual internal assessment and episodic publicly available data visualizations, the monitoring program should provide a periodic formal assessment of the Program's progress toward its recovery goals (Section 1.2.1). This assessment should include a public workshop and formal report at a logical, pre-determined interval (e.g., 5 years). The report and workshop will synthesize the Programs' achievements, summarize the trajectory toward Program goals using both statistical and narrative analysis, refine metrics and targets for recovery over the next 5-year interval, summarize adaptive management experiments, and describe instances where monitoring data was used to adapt, refine, or reprioritize restoration and conservation actions.

7.4 Data Management

Data are the currency of a monitoring and assessment program. The success of the monitoring program depends largely on how data are collected (by multiple partner agencies), stored, shared, and analyzed. Data management includes developing protocols for data capture that can be integrated by multiple agencies, providing a central repository for data and information storage, a process to support program-level and project-level assessment, as well as a structure and process for accessibility and disseminating information. Each aspect of data management and recommendations for the program is discussed below.

7.4.1 Data Capture

Data to support the monitoring and assessment program will be generated by multiple entities including Program partners (state and federal agencies, Native American Tribes, NGOs, and restoration practitioners), academia, citizen science, and others and will require coordination to maintain consistent formatting and transfer into storage equipment. Some of these entities have pre-existing data capture and storage protocols that the Program will need to accommodate. For example, CDFW's Aquatic Survey Program (ASP) database is a distributed database used for the California Monitoring Program. CDFW has specific protocols for collecting and entering data into the database. The California Monitoring Program is expected to be a primary partner in any future Eel River monitoring program, and maintaining compatibility with the shared database will be a priority. Other organizations may be flexible and able to accommodate novel data capture protocols.

Electronic data capture methods often surpass standard paper-based data collection in accuracy, integrity, timeliness, and cost-effectiveness (Mosa et al. 2015). Where possible, the program should develop electronic data capture protocols that are compatible with partner organization databases and use form-based data entry (such as Survey 123) to reduce quality control issues (such as spelling and version control) with large data entry efforts.

7.4.2 Data Storage

Monitoring data can be stored on local servers, hosted cloud-based servers, or hybrid storage systems. Typically, environmental monitoring data are stored in either a relational database or a data repository. Data repositories store data from multiple sources and use metadata to index the data (make it searchable) and control access. Relational databases store data in consistent column/row formats and limit the types of data that can be managed. Because multiple types of monitoring data will be collected or stored by the monitoring program (e.g., spreadsheet, text files, images, and maps), a data repository will be necessary; however, within the data repository, relational data may be stored for specific monitoring tasks.

Numerous database systems are available, including proprietary systems like Microsoft Access and open-source systems like My SQL, Sqlite, or PostgreSQL. While state and federal partners often use Microsoft Access, an open-source and web-based platform has many advantages. Microsoft Access is a relational database with its own file format that is not compatible with any other system, requires proprietary software, and does not allow much flexibility with access controls to address issues such as indigenous data sovereignty (see Section 7.4.3. below). An open-source platform like PostgreSQL, hosted by a reputable and insured cloud-based data repository manager (such as dataone.org or datadryad.org) would allow for flexible, open-source data storage of multiple data types, with multiple levels of access and user control. A hybrid system is also preferable with local storage back-up to provide redundancy for data security. Regardless of software platform adopted, transferability, transparency and utility of data across program partners will be essential.

7.4.3 Data Access

As with data capture, the Program should have a data repository that is compatible with partner organization's databases, including CDFW's database (e.g., ASP). In working with monitoring partners, CDFW has employed a distributed model where "copies" of the database are stored by partner agencies to use for data capture and entry, and then periodically copied to a central CDFW-managed platform that has retrieval and editing capability. The Planning Team recommends this approach for the monitoring program. Along with compatibility between partner entities, a critical access consideration is maintaining "indigenous data sovereignty," which is the right for Tribal partners of the program to own and govern data about their communities, resources, and lands and control access to their data. As such, the Planning Team envisions a data repository architecture that includes different levels of access and oversight, including the concept of having *core data* and *adjacent data* as follows:

- *Core Data*: Data the monitoring program requires to accomplish the monitoring objectives. These data should be overseen by Program monitoring staff (even if a contractor curates the database) and thus will receive more QA/QC review from Program staff.
- *Adjacent Data*: Data that supports the monitoring program but is not required to accomplish the monitoring program's objectives. These data should be curated in the Program's repository, but access may be controlled by partner organizations and will receive a lower degree of QA/QC review from Program staff.

Whichever platform is selected as a data repository, it is critical to maintain compatibility with the data visualization platforms discussed in Section 7.3.3.2. Compatibility with dynamic web-based data visualization platforms such as ArcGIS StoryMaps will dramatically increase the capacity of the monitoring program to share the recovery trajectory of the Eel River watershed with the public in accessible ways (see Section 7.1, goal 3).

7.5 Adaptive Management Opportunities

River ecosystems are incredibly complex, and the understanding of the myriad of interconnections between disciplines (e.g., fish habitat, fish behavior, physical processes, and foodscape) is limited. In contrast to engineering design and implementation, river ecosystems are governed by a mixture of physical processes and biological processes, many of which are driven by behavioral responses to the environment (e.g., a fish deciding to migrate downstream). In the face of this considerable uncertainty, a restoration framework for the Eel River must not be paralyzed by indecision. A structured assessment process called Adaptive Environmental Assessment and Management (AEAM, Holling 1978) that has been developed and applied to improve ecological management can be used to leverage monitoring data and improve Eel River restoration. AEAM is also synonymous with the more colloquial term *adaptive management*, which is used for this discussion.

Many restoration programs and practitioners say that they are using adaptive management in their restoration efforts, but few actually do. Adaptive management is a structured decision-making process based on the scientific method; it is not trial-and-error or simply monitoring a management or restoration action. Holling (1978) defines adaptive management as follows:

AEAM is a formal, systematic, and rigorous process of learning from the outcomes of management actions, accommodating change, and improvement management.

There are many other similar definitions in the literature (Walters 1986), but the core components follow:

- A structured decision-making process with a hard-wired feedback loop to future management decisions;
- Empowered managers to make decisions despite varying levels of uncertainty;
- Mandated change in management in response to learning and reduced uncertainty;
- Iteratively updated conceptual models and quantitative models to facilitate an evolving understanding of the ecological system that is being treated;
- Clearly articulated, agreed upon, quantitative management objectives;
- An integration of decision-making, monitoring, and assessment into an iterative process of learning-based management (Williams et al. 2009); and
- A range of restoration program participants (shared learning, not just internal scientists).

The adaptive management feedback loop shown in Figure 7-4 illustrates the structured Science and decision-making process, and an overview of each step is summarized in Table 7-3.

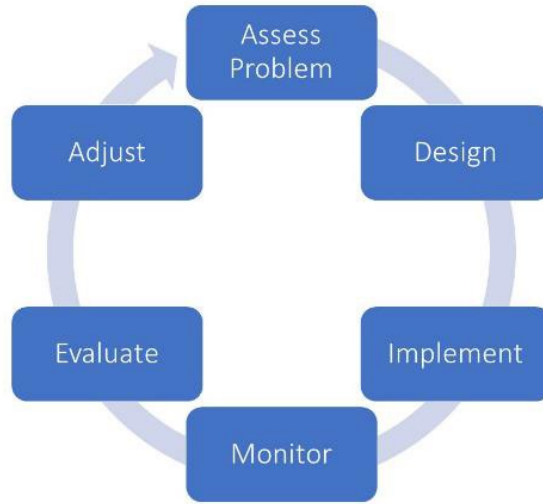


Figure 7-4. Six-step adaptive management feedback loop process.

Table 7-4. Summary of the steps in the adaptive management process that could be used for the Eel River Restoration and Conservation Plan, based on guidelines from USFWS and HVT (1999) and Pickard et al. (2023).

Step	Description
Assess problem	<ul style="list-style-type: none"> • Define management goals and specific ecological objectives that cascade from those management goals. • Develop conceptual models and hypotheses of key ecological relationships with management actions. • Prioritize relationships between management actions and ecological objectives. • Identify which priority relationships would benefit from an adaptive management approach. • Define targets for priority ecological objectives.
Design	<ul style="list-style-type: none"> • Simulate outcomes of management actions with qualitative conceptual models or quantitative predicted models to inform experimental design and expected/alternative outcomes. • Develop an experimental design for the adaptive management experiment (management actions, statistical design, monitoring and assessment), including active and passive adaptive management approaches (see Section 7.5.2). • Develop strategies for assessment, monitoring, and data management. • Develop study plan and cost and identify an acceptable level of investment with decision-makers. • Share/inform decision makers and partners on ecological objectives, conceptual models, hypotheses, and experimental design. • Develop potential next steps (including new management actions) for alternative outcomes to the experiment and obtain tentative agreement from decision-makers (e.g., look ahead).
Implement	<ul style="list-style-type: none"> • Collect baseline information identified in Monitoring Plan prior to implementation. • Implement management action(s).

Step	Description
Monitor	<ul style="list-style-type: none"> • Implement Monitoring Plan. • Manage and update database. • Document monitoring results.
Evaluate	<ul style="list-style-type: none"> • Compare monitoring results against desired ecological objectives and model simulations. • Document sensitivity of management action to desired ecological objectives. • Document reductions in uncertainties, update conceptual models and hypotheses based on learning. • Share learning with decision-makers and partners.
<i>Adjust</i>	<ul style="list-style-type: none"> • Update conceptual models and hypotheses based on learning and reduced uncertainty (update or restate system status). • Update quantitative simulation models based on learning and reduced uncertainty. • Update proposed management actions based on learning. • If needed, update ecological goals based on learning (should come on a longer time step).

Adaptive management can be used program-wide or applied to select ecological uncertainties depending on the specific needs of the watershed, details of the implementation program, and the technical abilities of participants. The appropriate use of adaptive management is described in the following subsections.

7.5.1 Guidelines for Applying Adaptive Management

Adaptive management is most effective in circumstances where (1) the ability to control an environmental outcome with a prescribed management action is high and (2) uncertainty in achieving the desired outcome is high (see Figure 7-5 for a conceptual model of adaptive management from Peterson et al. 2003). Some examples of this concept follow:

- *High Control*: A desired environmental outcome could include the flow inundation threshold of a floodplain restoration project (high control), but the uncertainty of achieving the desired outcome may be low (i.e., the floodplain can be precisely designed to achieve the desired flow inundation threshold). In this case, adaptive management is not needed because of the low uncertainty (i.e., structured experiments are not needed to improve the ability to achieve the desired outcome of floodplain inundation). This example reflects the *Optimal Control* zone shown in Figure 7-5.
- *Low Control, High Uncertainty*: A desired environmental outcome could include the effect of floodplain restoration projects resulting in improved adult salmon escapement. The large number of confounding factors that affect adult salmon escapement and the high uncertainty about the sensitivity of floodplain restoration projects on the drivers of adult escapement results in limited use of adaptive management because experiments would be unlikely to establish a cause-and-effect outcome and thus would be wasted effort. This example would fall into the *Scenario Planning* zone shown in Figure 7-5. Through the *Scenario Planning* (Peterson et al. 2003), conceptual models and/or quantitative models could be developed and evaluated for hypothesized cause-and-effect relationships between potential management actions and adult salmon escapement, and logical winnowing / prioritizing of these potential management actions could be done to better identify adaptive management experiments that could yield better results (higher controllability).

An important supplement to the conceptual model shown in Figure 7-5 is consideration of whether the adaptive management experiment can measure an environmental response on the performance metric in response to the experiment within a reasonable amount of time such that future management can respond to that learning. Using the preceding examples, if a large number of floodplain restoration projects were implemented and the adult escapement response were monitored, it could take multiple generations (decades) of salmon to detect a change in adult escapement, and there may likely still be high uncertainty in the cause of that change in adult escapement (e.g., ocean conditions, other confounding restoration actions that are occurring at the same time as the adaptive management experiment). Therefore, adaptive management experiments need to set up both the management action and the desired performance metric such that a learning outcome (1) can be achieved in a reasonable amount of time to inform future management decisions and (2) have a high certainty of assessing a cause-and-effect relationship. Both of these issues require careful consideration of the management actions and performance metrics as part of the Design process in Figure 7-4.

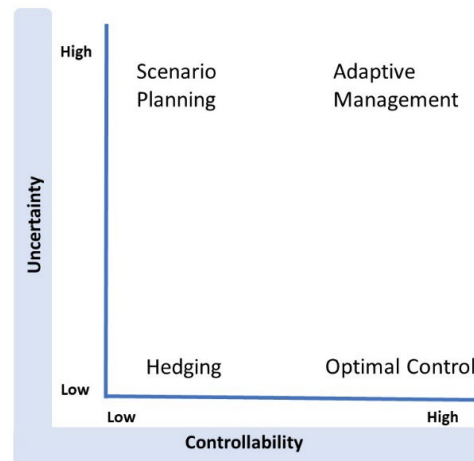


Figure 7-5. Conceptual guidance framework for when adaptive management may be appropriate based on uncertainty and controllability (from Peterson et al. 2003).

Using the preceding example again, a more appropriate adaptive management experiment would focus on a more direct performance measure (e.g., fry and juvenile salmonid growth on floodplains versus main channel) related to an aspect of floodplain restoration design (e.g., inundation threshold/timing/duration, complexity, large wood/cover) that could provide affirmative learning on the management action in a reasonable amount of time that would inform improved floodplain designs (a few years at most).

Additional guidelines for using adaptive management follow:

- Adaptive management should target ecological objectives that can inform management changes (“adjust”) within a reasonable time frame (months or years, not centuries).
- Adaptive management works best when there are experimental replicates, good baseline information, comparable control sites, and low sources of external variability and when the system response time is rapid.
- Adaptive management can be useful if there are significant scientific disagreements on conceptual models and hypotheses of relationships between management actions and expected ecological response. Adaptive management can help resolve these disagreements

by objectively developing and testing alternative hypotheses to foster a common understanding of system response. Objective implementation of adaptive management can turn an adversarial process into a collaborative process.

