Klamath Dam Removal Science Coordination Workshop

Summary Report

Hosted by the Yurok Tribe and Karuk Tribe

February 12-13, 2020

Medford, Oregon

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Executive Summary

Historically, the Klamath River was the third largest salmon-producing river on the West Coast of the continental United States. The river's rich resources and surrounding watershed have sustained native people since time immemorial. The health of the Klamath Basin ecosystem is intertwined with the well-being and identity of native people throughout the watershed, including the Yurok and Karuk people. Agricultural development, water diversions, resource extraction, over-fishing, and dams have degraded the river ecosystem and caused dramatic declines to native fish populations. The indigenous people of the Klamath Basin have suffered greatly as the river's health and fisheries have declined. In a historic effort to restore ecosystem function and fisheries, four Klamath River hydroelectric dams are slated for removal, representing the largest dam removal effort in US history.

Despite the unprecedented scope of the Klamath dam removal, formal coordination of dam removal research and monitoring has been limited. The Klamath River Basin, along with the dams slated for removal, straddle two states, a prominent mountain range, and the jurisdiction and interest of numerous state, federal, and tribal natural resource and land management agencies. With less than two years until the anticipated start of dam removal (2023 as of the time this publication), there is an urgent need to identify and prioritize research questions, plan data collection that will address these pressing questions, and begin collecting data in an efficient and well-coordinated manor.

Despite a relatively robust network of monitoring programs on the Klamath River, most existing monitoring was not designed to assess the results of dam removal on aquatic resources. Data from existing programs can be used to describe the condition of the river with dams in place and inform predictions following dam removal, however coordination is needed to integrate existing data collection efforts with new studies, so efficient study designs are implemented to assess the short and long-term effects of dam removal upon the Klamath River ecosystem.

Similarly, the Klamath River Renewal Corporation's (KRRC – the entity whose sole mission is to remove the Klamath River Dams to restore a free-flowing river) dam removal effort includes monitoring activities associated with dam removal in order to comply with federal, state, and local permit conditions. However, these activities are limited and designed as independent survey efforts to address specific questions rather than to address larger-scale ecological questions. Further, monitoring requirements associated with dam removal are primarily focused within the hydroelectric reach or on Endangered Species Act-listed species rather than addressing watershed-scale and whole ecosystem changes.

Support and coordination for more general understanding of how river geomorphology, ecology, and fisheries will recover following approximately 100 years of impoundment does not exist on a broad scale. Tribal governments, federal, state, and regional government agencies, non-profits, and academic institutions are now attempting to address the significant gaps in knowledge about river recovery following large-scale dam removal on the Klamath River with limited resources. In many cases, our understanding of the ecological effects of dam removal on the Klamath will be enhanced by current monitoring and planned future data collection, where researchers can leverage these existing data sources to address questions related to large-scale dam removal.

To address the current lack of coordination, the Yurok and Karuk Tribes initiated a process in the winter of 2020 to coordinate dam removal science and monitoring focused on fisheries, water quality, and physical processes. On February 12th and 13th, 2020, approximately 60 natural resource professionals from over 20 Tribes, agencies, and organizations met to discuss monitoring and research of the planned dam removals. The February workshop was preceded by a half-day meeting in November to begin discussions and gather feedback about planning an effective workshop, a webinar about the unique geomorphic conditions of the Klamath River, and a survey of meeting participants to gather preliminary information about their involvement and interest in dam removal science and monitoring related to aquatic resources. At the two-day workshop, invited speakers involved in research and monitoring of other large dam removals shared their experiences assessing the effects of dam removal.

Formal breakout groups were formed at the workshop to develop and document research priorities for the Klamath River dam removal. These groups were divided by discipline, with experts from each discipline contributing their perspectives of which monitoring efforts and studies were most needed to document changes to the Klamath River following dam removal. The four breakout groups included 1) Geomorphology and hydrology; 2) Water quality and lower trophic-level ecology; 3) Fisheries; and 4) Riparian, wildlife, and upland ecology. Each breakout group created a list of research questions followed by observations and monitoring needs that would help address each question. A large portion of this document is dedicated to summarizing the outcomes from these breakout groups.

River restoration is often carried out with limited effectiveness monitoring. The pending Klamath River dam removals offer a unique opportunity to conduct thorough, well-coordinated monitoring and gain a mechanistic understanding of ecosystem recovery following dam removal. Insights gained from this monumental restoration action will help inform future management and restoration goals on the Klamath River and rivers around the world.

1 Introduction

1.1 Meeting Purpose and Overview

On February 12th and 13th, 2020, approximately 60 natural resource professionals from over 20 Tribal governments, federal, state, and regional agencies, as well as other aquatic resource-focused organizations, met to discuss monitoring and research associated with the removal of hydroelectric dams from the Klamath River. The removal of the four dams will be an unprecedented restoration effort, representing the world's largest dam removal effort to date, which will reconnect salmon and other native fish to historic habitat while also improving water quality and physical processes within the river. The removal of these dams and their associated reservoirs will open up over 420 miles[1,2] of historic anadromous fisheries habitat above the dams, restore a dewatered and hydro-peaked river channel to a free-flowing river, and improve water quality and habitat condition in the 190 miles of river below the dams. Expected improvements to fisheries and ecosystem function will benefit local communities, including members of the Indigenous Tribes who have relied on a healthy Klamath River for millennia.

Despite the unprecedented scope of the Klamath dam removal, formal coordination around planning research and monitoring of the dam removal has been limited. The Klamath River Watershed and the dams to be removed straddle two states, a prominent mountain range, and the jurisdiction and interest of numerous state, federal, and tribal natural resource and land management agencies. Uncertainty surrounding the timing of dam removal, paired with limited financial resources for monitoring the effects of the dam removal has resulted in minimal formal coordination regarding dam removal monitoring on the Klamath River. With less than two years until the anticipated start of dam removal (2023 as of the time this publication), there is an urgent need to prioritize research and monitoring goals, plan data collection that will address these pressing questions, and initiate data collection in an efficient and well-coordinated manor.

Monitoring ecosystem recovery associated with dam removal on the Klamath River is a monumental opportunity that will inform future management and restoration on the Klamath River and rivers around the world. River restoration is often carried out with limited effectiveness monitoring. This limited monitoring, often of short duration and limited scope, can misrepresent the long-term results of restoration, or ignore the specific mechanisms associated with restoration, that change the ecosystem. Conducting thorough, well-coordinated monitoring of dam removal will lead to mechanistic understanding of ecosystem recovery. Documenting ecosystem response to dam removal will help inform future restoration and water management of the Klamath River, and can provide useful information to inform restoration in other rivers. Considering the long and winding path that large dam removals

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[1] Huntington, C.W. 2004. Klamath River flows within the J.C. Boyle Bypass and below the J.C. Boyle Powerhouse. Clearwater BioStudies, Canby, Oregon.
[2] Huntington, C.W. 2006. Estimates of anadromous fish runs above the site of Iron Gate Dam. Clearwater BioStudies, Inc., Canby, Oregon.

often take, monitoring ecosystem recovery should be part of the restoration efforts and should start as soon as possible to establish baseline conditions from which to compare the effects of this monumental restoration of the Klamath River.

1.2 Klamath Dam Removal Background and Karuk and Yurok Tribal Importance

1.2.1 Yurok and Karuk Tribal Connection to the Klamath River and Dam Removal

The indigenous people of the Klamath River Basin have relied upon the river's resources since time immemorial. Throughout history and continuing today, the Yurok and Karuk Tribes, among others, have depended upon the Klamath River for sustenance, culture, commerce, and religion. The Klamath River is integral to the indigenous way of life and the health of the Klamath Basin ecosystem is intertwined with the well-being and identity of Yurok and Karuk people.

The Klamath River has always been the cornerstone of Yurok culture. The importance of the river to the Yurok Tribe was not formally recognized by the federal government, however, until it demarcated the boundaries of the Yurok Reservation in 1855. The reservation was designed to extend one mile out from each side of the lower 44 miles of the Klamath River, making the river the central feature of the Tribe's homeland. The importance of the Klamath River to the Yurok People was also noted by the Ninth Circuit Court of Appeals who opined that the salmon fishery of the Yurok Tribe is "not much less necessary to the existence of the Indians than the atmosphere they breathed." The same court also confirmed that the executive orders that resulted in the creation of the Yurok Reservation also vested the Yurok Tribe with federally reserved fishing rights.

The Karuk Tribe is a historic tribe, and Karuk People today live in their ancestral homelands along the middle parts of the Klamath River. Since time immemorial, the Karuk people continue to practice their cultural traditions including fishing, gathering, hunting, basketmaking and ceremonies. Even though the Tribe has had a government-to-government relationship with the US federal government since 1851, the Tribe's treaties were not ratified by congress, so the Karuk Tribe has no formal reservation. Therefore, the Karuk Tribe manages cultural and natural resources within and upstream of Karuk Aboriginal Territory and on Tribal trust parcels of land. The Karuk Tribe is the second-largest tribe in California, with over 3,700 enrolled members.