- Adaptive management is more difficult with a larger spatial scale, fewer replicates, more environmental variability and confounding factors, and a slow system response time. Accordingly for the Eel River, adaptive management may be most suitable for project-level implementation actions rather than program-level actions given the larger uncertainty, wide range of confounding factors, and slow response time at the program-level.

As the decision-makers, the Program Management body and Governance body described in Section 6.1 must understand adaptive management and embrace structured decision-making in the face of uncertainty.

Another conceptual model to illustrate the benefits of adaptive management is shown in Figure 7-6 (Marmorek 2001). If a long-term management decision is made now, and casual monitoring is conducted to evaluate effectiveness of that long-term management decision, it could take decades (if ever) to gather enough information needed to reduce uncertainty and establish cause-and-effect to the management action that would justify a change in that management action (top graph in Figure 8-13). In contrast, Active and/or Passive Adaptive Management experiments conducted before the long-term management decision can greatly reduce uncertainty and improve the quality of that long-term management decision.

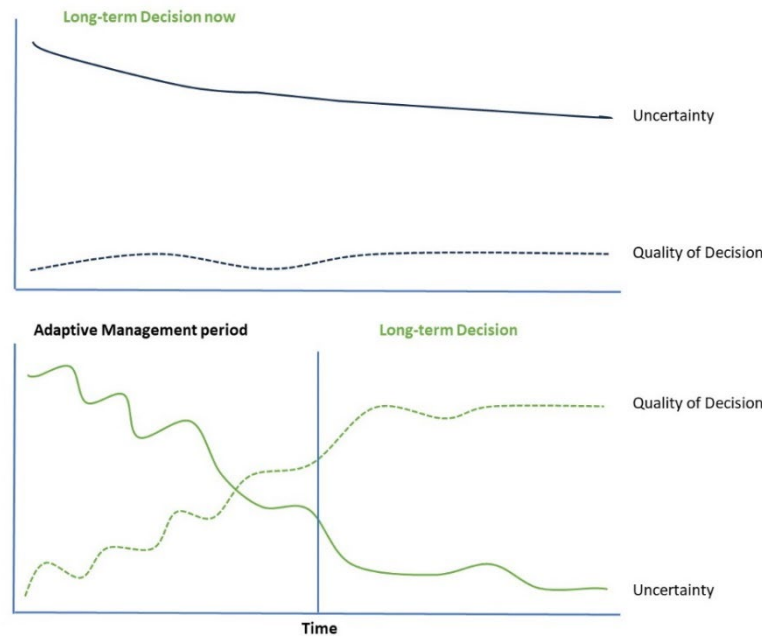


Figure 7-6. Conceptual model from Marmorek (2001), illustrating how adaptive management can reduce uncertainty and improve the quality of long-term decisions. The top figure illustrates uncertainty and quality of management decision made with no adaptive management compared with the bottom figure that illustrates more rapid improvement in uncertainty and quality of decision if adaptive management is used to inform long-term decisions. While more expensive in the short term, the time saved may result in overall cost savings, and more rapid achieving of desired ecological outcomes.

7.5.2 Recommended Application of Adaptive Management within the Eel River Restoration Monitoring and Assessment Framework

To apply the adaptive management principles, use the conceptual models provided in Section 3.2 and restoration and conservation actions provided in Section 4.3 to evaluate and prioritize uncertainties between restoration actions and ecological response (e.g., salmon productivity) and use guidelines above to identify and prioritize adaptive management experiments. This evaluation and prioritization process should be conducted as part of the upcoming Monitoring Plan implemented in Phase 2 (Table 7-1).

Adaptive management experiments should focus on those management actions and prioritized performance metrics that have the following:

- High controllability,
- High uncertainty (and the adaptive management experiment will drastically reduce this uncertainty),
- High ability to detect a change in performance metric in response to management actions (avoiding confounding factors and having high replicates to quantify sample variability and increase power of experiment), and
- Reasonable response time between the adaptive management action and learning (months to years, not decades) to enable learning and management change.
- Adaptive management experiments may be limited compared to the overall monitoring and assessment portfolio and budget and be most appropriate for project-scale management actions that satisfy the guidelines discussed above.
- If opportunities for adaptive management experiments are identified for inclusion the Program, then Program staff should develop an adaptive management component within the Phase 2 monitoring plan that documents the logical/analytical process used to prioritize adaptive management experiments and integrate these experiments into the annual work plans.
- When recruiting and hiring Program staff (Section 6.1.2), ensure that the Science body leadership staff fully understand and embrace the adaptive management structure and process, and are capable of overseeing the process and working with the program decision-makers to act upon results.
- Program budgets should accommodate flexibility for conducting and assessing adaptive management experiments (not be fixed and obligated for specific/repetitive monitoring actions).
- When developing adaptive management experiments, use *active* adaptive management (Williams et al. 2009, Marmorek 2001) whenever possible to increase the rate of learning, save time and resources, and more rapidly improve environmental response compared to *passive* adaptive management (or no adaptive management).

7.6 Program Linkages and Monitoring Plan Development Process

Monitoring and assessment are integral components to the success of the Program. Monitoring results will fill key data gaps and provide feedback to refine the conceptual life-cycle models and potential limiting factors developed in Section 3. Any refinements to the conceptual life-cycle models, limiting factors, and data gaps will inform the prioritization process and help refine appropriate restoration and conservation actions during the implementation phase. Monitoring results also provide direct feedback to Phase 2 by, for example, providing information that can be

used for shifting or refining priority actions and/or implementation designs based on the effectiveness of similar actions that have been implemented and monitored.

Developing the monitoring plan will be performed within two Program phases, with the draft monitoring plan, and monitoring method assessment, conducted during Phase 2 and the final monitoring plan developed during Phase 3 (Table 7-5). The Planning Team would lead development of the draft monitoring plan in coordination with program partners and science advisors early during Phase 2. This approach would provide early coordination with program partners on ongoing monitoring and allow the initiation of key baseline monitoring elements. Program management and science staff would be hired during Program Formation (Phase 2) to lead the prioritization process. Coordinated projects would be implemented during Phase 3 and the monitoring plan would be revised as needed and adopted to guide Program-level and Project-level monitoring and assessment. After initial prioritization, implementation, and monitoring and assessment, an iterative process would be used where knowledge gained from implementation, monitoring, and assessment provides feedback to refine process components (e.g., species conceptual models, limiting factors, data gaps) within the process.

Table 7-5. Monitoring program linkages and monitoring plan development.

Program components	Phase 1: Planning	Phase 2: Program Formation and Prioritization	Phase 3: Implementation, Monitoring, and Assessment
Monitoring plan development	Monitoring Framework	Draft Monitoring Plan	Final Monitoring Plan
Intended use	<ul style="list-style-type: none"> • Informs Phases 2 and 3 	<ul style="list-style-type: none"> • Provides additional guidance on roles and responsibilities of Science staff. • Identifies priorities for early (e.g., baseline) monitoring needs. 	<ul style="list-style-type: none"> • Provides guidance on the actual monitoring and assessment plan that will be developed and implemented by Science staff in Phase 3 • Reporting and communications schedule
Actions		<ul style="list-style-type: none"> • Baseline monitoring • Prioritize actions 	<ul style="list-style-type: none"> • Implement projects • Monitor and assess
Feedback loops	<ul style="list-style-type: none"> • Reevaluate goals and objectives • Refine species conceptual models • Reassess limiting factors • Reassess data gaps 	<ul style="list-style-type: none"> • Refine designs • Reassess priorities • Refine restoration approaches 	<ul style="list-style-type: none"> • Refine designs • Refine monitoring

During Program implementation, these feedback loops will provide information over a range of spatial and temporal scales. As described above (Section 7.3), project-level monitoring is typically performed at relatively smaller spatial scales and shorter temporal scales than program-level monitoring. Therefore, feedback from project-level monitoring to inform future project design and implementation will typically occur relatively quickly (e.g., annually or semi-annually). Comparatively, program-level monitoring can occur relatively infrequently (e.g., 5- to

10-year interval) or require extended periods to assess trends such that the feedback also occurs over an extended period (e.g., 10–20 years, or more).

In application, an approximately annual timestep for summarizing monitoring results and updating analyses related to Program goals and objectives (both project-level and program-level) is recommended, with the understanding that different monitoring types occur over different periods and durations, and some monitoring will occur over a much greater timestep. Therefore, monitoring results for different activities would be available at different times throughout the year. A specific schedule for how and when monitoring results will feedback into Phases 1 and 2, will be developed for the final monitoring plan.

7.7 Recommendations and Discussion

During Phase 2 of the Program, the Planning Team will convene with monitoring partners (i.e., state and federal agencies, Native American Tribes, contractors, and NGOs) to develop a draft monitoring plan and begin executing key elements of a monitoring program. The monitoring plan should leverage existing monitoring efforts and identify where monitoring needs to be expanded, or extended in time, to meet Program needs. As described in the introduction to Section 7, the monitoring plan will depend on which actions are *necessary, feasible, and practical* to meet the program’s monitoring objectives. What is “feasible” will depend in large part on the support and capacity of partner organizations as well as funding for the Program, and likewise the monitoring program itself. What is necessary and practical depends on tradeoffs between programmatic monitoring options (e.g., as described in Section 7.3 above, monitoring priorities that have been previously identified in state and federal recovery plans (e.g., NMFS 2014 and 2016, Adams et al. 2011, and South Fork Eel River SHaRP Collaborative 2021), and restoration and conservation action prioritization analysis conducted during Phase 2 of the Program.

Implementation of the monitoring plan will be coordinated by the Science body of the Program. The science coordinator (Figure 6-2) would work with Program partners to develop an annual monitoring and implementation plan that outlines monitoring roles and responsibilities for each agency, including staffing, monitoring schedules, equipment plans, and data management. Because the monitoring program will be a multi-partner endeavor, productive coordination, mutually supported, well-understood assignments, and open lines of communication between Program partner agencies and the Program are vital to success. The science coordinator will be responsible for instituting and maintaining this collaboration and will report to the executive director; however, Program partners must also be willing to coordinate work, commit staff/hours, and funding toward the Program’s monitoring goals.

As described in Section 7.6, the monitoring program’s initial structure and focus will be determined in Phase 2 via a draft monitoring plan; however, an initial suite of recommendations for program-level and project-level monitoring is provided below.

7.7.1 Data Management Recommendations

The Planning Team recommends creating a steering committee during Phase 2 composed of Program partners who are engaged with monitoring in the Eel River (e.g., CDFW, NMFS, Wiyot Tribe, Round Valley Indian Tribes, CalTrout, NGOs, and other practitioners) to establish organization-specific needs and commitments for a coordinated data repository. Key topics for the steering committee would be (1) ensuring compatibility with the CDFW’s database,

(2) maintaining indigenous data sovereignty, and (3) maintaining a pipeline between data storage and data visualization tools, and (4) creating a foundation for eventual program data management. A key product from this steering committee would be a description for the database/GIS manager position (Figure 6-2), communication with reputable data repository hosting organizations, and a recommendation for a Program data repository that addresses the challenges identified in Section 7.4. This data repository would be used to store and manage the program- and project-level data collected once Phase 2 monitoring and Phase 3 implementation begins.

7.7.2 Initial Program-level Monitoring Recommendations

As discussed, a fundamental tradeoff exists between spatial scale and the resolution of monitoring data—e.g., a tradeoff between monitoring at the primary sub-watershed scale (e.g., 136–2,072 km²) and the IMW/HUC-12 sub-basin scale (e.g., 26–104 km²). Here, the Planning Team suggests an initial monitoring effort that integrates spatial scales to develop multiple lines of evidence for the status and trends of focal species populations. For a review of the methods discussed below, please refer to Section 7.3.1. Prior to initiating these monitoring recommendations, the data infrastructure and accessibility procedures for the monitoring program must be developed to ensure that data are collected, stored, and shared responsibly (see Section 7.4).

At the primary sub-watershed scale, the Planning Team suggests continuing and expanding the existing array of sonar cameras that provide estimates of adult abundance (fish in). Fish-in data would be collected on the Lower Eel, Van Duzen, Middle Fork Eel, South Fork Eel, and Upper Main Eel sub-watersheds. Fish-out monitoring would also be implemented initially at the sub-watershed scale using a paired-watershed study design. The paired watersheds should focus on the Upper Main Eel and South Fork Eel sub-watersheds (see Figure 2-1). These two sub-watersheds were selected because: (1) they represent two key diversity strata identified by NMFS (2016 NMFS and Jording 2020), and (2) the Potter Valley Project work will focus on the Upper Main Eel sub-watershed, whereas the South Fork Eel sub-watershed represents both a quasi-control and the sub-watershed with the most potential for life-history diversity across multiple focal species. The success of fish-out monitoring at this scale will be determined based on recapture rates in approximately the first 2 years of operation, and if it proves ineffective, fish-out monitoring would be transferred to a suite of IMWs within each of the paired sub-watersheds. The Planning Team also suggests conducting spatial structure sampling (following California Monitoring Program design, and NMFS 2016 recommendations) at smaller HUC-12 sub-basins within each of the paired sub-watersheds, in addition to the Middle Fork Eel sub-watershed—which provides critical habitat for Chinook Salmon and steelhead. Finally, conducting a combination of telemetry studies and isoscape development to compute baseline life-history diversity metrics (Section 3.2) is suggested within each of these three sub-watersheds (Middle Fork Eel, Upper Main Eel, and South Fork Eel) prior to Phase 3 implementation (Section 4). Collectively, these monitoring approaches will provide an index of adult abundance and juvenile production (fish in–fish out), at a large enough scale to meaningfully reflect the Eel River population, paired with higher spatial resolution studies (spatial structure, isoscape and telemetry) to evaluate the recovery of life-history diversity in response to restoration actions—which is a key goal of the Program. This scale of monitoring is estimated to cost \$1–2 million per year and require at least 10–15 staff (depending on season) across all Program partner organizations.

7.7.3 Initial Project-level Monitoring Recommendation

Existing project-level monitoring is being carried out across the Eel River; however, this monitoring is not standardized, stored in a common repository, or synthesized to inform future

restoration implementation throughout the watershed. Therefore, the Planning Team recommends creating a template for project-level monitoring data. The template would include each of the factors described in Table 7-3: impact, restoration action, hypotheses to test, parameter selection, sampling design with adequate spatial and temporal replication, and monitoring and sampling methodology. The Planning Team also recommends creating a space in the Program's data repository (Section 7.4.2) for contributing restoration practitioners to share project-level data and template results. Finally, the Planning Team recommends implementing a knowledge integration workshop as soon as feasible (Section 7.3.3), where program monitoring staff share information directly with restoration practitioners and work to ensure that fish population and habitat data are being used to inform restoration design and implementation. Ultimately, the knowledge integration workshop will become a Program deliverable, but initiating this workshop at an ad-hoc level still provides great value to achieve the goals of this monitoring framework.

8 RECOMMENDATIONS AND NEXT STEPS

The purpose of this section is to present major recommendations from Phase 1: Planning (Section 8.1) and outline the primary next steps required for Phase 2: Program Formation and Prioritization (Section 8.2) to begin execution of the Plan.

8.1 Recommendations

The recommendations presented here are based on the understanding gained from and outcomes of each component of the Phase 1 planning process and reflect input from the Planning Team, the TAC, and participants in Eel River Forum meetings held during the planning process. This list is not comprehensive; it includes recommendations that are considered important for establishing and implementing a successful restoration and conservation program in the Eel River watershed that can achieve the vision and goals of the Program presented in Section 1.2.1. These recommendations are based on the current understanding of major components of the Plan and will be refined and expanded as new information is gained and additional input from watershed partners is received as the Program is developed during Phase 2.

8.1.1 Program Management

The Planning Team considered a range of potential management frameworks for the Program based on review of other large-scale restoration programs in the western United States and recommends a centralized management framework based on the current understanding of management needs and potential future funding strategies. The Planning Team recommends a management framework that is similar to the Klamath River Renewal Corporation because of several functional benefits provided by that structure, including (1) minimizing the size of the Program's staff, (2) relying on the existing structures of state and federal agencies, Native American Tribes, academic institutions, and NGOs to implement and monitor priorities developed by the Program, and (3) enabling better adaptability of Program staffing, responsibilities, implementation, and monitoring as the Program is implemented and evolves over time.

8.1.1.1 Management Framework

The recommended management framework is described in Section 6 and includes four internal and two external program management components. Internal Program management components include a Program Management body (executive director) and three technical bodies (Science, Planning, and Implementation). External program components include a Program Governance body and External Review body. Also included in the framework are recommended pathways for external coordination with advisors (science and legal) and other external entities (agencies, Program partners, and the public/media). A summary of recommended roles and responsibilities to be established follows:

- Governance body—a non-profit corporation with board of directors;
- Program Management body—an executive director responsible for coordinating with board, coordinating with external entities, and managing Program staff within the Science, Planning, and Implementation bodies:
 - Science body—oversees monitoring and assessment (monitoring and assessment priorities),

- Planning body—provides program coordination and administration, and
- Implementation body—coordinates prioritization and implementation, and conducts public outreach and information sharing (coordination with Program Partners, website development and maintenance, data sharing, Tribal liaison);
- SAB—an external multi-disciplinary team to provide technical input and review to the Program.

8.1.1.2 Funding Strategies

The program management framework assumes that a large-scale, centralized restoration and conservation program is needed for the Eel River and will require stable funding to be effective. Ideally, a large capital endowment (e.g., similar to the Headwaters Fund) could be obtained where interest revenue generated by the endowment would be sufficient to fund all Program administration and operational costs in perpetuity and, ideally, a portion of annual restoration and conservation action implementation costs. There is not currently a large capital endowment in place, although several potential sources are being explored. Even with an endowment, a portfolio of potential funding and in-kind support sources will likely be needed to fully implement the Program. Therefore, a primary role of the board of directors and executive director will be to strategize and obtain funds and in-kind support necessary to fully implement the Program and minimize interruptions to the funding stream that would delay implementation of restoration and conservation actions.

8.1.2 Restoration and Conservation Priorities

This section provides initial recommendations for priority restoration and conservation actions and related assessments and strategies aimed at protecting and accelerating recovery of focal species and achieving other Program goals (Section 1.2.1) and restoration and conservation objectives (Section 4.2). These initial recommendations are based on review of existing plans and other documents (e.g., NMFS 2014, 2016; South Fork Eel River SHaRP Collaborative 2021), species conceptual models, input from the TAC and other natural resource professionals, and professional judgement from the Planning Team. As described in Section 5, more specific restoration objectives and actions needed to achieve them will be systematically prioritized during Phase 2 of the Program.

8.1.2.1 Dam removal and upper mainstem Eel River restoration

The anticipated decommissioning of PG&E's Potter Valley Project and removal of two mainstem Eel River dams is a pivotal moment and significant opportunity to help restore Eel River fish populations. The decommissioning is an important opportunity that will accelerate restoration through several outcomes. Recommendations around the outcomes of the decommissioning to best benefit focal fish populations and watershed processes follow:

- Ensure volitional access to the estimated 288 miles of historically available, high-quality fish habitat upstream of Scott Dam;
- Remove any lentic habitats that harbor and support non-native predators;
- Restore functional flow components and minimize risk to the upper mainstem Eel River ecosystem below any potential infrastructure for diverting flow to the Russian River;
- Conduct careful planning to limit the short-term impacts of releasing sediment stored in Lake Pillsbury;

- Evaluate restoration opportunities within the footprints of Lake Pillsbury and Van Arsdale Reservoir to supplement actions planned under decommissioning; and
- Evaluate restoration opportunities upstream of lake Pillsbury to maximize the benefits of newly accessible habitats.

8.1.2.2 Coldwater habitat protection and restoration

Protection and restoration of coldwater habitats—both at the watershed scale and microhabitat scale within channel segments—are essential for maintaining, restoring and promoting focal species life histories and protection from ongoing climate and environmental change. Key recommendations include the following:

- At the watershed-scale, identify, protect, restore, and provide access to coldwater tributaries, headwater streams, and coastal and estuarine habitats that can support focal species through the summer during drought years. Restoring anadromous fish access to and improving habitat within the coldwater habitats upstream of Scott Dam is a high priority;
- At the channel-segment scale, locate and characterize thermal refugia and implement actions to restore physical habitat at and improve fish access to these locations, for example, thermal refugia may include thermally stratified pools, coldwater plumes associated with tributaries and springs, coldwater reaches associated with upstream hyporheic or sub-surface flows;
- Prioritize pikeminnow suppression in locations with thermal refugia capable of supporting large numbers of juvenile salmonids and other native aquatic species; and
- Take actions that help maintain and improve coldwater habitats, such as stream flow protection and enhancement and riparian plantings.

8.1.2.3 Life-history diversity and habitat heterogeneity

As described in Section 3, life-history diversity plays a fundamental role in abundance, persistence, and stability of native anadromous fish populations. Non-natal juvenile life histories increase the overall carrying capacity for fish populations of a watershed, thereby increasing population abundance and resilience. Recovery of the Eel River’s fish populations depends on recovering life histories that are currently depressed or rare, not just increasing the capacity of life histories that are common today. For this reason, understanding, protecting, and restoring non-natal juvenile life-history strategies—as well as less commonly recognized adult life-history strategies—are fundamental to recovering native fish populations and are a core focus of the Plan. A primary strategy for promoting life-history diversity involves protecting and restoring a mosaic of habitats across the watershed that provide variable conditions within and between years. This mosaic includes habitats that may provide only temporary high-quality rearing or high-growth environments (Armstrong et al 2021), like warm mainstems or intermittent tributaries, especially if they are in close proximity to seasonal refuges and key natal streams. Key recommendations for promoting life-history diversity include the following:

- Prioritize actions that protect and recover non-natal life history strategies.
- Restore habitats in the estuary and lower mainstem corridor, which are important non-natal rearing habitats for several focal species.
- Restore and increase connectivity with off-channel habitat features along mainstem corridors.

- Restore and improve access to habitat in low-gradient tributaries, focusing on those in lower watershed—including small and intermittent streams—to support juvenile life-history diversity.
- Restore and protect thermal refugia across spatial scales.
- Conduct focused planning assessments to identify opportunities and implement restoration in large, rare valleys, which include Round Valley, Little Lake Valley/Outlet Creek, upper Ten Mile Creek, Gravelly Valley in the upper Eel River (once the Potter Valley Project is decommissioned). These valleys historically supported, and in some cases currently support, unique life history strategies, such as the inland Coho Salmon strategy described in Appendix C.
- Identify and restore unique habitats, such as locally unconfined mainstem channel segments with high potential for floodplain connectivity in otherwise confined reaches.
- Increase juvenile rearing and survival in mainstem rivers by increasing habitat complexity and suppressing non-native predators.

8.1.2.4 Riverscape connectivity and mainstem rivers

While it may not be possible to completely restore the full mosaic of habitat heterogeneity that gave rise to historical life-history diversity, as described above, increasing function in more habitats will increase habitat capacity for focal species. For fish species to fully occupy currently functioning and/or newly restored habitats, it is important to maintain or restore connectivity between them. Mainstem rivers, which are the “arteries” of the riverscape, are critical in maintaining connectivity throughout the watershed. Key recommendations for riverscape connectivity follow:

- Remove anthropogenic physical passage barriers in mainstem rivers and into tributaries for focal fish species to move between seasonally suitable habitats and refugia;
- Restore and/or protect “stop-over” habitats, or local refugia in mainstem rivers, that allow fish to pass through longer lengths of inhospitable river to disperse to better habitats;
- Reduce predation, especially from non-native pikeminnow, in the mainstem rivers to allow for increased survival while out-migrating or dispersing; and
- Ensure connectivity between suitable holding habitats for adults that migrate and hold in lower flows. For example, ensure environmental flow management does not limit passage over critical/shallow riffles or implement instream restoration actions that increase successful passage between low-flow holding habitats.

8.1.2.5 Estuary and lower mainstem corridors

For the reasons described in Section 3.2.4.2, restoring and conserving aquatic and riparian habitats in the estuary and lower mainstem corridors of the Eel, Van Duzen, and South Fork Eel Rivers are fundamental to the recovering populations of focal fish species. Key recommendations include the following:

- Continue to implement and monitor outcomes of high-value restoration projects across the stream-estuary ecotone and the estuary;
- Restore natural tidal processes and improve fish access to tidal slough and marsh habitats through tide gate removal or modification;
- Restore floodplain connectivity and off-channel features (particularly locations fed by tributaries) along the estuary and lower mainstem corridors;

- Restore access to and habitat within the lower reaches of tributaries to the estuary and lower mainstem corridors;
- Evaluate feasibility of and implement actions that improve adult holding habitats and connectivity between them in the lower mainstem Eel River; and
- Identify and implement additional habitat restoration and conservation actions in the estuary and lower mainstem in coordination with the ongoing Lower Eel River SHaRP process and ongoing restoration efforts in the estuary (e.g., Salt River, Cannibal Island, Cock Robin Island, and Ocean Ranch).

8.1.2.6 Sediment management

Sediment supply plays an important role in creating and maintaining riverine habitat, affecting both the quality and quantity of aquatic and riparian habitat conditions over time. Sediment supplied to a channel reach or floodplain can enhance or degrade conditions depending on the incoming and existing grain-size distribution, supply rate relative to transport rate, and the capacity of a channel to store and process sediment into functional habitat. Information about past and present supply rate can be critical to understanding the disturbance history, appropriate upland and riverine restoration treatments and their anticipated longevity, and the trajectory of recovery with and without intervention. Key recommendations include the following:

- Inventory and assess existing and potential erosion and sediment delivery in key sub-watersheds and/or source areas known to have high rates of management or disturbance related sediment delivery to reaches identified as a high priority for restoration, enhancement, or conservation;
- Implement sediment source reduction measures in watersheds with high rates of erosion and sediment production, or where disturbance (e.g., high intensity wildfire) has the potential to result in severe erosion and sediment deliver to reaches with a high priority for restoration, enhancement, and conservation;
- Monitor flow and suspended sediment concentrations in select reaches known to be fine sediment impaired and/or are sources of input to reaches identified as a high priority for restoration, enhancement, or conservation;
- Assess channel and floodplain sediment storage characteristics (e.g., volume, grain size distribution and bed surface texture, scour and deposition, turnover rate) in responsive reaches identified as a high priority for restoration, enhancement, or conservation;
- Develop sediment budgets to help understand sediment fluxes into and out of key reaches, storage changes, and the associated effects to aquatic and riparian habitats over time; and
- Synthesize and use the above information about sediment dynamics to inform appropriate fisheries restoration, enhancement, and conservation strategies.

8.1.2.7 Non-native species management

Non-native aquatic and riparian species have potential to adversely impact native fish and other aquatic species through predation, competition, or habitat modification. For example, Sacramento Pikeminnow, which occur at high densities in many parts of the Eel River watershed have fundamentally altered the aquatic ecosystem, by preying on, competing with, or altering the behavior of native fish species (Georgakakos 2020). The presence of pikeminnow has likely selected against important life-history strategies that may have been historically abundant, such as mainstem rearing in the spring and summer by juvenile salmonids. Primary recommendations for non-native species management include the following:

- Continue ongoing monitoring and management of non-native Sacramento Pikeminnow in the South Fork Eel River, upper mainstem Eel River, and North Fork Eel River. Expand monitoring and management across the watershed, focusing effort on locations with high concentrations of the species and low survival of juvenile salmonids;
- Continue studies and field experiments to improve understanding of pikeminnow biology and evaluate effectiveness of management actions;
- Develop management plans for controlling invasive plant and aquatic species during and after the decommissioning of PG&E's Potter Valley Project;
- Prevent and control invasive plant and aquatic species spread throughout the basin; and
- Remove warm water and lentic habitats associated with the Potter Valley Project.