In light of the importance of the river to Yurok and Karuk Tribes, one of the highest tribal priorities is to protect the resources of the river and to restore the anadromous fish runs of the Klamath Basin. By restoring anadromous fish runs, the Tribes will strengthen and re-establish traditional connections to the Klamath River and maintain subsistence, cultural, commercial, and religious uses. Historically, the river was filled with abundant populations of salmon, steelhead, Eulachon, lamprey, and Green Sturgeon. Today, Klamath River fish populations are a small fraction of their historic abundance. The decline of the Tribal fishery resources is the result of numerous legacy land and water management practices that were implemented with little regard to the health of the fishery and with minimal input from the tribes of the basin. These land and water management practices include, but are not limited to, gold mining, timber harvest, road construction, cattle grazing, water diversions, and construction of hydroelectric dams. The indigenous people of the Klamath Basin have suffered greatly due to the management of the river and have borne the brunt of the negative ramifications from the destruction of the ecosystem they continue to rely upon.

Since the Yurok constitution was adopted in 1993, a high priority for the Yurok Council has been to develop the infrastructure necessary to responsibly conserve, manage, and restore the fishery resource of the Tribe. This strategy involves the integration of the best available science with existing tribal knowledge. The Tribe has made great strides toward this goal, especially given the relatively short time since the government has been formally organized, with the development of a Fisheries Department, Watershed Restoration Department, Environmental Program, and Wildlife Department. These departments employ dozens of professionals and technicians to protect, restore and responsibly manage the Tribe's resources. However, the stressors affecting the fishery resource and Klamath River ecosystem are numerous, and much work is needed to reverse ecosystem degradation and the associated downward trend facing fish populations.

The Karuk Tribe's constitution was adopted in 1985 and the Karuk Department of Natural Resources was established in 1989. The mission of the Karuk Department of Natural Resources is to protect, enhance and restore the cultural/natural resources and ecological processes upon which Karuk people depend. Natural Resources staff ensure that the integrity of natural ecosystem processes and traditional values are incorporated into resource management strategies. The Karuk Department of Natural Resources actively leads, coordinates, and manages monitoring, research, and restoration related to tribal trust resources within and beyond Karuk Aboriginal Territory.

A key element of the Tribal strategy to restore the Klamath River is dam removal. The indigenous people of the Klamath Basin have always known and experienced the detrimental effects of the Klamath River dams, thus dam removal has continually been a primary objective. In the early 2000's, the Tribes took a strategic scientific approach by acquiring and reviewing existing technical information and determined that dam removal was feasible and would have significant benefits to the Klamath River ecosystem. As more information was developed, including a large amount of scientific evidence acquired by Tribal monitoring and research efforts, the long-term impacts of the dams and the benefits of removal became even more apparent. This work helped link dam removal to long-term survival of Klamath River anadromous fish runs in the face of climate change. Some important tasks undertaken by the Tribes include: the scoping and development of NEPA documents required for the United States to determine if dam removal was in the public interest; participation in key water quality studies related to dam removal; assessing the amount and quality of fish habitat above the dams, evaluating the feasibility of fish passage options to show decommissioning as the more cost effective option; analyzing data related to fish diseases (*Ceratanova shasta* in particular) along with federal partners and universities to develop a better understanding of the link between the dams and fish disease on the Klamath; partnering with USGS and the Army Corps of Engineers to develop detailed above and below-surface topography of the Klamath River using a combination of LIDAR and side-scan sonar techniques; developing and evaluating aquatic resource mitigation measures; specific drawdown plans; restoration plans; and having Yurok and Karuk representatives on the Board of Directors of the Klamath River Renewal Corporation (KRRC), the entity responsible for removal of the dams.

Throughout this process, the Tribes have worked to blend science with existing tribal knowledge to take a more holistic and landscape-oriented approach to dam removal. Our work continues, as we strive to develop short and long-term plans for dam removal itself and fisheries management in a post dam removal world.

1.2.2 Unique Aspects of the Klamath River and the Dam Removals

Taken together, Link, Keno, J.C. Boyle, Copco 1, Copco 2, and Iron Gate dams form the Klamath Hydroelectric Project, which is currently owned and operated by PacifiCorp. Under the terms of the Modified (2016) Klamath Hydroelectric Settlement Agreement, the two uppermost dams, Link and Keno, would be transferred to the U.S. Bureau of Reclamation, while licenses for the remaining four lower dams would be transferred to the non-profit Klamath River Renewal Corporation and subsequently surrendered for the purposes of removing the dams.

Dam removal in the Klamath Basin is different from many recent removals in the American West due to the position of the dams in the watershed, the low gradient headwaters, and the extensive modifications from agriculture above the hydroelectric reach. As a result of the basin's geology and additional hydrologic modifications, the hydrologic response to the removal of the four Klamath Hydroelectric Project (KHP) dams is expected to be muted in comparison with many other dam removals. Nevertheless, the restored fish habitat and expected improvements in water quality are large compared to that achieved in the other dam removals, making removal of the KHP dams a compelling restoration objective.

Many lessons from prior dam removals are transferable to the removal of the four KHP dams, but differences among previous dam removals and the removal of Klamath River dams are also anticipated. Among these factors are the geological and hydrological settings and the effects the dams have had on water quality and native fish. The removal of four hydroelectric dams from the Klamath River will result in 1) relatively small changes to the flow regime; 2) the release of mostly fine sediment from the reservoirs due the geological and water quality context of these dams; 3) large improvements in water quality associated with the elimination of the reservoirs, including the return to a thermal regime more similar to what fish evolved with; and 4) improvements to native fish populations in response to increased habitat connectivity and expected decreases in fish disease. These factors will influence the ways in which monitoring and research of dam removal will be carried out.

1.2.3 Klamath River Geography, Hydrology and Geology

The Klamath River Watershed covers over 12,000 square miles in southern Oregon and northern California, including Cascade Mountains, high desert, and coastal forests (Figure 1). The Upper Klamath Basin, lying between the Cascade Range and the Basin and Range Province has relatively high elevation and typically receives substantial snow in winter, resulting in a snowmelt-driven hydrograph in the upper half of the watershed. The upper basin is relatively dry with little precipitation for the remainder of the year. As a result of the Cascades' volcanic geology, groundwater is also a major contributor to stream flows here, including several large spring complexes and wetlands with steady flows[3]. Many of the upper basin streams are groundwater-fed and historically provided critical habitat and cold-water refugia for salmonids[3,4]. These surface and groundwater flows enter the large, shallow, Upper Klamath Lake, which is the source of the Klamath River. The U.S. Bureau of Reclamation built dams on the Klamath River at the outflow of Upper Klamath Lake (Link River Dam) and 21 miles downstream near Keno, Oregon (Keno Dam), to store and divert water as part of the Klamath Irrigation Project. These two dams and associated diversions are not part of the planned dam removals and will remain in operation. Water management in the basin is largely controlled by Link River and Keno dams, where water is stored in Upper Klamath Lake during snowmelt and then released to irrigated lands and the Klamath River in the summer and fall. Unlike most dams, Link River Dam was not built to store more water, but instead it was built as a control outlet for Upper Klamath Lake. Lake water levels are regularly lowered below natural levels to support irrigated agriculture in the Upper Klamath Basin.

Downstream of Keno Dam, the Klamath River steepens as it cuts through the Cascade Mountains and the associated volcanic bedrock. The four dams slated for removal, J.C. Boyle, Copco 1, Copco 2, and Iron Gate sit in this geologic transition region between the relatively low-gradient and groundwater-dominated upper basin and the higher gradient, rainfall runoff-dominated lower basin (Figure 2)[5]. In the approximately 30 miles between Keno and Iron Gate dams (referred to as the "Hydroelectric Reach"), several tributaries enter that are important sources of water, sediment, and habitat for anadromous fish. Among these are Spencer, Shovel, and Jenny Creeks, which have runoff-dominated hydrology, and Fall Creek which has a large groundwater source and correspondingly steady flows and cool temperatures. Fall Creek also has a natural waterfall a short distance upstream of its mouth that is a fish migration barrier.

Downstream of Iron Gate Dam, the river enters the Siskiyou Mountains, where it is laterally constrained by confined valley walls and flows freely for 190 miles to its terminus with the Pacific Ocean. Major tributaries, including the Shasta River, Scott River, Indian Creek, Salmon River, Trinity River, and Blue Creek, among numerous smaller tributaries, contribute flows to the Klamath. In the winter, the flows from these tributaries are substantial (up to > 10 times the contribution from the upper basin as measured at Iron Gate Dam). In the summer, tributary inflow is low due to a lack of precipitation and due to diversions for agricultural uses. As a

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[3]Gannett, M.W., Lite Jr., K.E., La Marche, J.L., Fisher, B.J., and Polette, D.J., 2007, Ground-Water Hydrology of the Upper Klamath Basin, Oregon and California: U. S. Geological Survey Scientific Investigations Report, 84 p., https://pubs.usgs.gov/sir/2007/5050/

[4]Hamilton, J.B., Curtis, G.L., Snedaker, S.M. and White, D.K., 2005. Distribution of anadromous fishes in the upper Klamath River watershed prior to hydropower dams—a synthesis of the historical evidence. *Fisheries*, *30*(4), pp.10-20.