8.1.2.8 Environmental flow management

The focal species of the Plan have life histories that have co-evolved with the Eel River's natural flow regime. Flows on the Eel River are currently impacted by Potter Valley Project flow management, the cumulative effect of many small diversions throughout the watershed, land use practices, and climate change impacts. While there may be limited local solutions to climate change induced flow changes, several restorative actions can be done to improve flows in the Eel River:

- Develop a future flow regime for the Eel River downstream of the Potter Valley Project that fosters improved flow conditions and retains the functional flow components of the natural hydrograph;
- Continue curtailments of illegal water diversions throughout the Eel River watershed, particularly during the more sensitive spring and summer months for salmonid growth and outmigration;
- Support forbearance programs and incentives for legal water diversions that enable winter water off channel diversion and storage for use in the spring and summer and that reduce or eliminate summer diversions on small streams throughout the Eel River watershed;
- Apply and use relevant State Water Resources Control Board tools and criteria for establishing instream flow objectives and targets based on the California Environmental Flows Framework; and
- Establish and maintain necessary long-term flow monitoring stations in key sub-watersheds and/or reaches identified as a high priority for restoration, enhancement, or conservation.
- Identify and implement water conservation and efficiency measures.

8.1.2.9 Beaver-assisted habitat restoration

A promising strategy for increasing summer base flows involves reintroduction of beavers or simulating their habitat influences by constructing beaver dam analogs. Because their dams slow and spread-out stream flows, beaver can create wetlands and promote groundwater recharge that can enhance stream flows and fish habitats in downstream reaches (Lundquist and Dolman 2020, Dewey et al. 2022). Beaver dams and associated ponds, bank lodges, side channels, and burrows can also create large areas of prime summer and winter rearing habitat for juvenile salmonids and other fish. By changing geomorphic and hydrological process of stream channels and riparian corridors, beaver can also increase overall ecosystem resilience to climate change and forest fire. For these reasons, key recommendations include the following:

- Conduct focused assessments of present-day distribution and the potential for beaver reintroduction in the watershed are needed; and
- Reintroduce beaver and construct beaver dam analogs in appropriate habitats and channels.

8.1.2.10 Conservation priorities

While high-priority lands and parcels for conservation in the Eel River will be determined during the Phase 2 prioritization process, the Planning Team has identified several initial conservation priorities during this Planning phase and has the following recommendations:

- Seek a state or federal land designation for long-term Eel River watershed-wide conservation; this designation would serve as a mechanism for identifying priority acquisitions and transferring private properties into public ownership and management;
- Emphasize the Eel River watershed as a place that could greatly contribute to the California 30x30 Initiative (CNRA 2022);
- Expand and add to the edges of existing conservation areas through public ownership, land conservation easements, and restoration;
- For lands within federal management, plan for partial transition of public ownership from non-protected to protected status;
- Explore opportunities to identify the Eel River as a pilot climate refugia within the North Coast region;
- Identify “critical biodiversity hotspots” that are especially vulnerable to climate change, to prioritize for conservation;
- Identify “fish productivity hotspots” with unique geology, hydrology, and water quality that currently provide resilient fish production in the basin that should be prioritized for conservation;
- Identify conservation opportunities in rare low-gradient valleys (e.g., Round Valley, Little Lake Valley/Outlet Creek, upper Ten Mile Creek, and Gravelly Valley in the upper Eel River);
- Promote and coordinate with land conservation and planning organizations in the Eel River (e.g., the Great Redwood Trail Agency, the Wildlands Conservancy);
- Develop conservation easements or transfer land to public ownership in the lower Eel River given that this part of the watershed is used by all focal fish species;
- Coordinate with and support the Lower Eel River SHaRP process;
- Support land-back acquisitions by Native American Tribes;
- Assess opportunities for Outstanding National Resource Waters designation; and
- Engage with the public and community to promote interest in conservation easements.

8.1.3 Monitoring, Assessment, and Research Priorities

Initial recommendations for monitoring and assessment priorities are described in Section 7.7 and recommendations are summarized below for data management, program-level monitoring, and project-level monitoring. In addition, adaptive management experiments are also encouraged where it makes sense to do so, given the ability to conduct controlled management experiments (replicates, statistical power). Monitoring and assessment recommendations follow:

8.1.3.1 Data Management

- Create a steering committee to establish organization-specific needs and commitments for a coordinated data repository and prepare the following products:
 - Job description for the database/GIS manager position,
 - Recommendation for a Program data repository that is compatible with CDFWs database (e.g., ASP),
 - Review the Klamath Basin Fisheries Collaborative Memorandum of Understanding as a potential example structure for data storage and sharing agreement.

8.1.3.2 Program-level monitoring

- Continue and expand fish in–fish out monitoring. Adult abundance is identified as the highest priority in the NMFS Coastal Multispecies Recovery Plan, and juvenile abundance is identified as the second highest priority (NMFS 2016, Table 25).
- Continue and expand sonar camera monitoring to estimate adult escapement (fish in) focusing on the Lower Eel, Van Duzen, Middle Main Eel, South Fork Eel, and Upper Main Eel sub-watersheds.
- Initiate juvenile outmigrant trapping to estimate juvenile/smolt production (fish out) using a paired sub-watershed study design focusing on the Upper Main Eel and South Fork Eel sub-watersheds.
- Conduct spatial structure sampling within paired sub-watersheds (Upper Main Eel and South Fork Eel) to understand the distribution of focal species on the landscape. These basins represent key diversity strata for Coho, Chinook, and steelhead identified by NMFS (2016 NMFS and Jording 2020).
- Monitor life-history diversity within paired sub-watersheds (Upper Main Eel and South Fork Eel) to estimate current array and success of juvenile life histories and provide empirical support/refinement for the species conceptual models:
 - Conduct telemetry studies in both sub-basins to understand movement and timing and survival of emigrating juvenile fish, and
 - Implement isoscape development in both sub-basins to inform juvenile life histories and habitat use and understand the relevant contribution of different life histories to adult production.

8.1.3.3 Project-level Monitoring

Current ongoing and near-term monitoring needs to be standardized, stored in a common repository, and synthesized to inform future restoration implementation throughout the watershed. Project-level monitoring priorities include the following:

- Creating standardized templates for project-level monitoring data that consider the following factors: impact, restoration action, hypotheses to test, parameter selection, sampling design with adequate spatial and temporal replication, and monitoring and sampling methodology;
- Creating a space in the Program’s data repository for contributing restoration practitioners to share project-level data and template results; and
- Convene a knowledge integration workshop, where program monitoring staff share information directly with restoration practitioners and work to ensure that fish population and habitat data are being used to inform restoration design and implementation.

8.1.3.4 Additional research and information needs

The development of life-history conceptual models has revealed various data gaps and information needs related to focal fish species and watershed conditions (Section 3.2.4.3). In addition to the program-level and project-level monitoring recommended above, various assessments and analyses are needed to (1) establish a more robust understanding of controls abundance and life-history diversity of focal specie, (2) inform prioritization of restoration and conservation action in Phase 2, and (3) increase the efficacy of future phases of the Program. Key recommendations follow:

- Review data gaps from focal species conceptual models (Section 3.2.4.3; Appendix C) and establish feasible research projects and linkages with ongoing and future monitoring improve understanding of the controls on production and life-history diversity of focal fish species;
- To help fill these data gaps, take the following steps:
 - Foster collaboration with academic institutions and researchers, including graduate students and post-doctoral researchers, to fill data gaps,
 - Create fellowships, grants, and/or additional funding opportunities to support research in the Eel River watershed by graduate students,
 - Support and promote field tours of the Eel River at technical conferences to widen engagement in the watershed from technical experts, and
- Promote collaboration around the anticipated Potter Valley Project decommissioning, including outreach to agencies, scientists, and engineers to synthesize lessons learned from recent and ongoing dam removals in the region (Elwha Dam, Klamath River dams).

8.2 Next Steps

This Plan, as the outcome of Phase 1: Planning of the Eel River Restoration and Conservation Program, outlines the fundamental components for creating and implementing a successful watershed-wide program. This section describes a series of important next steps that will be the focus of Phase 2: Program Formation and Project Prioritization). The steps listed here are not intended to be an exhaustive list or a detailed road map; rather, they are the major milestones that need to be achieved in the next phase of the Program's development. Additional steps and actions will be identified as planning and development of the Program continues in Phase 2.

- *Distribution and Outreach:* Outreach and distribution of the Plan is crucial to its success. Community members or organizations that have not been exposed to the Plan development process and the goals that were developed should have the opportunity to provide input. The document will be published on CalTrout's website and released via local media outlets to ensure broad distribution across the community.
- *Partner Coordination:* During Phase 2, effective and frequent coordination with Tribal, state, NGO, and federal partners will be fundamental to the success of the Programs' development and for restoration prioritization. Coordination will include gathering input from leadership from each organization on how to structure an effective Program, integrating the information from existing and ongoing restoration plans into the prioritization process, and ultimately the restoration of the Eel River.
- *Entity Formation, Board of Directors, and Staff:* Building on Section 6, there must be a Program entity to begin executing the strategies in this Plan. Legal council should be

retained to determine the type and structure of the entity. The Planning Team (with input from the TAC and agency partners) in parallel with the entity formation, should identify the members of the board of directors that will govern the Program. The board of directors will then solicit applications or seek out an executive director who can begin implementing the directives given by the board, including hiring of support staff and execution of restoration and conservation action prioritization.

- *Financing and Budget:* Phase 2 of the Program development will require additional funding support. The budgeting process will be a detailed accounting of the Program needs. The needs will include financial requirements for developing the entity, startup costs (office space, supplies, legal costs, licenses), the board of directors' compensation (if any), the executive director salary, support staff salaries, and the funding needed to refine and execute the restoration and conservation action prioritization process (Section 5) and initial monitoring needs (Section 7). Development of a detailed budget will support procurement of funding to support Phase 2.
- *Prioritization of Restoration and Conservation Actions:* A framework to identify and prioritize specific and broad restoration and conservation actions was developed as part of the Plan (Sections 4 and 5). In parallel with the steps listed above, the prioritization framework should be refined and implemented, including advancing the highest priority analyses and syntheses that will be used as inputs to the prioritization process. Moving forward with action prioritization is important so that the implementation of actions can be best informed by prioritization outcomes.
- *Baseline Monitoring:* Continuation and expansion of the baseline monitoring of juvenile and adult salmonids being conducted in the Eel River watershed is imperative. This baseline monitoring will serve multiple purposes. First, it will help establish the current fish population status, making directional changes clearer as restoration actions are completed. Second, baseline monitoring will be the foundation for the hypothesis testing framework described in Section 7.3.3.1. Lastly, baseline monitoring will fill existing data gaps and help identify additional data needs.

9 REFERENCES

- Adams, P. B., L. B. Boydstun, S. P. Gallagher, M. K. Lacy, T. McDonald, and K. E. Shaffer. 2011. California coastal salmonid population monitoring: strategy, design, and methods. Fish Bulletin 180. Prepared for California Department of Fish and Game, Sacramento, California.
- Albert, D., L. Baker, S. Howell, K. V. Koski, and R. Bosworth. 2008. A framework for setting watershed-scale priorities for forest and freshwater resources on Prince of Wales Island. The Nature Conservancy.
- Allen, P. J., J. A. Hobbs, J. J. Cech, J. P. Van Eenennaam, and S. I. Doroshov. 2009. Using trace elements in pectoral fin rays to assess life history movements in sturgeon: estimating age at initial seawater entry in Klamath River Green Sturgeon. *Transactions of the American Fisheries Society* 138: 240–250.
- Anderson, J. H., G. R. Pess, R. W. Carmichael, M. J. Ford, T. D. Cooney, C. M. Baldwin, and M. M. McClure. 2014. Planning Pacific salmon and steelhead reintroductions aimed at long-term viability and recovery. *North American Journal of Fisheries Management* 34: 72–93.
- Anderson, M. G., M. Clark, A. P. Olivero, A. R. Barnett, K. R. Hall, M. W. Cornett, M. Ahlering, M. Schindel, B. Unnasch, C. Schloss, and D. R. Cameron. 2023. A resilient and connected network of sites to sustain biodiversity under a changing climate.
- Armstrong, J. B., A. H. Fullerton, C. E. Jordan, J. L. Ebersole, J. R. Bellmore, I. Arismendi, B. E. Penaluna, and G. H. Reeves. 2021. The importance of warm habitat to the growth regime of cold-water fishes. *Nature Climate Change* 11: 354–361.
- Atlas, W. I., M. R. Sloat, W. H. Satterthwaite, T. W. Buehrens, C. K. Parken, J. W. Moore, N. J. Mantua, J. Hart, and A. Potapova. 2023. Trends in Chinook Salmon spawner abundance and total run size highlight linkages between life history, geography and decline. *Fish and Fisheries* 24: 595–617.
- Ball, I. R., H. P. Possingham, and M. E. Watts. 2009. Marxan and relatives: software for spatial conservation prioritization. Pages 185–201 in A. Moilanen, K. A. Wilson, and H. P. Possingham, editors. *Spatial conservation prioritization: Quantitative methods and computational tools*. Oxford University Press.
- Bauer, S., J. Olson, A. Cockrill, M. van Hattem, L. Miller, M. Tauzer, and G. Leppig. 2015. Impacts of surface water diversion for marijuana cultivation on aquatic habitat in four northwestern California watersheds. *Plos One* 10: e0120016.
- Beechie, T., E. Buhle, M. Ruckelshaus, A. Fullerton, and L. Holsinger. 2006. Hydrologic regime and the conservation of salmon life history diversity. *Biological Conservation* 130: 560–572.
- Beechie, T., G. Pess, P. Roni, and G. Giannico. 2008. Setting river restoration priorities: a review of approaches and general protocol for identifying and prioritizing actions. *North American Journal of Fisheries Management* 28: 891–905.

- Beechie, T. J., C. Fogel, C. Nicol, and B. Timpone-Padgham. 2021. A process-based assessment of landscape change and salmon habitat losses in the Chehalis River basin, USA. *PLoS ONE* 16: 1–28.
- Bennett, T. R., P. Roni, K. Denton, M. McHenry, and R. Moses. 2015. Nomads no more: early juvenile Coho Salmon migrants contribute to the adult return. *Ecology of Freshwater Fish* 24: 264–275.
- Bilby, R. E., K. P. Currens, K. L. Fresh, D. B. Booth, R. R. Fuerstenberg, and G. L. Lucchetti. 2024. Why aren't salmon responding to habitat restoration in the Pacific Northwest? *Fisheries* 49: 16–27.
- Bisson, P. A., and R. E. Bilby. 1982. Avoidance of suspended sediment of juvenile Coho Salmon. *North American Journal of Fisheries Management* 2: 371–374.
- Blair, G. R., L. C. Lestelle, and L. E. Mobrand. 2009. The ecosystem diagnosis and treatment model: a tool for assessing salmonid performance potential based on habitat conditions. *American Fisheries Society Symposium* 71: 289–299.
- Blake, Jr., M. C., W. P. Irwin, and R. G. Coleman. 1967. Upside-down metamorphic zonation, blueschist facies, along a regional thrust in California and Oregon. Pages C1–C9 in *Geological Survey Research, U.S. Geological Survey Professional Paper* 575–C.
- Bond, M. H., S. A. Hayes, C. V. Hanson, and R. B. MacFarlane. 2008. Marine survival of steelhead (*Oncorhynchus mykiss*) enhanced by a seasonally closed estuary. *Canadian Journal of Fisheries and Aquatic Sciences* 65: 2,242–2,252.
- Bottom, D. L., K. K. Jones, T. J. Cornwell, A. Gray, and C. A. Simenstad. 2005. Patterns of Chinook Salmon migration and residency in the Salmon River Estuary (Oregon). *Estuarine Coastal and Shelf Science* 64: 79–93.
- Bouma-Gregson, K., M. E. Power, and M. Bormans. 2017. Rise and fall of toxic benthic freshwater cyanobacteria (*Anabaena* spp.) in the Eel river: buoyancy and dispersal. *Harmful Algae* 66: 79–87.
- Botkin, D. B., D. L. Peterson, and J. M. Calhoun, technical editors. 2000. The scientific basis for validation monitoring of salmon for conservation and restoration plans. Olympic Natural Resources Technical Report. University of Washington, Olympic Natural Resources Center, Forks, Washington.
- Boyce, J., D. H. Goodman, and S. B. Reid. 2022. Regional implementation plan for measures to conserve Pacific Lamprey (*Entosphenus tridentatus*), California—North Coast Regional Management Unit. Arcata Fisheries Technical Report Number TR 2022-41. U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata, California.
- Braun, D. C., J. W. Moore, J. Candy, and R. E. Bailey. 2016. Population diversity in salmon: linkages among response, genetic and life history diversity. *Ecography* 39: 317–328.
- Brown, L. R., and P. B. Moyle. 1997. Invading species in the Eel River, California: successes, failures, and relationships with resident species. *Environmental Biology of Fishes* 49: 271–291.

- Brown, W., and J. Ritter. 1971. Sediment transport and turbidity in the Eel River basin, California. U.S. Geological Survey Water Supply Paper 1986.
- Bustard, D. R., and D. W. Narver. 1975. Aspects of the winter ecology of juvenile Coho Salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). Journal of the Fisheries Research Board of Canada 32: 667–680.
- California Fish and Game Commission. 2022. Staff summary for April 20–21, 2022. Available at: <https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=200663&inline>.
- California Historical Society. 186–1960. Panoramic view of Gravelly Valley near Ukiah, ca.1910, California Historical Society Collection, 1860–1960 collection. Available at: https://digitallibrary.usc.edu/asset-management/2A3BF1123_U?FR_=1&W=2400&H=1172.
- Cameron, D. R., C. A. Schloss, D. M. Theobald, and S. A. Morrison. 2022. A framework to select strategies for conserving and restoring habitat connectivity in complex landscapes. Conservation Science and Practice 4: e12698.
- Cannata, S., and T. Hassler 1995. Juvenile salmonid utilization of the Eel River estuary. California Cooperative Fishery Research Unit, Humboldt State University, Arcata.
- Carlson, S. M., and W. H. Satterthwaite. 2011. Weakened portfolio effect in a collapsed salmon population complex. Canadian Journal of Fisheries and Aquatic Sciences 68: 1,579–1,589.
- Carwardine, J., C. J. Klein, K. A. Wilson, R. L. Pressey, and H. P. Possingham. 2009. Hitting the target and missing the point: target-based conservation planning in context. Conservation Letters, 2: 4–11.
- Carwardine, J., K. A. Wilson, S. A. Hajkiewicz, R. J. Smith, C. J. Klein, M. Watts, M., and H. P. Possingham. 2010. Conservation planning when costs are uncertain. Conservation Biology 24: 1,529–1,537.
- CDFG (California Department of Fish and Game). 1972. Fish and wildlife aspects of alternative plans Eel River development. Advance Planning Program, Middle Fork Eel River development. Memorandum Report. CDFG, Region 1.
- CDFG. 2010. Lower Eel River watershed assessment. Coastal Watershed Planning and Assessment Program.
- CDFG. 2012. Van Duzen River Watershed Assessment. Coastal Watershed Planning and Assessment Program. Draft. California Department of Fish and Game.
- CDFG. 2004. Recovery strategy for California Coho Salmon. Prepared by CDFG for California Fish and Game Commission.
- CDFW (California Department of Fish and Wildlife). 2014. South Fork Eel River watershed assessment. Coastal Watershed Planning and Assessment Program, Fortuna, California.
- Chan, K. M. A., M. R. Shaw, D. R. Cameron, E. C. Underwood, and G. C. Daily. 2006. Conservation planning for ecosystem services. PLoS Biology 4: 2,138–2,152.

Cluer, B., and C. Thorne. 2014. A stream evolution model integrating habitat and ecosystem benefits. *River Research and Applications* 30: 135-154.

CNDBB (California Natural Diversity Database). 2024. Special animals list. California Department of Fish and Wildlife, Sacramento, California.

CNRA (California Natural Resources Agency). 2022. Pathways to 30x30 California: Accelerating conservation of California's nature. Available at: <https://www.californianature.ca.gov/>.

CNRA. 2023. California Natural Resources Agency. California Protected Areas Database. Retrieved December 1, 2023. California Protected Areas Database – Dataset – California Natural Resources Agency Open Data.

Eastern Conservation Science, and The Nature Conservancy. (n.d.). Resilient Lands Conservation Strategies Resilient and Connected Landscapes for Terrestrial Conservation Resilient Lands Connected Landscapes Conservation Strategies Eastern Conservation Science.

Cooper, E. J., A. P. O'Dowd, J. J. Graham, D. W. Mierau, W. J. Trush, and R. Taylor. 2020. Salmonid habitat and population capacity estimates for steelhead trout and Chinook Salmon upstream of Scott Dam in the Eel River, California. *Northwest Science* 94: 70–96.

Cordoleani, F., C. Phllis, A. Sturrock, A. FitzGerald, G. Whitman, A. Malkassian, P. Weber, and R. Johnson. 2021. Threatened salmon rely on a rare life history strategy in a modified and warming landscape. *Nature Climate Change* 11: 982–988.

Cordoleani, F. C. C. Phillis, A. M. Sturrock, M. Willmes, G. Whitman, E. Holmes, P. K Weber, C. Jeffres, and R. C. Johnson. 2024. Restoring freshwater habitat mosaics to promote resilience of vulnerable salmon populations. *Ecoshpere* 15: e4803.

Dai, A. 2013. Increasing drought under global warming in observations and models. *Nature Climate Change* 3. 52–58.

Daigle, R. M., A. Metaxas, A. C. Balbar, J. McGowan, E. A. Treml, C. D. Kuempel, H. P. Possingham, and M. Beger. 2020. Operationalizing ecological connectivity in spatial conservation planning with Marxan Connect. *Methods in Ecology and Evolution* 11: 570–579.

Dale, V. H., S. Brown, R. A. Haeuber, N. T. Hobbs, N. J. Huntley, R. J. Naiman, W. E. Riebsame, M. G. Turner, and T. J. Valone. 2001. Ecological guidelines for land use and management. Pages 3–33 *in* V. H. Dale, and R. A. Haeuber, editors. *Applying Ecological Principles to Land Management*. Springer Science+Business Media, New York.

Davis, C. R. 2020. Strategizing for climate corridor conservation in the South Puget Sound, Washington. Master's thesis, The Evergreen State College.

Detenbeck, N. E., C. A. Johnston, and G. J. Niemi. 1993. Wetland effects on lake water quality in the Minneapolis/St. Paul metropolitan area. *Landscape Ecology* 8: 39–61.

Dettinger, M., B. Udall, and A. Georgakakos. 2015. Western water and climate change. *Ecological Applications* 25: 2,069–2,093.

- Dewey C., P. M. Fox, N. J. Bouskill, D. Dwivedi, P. Nico, and S. Fendorf. 2022. Beaver dams overshadow climate extremes in controlling riparian hydrology and water quality. *Nature Communications* 13: 1–9.
- Dietrich, W. E., and F. Ligon. 2008. RIPPLE – A digital terrain-based model for linking salmon population dynamics to channel networks. Prepared by Stillwater Sciences, Berkeley, California.
- Doherty, T. S., L. M. Bland, B. A. Bryan, T. Neale, E. Nicholson, E. G. Ritchie, and D. A. Driscoll. 2018. Expanding the role of targets in conservation policy. *Science & Society* 33: P809–812.
- Donald, P. F., and A. D. Evans. 2006. Habitat connectivity and matrix restoration: the wider implications of agri-environment schemes. *Journal of Applied Ecology* 43: 209–218.
- Downie, S. T. and K. P. Lucey. 2005. Salt River Watershed Assessment. Coastal Watershed Planning and Assessment Program. California Department of Fish and Game.
- Dralle, D. N., G. Rossi, P. Georgakakos, W. J. Hahm, D. M. Rempe, M. Blanchard, M. E. Power, W. E. Deitrich, and S. M. Carlson. 2023. The salmonid and the subsurface: hillslope storage capacity determines the quality and distribution of fish habitat. *Ecosphere* 14: e4436.
- Drenner S. M., T. D. Clark, C. K. Whitney, E. G. Martins, and S. J. Cooke. 2012. A synthesis of tagging studies examining the behavior and survival of anadromous salmonids in marine environments. *PLOS ONE* 7: e31311.
- Dunn, C. G., and P. L. Angermeier. 2019. Remaining populations of an upland stream fish persist in refugia defined by habitat features at multiple scales. *Diversity and Distributions* 25: 385–399.
- Ebersole, J. L., P. J. Wigington, Jr., J. P. Baker, M. A. Cairns, M. Robbins Church, B. P. Hansen, B. A. Miller, H. R. LaVigne, J. E. Compton, and S. G. Leibowitz. 2006. Juvenile Coho Salmon growth and survival across stream network seasonal habitats. *Transactions of the American Fisheries Society* 135: 1,681–1,697.
- Ecotrust and USFS (U.S. Forest Service). 2010. Prioritizing aquatic conservation and restoration in the Pacific Northwest. Available at: <http://madrona.ecotrust.org/experience/aquatic-priorities>.
- Eel River Forum. 2016. The Eel River Action Plan: a compilation of information and recommended actions.
- Eken, G., L. Bennun, T. M. Brooks, W. Darwall, L. D. C. Fishpool, M. Foster, D. Knox, P. Langhammer, P. Matiku, E. Radford, P. Salaman, W. Sechrest, M. L. Smith, S. Spector, and A. Tordoff. 2004. Key Biodiversity Areas as Site Conservation Targets. *Bioscience* 54: 1110.
- Elliot, W. W. and Co. 1881. History of Humboldt County, California, with illustrations descriptive of its scenery, farms, residences, public buildings, factories, hotels, business houses, schools, churches, etc., from original drawings, including biographical sketches. From the Humboldt State University Digital Commons, Archives and Reprint Series.
- ESSA (ESSA Technologies Ltd.). 2019. Klamath Basin Integrated Fisheries Restoration and Monitoring Plan (IFRMP): Phase 2. Draft.

ESSA and Klamath Basin Working Groups. 2023. Klamath Basin Integrated Fisheries Restoration and Monitoring Plan (IFRMP): Plan Document. Prepared by ESSA Technologies Ltd. for the Pacific States Marine Fisheries Commission and the U.S. Fish and Wildlife Service.

Fairfax, E., and A. Whittle. 2020. Smokey the beaver: beaver-dammed riparian corridors stay green during wildfire throughout the western United States. *Ecological Applications*: 30: Article e02225.

FitzGerald, A. M., D. A. Boughton, J. Fuller, S. N. John, B. T. Martin, L. R. Harrison, and N. J. Mantua. 2022. Physical and biological constraints on the capacity for life-history expression of anadromous salmonids: an Eel River, California, case study. *Canadian Journal of Fisheries and Aquatic Sciences* 79: 1,023–1,041.

FitzGerald, A. M., S. N. John, T. M. Apgar, N. J. Mantua, and B. T. Martin. 2021. Quantifying thermal exposure for migratory riverine species: Phenology of Chinook salmon populations predicts thermal stress. *Global Change Biology* 27: 536–549.