[5]Asarian, E., Kann, J., and Walker, W.W., 2010, Klamath River Nutrient Loading and Retention Dynamics in Free-Flowing Reaches, 2005-2008. Final Report to the Yurok Tribe Environmental Program, 59 p. + appendices.

result, the river's flow during summer is largely derived from above Iron Gate Dam, although the Trinity River is a major source of water in the final 40 miles of the Klamath River (the Trinity River is regulated by large upstream dams).

The Klamath River Estuary is relatively small with a short hydraulic residence time, but with a large depositional and forested area with backwater habitats and side channels with important low velocity rearing habitat for fish. The estuary has a lagoon bounded on the west by a large sandy spit, with an opening to the ocean that can migrate periodically and on occasion, can become temporarily closed off. The location of the riverine breach in the spit, through which most of the tidal exchange occurs, determines velocity and sediment dynamics in the estuary. Marine water intrusion extends approximately 6 miles upstream, to above the Highway 101 bridge.

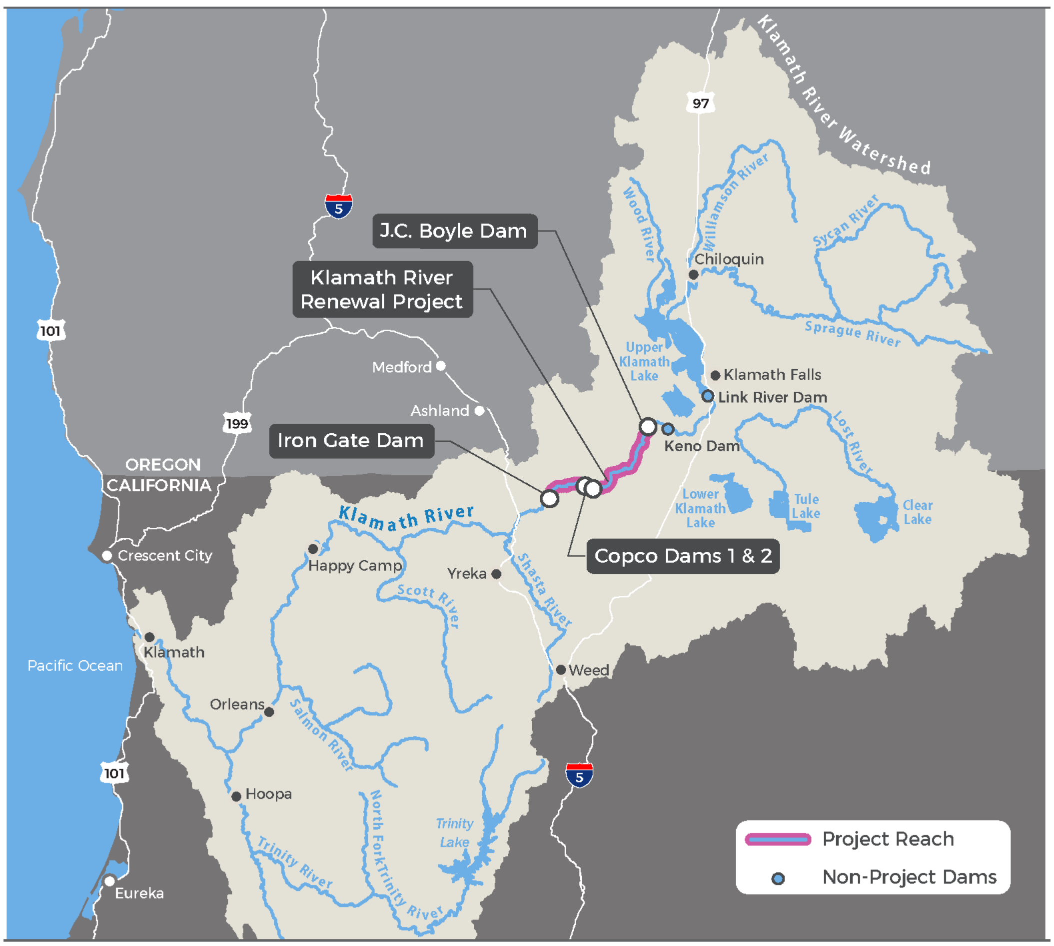

Figure 1. Map showing the Klamath River Basin. From www.klamathrenewal.org.

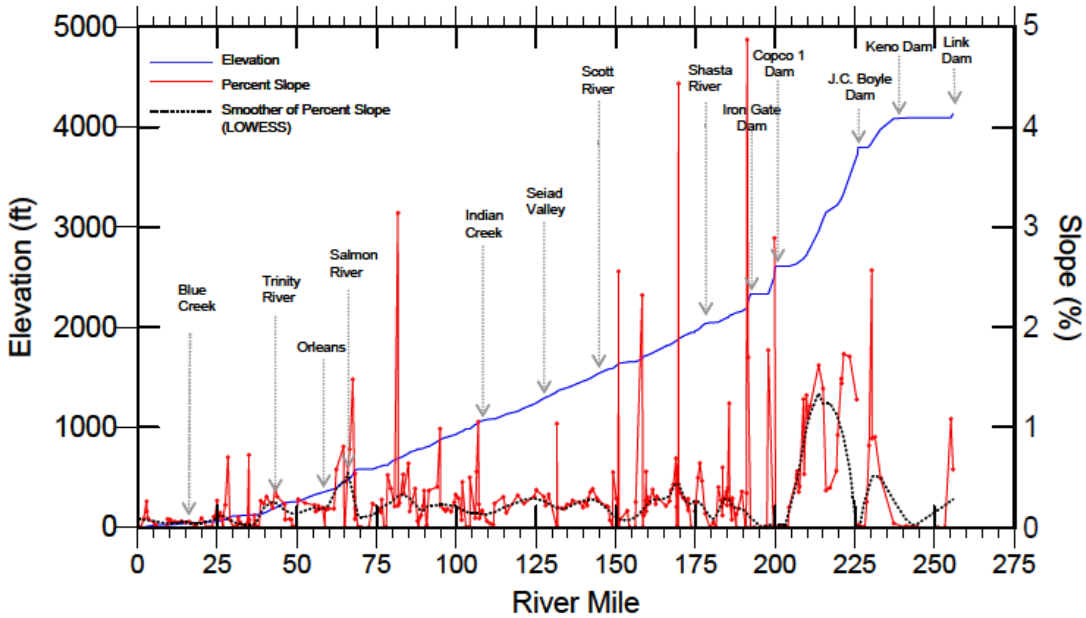

Figure 2. Elevational and river-bed slope profile of the Klamath River. Grey arrows show where tributaries enter (Asarian and others (2010)[5].

1.2.4 Motivating Factors for Dam Removal

Poor water quality and declines in fish populations can be attributed to multiple stressors in the Klamath Basin. The construction and operation of hydroelectric dams, loss of wetlands, water diversion and nutrient enrichment associated with agriculture, mining, road building, and timber harvest have contributed to the decline in fisheries, resulting in severe hardships for indigenous communities and the commercial and sports fishing industries.

Flow regimes and water quality in the Klamath River are heavily altered due to the operation of the hydroelectric dams and reservoirs, as well as diversions and discharges associated with irrigated agriculture. The continuation of large alterations in the headwaters of the Klamath River distinguish the Klamath from other large dam removals where the headwaters above other dams have been in a more pristine and free-flowing state, and where the affected downstream reaches have been relatively short. Due to combined impacts of continued flow alteration and nutrient enrichment from above the dams, the impacts of the dams on the Klamath River ecosystem are different than those in less-altered watersheds. The potential benefits of dam removal not only go beyond opening up additional habitat for fish, but they also address water quality problems and an interrupted sediment supply downstream of the dams; both are linked to multiple stressors for fish.

1.2.4.1 Impacts of Dams on Water Quality and Native Fish

The effect of the KHP dams on water quality and fisheries share some commonalities with other dammed rivers, while also displaying unique impacts associated with additional stressors. Most of the recent large dam removals in the west have been at least partially motivated by concern for salmonids, where dams have blocked salmon passage and intercepted sediment, causing decreased spawning habitat downstream of the dams. Similarly, Iron Gate Dam blocks fish passage, preventing salmon access to over 420 miles[1,2] of habitat, including spawning and rearing habitat and cold-water refugia. Furthermore, disruption of sediment transport processes and reduced magnitude and duration of peak flows have adversely affected mainstem spawning and rearing habitats in the Klamath.

The combined effect of warm water, high organic loads, stable flows, lack of upstream sediment inputs that result in reduced scouring and less bed mobility, and fish crowding near Iron Gate Dam has resulted in conditions enhancing the myxozoan parasite, *Ceratamyxa shasta,* that infects juvenile salmonids and that in recent years has decimated native Coho and fall Chinook populations[6,7]. Since water year 2017, managing the Klamath River to minimize the effects of fish disease has included releases of pulse flows from Upper Klamath Lake to scour surface sediments of the riverbed and reduce infection rates in juvenile fish.