Flitcroft, R. L., D. L. Bottom, K. L. Haberman, K. F. Bierly, K. K. Jones, C. A. Simenstad, A. Gray, K. S. Ellingson, E. Baumgartner, T. J. Cornwell, and L. A. Campbell. 2016. Expect the unexpected: place-based protections can lead to unforeseen benefits. *Aquatic Conservation-Marine and Freshwater Ecosystems* 26: 39–59.

Fremier, A. K., M. Kiparsky, S. Gmur, J. Aycrigg, R. K. Craig, L. K. Svancara, D. D. Goble, B. Cosens, F. W. Davis, and J. M. Scott. 2015. A riparian conservation network for ecological resilience. *Biological Conservation* 191: 29–37.

Gasith, A., and V. H. Resh. 1999. Streams in Mediterranean climate regions: abiotic influences and biotic responses to predictable seasonal events. *Annual Review of Ecology and Systematics* 30: 51–81.

Geldmann, J., M. Barnes, L. Coad, I. D. Craigie, M. Hockings, and N. D. Burgess. 2013. Effectiveness of terrestrial protected areas in reducing habitat loss and population declines. *Biological Conservation* 161: 230–238.

Georgakakos, P. B. 2020. Impacts of native and introduced species on native vertebrates in a salmon-bearing river under contrasting thermal and hydrologic regimes. Doctoral dissertation. University of California, Berkeley.

Groves and Game 2016. *Conservation Planning: Informed decisions for a healthier planet*. Roberts and Co. Publishers, Greenwood, Colorado. ISBN 978-1936221516.

Groves, C. R., E. T. Game, M. G. Anderson, M. Cross, C. Enquist, A. Ferdaña, E. Girvetz, A. Gondor, K. R. Hall, J. Higgins, R. Marshall, K. Popper, S. Schill, and S. L. Shafer. 2012. Incorporating climate change into systematic conservation planning. *Biodiversity and Conservation* 21: 1,651–1,671.

Haddad, N. M., L. A. Brudvig, J. Clobert, K. F. Davies, A. Gonzalez, R. D. Holt, T. E. Lovejoy, J. O. Sexton, M. P. Austin, C. D. Collins, W. M. Cook, E. I. Damschen, R. M., Ewers, B. L. Foster, C. N. Jenkins, A. J. King, W. F. Laurance, D. J. Levey, C. R. Margules, and J. R. Townshend. 2015. Habitat fragmentation and its lasting impact on Earth's ecosystems. *Science Advances* 1: e1500052.

- Hahm, W. J., D. M. Rempe, D. N. Dralle, T. E. Dawson, S. M. Lovill, A. Bryk, D. L. Bish, J. Schieber, and W. E. Dietrich. 2019. Lithologically controlled subsurface critical zone thickness and water storage capacity determine regional plant community composition. *Water Resources Research* 55: 3,028–3,055.
- Hayes, S. A., M. H. Bond, C. V. Hanson, E. V. Freund, J. J. Smith, E. C. Anderson, A. J. Ammann, and R. B. MacFarlane. 2008. Steelhead growth in a small central California watershed, upstream and estuarine rearing patterns. *Transactions of the American Fisheries Society* 137: 114–128.
- Hayes, S., M. Bond, C. Hanson, A. Jones, A. Ammann, J. Harding, A. Collins, J. Perez, B. MacFarlane, and M. Bradford. 2011. Down, up, down and “smolting” twice? Seasonal movement patterns by juvenile steelhead (*Oncorhynchus mykiss*) in a coastal watershed with a bar closing estuary. *Canadian Journal of Fisheries and Aquatic Sciences* 68: 1,341–1,350.
- Heller, N. E., J. Kreidler, D. D. Ackerly, S. B. Weiss, A. Recinos, R. Branciforte, L. E. Flint, A. L. Flint, and E. Micheli. 2015. Targeting climate diversity in conservation planning to build resilience to climate change. *Ecosphere* 6: Article 65.
- Higgins, P. 2020. Sacramento pikeminnow South Fork Eel River: ERRP index reach 2020 trend monitoring survey. Eel River Recovery Project.
- Hilborn, R., T. P. Quinn, D. E. Schindler, and D. E. Rogers. 2003. Biocomplexity and fisheries sustainability. *Proceedings of the National Academy of Sciences* 100: 6,564–6,568.
- Holling, C. S. 1978. *Adaptive Environmental Assessment and Management*. John Wiley and Sons, New York, New York.
- Jayko, A. S., M. C. Blake Jr., R. J. McLaughlin, H. N. Ohlin, S. D. Ellen, and H. Kelsey. 1989. Reconnaissance geologic map of the Covelo 30- by 60-minute quadrangle, northern California: U.S. Geological Survey Miscellaneous Field Studies Map MF-2001, scale 1:100,000.
- Jefferts, K. B., P. K. Bergmann, and H. F. Fiscus. 1963. A coded wire tag identification system for macro-organisms. *Nature (London)* 198: 460–462.
- Jones, K. K., T. J. Cornwell, D. L. Bottom, L. A. Campbell, and S. Stein. 2014. The contribution of estuary-resident life histories to the return of adult *Onchorynchus kisutch*. *Journal of Fish Biology* 85: 52–80.
- Jones, K. R., J. E. M. Watson, H. P. Possingham, and C. J. Klein. 2016. Incorporating climate change into spatial conservation prioritization: A review. In *Biological Conservation*.
- Jording, J. 2020. Review of Southern Oregon / Northern California Coast Coho status and recovery: SONCC Coho workshop, June 9, 2020. NOAA Fisheries, West Coast Regional Office.
- Jorgensen, J. C., C. Nicol, C. Fogel, and T. J. Beechie. 2021. Identifying the potential of anadromous salmonid habitat restoration with life-cycle models. *PLoS ONE* 16: 1–22.
- Justin, W., and J. Black. 2019. An indigenous forward. In *State of Alaska Salmon and People (SASAP)*. State of Alaska salmon and people. NCEAS, Santa Barbara, California. Available at: <https://alaskasalmonandpeople.org/wp-content/uploads/2019/03/An-Indigenous-Forward.pdf>.

Kajtaniak, D., and K. Roberts. 2022. Sonar estimation of California Coastal (CC) Chinook Salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) abundance in the lower mainstem Eel River, Humboldt County, California. 2021-2022. Final Report.

Keeley, A. T. H., D. D. Ackerly, D. R. Cameron, N. E. Heller, P. R. Huber, C. A. Schloss, J. H. Thorne, and A. M. Merenlender. 2018. New concepts, models, and assessments of climate-wise connectivity. *Environmental Research Letters* 13: 073002.

Kelsey, H. M. 1980. A sediment budget and an analysis of geomorphic process in the Van Duzen River basin, north coastal California, 1941–1975: summary. *Geological Society of America Bulletin Part I* 91: 190–195.

Kelsey, H. M., M. Coghlan, J. Pitlick, and B. Best. 1995. Geomorphic analysis of streamside landslides in the Redwood Creek Basin, northwestern California. Pages J1–J12 in Nolan, K. M., H. M. Kelsey, and D. C. Marron, editors. *Geomorphic Processes and Aquatic Habitat in the Redwood Creek Basin, Northwestern California: U.S. Geological Survey Professional Paper 1454-J*.

Kinziger, A. P., R. J. Nakamoto, and B. C. Harvey. 2014. Local-scale invasion pathways and small founder numbers in introduced Sacramento pikeminnow (*Ptychocheilus grandis*). *Conservation Genetics* 15: 1–9.

Koski, K. V. 2009. The fate of Coho Salmon nomads: the story of an estuarine-rearing strategy promoting resilience. *Ecology and Society* 14: 4.

Kline, T. C., Jr., J. J. Goering, O. A. Mathisen, P. H. Poe, and P. L. Parker. 1990. Recycling of elements transported upstream by runs of Pacific salmon: I. $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ evidence in Sashin Creek, southeastern Alaska. *Canadian Journal of Fisheries and Aquatic Sciences* 47: 136–144.

Krosby, M., R. Norheim, and D. M. Theobald. 2015. Riparian climate corridors-identifying priority areas for conservation in a changing climate riparian climate-corridors: analysis extension, improvements, and validation.

Krosby, M., D. M. Theobald, R. Norheim, and B. H. McRae. 2018. Identifying riparian climate corridors to inform climate adaptation planning. *PLOS One* 13: e0205156.

Lambeck, R. J. 1997. Focal species: a multi-species umbrella for nature conservation. *Conservation Biology* 11: 849–856.

Lando, J. B., D. B. Booth, and S. C. Ralph. 2013. Monitoring investment strategy for the Salmon Recovery Funding Board. Prepared by Stillwater Sciences, Portland, Oregon, for Washington State Recreation and Conservation Office, Olympia.

Lawler, J. J., D. D. Ackerly, C. M. Albano, M. G. Anderson, S. Z. Dobrowski, J. L. Gill, N. E. Heller, R. L. Pressey, E. W. Sanderson, and S. B. Weiss. 2015. The theory behind, and the challenges of, conserving nature's stage in a time of rapid change. *Conservation Biology* 29: 618–629.

- Lestelle, L. C., L. E. Mobernd, and W. E. McConaha. 2004. Information structure of ecosystem diagnosis and treatment (EDT) and habitat rating rules for Chinook Salmon, Coho Salmon, and steelhead trout. Prepared by Mobernd Biometrics, Inc., Vashon Island, Washington.
- Lichatowich, J. L. 1999. *Salmon without rivers*. Island Press, Washington, D.C.
- Lindley, S. T., D. L. Erickson, M. L. Moser, G. Williams, O. P. Langness, B. W. McCovey Jr., M. Belchik, D. Vogel, W. Pinnix, J. T. Kelly, J. C. Heublein, and A. P. Klimley. 2011. Electronic tagging of Green Sturgeon reveals population structure and movements among estuaries. *Transactions of the American Fisheries Society* 140: 108–122.
- Lisi, P. J., D. E. Schindler, K. T. Bentley, and G. R. Pess. 2013. Association between geomorphic attributes of watersheds, water temperature, and salmon spawn timing in Alaskan streams. *Geomorphology* 185: 78–86.
- Loomis, C. 2021. Results of regional spawning ground surveys and estimates of salmonid redd abundance in the South Fork Eel River, Humboldt and Mendocino Counties, California, 2020–2021. California Coastal Salmonid Monitoring Program Annual Report prepared in partial fulfillment of CDFW Restoration Grant Program. Grantee Agreement Number: CMP-18R1001. State of California, Department of Fish and Wildlife.
- Lundquist, K., and B. Dolman. 2020. *Beaver in California: creating a culture of stewardship*. Prepared by Occidental Arts and Ecology Center WATER Institute, Occidental, California.
- Lundquist, K., B. Dolman, R. B. Lanman, M. M. Pollock, and J. R. Baldwin. 2013. The historic range of beaver in the north coast of California: a review of the evidence. Final Report. Prepared by Occidental Arts and Ecology Center WATER Institute for The Nature Conservancy.
- Mackey, B., and J. Roering. 2011. Sediment yield, spatial characteristics, and the long-term evolution of active earthflows determined from airborne LiDAR and historical aerial photographs, Eel River, California. *Geological Society of America Bulletin* 123: 1,560–1,576.
- MacKinnon, J. B. 2015. “Salvation fish” that sustained native people now needs saving. *National Geographic*. July 7, 2015.
- Margules, C. R., and R. L. Pressey. 2000. Systematic conservation planning. *Nature* 405: 243–253.
- Marmorek, D. 2001. Decision analysis of flow management in Clear Creek, Shasta County, California, presentation to the Bay-Delta Modeling Forum and Interagency Ecological Program Workshop, Asilomar, California, February 28, 2001.
- McBain Associates. 2017. *Eel River fishery restoration strategy*. Prepared by McBain Associates for Round Valley Indian Tribes.
- McElhany, P., M. H. Ruckelshaus, M. J. Ford, T. C. Wainwright, and E. P. Bjorkstedt. 2000. Viable salmonid populations and the recovery of Evolutionarily Significant Units. NOAA Technical Memorandum NMFS-NWFSC-42. Prepared by the Northwest Oceanic and Atmospheric Administration, Northwest Fisheries Science Center, Seattle, Washington.

McLaughlin, R. J., W. V. Sliter, N. O. Frederikson, W. P. Harbert, and D. S. McCulloch. 1994. Plate motions recorded in tectonostratigraphic terranes of the Franciscan Complex and evolution of the Mendocino triple junction, northwestern California. U.S. Geological Survey Bulletin 1997.

McLaughlin, R. J., S. D. Ellen, M. C. Blake Jr., A. S. Jayko, W. P. Irwin, K. R. Aalto, G. A. Carver, and S. H. Clarke, Jr. 2000. Geology of the Cape Mendocino, Eureka, Garberville, and southwestern part of the Hayfork 30- × 60-minute quadrangles and adjacent offshore area, northern California: U.S. Geological Survey Miscellaneous Field Studies Map MF-2336, scale 1:100,000, 6 sheets including maps, explanation, cross sections, pamphlet, <http://geopubs.wr.usgs.gov/map-mf/mf2336/>.

McLaughlin, R. J., B. C. Moring, C. S. Hitchcock, and Z. C. Valin. 2018. Framework geologic map and structure sections along the Bartlett Springs Fault Zone and adjacent area from Round Valley to Wilbur Springs, northern Coast Ranges, California (ver. 1.1, September 2018): U.S. Geological Survey Scientific Investigations Map 3395.

McNeely, C., J. C. Finlay, and M. E. Power. 2007. Grazer traits, competition, and carbon sources to a headwater-stream food web. *Ecology* 88: 391–401.

Metheny, M. 2020. Field notes for August 3, 2020. Adult Salmonid SONAR Monitoring Program South Fork Eel River, Tributary to Eel River.

Metzger, J. P., and P. H. S. Brancalion. 2013. Challenges and opportunities in applying a landscape ecology perspective in ecological restoration: A powerful approach to Shape Neolandscapes. *Natureza a Conservacao* 11: 103–107.

Michel, C. J. 2019. Decoupling outmigration from marine survival indicates outsized influence of streamflow on cohort success for California's Chinook Salmon populations. *Canadian Journal of Fisheries and Aquatic Sciences* 76: 1,398–1,410.

Miller, B. A., and S. Sadro. 2003. Residence time and seasonal movements of juvenile Coho Salmon in the ecotone and lower estuary of Winchester Creek, South Slough, Oregon. *Transactions of the American Fisheries Society* 132: 546–559.

Moilanen, A., K. A. Wilson, and H. P. Possingham. 2009. *Spatial conservation prioritization: Quantitative methods and computational tools*. Oxford University Press.

Moore, J. W., M. McClure, L. A. Rogersand, and D. E. Schindler. 2010. Synchronization and portfolio performance of threatened salmon. *Conservation Letters* 3: 340–348.

Moore, J. W., J. D. Yeakel, D. Peard, J. Lough, and M. Beere. 2014. Life-history diversity and its importance to population stability and persistence of a migratory fish: steelhead in two large North American watersheds. *Journal of Animal Ecology*: 83: 1,035–1,046.

Mosa, A. S. M., I. Yoo, and J. C. Parker. 2015. Online electronic data capture and research data repository system for clinical and translational research. *Missouri Medicine* 112:46–52.

Moyle, P. B., R. M. Quiñones, J. V. Katz, and J. Weaver. 2015. *Fish Species of Special Concern in California*. California Department of Fish and Wildlife, Sacramento, California.

- Moyle, P. R. Lusardi, P. Samuel, and J. Katz. 2017. State of the salmonids II: Status of California's emblematic fishes. 2017. Center for Watershed Sciences; University of California, Davis; and California Trout, San Francisco, California.
- Muhs, D. R., R. M. Thorson, J. J. Clague, W. H. Mathews, P. F. McDowell, and H. M. Kelsey. 1987. Pacific Coast and mountain system. Pages 517–581 in W. L. Graf, editor, Geomorphic Systems of North America. Geological Society of America, Boulder, Colorado.
- Naiman, R. J., C. A. Johnston, and J. C. Kelley, 1988. Alteration of North American streams by Beaver. *BioScience* 38: 753–762.
- Nakamoto, R. J., and B. C. Harvey. 2003. Spatial, seasonal, and size dependent variation in the diet of Sacramento Pikeminnow in the Eel River, northwestern California. *California Fish and Game* 89: 30–45.
- Nakamoto, R. J., T. T. Kisanuki, and G. H. Goldsmith. 1995. Age and growth of Klamath River Green Sturgeon (*Acipenser medirostris*). Project #93-FP-13. U.S. Fish and Wildlife Service.
- NCRP (North Coast Resource Partnership). 2020. North Coast Resource Partnership Plan—Healthy communities, functional ecosystems, and vibrant economies, Phase IV. January 2020. Prepared for California Department of Water Resources. Available at: https://northcoastresourcepartnership.org/site/assets/uploads/2020/02/NCRP_Plan_IV_January_2020.pdf.
- Nel, J. L., B. Reyers, D. J. Roux, and R. M. Cowling. 2009. Expanding protected areas beyond their terrestrial comfort zone: Identifying spatial options for river conservation. *Biological Conservation* 142: 1,605–1,616.
- NMFS (National Marine Fisheries Service). 2006. Endangered and threatened wildlife and plants: threatened status for Southern Distinct Population Segment of North American Green Sturgeon, Final Rule. *Federal Register* 71: 17,757–17,766.
- NMFS. 2014. Final Recovery Plan for the Southern Oregon/Northern California Coast Evolutionarily Significant Unit of Coho Salmon (*Oncorhynchus kisutch*). National Marine Fisheries Service, Arcata, California.
- NMFS. 2016. Coastal Multispecies Recovery Plan: California Coastal Chinook Salmon ESU, Northern California Steelhead DPS, and Central California Coast Steelhead DPS. National Marine Fisheries Service, West Coast Region, Santa Rosa, California.
- NOAA (National Oceanic and Atmospheric Administration). 2022. Salmonid egg-to-fry survival and capture methods. Bibliography. NCRL subject guide 2023-02.
- Ohlin, H. N., R. J. McLaughlin, B. C. Moring, and T. L. Sawyer. 2010. Geologic map of the Bartlett Springs Fault Zone in the vicinity of Lake Pillsbury and adjacent areas of Mendocino, Lake, and Glenn Counties, California: U.S. Geological Survey Open-File Report 2010–1301, scale 1:30,000.
- Office of the Governor of California. 2024. California salmon strategy for a hotter, drier future: Restoring aquatic ecosystems in the age of climate change. Released by Governor Newsom on January 30, 2024. Lead Agency: California Department of Fish and Wildlife; Primary Partners: Tribal Nations, Water Boards, Department of Water Resources, California Department of

Transportation, and Wildlife Conservation Board. Available at: <https://www.gov.ca.gov/wp-content/uploads/2024/01/Salmon-Strategy-for-a-Hotter-Drier-Future.pdf>.

Parish, M. M. 2016. Beaver bank lodge use, distribution and influence on salmonid rearing habitats in the Smith River, California. Master's thesis, Humboldt State University, Arcata, California.

Parmesan, C., G. Yohe, and J. E. Andrus. 2003. A globally coherent fingerprint of climate change impacts across natural systems.

Pearson, R. G., and T. P. Dawson. 2005. Long-distance plant dispersal and habitat fragmentation: Identifying conservation targets for spatial landscape planning under climate change. *Biological Conservation* 123: 389–401.

Perry, R.W., Plumb, J.M., Jones, E.C., Som, N.A., Hetrick, N.J., and T.B. Hardy. 2018. Model structure of the stream salmonid simulator (S3)—A dynamic model for simulating growth, movement, and survival of juvenile salmonids: U.S. Geological Survey Open-File Report 2018-1056. <https://doi.org/10.3133/ofr20181056>.

Peterson, N. P. 1982. Immigration of juvenile Coho Salmon (*Oncorhynchus kisutch*) into riverine ponds. *Canadian Journal of Fisheries and Aquatic Sciences* 39: 1,308–1,310.

Peterson, G. D, G. S. Cumming, and S. R. Carpenter. 2003. Scenario planning: a tool for conservation in an uncertain world. *Conservation Biology*, 17: 358–366.

Peterson, L. K., M. L. Jones, T. O. Brenden, C. S. Vandergoot, and C. C. Krueger. 2021. Evaluating methods for estimating mortality from acoustic telemetry data. *Canadian Journal of Fisheries and Aquatic Sciences* 78: 1,444–1,454.

PG&E (Pacific Gas and Electric Company). 2017. Pottery Valley Hydroelectric Project FERC Project No. 77, Relicensing Pre-Application Document (PAD). Volume 1: Public Information Sections 107.

PG&E. 2020. Pikeminnow monitoring and suppression results, 2019. Addressing NMFS RPA Section G.2 and Measures 1 and 2 (in part). Potter Valley Hydroelectric Project, FERC Project No. 77.

PG&E. 2023. Potter Valley Hydroelectric Project, FERC Project No. 77: Initial Draft Surrender Application and Conceptual Decommissioning Plan. Prepared by Stantec Consulting Services, Sacramento, California. Prepared for Pacific Gas and Electric Company, Auburn California.

Pickard, D., J. Alvarez, K. De Juilio, L. Gogan, J. Lee, K. Lindke, S. Naman, C. Smith, N. Som, and P. Zedonis. 2022. Trinity River Restoration Program: Science Plan, Weaverville, California.

Pollock M. M., M. Heim, and D. Werner. 2003. Hydrologic and geomorphic effects of beaver dams and their influence on fishes. Pages 213–233 in Gregory S.V., K. Boyer, A. Gurnell, editors. *The Ecology and Management of Wood in World Rivers*. American Fisheries Society, Bethesda, Maryland.

- Pollock M. M., G. R. Pess, T. J. Beechie, and D. R. Montgomery. 2004. The importance of beaver ponds to coho salmon production in the Stillaguamish River Basin, Washington, USA. *North American Journal of Fisheries Management* 24: 749–760.
- Pollock M. M., T. J. Beechie, and C. E. Jordan. 2007. Geomorphic changes upstream of beaver dams in Bridge Creek, an incised stream in the interior Columbia River basin. *Earth Surface Processes and Landforms* 32: 1,174–1,185.
- Pollock, M. M., T. J. Beechie, J. M. Wheaton, C. E. Jordon, N. Bouwes, N. Weber, and C. Volk. 2014. Using beaver dams to restore incised stream ecosystems. *BioScience* 64: 279–290.
- Polvi, L. E., L. Lind, H. Persson, A. Miranda-Melo, F. Pilotto, X. Su, and C. Nilsson. 2020. Facets and scales in river restoration: nestedness and interdependence of hydrological, geomorphic, ecological, and biogeochemical processes. *Journal of Environmental Management* 265: 110288.
- Possingham, H., I. Ball, and S. Andelman. 2000. Mathematical methods for identifying representative reserve networks. *In Quantitative Methods for Conservation Biology*. Springer, New York, New York.
- Power, M. E., M. S. Parker, and W. E. Dietrich. 2008. Seasonal reassembly of a river food web: floods, droughts, and impacts of fish. *Ecological Monographs* 78: 263–282.
- Power, M. E., K. Bouma-Gregson, P. Higgins, and S. M. Carlson. 2015. The thirsty Eel: summer and winter flow thresholds that tilt the Eel River of Northwestern California from Salmon supporting to cyanobacterially degraded states. *Copeia* 1: 200–2011.
- Power, M. E., J. R. Holomuzki, and R. L. Lowe. 2013. Food webs in Mediterranean rivers. *Hydrobiologia* 719: 119–136.
- Power, M., R. Lowe, P. Furey, J. Welter, M. Limm, J. Finlay, C. Bode, S. Chang, M. Goodrich, and J. Sculley. 2009. Algal mats and insect emergence in rivers under Mediterranean climates: Towards photogrammetric surveillance. *Freshwater Biology* 54: 2,101–2,115.
- Peterson, L. K., M. L. Jones, T. O. Brenden, C. S. Vandergoot, and C. C. Krueger. 2021. Evaluating methods for estimating mortality from acoustic telemetry data. *Canadian Journal of Fisheries and Aquatic Sciences* 78: 1,444–1,454.
- Pressey, R. L., and M. C. Bottrill. 2009. Approaches to landscape- and seascape-scale conservation planning: Convergence, contrasts and challenges. *ORYX* 43: 464–475.
- Railsback, S. F., D. Ayllón, and B.C. Harvey. 2021. InSTREAM 7: Instream flow assessment and management model for stream trout. *River Research and Applications* 37: 1,294–1,302.
- Rebenack, J. J., S. Ricker, C. Anderson, M. Wallace, and D. M. Ward. 2015. Early emigration of juvenile Coho Salmon: implications for population monitoring. *Transactions of the American Fisheries Society* 144: 163–172.
- Reese, C. D., and B. C. Harvey. 2002. Temperature-dependent interactions between juvenile steelhead and Sacramento Pikeminnow in laboratory streams. *Transactions of the American Fisheries Society* 131: 599–606.

Reeves, G H., J. D. Hall, T. D. Roelofs, T. L. Hickman, and C. O. Baker. 1991. Rehabilitating and modifying stream habitats. Pages 519–557 in W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society, Special Publication 19, Bethesda, Maryland.

Reimchen, T. E., D. D. Mathewson, M. D. Hocking, J. Moran, and D. Harris. 2003. Isotopic evidence for enrichment of salmon-derived nutrients in vegetation, soil, and insects in riparian zones in coastal British Columbia. American Fisheries Society Symposium. American Fisheries Society, Bethesda, Maryland.

Resh, V. H., A. V. Brown, A. P. Covich, M. E. Gurtz, H. W. Li, G. W. Minshall, S. R. Reice, A. L. Sheldon, J. B. Wallace, and R. C. Wissmar. 1988. The role of disturbance in stream ecology. *Journal of the North American Benthological Society* 7: 433–455.

Roering, J., B. Mackey, A. Handwerger, A. Booth, D. Schmidt, G. Bennett, C. Cerovski-Darriau. 2015. Beyond the angle of repose: A review and synthesis of landslide processes in response to rapid uplift, Eel River, Northern California. *Geomorphology* 236: 109–131.

Roff, D. A. 1992. The evolution of life histories. Chapman and Hall, New York, New York.

Roni, P., T. Beechie, S. Schmutz, and S. Muhar. 2013. Prioritization of watersheds and restoration projects. Pages 189–214 in P. Roni and T. Beechie, editors. *Stream and Watershed Restoration: A Guide to Restoring Riverine Processes and Habitats*. Wiley-Blackwell, Chichester, UK.

Roni, P., P. J. Anders, T. J. Beechie, , and D. J. Kaplowe. 2018. Review of tools for identifying, planning, and implementing habitat restoration for Pacific Salmon and Steelhead. *North American Journal of Fisheries Management* 38: 355–376.

Roni, P., J. Steele, K. Morinaga, A. Towne, I. Wilson, and M.J. Camp. 2023. The Grande Ronde Model Watershed: Integrating Science into Restoration Implementation and Adaptive Management. *Environmental Management* 72: 221–245.

Rossi, G. J., M. E. Power, S. M. Carlson, and T. E. Grantham. 2022. Seasonal growth potential of *Oncorhynchus mykiss* in streams with contrasting prey phenology and streamflow. *Ecosphere* 13: e4211.

Rossi, G. J., J. R. Bellmore, J. B. Armstrong, C. Jeffres, S. M. Naman, S. M. Carlson, T. E. Grantham, J. M. Kaylor, S. White, J. Katz, M. E. Power. 2024. Foodscapes for salmon and other mobile consumers in river networks. *Bioscience* 10.1101/2023.08.30.555604.