The hydroelectric dams negatively affect water quality within the reservoir reach and in the river below the dams, extending to the Klamath River Estuary. The primary water quality concern has been the extensive proliferations of toxin-producing cyanobacteria in the reservoirs that are transported downstream throughout the Klamath River[8]. Levels of microcystin toxin have continuously exceeded public health thresholds in the reservoirs and rivers annually in late summer, where visitors and basin residents rely on the river for recreation, ceremonial use, and subsistence fishing, among others. These blooms are associated with high levels of nutrients entering the stagnant water of Copco 1 and Iron Gate reservoirs where plankton are able to proliferate, which would not be possible in the naturally high gradient, high velocity flowing waters of the Klamath River below Keno.

Other water quality concerns associated with the KHP include seasonally increased or decreased downstream water temperatures, where water is cooler for longer during the spring months, thereby reducing fish growth and delaying emigration to the ocean, and water is warmer for longer in the fall, thereby compromising conditions for adult fish migration. Both of these temperature related phenomena are due to thermal inertia within the reservoirs.

Alterations to sediment regimes and scour likely increase downstream eutrophication, with nuisance growth of benthic algae, high rates of primary productivity, and concomitant impairments of dissolved oxygen and pH[9,10]. As a result of these water quality issues, the Klamath River is under a set of Total Maximum Daily Load (TMDL) allocations, since 2009, with separate individual TMDLs for the different riverine and reservoir segments.

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[6] Stocking, R.W., and Bartholomew, J.L., 2007, Distribution and Habitat Characteristics of Manayunkia speciosa and Infection Prevalence With The Parasite Ceratomyxa shasta in The Klamath River, Oregon–California: Journal of Parasitology, v. 93, no. 1, p. 78-88, doi: 10.1645/ge-939r.1, http://www.journalofparasitology.org/doi/abs/10.1645/GE-939R.1

[7] Fujiwara, M., Mohr, M.S., Greenberg, A., Foott, J.S., and Bartholomew, J.L., 2011, Effects of Ceratomyxosis on Population Dynamics of Klamath Fall-Run Chinook Salmon: Transactions of the American Fisheries Society, v. 140, no. 5, p. 1380-1391, doi: 10.1080/00028487.2011.621811, https://doi.org/10.1080/00028487.2011.621811

[8] Genzoli, L and J. Kann. 2017. Toxigenic Cyanobacterial Trends in the Middle Klamath River, 2005-2016. Prepared by Aquatic Ecosystem Sciences LLC for the Karuk Tribe Department of Natural Resources. 50 p. + appendices.

[9] Gillett, N.D., Pan, Y., Eli Asarian, J., and Kann, J., 2016, Spatial and temporal variability of river periphyton below a hypereutrophic lake and a series of dams: Science of The Total Environment, v. 541, p. 1382-1392, doi: http://dx.doi.org/10.1016/j.scitotenv.2015.10.048

[10] Genzoli, L., and Hall, R.O., 2016, Shifts in Klamath River metabolism following a reservoir cyanobacterial bloom. Freshwater Science, v. 35, p. 795–809. https://doi.org/10.1086/687752

Water quality factors associated with the dams and their removal have resulted in regulatory oversight and permitting of Klamath dam removal through the water quality agencies in Oregon (Oregon Department of Environmental Quality) and California (State Water Control Board), via Section 401 of the Clean Water Act. Each agency must issue certifications that the dam removal project will ultimately meet the states' water quality requirements, with associated mitigation and/or monitoring.[11,12] Correspondingly, there is likely to be more emphasis on water quality, along with the fisheries, geomorphic, and sediment transport components typical with permitting for dam removals.[11,12]

1.2.5 Lessons Learned from Previous Dam Removals

Scientific studies and monitoring of large (Elwha, Glines Canyon, Marmot, Condit, and the Penobscot) and smaller dam removals have led to notable scientific advances, many of which were synthesized by a recent Powell Center working group.[13] Their primary findings were: 1) Rivers are resilient and physical responses to dam removal can be relatively rapid, on the timescale of months to years rather than decades. Much of the sediment stored within the former reservoir can be eroded and transported within weeks to months of dam breaching, and phased removals extend river recovery time. 2) Rivers typically trend toward their pre-dam physical state following removal, although dam size, river size, reservoir size and shape, and sediment volume and grain size all exert first order controls on the responses to dam removal. And, 3) Migratory fish have responded quickly to restored river connectivity; however, local environment, habitat, and population conditions affect the trajectory of physical and ecological responses. The growing body of knowledge has guided removal and monitoring strategies that can help avoid negative outcomes, but cannot fully predict fine-scale changes that drive many ecological processes. Quantifying species and ecosystem responses through modeling lag even further behind. The findings by the Powell Center working group support conclusions that removal of Klamath River dams will be a successful restoration strategy, yet there are enough specific factors unique to Klamath (e.g. modified upper basin hydrology and land use, large proportion of fines in reservoir sediments, and the dams' effects on downstream water quality) that application of results from other dam removals requires adaptation and verification.

While the Powell Center working group was able to derive important insights from the dam removal studies conducted to date, it remains challenging to gain a comprehensive understanding of fluvial and ecosystem responses to dam removal. These challenges arise from basin-specific issues, differences in dam removal and study objectives and protocols among rivers, limited coordination among disciplines, and limited systematic monitoring and research both before and after dam removal. Most dam-removal studies have been short-lived,

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[11] Stine, Chris. 2018. Evaluation and Findings Report Section 401 Water Quality Certification for the Removal of the Lower Klamath Project (FERC Project Number 14803). State of Oregon Department of Environmental Quality. September 2018. https://www.oregon.gov/deq/FilterDocs/ferc14803report.pdf

[12] STATE OF CALIFORNIA, STATE WATER RESOURCES CONTROL BOARD. 2020. Final Water Quality Certification for Lower Klamath Project License Surrender. April 2020. https://www.waterboards.ca.gov/waterrights/water_issues/programs/water_quality_cert/docs/lower_klamath_ferc14803/lkp_final_wqc_7april2020.pdf

[13] The Powell Center is a USGS-sponsored Center for collaborative analysis and synthesis. The Dam Removal Working group, which included about 20 experts from agencies, academia, and NGOs, was formed in 2014 and produced numerous papers and products. See the following website for a list: https://www.usgs.gov/centers/powell-ctr/science/dam-removal-synthesis-ecological-and-physical-responses?qt-science_center_objects=0#qt-science_center_objects

opportunistic, and have not covered a full range of scientific disciplines. Studies that truly integrate the biological and physical responses are rare. Moreover, very few dam removals have occurred in rivers where flows remain altered even after dam removal and where large volumes of fine-grained sediment have been released. Only one dam removal that was studied involved more than one dam in a river corridor being removed at a time. The simultaneous removal of four dams on the Klamath River provides a unique opportunity to fill these critical information gaps.

1.2.6 Benefits of Coordinated Klamath River Dam Removal Studies

Although much scientific information has been prepared to inform a general decision regarding Klamath River dam removal, detailed studies of the Klamath Ecosystem before, during, and after dam removal are vital to assess ecosystem response and restoration progress. These studies would:

1. Support adaptive management and inform real-time adjustments to minimize or mitigate effects to important human, ecological, and cultural resources in the Klamath River basin, including vast federal and tribal trust resources for six federally recognized Indian tribes in the basin (Karuk Tribe, Yurok Tribe, Hoopa Tribe, Resighini Rancheria, Quartz Valley Indian Reservation, and Klamath Tribes).
2. Improve our general understanding and ability to model and predict ecosystem and riverine responses following large dam removals, which ultimately helps resource managers and dam owners properly assess and plan for future dam removals.
3. Expand our specific understanding of how removal of reservoirs dominated by fine-grained cohesive bottom sediments (silts and clays) spatially and temporally impacts a river, an estuary, near-shore ocean environment, and their biota. Recent large dam removals in the western U.S. (e.g. Elwha, Mills, Marmot, and Condit dams) primarily included reservoirs with sediments dominated by larger-sized material.
4. Assess the response of rivers to removal of multiple large dams that are over 190 miles upstream from an estuary, a rarity in prior removals. There is potential for select Klamath River reaches to be negatively impacted by dam removal in the short term (<2 years) even while expectations are for long-term benefits. There would be a unique opportunity to understand how multiple dams in a series interact to control channel morphology as well as how their removal will affect landscape structure, hydro-geomorphic function, and ecosystem connectivity.

1.2.7 Expected Effects of Dam Removal in the Klamath River Basin

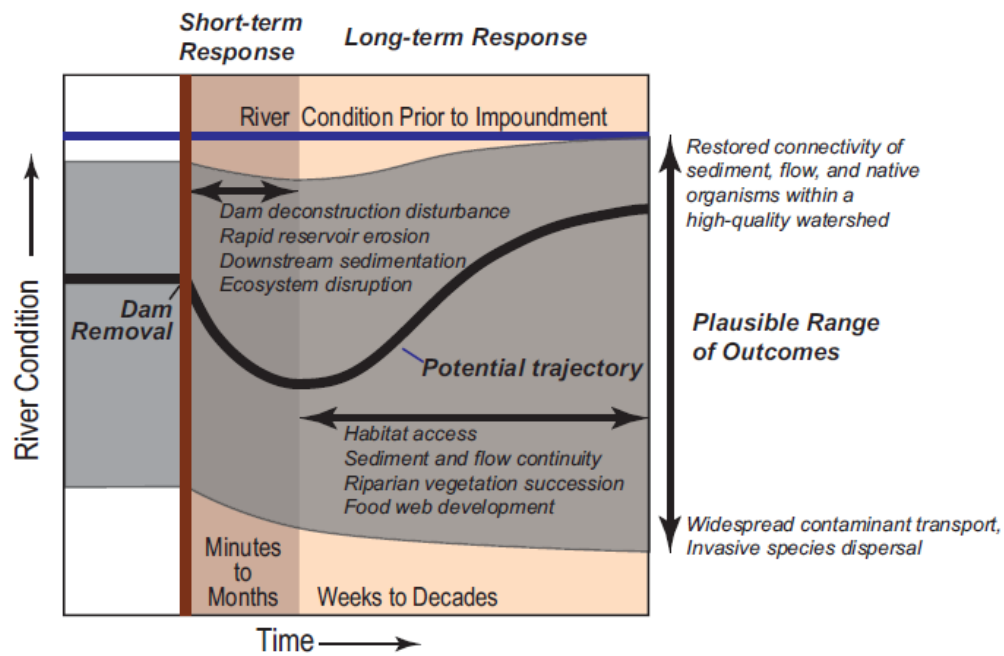

Figure 3. Conceptual river response to dam removal. Prior to dam removal, physical and ecological river condition is likely altered to some degree from pre-impoundment conditions by changed flow, sediment regime and aquatic connectivity. Dam removal will typically result in short-term disturbance, but the system will approach a new steady state dictated by overall watershed conditions. The indicated potential trajectory is just one of many possible outcomes within the gray shaded area depending on the original effects of the dam and reservoirs, their sizes, removal strategy, and regional environmental conditions. Source: Foley and others[14]

In the Klamath River Basin, the responses of different resources following dam removal are expected to follow trajectories similar to that described by Foley and others[14], (Figure 3). As a river restoration measure, dam removal is expected to be a long-term benefit for fish, especially anadromous salmonids, through a combination of opening up over 400 miles of habitat upstream of the dams and improving water quality and habitat conditions downstream of the Hydroelectric Project. Under existing conditions, there is no fish passage at Iron Gate, Copco 1, or Copco 2 dams, and their removal would ultimately provide volitional passage through the hydroelectric reach. Newly restored habitat will include free-flowing mainstem reaches currently inundated by reservoirs, smaller tributaries entering the mainstem along the Hydroelectric Reach, and ultimately the upper Klamath Basin above Keno Dam.

[14] Foley, M.M., Bellmore, J.R., O'Connor, J.E., Duda, J.J., East, A.E., Grant, G.E., Anderson, C.W., Bountry, J.A., Collins, M.J., Connolly, P.J., Craig, L.S., Evans, J.E., Greene, S.L., Magilligan, F.J., Magirl, C.S., Major, J.J., Pess, G.R., Randle, T.J., Shafroth, P.B., Torgersen, C.E., Tullos, D., and Wilcox, A.C., 2017, Dam removal: Listening in: Water Resources Research, v. 53, no. 7, p. 5229-5246, doi: 10.1002/2017WR020457, http://dx.doi.org/10.1002/2017WR020457

Hydrology and water quality in the Klamath River upstream of J. C. Boyle Reservoir will be minimally affected by dam removal. Although marine derived nutrients from an influx of salmonids recolonizing habitats upstream of Iron Gate Dam may have local impacts to food webs and primary productivity in tributaries, changes to flows or other management changes affecting upstream water quality will take place under policy discussions independent of the current dam removal process. Hydrologically, the implication is that, unlike dam removals such as the Elwha, Condit, Marmot, and Carmel River dams, there will not be a substantially different hydrologic regime in the river downstream of the removed dams that might otherwise be able to rework channels or transport large amounts of sediment. This is because management at Upper Klamath Lake and Keno Dam will continue to regulate downstream flow, with changes to the downstream hydrology associated with dam removal dictated by inputs from tributaries within the project reach (whose flows tend not to be substantial compared to the flows in the Klamath River at this point in the watershed).

Over the long-term (Figure 3), dam removal is expected to benefit the Klamath River and its biota in the following critical ways[15]:

- Reopen access to over 420 miles of habitat for anadromous salmonids.
- Improve water temperatures in the existing hydroelectric reach and downstream to near the Scott River confluence, such that water temperatures are closer to natural thermal regime.
- Eliminate cyanobacterial blooms in the reservoirs and river downstream, including associated algal toxins that currently threaten human and possibly ecological health.
- Reduce the severity of juvenile fish disease from *C. shasta* via dispersion of fish into new habitats, reductions in detrital food sources for the intermediate host (the annelid worm *Manayunkia speciosa*), changes in water temperatures, and resumption of sediment scouring processes with inputs from the tributaries between Iron Gate and Keno dams.
- Improve dissolved oxygen and pH conditions that are currently impaired due in part to reservoir algae blooms.
- Eliminate the seasonal release of nutrients and detrital material from the reservoirs into the river downstream of the dams, which contribute to increased eutrophication from nuisance growth of benthic algae (periphyton) and macrophytes. (Note that elevated nutrient concentrations from the upper basin would continue to be released through Keno Dam, such that nuisance periphyton and macrophyte could still persist although likely with changed longitudinal and seasonal patterns and community compositions).

However, as described by Foley and others[14] (Figure 3), short-term negative effects can be expected in the Klamath River. These include increased suspended sediment, nutrient, and carbon concentrations and an oxygen demand from resuspended reservoir sediment that reduces water column dissolved oxygen to levels potentially harmful to aquatic biota. Suspended sediment concentrations from dam removal were modeled by U.S. Bureau Of

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[15] U.S. Department of Interior, U.S. Department of Commerce, and National Marine Fisheries Service, 2012, Klamath Dam Removal Overview Report for the Secretary of the Interior -- An Assessment of Science and Technical Information, 399 p., http://klamathrestoration.gov/

Reclamation[16] during the Secretarial Determination, assuming removal of the dams during a 3-month period in January to March of the removal year. Among their findings and others were that:

- Most reservoir sediment will be flushed downstream, through the Klamath River Estuary, and into the marine near shore environment off the coast of California.
- The period of active erosion and evolution of reservoir sediment would be about two years, beyond which direct effects of reservoir sediment would be more difficult to detect.
- The amounts and timing of sediment erosion and transport are highly dependent on the dam removal scenarios and the hydrology of the year of removal.
- The largest negative impacts will be in the reach immediately below Iron Gate Dam, to approximately the I-5 bridge. In this reach, reservoir sediment deposition of approximately 0.3–1.7 feet is possible.
- Suspended sediment concentrations (SSC) could peak near or above 10,000 mg/L near Iron Gate Dam and would attenuate downstream, with relatively high concentrations lasting through the spring.
- Some negative physical effects on fish are predicted from the high suspended sediment concentrations, depending on the species, but large fish kills are not expected. Timing of the dam removal was planned to minimize these effects including reduced presence of sensitive species and life stages and higher stream flows that would limit reservoir sediment evacuation to as short of a time period as possible[17,15].
- Resuspension of reservoir sediment will introduce an oxygen demand that could reduce water column dissolved oxygen concentrations to 4 mg/L or less, from Iron Gate Dam to below the Shasta River, depending on hydrology and the final dam removal scenario. This oxygen demand would abate in proportion to evolution of reservoir sediment[15].
- Deposition in pools is expected to happen throughout the river but would mostly be temporary (less than two years). Deposition on bars may occur, depending on the hydrology.
- There is little opportunity for channel migration resulting from sediment deposition or erosion, due to the highly constrained valley as the river cuts through the Siskiyou Mountains. Some bar formation is possible, especially in the Iron Gate reach, but in most cases would be temporary.
- Downstream tributaries contribute substantial water and sediment during the winter. The amount of reservoir sediment expected to erode with dam removal is equivalent to the annual sediment load of the Trinity River alone. Therefore, effects on the lower river, especially below the Trinity, are expected to be reduced and during some periods, might be hard to distinguish from other sources.

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[16] U.S. Bureau Of Reclamation, 2011, Hydrology, Hydraulics and Sediment Transport Studies for the Secretary's Determination on Klamath River Dam Removal and Basin Restoration: Prepared for Mid-Pacific Region, US Bureau of Reclamation, Technical Service Center, Technical Report No. SRH-2011-02

[17] Stillwater Sciences, 2009, Effects of sediment release following dam removal on the aquatic biota of the Klamath River: Prepared for California Coastal Conservancy Final Technical Report, 85 p.

- The Klamath River Estuary may experience some deposition, including in the South Slough. Duration and effect magnitude will depend on hydrology in the following winters, including inputs from the Trinity, and on the location of the lagoon breach/mouth at the spit.

Within the Hydroelectric Reach, the physical, chemical, and biotic changes are expected to be the most dramatic, consistent with the findings of Bellmore and others[18]. Among the changes will be a significant conversion from the reservoir areas back to riverine habitat, which fundamentally affects all aspects of local hydrology, geomorphology, sediment and solute transport, and both aquatic and terrestrial ecology. A particularly unique aspect of dam removals in the Klamath River is the four-dam sequence, all of which would be removed together within a relatively short period. A key factor in how these changes affect the river, including the downstream reaches and especially in the short term, will be the specific dam removal scenario, including the timing and resulting hydrology. A specific set of scenarios were explored during the Secretarial Determination[15], however final plans have not yet been released by KRRC and approved by FERC, so any differences between the originally determined expectations and those expected with the final plan cannot be fully anticipated at this time. Under the terms of the KHSA, mitigation and monitoring for many of these effects will be the responsibility of KRRC, as specified in the 401 Certifications from the States of Oregon and California.