Rouget, M., R. M. Cowling, A. T. Lombard, A. T. Knight, and G. I. H. Kerley. 2006. Designing large-scale conservation corridors for pattern and process. *Conservation Biology* 20: 549–561.

Sabo, J. L., J. C. Finlay, T. Kennedy, and D. M. Post. 2010. The role of discharge variation in scaling of drainage area and food chain length in rivers. *Science* 330: 965–967.

Salviano, I. R., F. R. Gardon, and R. F. dos Santos. 2021. Ecological corridors and landscape planning: a model to select priority areas for connectivity maintenance. *Landscape Ecology* 36: 3,311–3,328.

Schindler, D. E., R. Hilborn, B. Chasco, C. P. Boatright, T. P. Quinn, L. A. Rogers, and M. S. Webster. 2010. Population diversity and the portfolio effect in an exploited species. *Nature* 465: 609–613.

Schloss, C. A., D. R. Cameron, B. H. McRae, D. M. Theobald, and A. Jones. 2022. “No-regrets” pathways for navigating climate change: planning for connectivity with land use, topography, and climate. *Ecological Applications* 32: e02468.

SEC (Steiner Environmental Consulting). 1998. Potter Valley Project Monitoring Program (FERC No. 77, Article 39), effects of operations on upper Eel River anadromous salmonids. Final Report. March 1998. Prepared for Pacific Gas and Electric Company, Technical and Ecological Services, San Ramon, California.

Sedell, J. R., G. H. Reeves, F. R. Hauer, J. A. Stanford, and C. P. Hawkins. 1990. Role of refugia in recovery from disturbance: modern fragmented and disconnected river systems. *Environmental Management* 14: 711–724.

Serra, N., A. Kockel, E. T. Game, H. Grantham H. P. Possingham, and J. McGowan. 2020. Marxan user manual for Marxan version 2.43 and above. The Nature Conservancy (TNC), Arlington, Virginia, and Pacific Marine Analysis and Research Association (PacMARA), Victoria, British Columbia, Canada.

Simenstad, C. A., J. L. Burke, J. E. O’Connor, C. Cannon, D. W. Heatwole, M. F. Ramirez, I. R. Waite, T. D. Counihan, and K. L. Jones. 2011. Columbia River estuary ecosystem classification—concept and application: U.S. Geological Survey Open-File Report 2011-1228.

Sedell, J. R., G. H. Reeves, F. R. Hauer, J. A. Stanford, and C. P. Hawkins. 1990. Role of refugia in recovery from disturbance: modern fragmented and disconnected river systems. *Environmental Management*. 14: 711–724.

SJRRP (San Joaquin River Restoration Program). 2007. Implementing the stipulation of settlement in NRDC v. Rodgers and Bureau of Reclamation, Program Management Plan, May 1, 2007.

Skeesick, D. G. 1970. The fall immigration of juvenile Coho Salmon into a small tributary. Research Report Fish Commission of Oregon 2: 90–95.

Smith, W. 2022. Round Valley Indian Tribes Middle Fork Eel River DIDSON Pilot Program: October 2021–March 2022 Summary of Operations, Results, and Recommended Refinements, December 2022.

Soto, T., D. Hillemeier, S. Silloway, A. Corum, A. Antonetti, M. Kleman, and L. Lestelle. 2016. The role of the Klamath River mainstem corridor in the life history and performance of juvenile Coho Salmon (*Oncorhynchus kisutch*). Prepared for U.S. Bureau of Reclamation Mid-Pacific Region, Klamath Area Office.

Soule, M. E., and J. Terborgh. 1999. Conserving nature at regional and continental scales—a scientific program for North America. *BioScience* 49: 809–817.

South Fork Eel River SHaRP Collaborative. 2021. SHaRP Plan for the South Fork Eel River.

Spencer, W. D., P. Beier, K. Penrod, K. Winters, C. Paulman, H. Rustigian-Romsos, J. Strittholt, M. Parisi, and A. Pettler. 2010. California Essential Habitat Connectivity Project: a strategy for conserving a connected California. Prepared for California Department of Transportation, California Department of Fish and Game, and Federal Highways Administration.

Starfield, A. M., and A. L. Bleloch. 1986. Building models for conservation and wildlife management. Macmillan, New York.

Steidl, R. J., W. W. Shaw, and P. Fromer. 2009. A science-based approach to regional conservation planning. Pages 217–322 in A. X. Esparza and G. McPherson, editors. The Planner's Guide to Natural Resource Conservation. Springer, New York, New York.

Stillwater Sciences. 2014. A conceptual framework for understanding factors limiting Pacific Lamprey production in the Eel River basin. Prepared by Stillwater Sciences, Arcata, California, for Wiyot Tribe, Loleta, California.

Stillwater Sciences. 2021. Sediment supply to the upper Eel River. Prepared by Stillwater Sciences, Arcata, California for the Two-Basin Solution Partners. November.

Stillwater Sciences. 2023. South Fork Ten Mile River Coho Salmon Restoration Project: Phase 1 validation monitoring and life history characterization. Final Report. Prepared by Stillwater Sciences, Arcata, California for The Nature Conservancy, San Francisco, California.

Stillwater Sciences and McBain Associates. 2021. Fisheries restoration framework for the Eel River watershed and Phase 1 Scope of Work. Prepared for Two-Basin Solution Partners. November.

Stillwater Sciences and Wiyot Tribe Natural Resources Department. 2017. Status, distribution, and population of origin of Green Sturgeon in the Eel River: results of 2014–2016 studies. Prepared by Stillwater Sciences, Arcata, California, and Wiyot Tribe Natural Resources Department, Loleta, California, for National Oceanic and Atmospheric Administration, Fisheries Species Recovery Grants to Tribes, Silver Springs, Maryland.

Stillwater Sciences and Wiyot Tribe Natural Resources Department. 2020. Evaluation of Population Monitoring and Suppression Strategies for Invasive Sacramento Pikeminnow in the South Fork Eel River. Prepared by Stillwater Sciences, Arcata, California and Wiyot Tribe Natural Resources Department, Table Bluff, California for U.S. Fish and Wildlife Service, Sacramento, California.

Stock, J. D., and W. E. Dietrich. 2006. Erosion of steepland valleys by debris flows: Geological Society of America Bulletin 118: 1,125–1,148.

Sturrock, A. M., J. D. Wikert, T. Heyne, C. Mesick, A. E. Hubbard, T. M. Hinkelman, P. K. Weber, G. E. Whitman, J. J. Glessner, R. C. Johnson. 2015. Reconstructing the migratory behavior and long-term survivorship of juvenile Chinook Salmon under contrasting hydrologic regimes. PLOS One 10: e0122380.

Swain, D. L., B. Langenbrunner, J. D. Neelin, and A. Hall. 2018. Increasing precipitation volatility in twenty-first century California. Nature Climate Change 8: 427–433.

- Swales, S., R. B. Lauzier, and C. D. Levings. 1986. Winter habitat preferences of juvenile salmonids in two interior rivers in British Columbia. *Canadian Journal of Zoology* 64: 1,506–1,514.
- Tallis, H., J. Fargione, E. Game, R. McDonald, L. Baumgarten, N. Bhagabati, R. Cortez, B., Griscom, J. Higgins, C. M. Kennedy, J. Kiesecker, T. Kroeger, T. Leberer, J. McGowan, L. Mandle, Y. J. Masuda, S. A. Morrison, S. Palmer, R. Shirer, and H. P. Possingham. 2021. Prioritizing actions: spatial action maps for conservation. *Annals of the New York Academy of Sciences* 1505: 118–141.
- Tappel, P. D., and T. C. Bjornn. 1983. A new method of relating size of spawning gravel to salmonid embryo survival. *North American Journal of Fisheries Management* 3: 123–135.
- Tetra Tech. 2017. Catherine Creek and Upper Grande Ronde River Atlas Prioritization Framework: User's Manual. Prepared by Tetra Tech, Inc., Bothell, Washington for Bonneville Power Administration and Atlas Partners. Available at: <https://paluut.ctuir.org/services/uploads/P/2228/CC%20and%20UGR%20Atlas%20Users%20Manual%20Final%2020171024.pdf>.
- Theobald, D. M., C. Kennedy, B. Chen, J. Oakleaf, S. Baruch-Mordo, J. Kiesecker. 2020. Earth transformed: detailed mapping of global human modification from 1990 to 2017. *Earth System Science Data* 12: 1,953–1,972.
- Torgersen, C. E., C. le Pichon, A. H. Fullerton, S. J. Dugdale, J. J. Duda, F. Giovannini, É. Tales, J. Belliard, P. Branco, N. E. Bergeron, M. L. Roy, D. Tonolla, N. Lamouroux, H. Capra, and C. V. Baxter. 2022. Riverscape approaches in practice: perspectives and applications. *Biological Reviews* 97: 481–504.
- TRRP and ESSA (Trinity River Restoration Program and ESSA Technologies Ltd.). 2009. Trinity River Integrated Assessment Plan, Version 1.0. Draft report prepared for the Trinity River Restoration Program, Weaverville, California.
- Underwood, A. J.. 1992. Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. *Journal of Experimental Marine Biology and Ecology* 161: 145–178.
- Uno, H., and M. E. Power. 2015. Mainstem-tributary linkages by mayfly migration help sustain salmonids in a warming river network. *Ecology Letters* 18: 1,012–1,020.
- USEPA (U.S. Environmental Protection Agency). 1999a. South Fork Eel River total maximum daily loads for sediment and temperature. Prepared by EPA, Region IX, San Francisco, California.
- USEPA. 1999b. Van Duzen River and Yager Creek total maximum daily load for sediment. Prepared by EPA, Region IX, San Francisco, California.
- USEPA. 2002. North Fork Eel River total maximum daily loads for sediment and temperature. Prepared by EPA, Region IX, San Francisco, California.
- USEPA. 2003. Middle Fork Eel River total maximum daily loads for temperature and sediment. Prepared by EPA, Region IX, San Francisco, California.

- USEPA. 2004. Upper Main Eel River and tributaries (including Tomki Creek, Outlet Creek and Lake Pillsbury) total maximum daily loads for sediment and temperature. Prepared by EPA, Region IX, San Francisco, California.
- USEPA. 2007. Lower Eel River total maximum daily loads for temperature and sediment. Prepared by EPA, Region IX, San Francisco, California.
- USFWS and HVT (U.S. Fish and Wildlife Service and Hoopa Valley Tribe). 1999. Trinity River Flow Evaluation Final Report: a report to the Secretary of Interior, Washington DC, Appendix N: Adaptive Environmental Assessment and Management.
- USFWS, Reclamation, HVT, and Trinity County (U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, Hoopa Valley Tribe, and Trinity County). 2000. Trinity River Mainstem Fishery Restoration Final Environmental Impact Statement/Environmental Impact Report, Appendix C: Implementation Plan for the preferred alternative of the Trinity River EIS/EIR.
- Van Kirk, S. 1996. Eel River fisheries articles and excerpts, 1854–1890. Available at: https://www.krisweb.com/krisumboldtбай/krisdb/html/krisweb/humbay_historic/eelfish1.htm.
- Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 130–137.
- Volkhardt, G. C., S. L. Johnson, B. A. Miller, T. E. Nickelson, and D. E. Seiler. 2007. Rotary screw traps and inclined plane screen traps. Pages 235–266 in D. H. Johnson, B. M. Shrier, J. S. O’Neal, J. A. Knutzen, X. Augerot, T. A. O’Neil, and T. N. Pearsons. *The Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations*. American Fisheries Society, Bethesda, Maryland.
- Wallace, M., S. Ricker, J. Garwood, A. Frimodig, and S. Allen. 2015. Importance of the stream-estuary ecotone to juvenile Coho Salmon (*Oncorhynchus kisutch*) in Humboldt Bay, California. *California Fish and Game* 101: 241–266.
- Walters, C. J. 1986. *Adaptive management of renewable resources*. Blackburn Press, Caldwell, New Jersey.
- White, J. L., and B. C. Harvey. 2001. Effects of an introduced piscivorous fish on native benthic fishes in a coastal river. *Freshwater Biology*. 46: 987–995.
- Williams, B. K., R. C. Szaro, and C. D. Shapiro. 2009. *Adaptive Management: The U.S. Department of the Interior Technical Guide*. Adaptive Management Working Group, U.S. Department of the Interior, Washington, DC.
- Wigington, P. J., J. L. Ebersole, M. E. Colvin, S. G. Leibowitz, B. Miller, B. Hansen, and J. E. Compton. 2006. Coho Salmon dependence on intermittent streams. *Frontiers in Ecology and the Environment* 4: 513–518.
- Wiyot Tribe Natural Resources Department and Stillwater Sciences. 2016. *Wiyot Tribe Pacific Lamprey Adaptive Management Plan framework*. Prepared by Wiyot Tribe Natural Resources Department, Table Bluff Reservation, Loleta, California, and Stillwater Sciences, Arcata, California, for U.S. Fish and Wildlife Service, Sacramento, California.

Wohl, E., J. Castro, B. Cluer, D. Merritts, P. Powers, B. Staab, and C. Thorne. 2021. Rediscovering, reevaluating, and restoring lost river-wetland corridors. *Frontiers in Earth Science* 9: Article 653623.

Yoshiyama, R. M., and P. B. Moyle. 2010. Historical review of Eel River anadromous salmonids, with emphasis on Chinook Salmon, Coho Salmon, and steelhead. UC Davis, Center for Watershed Sciences.

Zavaleta, E., and N. Heller. 2009. Chapter III.18: Responses of communities and ecosystems to global changes. *Princeton Guide to Ecology* Princeton University Press.

Zimmerman, M. S., K. Krueger, B. Ehinger, P. Roni, R. E. Bilby, J. Walter, and T. Quinn. 2012. Intensively monitored watersheds program: an updated plan to monitor fish and habitat responses to restoration actions in the Lower Columbia watersheds. FPA 12-03. Washington Department of Fish and Wildlife, Olympia, Washington.