1.3 Research and Monitoring on the Klamath River

1.3.1 Past and Current Monitoring

Compared to many rivers, the Klamath has a relatively robust network of monitoring programs, whose data can help describe the condition of the river with dams in place and inform predictions following dam removal. Reasons for existing monitoring of fisheries and water quality in the Klamath River include the key role that Tribal governments have taken in the monitoring and management of the river, harvest sharing mandates between tribal and non-tribal fisheries, as well as poor water quality and fisheries declines that have triggered more monitoring. The poor condition of water quality and fisheries in the Klamath River has led state and federal agencies to increase their monitoring and restoration efforts to fulfill expectations associated with the clean water act and the endangered species act, as well as state standards. Additionally, federal agencies have tribal trust obligations which require them to ensure protection of tribal trust resources, including harvestable populations of fish.

A mix of long-term monitoring and special studies has informed current knowledge describing the ecological and physical state of the Klamath River. For example, Tribal Natural Resource Departments, as well as federal agencies, have been conducting regular monitoring of water

[18] Bellmore, J.R., Pess, G.R., Duda, J.J., O'Connor, J.E., East, A.E., Foley, M.M., Wilcox, A.C., Major, J.J., Shafroth, P.B., Morley, S.A., Magirl, C.S., Anderson, C.W., Evans, J.E., Torgersen, C.E., and Craig, L.S., 2019, Conceptualizing Ecological Responses to Dam Removal: If You Remove It, What's to Come?: BioScience, v. 69, no. 1, p. 26-39, doi: 10.1093/biosci/biy152, https://doi.org/10.1093/biosci/biy152

quality and fisheries in the Klamath River for over a decade (see supplemental materials for a partial list of monitoring activities; SI-3). Special studies have been conducted to address questions about specific water quality impacts and seeking to identify mechanisms driving water quality impairments and fisheries declines. Reports presenting monitoring data and the results of special studies can be found on selected websites of agencies and organizations involved in monitoring and coordinating monitoring throughout the Klamath Basin (see supplemental materials for a list of websites with links to monitoring and research reports and manuscripts, SI-1).

1.3.2 Planned Monitoring to Comply with Government Approvals for Dam Removal

Contributed by KRRC and Dan Chase of Resource Environmental Solutions

As part of the Klamath River Renewal Project (KRRP), a number of biological and ecologically focused surveys and monitoring efforts associated with dam removal activities will occur. The purpose of the monitoring is to comply with federal, state, and local permit conditions (collectively Government Approvals). The KRRP Government Approvals include, but are not limited to, Federal Energy Regulatory Commission requirements, Clean Water Act sections 404 and 401, state and federal Endangered Species Acts, National Environmental Policy Act, and California Environmental Quality Act requirements. The approach, frequency, and duration of monitoring actions are intended to meet Government Approval requirements. Monitoring activities are also intended to inform restoration and maintenance actions associated with dam removal and support the process-based and adaptively managed restoration approach. An overview of these activities was presented by Resource Environmental Solutions, LLC (RES) during the February technical workshop, and they are summarized below in relation to the topics covered during the technical workshop and anticipated work RES will conduct as part of the KRRP[19].

<u>Aquatic Resources and Fisheries</u>

Prior to reservoir drawdown, monitoring and survey work will take place downstream of Iron Gate Dam and within the KRRP reservoir footprints of Iron Gate Reservoir, Copco Lake, and JC Boyle Reservoir to meet Government Approval requirements for aquatic resources. Planned work includes the relocation of juvenile Coho Salmon from the mainstem Klamath River below Iron Gate Dam in early winter prior to the start of reservoir drawdown. Within the KRRP reservoir footprints, and prior to the start of reservoir drawdown, targeted collection of Lost River and Shortnose Suckers will occur to relocate protected sucker species from the KRRP project footprint.

Following reservoir drawdown, surveys will be conducted to assess spawning habitat availability within the KRRP project footprint for salmon and steelhead. Surveys will be conducted upstream of the former Iron Gate Dam location within the mainstem Klamath River and key

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[19] Survey and monitoring requirements for the KRRP will be based on finalization of all necessary Government Approvals. Final Government Approvals might contain different requirements, approach, duration, and/or frequency of activities. The following is only intended for planning purposes and does not represent the full extent of RES KRRP related work.

tributaries. Survey work is also planned to assess and monitor volitional fish passage within the KRRP area for the restored Klamath mainstem and fish bearing tributaries. Coordination with federal, state, and tribal partners on fish presence surveys within the KRRP will also occur.

Water Quality, Sediment, and Geomorphology

To comply with Government Approvals, three categories of water quality sampling will be conducted throughout the KRRP project period within mainstem Klamath River at locations in Oregon and California. These include water quality continuous monitoring, water quality grab samples, and sediment grab sampling. For the first category (continuous monitoring), initial KRRP baseline monitoring data will be collected 12 months prior to the start of reservoir drawdown. Twelve monitoring sites, beginning with the US Geological Survey (USGS) Klamath River at Keno (Keno) station and extending to the Klamath River Estuary have been identified for continuous monitoring of five water quality parameters. The second category, water quality grab samples, is planned at nine locations from the USGS Keno station to the Klamath River Estuary. Monthly water column grab samples will be analyzed for 16 water quality parameters, and will occur prior to, during, and following reservoir drawdown. The third category, sediment water column grab samples, is anticipated at seven sites with 17 parameters analyzed. Two rounds of sediment grab samples are anticipated and will occur prior to and following reservoir drawdown.

Additional sediment and geomorphic monitoring activities will occur at tributary confluences during and following reservoir drawdown. The survey area is planned to include an eight-mile reach downstream of Iron Gate Dam and extend upstream to the confluence of Spencer Creek and the Klamath River. The purpose of these surveys is to monitor for and address reservoir sediment and associated debris blockages that may occur at tributary confluences. Sediment load quantification, for the reservoir and eight-mile reach downstream of Iron Gate Dam, is also anticipated. LIDAR surveys utilizing Unmanned Aerial Vehicles (UAV) are planned to monitor residual reservoir sediments within the KRRP footprint beginning in the drawdown year. UAV aerial images and LIDAR will be used to monitor reservoir footprint topography during reservoir restoration periods.

General Ecology

Ecological monitoring and survey activities are planned to support and facilitate the restoration of the former reservoir area footprints within the KRRP. Survey work is planned to map and treat Invasive Exotic Vegetation (IEV) prior to and following reservoir drawdown. IEV treatment is focused on methods to control high and medium priority IEV species to provide an advantage for native vegetation reestablishment. Survey and restoration measures for upland vegetation will include native seed collection, propagation, pioneer seeding, and permanent seed broadcasting. Stream habitat measures will focus on enhancing bank stability and channel fringe complexity through riparian revegetation or translocation and the addition of large wood material.

Following reservoir drawdown and initial restoration actions, long-term monitoring of sediment stabilization and native plant establishment will occur to inform potential adaptive management actions. Ground surveys, photo point monitoring, and UAV aerial imaging will be utilized at fixed locations and over time to establish initial conditions and to monitor progress.

The KRRP fits within a broader framework of surveys, monitoring, and research taking place within the Klamath River Watershed. Dedicated stakeholders across non-profit organizations, academic institutions, resource agencies, and tribal governments will engage in actions to document and study the changes that stem from dam removal and river restoration. The participation and collaboration presented at the technical workshop was a testament to the strong scientific network already at practice in the basin. While KRRP monitoring and survey actions are focused on compliance with government regulatory approvals, RES recognizes the importance coordination and data sharing will play in advancing the science of dam removal and large-scale river restoration.

1.3.3 The Need for Additional Research and Monitoring

Despite existing monitoring programs and dam removal monitoring requirements, there is an unmet need to conduct the research and monitoring that will improve management of the Klamath River and bring insight into globally relevant river restoration. Most current monitoring has not been designed to specifically address questions about how dam removal will affect the Klamath River, while monitoring requirements associated with the dam removal are primarily focused in the hydroelectric reach, with limited monitoring of water quality and sediment dynamics downstream of the dams. Support and coordination for more general understanding of how river geomorphology, ecology, and fisheries will recover following over 100 years of impoundment does not exist on a broad scale. Tribal governments, other government agencies, non-profits, and academic institutions are attempting to address the significant gap in knowledge about river recovery following large-scale dam removal on the Klamath River with limited resources. Dedicated funding for both scientific studies and coordinating these research efforts will lead to the creation of knowledge that will inform management of the Klamath River and future river restoration efforts on other rivers. A monumental opportunity exists to learn from the recovery of a river following the largest planned dam removal in history.

2 Workshop Components

Dam removal science and monitoring coordination efforts, which were formally initiated in winter of 2020, provide a platform for collaboration that will increase the effectiveness of research efforts surrounding dam removal on the Klamath River. In February of 2020, the Yurok and Karuk Tribes carried out a two-day workshop attended by over 60 natural resource practitioners (SI-2) who monitor, study, and manage water quality and fisheries on the Klamath River. The February workshop was preceded by a half-day meeting in November to begin discussions and gather feedback about planning an effective workshop, a webinar about the unique geomorphic conditions of the Klamath River, and a survey of meeting participants to gather preliminary information about their involvement and interest in dam removal science and monitoring. At the two-day workshop, invited speakers involved in research and monitoring of other major dam removals shared their experiences working on coordinated dam removal science and monitoring. Formal breakout groups were held to develop and document research priorities for the Klamath River dam removal and networking and research planning occurred throughout the workshop. The components of pre-workshop activities and details of the two-day workshop are outlined below.

2.1 Pre-Workshop Activities

November 2019 meeting: On November 12, 2019 the Yurok and Karuk Tribes held a half-day meeting in Yreka, CA (with an option to attend via phone) to discuss the need for a dam removal science coordination workshop. Approximately 30 people attended from state, federal, and tribal natural resource agencies. Participants expressed overwhelming support for and interest in participating in a formal, multi-day workshop to coordinate dam removal science efforts.

January 2020 webinar: Prior to the 2-day workshop, a webinar about the geomorphic context of the Klamath River dam removals was presented. This webinar covered the unique geological conditions of the Klamath River Watershed and the location of the four hydroelectric dams located in the Southern Cascade Mountains, near the transition zone between the low gradient volcanically influenced upper basin and the high gradient, tightly constrained lower river. The Webinar covered the hydrologic conditions of the basin and the expected changes with dam removal, information about sediments stored in the reservoirs, and information about how the dams influence water quality and fisheries.

Pre-workshop surveys: Prior to the Klamath River dam removal science coordination workshop, participants completed a survey, in which participants submitted a list of current monitoring activities that were related to establishing baseline conditions prior to dam removal. Participants also submitted anticipated monitoring and research activities, as well priority research questions related to their natural resource specializations. Results of the monitoring activities reported in the survey are documented in the appendix (SI-3) and research questions submitted in the survey were used to begin breakout group discussions, which ultimately lead to the research and monitoring priorities outlined in this document (section 3).

2.2 February Workshop Components

2.2.1.1 Klamath River Dam Removal Status and Context

The two-day workshop began with presentations on the background, context, and status of Klamath River dam removal.

- Meeting participants heard from Klamath River Renewal Corporation Chief Executive Officer, Mark Branson, about the current status and timeline of the Klamath River dam removal. As of the date of the February 2020 meeting, the dam removals were on track to proceed in winter of 2022 (although as of the date of this meeting summary report, dam removal is now planned for 2023).

- A presentation by US Geological Survey Water Quality Specialist Chauncey Anderson reviewed the geographic, geologic, and ecological context of the Klamath River. This presentation assured that meeting participants understood the physical and biological context of the Klamath River dams, and provided a framework for the research questions developed in the breakout sessions on the second day of the workshop.

- Dan Chase from Resource Environmental Solutions (RES), the lead restoration contractor for the dam removal, presented the monitoring framework and tentative monitoring tasks that would be undertaken as part of the dam removal project (see section 1.3.2, above, for details).

2.2.1.2 Invited Speakers and Lessons Learned from the Elwha and Carmel Dam Removals

During the first day of the workshop, six speakers were invited to present research related to large dam removals and to share their experience and advice on coordinating research efforts surrounding the Klamath dam removal. Five of the invited speakers presented work from the Elwha River, which is the largest dam removal completed to date. Although the dam removal occurred between 2011 and 2014, research coordination, planning, and execution took place many years before the dam removal, and some research is still in progress. A sixth presenter has worked extensively on documenting habitat and anadromous fish recovery on the Carmel River, the site of the largest dam removal completed to date in California.

- **Jennifer Bountry** presented results and lessons learned from six years of an interagency, adaptive sediment management program for the Elwha and Glines Canyon dam removals, where she focused on reservoir sedimentation response to dam removal. These dams trapped all coarse sediment and ~3/4 of incoming fine sediments, resulting in 27 million cubic yards of sediment stored in the reservoirs. Landscape evolution started as the river incised into reservoir delta sediments, forming terraces after each increment of dam removal and reservoir drawdown. The river in the former reservoirs reached the valley bottom, floods increased the width of the new floodplain, and meander bends formed as the rate of lateral migration slowed following dam removal. Both reservoirs are now in the last phase of landscape evolution with vegetation flourishing on hillslopes and becoming established in portions of the new floodplain. Real-time monitoring, open and collaborative communication and data sharing, and the ability to quickly respond to adaptive management needs were all important to making the program a success.

- **George Pess** presented on salmonid response to dam removal on the Elwha River. Although short-term increases in transported sediments caused reductions in the egg to fry survival stage for Chinook Salmon during dam removal, these fish have since rebounded, showing that sediment impacts were short-term. The resumption of free passage has re-established anadromous fishes after 100 years, prompting rapid increases in spawning redds and an increase in salmonid life history diversity above the former dams. Most salmon redds now occur above the former dams, averaging over 1,400 observed redds annually. There has been a "re-awakening" of life history types for bull trout, Coho Salmon, Chinook Salmon, and steelhead and Pacific Lamprey are now present. Native fish are adapting to the local environmental conditions in the newly connected habitats, resulting in increasing abundance and life history diversity. Results from the Elwha demonstrate the critical importance of maintaining longitudinal connectivity for proper functioning of watershed processes and ecosystem services.

- **Joshua Chenoweth** highlighted results and lessons learned from the revegetation the former Elwha and Glines Canyon reservoirs, where the goals of the revegetation program were to minimize invasive species establishment in the newly exposed surfaces, restore ecosystem processes and accelerate forest development. They used growth trials to determine species performance, and set up permanent monitoring plots to help drive adaptive management of the revegetation program. Natural seedling establishment was high in fine sediments, and trees and shrubs that performed poorly in the pre-dam removal plant trials had high survival in the dewatered reservoirs, leading to novel species compositions on upland terraces dominated by natives. Planting increased species richness and species composition. Seeding native herbaceous species significantly reduced non-native plant frequency. Vegetation establishment was poor in course sediments, with the exception of herbaceous species (primary lupine). A robust monitoring program is critical to adaptively manage revegetation of reservoirs after large dam removal, where local conditions will influence revegetation.

- **Jeff Duda** presented a template for predicting how river ecosystems will respond to dam removal. He suggested that the trajectory of ecological recovery can be predicted, despite differences in each river's history, land use, regional setting, and dam sizes. He presented results from ecosystem studies on the Elwha, where they tracked fish passage and functional use of habitats that were disconnected due to the former dams through the use of eDNA. They tracked aquatic food web response to the sediment pulse associated with dam removal, and traced the return of marine derived nutrients from returning anadromous fish into aquatic invertebrates, fish, and birds. In the years following dam removal, many of the changes seen during dam removal returned to levels seen prior to dam removal, suggesting that the river recovers from dam removal-induced changes. When aquatic invertebrate availability was lower during the dam removal, fish transitioned their diet to favor terrestrial sources of food, which allowed for similar levels of energy density as pre-dam removal levels.

- **Andie Ritchie** presented a study of orthoimagery to document reservoir geomorphic change on the Elwha River, where removal of two dams represented the largest dam removal and managed sediment release in U.S. history, with roughly a 20-year supply of coarse sediment and a 5-year supply of fine sediment released from October 2012 to March 2013 alone. Monitoring changes during dam removal presented a significant challenge due to limited monitoring resources, the large area affected by dam removal (approximately 16.5 river miles with an average valley width of about 3000 ft) and the near-real-time need for data from both reservoir and river reaches for adaptive project management decisions. A rapid-deployment, low-cost method was developed to collect aerial imagery and generate orthoimagery and digital elevation models (DEMs) of the Elwha River during removal of Elwha and Glines Canyon dams. Orthoimage resolution allowed identification and measurement of features such as individual logs and sediment texture differences. Data were used to determine maximum inundation/erosion width, map banklines and evolution of depositional and erosional features, and to evaluate significant features affecting river morphology such as logjams and channel braidedness. The temporal frequency of flights made it possible to compute bank erosion rates, meander migration rates, and the evolution of potential hazards.

- **Tommy Williams** presented a summary of his research on the response of steelhead and steelhead habitat to the removal of the San Clemente Dam on the Carmel River in 2015, the largest dam removed to date in California. Channel changes were most dramatic following high flows in 2017, which deposited gravel and large woody debris from above the old dam site all the way to the river's terminus. Increased habitat complexity was associated with increased variation in steelhead size classes and abundance at four study reaches. Both steelhead and Pacific Lamprey were observed passing above the former dam site (via the reroute channel), but Williams notes that recovery of fish populations will take place on the generation time of these fish, which is on average four years for steelhead in the Carmel River. Thus, continued monitoring is needed to document recovery patterns of anadromous fish.

2.2.1.3 Breakout Groups

The second day of the Klamath dam removal science coordination workshop was dedicated to developing a set of priority research questions related to Klamath River dam removal. Meeting participants joined focus groups to review research questions submitted in the pre-workshop survey, and to build upon and refine these questions. Through a series of guided group discussions, professional fisheries biologists, water quality scientists, ecologists, wildlife biologists, hydrologist, and geomorphologists compiled research questions about the biological and physical responses of dam removal to the Klamath River. Participants were asked to consider how their questions would benefit management of the Klamath River, and broad scale river restoration as it could apply to rivers beyond the Klamath Basin. Invited speakers with experience researching and coordinating dam removal research helped guide these discussions and contributed to the development of dam removal research questions for the Klamath River.

3 Research and Monitoring Priorities for Klamath River Dam Removal

The following section contains the text of the research questions developed in the breakout groups held during the Klamath dam removal science coordination workshop. Research objectives, questions, and observations and monitoring needs were edited and formatted for consistency and clarity, with review by a subset of meeting participants in each subject area. The research questions articulated below are relatively broad and are thus supported by more specific questions that will be further developed as the scientific process continues. Eventually, several of the more specific questions will be refined into testable hypotheses, whereas others may remain as questions focused on status and trends monitoring

3.1 Geomorphology and Hydrology

3.1.1 Reservoir Sediments

Objectives: Understand how sediments stored in the reservoirs respond to reservoir drawdown on a time scale relevant to adapting the drawdown strategy to maximize sediment evacuation during dam removal.

Question 1: How will reservoir sediment deposits respond to drawdown?

- What will erosion rates be through time and space and how will this affect channel formation and evolution in the reservoirs as they are drained?
- How will tributary deltas adjust, affecting channel formation and connectivity between these tributaries and the river channel located in the former reservoirs?
- How permanent will surfaces in the former reservoirs be and how will this affect vegetation establishment on these surfaces?
- How will variable drawdown rates and sequencing influence erosion or sediment evacuation rates, and can drawdown rates and sequences be modified to maximize sediment evacuation during desired time periods?
- How will sediments be transported, deposited, and stored between reservoirs, and how will this influence sediment transport downstream of Iron Gate Dam?
- Will slope stability safety issues arise during reservoir drawdown?
- What will be the long-term erosion risk with abandoned sediments not evacuated during initial drawdown?

Observations/monitoring needs: These questions can be addressed using a mix of monitoring strategies including airborne remote sensing methods, sediment transport measurements between the reservoirs, bulk density measurements, bathymetric surveying, land-based remote sensing such as stereocameras, web cameras, and documenting stratigraphy. Monitoring should be conducted in all of the reservoirs, but additional focus on Iron Gate Reservoir will provide valuable information about sediment inputs to the river.

Connection with other research and monitoring themes: Understanding reservoir sediment dynamics will inform predictions and monitoring of sediment and geomorphic condition below Iron Gate Dam, as well as fish habitat and water quality conditions throughout the reservoir reach and the river below Iron Gate Dam. Fish habitat, riparian function, and tributary connectivity in the reservoir reach is closely tied to reservoir sediment dynamics.

3.1.2 Downstream Geomorphic Changes

Objectives: Understand the location, type, and magnitude of riverbed elevation and channel changes to the Klamath River below Iron Gate Dam and consider possible interventions to retain sediments in beneficial locations.

Question 1: How will the downstream river respond to sediment released from Iron Gate?

- How will bed elevation and grain size distributions change in the reach from Iron Gate to Cottonwood Creek during and following dam removal?
- How will embeddedness and bed mobility change in currently armored reaches?
- What will be the impacts on grain size, burial, and embeddedness of currently mapped spawning habitats?
- Where will locations of substantial sediment deposition, e.g. pools, shorelines, low bars, and eddies, occur throughout the river?
- How will bed elevation, grain size distributions, embeddedness, bed mobility change long-term, after the effect of the sediment pulse has passed?
- In what locations would fine sediment deposition be beneficial and are certain flows needed to sequester sediments in identified locations?
- What changes will occur in bathymetry and bed grain size in the estuary?
- How will sediment deposition downstream of the dams change channel bed hydraulic controls and in turn hydraulic-flow relationships that facilitate ecological processes?

Observations/monitoring needs: Bathymetric surveys, grain size surveys, sediment tracer analyses, and airborne remote sensing at specified reaches from Iron Gate to the ocean. Monitoring of sediment loads from tributaries downstream from Iron Gate. Monitoring should be focused on critical habitats such as side channels, pools, margin rearing habitat, and other areas defined by fisheries biologist and using 2-D habitat models from USBR. Survey locations should be along the entire length of the Klamath River, from below the dams to the ocean, with intensive study reaches, including detailed locations below the Trinity River where slope decreases. Monitoring methods for margins are currently undefined, and chosen methods will need field-testing. Additional high precision baseline surveys are needed in the estuary to understand changes to the estuary from reservoir sediment deposition. There may be a need for evaluation of spit dynamics related to ocean transport (grain size and topographic transects) to understand the changes to the estuary.

Connection with other research and monitoring themes: Changes in geomorphic conditions below Iron Gate Dam will influence fish habitat, primary producer growth, and aquatic invertebrate communities. Incorporating information about geomorphic change into these biological monitoring components will help identify mechanisms responsible for changes in river ecology associated with dam removal. Using similar study sites for geomorphic and ecological studies and data sharing among these research efforts will bring a larger scale picture of ecosystem changes associated with dam removal.

3.1.3 Changes to Sediment Budgets

Objectives: Understand how dam removal affects sediment concentrations, loads, and budgets in the Klamath River.

Question 1: How will the sediment budget respond to dam removal?

- How will sediment concentrations, loads, and budgets change by reach during drawdown?
- How will sediment concentrations, loads, and budgets change by reach in the years following removal, as the river achieves a new equilibrium without the four hydroelectric dams?
- What is the longitudinal variability and influence of tributaries on sediment budgets and how will this change with dam removal?
- What is the grain size variability; suspended-sediment, bedload budgets now and how will that change with dam removal?
- How long will it take to achieve a new sediment budget regime?

Observations/monitoring needs: Current and long-term monitoring of turbidity, discharge, and suspended sediment from USGS gaging stations along the Klamath River and tributaries are needed. Turbidity and discharge data will be used to estimate transport of suspended sediments before, during, and after dam removal. A proposed gauge at Walker Bridge (or nearby location) to represent changing condition between Iron Gate Dam and Seiad Valley is needed to provide data in a part of the river expected to experience more change due to proximity to the dam. This part of the river currently has limited data collection, despite hypotheses that this reach will be more influenced by dam removal. Sediment tracers can also be used to inform sediment budgets.

Connection with other research and monitoring themes: Changes in sediment budgets will influence ecosystem flux estimates of carbon, nutrients, and other inorganic and organic materials, including contaminant transport. Changes to sediment budgets are expected to influence a wide range of ecological structures and functions in the river from water quality to fish habitat. Data sharing and study site overlap of sediment budgets and ecological themes will help identify mechanisms of ecological change associated with dam removal on the Klamath River.

3.2 Water Quality and Lower Trophic Level Aquatic Ecology

3.2.1 Physical and Chemical Water Quality

Objective: To understand how dam removal will affect physical and chemical water quality parameters in the restored hydroelectric reach and in the Klamath River below Iron Gate Dam.

Question 1: How will temporarily elevated turbidity, suspended sediments associated with reservoir drawdown and dam removal affect water quality in the Klamath River through space and time? This overarching question is short-term in scope and directed at how disturbance associated with the dam removal process will affect water quality.

- How long will erosion of reservoir sediments contribute to elevated turbidity and suspended sediment levels in the Klamath River and how will these elevated turbidity and suspended sediment levels vary in magnitude within this period?
- How will turbidity and suspended sediment levels change longitudinally in the Klamath River, including at sites within the hydroelectric reach, directly below Iron Gate Dam, and at sites farther downstream?

- What will be the effects of elevated turbidity and suspended sediments on reach-scale primary productivity and respiration (i.e., planktonic and benthic) and how will this change with season?
- How will different components of the annual hydrograph, such as snowmelt peaks vs. rain-driven high flows, differentially affect turbidity and suspended sediments in the Klamath River during erosion of the reservoir sediment deposits?
- Are there periods during which elevated turbidity and suspended sediment levels will negatively impact tribal trust species (e.g., Chinook Salmon, Coho Salmon, steelhead, Pacific Lamprey, Eulachon and others), and how long will these periods last?
- What will be the oxygen demand associated with suspended sediment release during reservoir drawdown and dam removal, and how will this affect short-term river dissolved oxygen concentrations through space and time?
- How will the suspended sediment load associated with reservoir drawdown change carbon, nitrogen, and phosphorus concentrations, across nitrogen and phosphorus species, both during winter high flows and summer periods of high biological activity?
- How will elevated turbidity and suspended sediments affect concentrations of organic and inorganic constituents, including potential contaminants, and how will these levels change longitudinally and over time in the Klamath River, including at sites within the hydroelectric reach, directly downstream of the dams, and at sites farther downstream?

Observations/monitoring needs: Monitoring for suspended sediments, turbidity, dissolved oxygen, oxygen demand, carbon (dissolved and particulate), and nutrients (nitrogen and phosphorus species) in the mainstem Klamath River should be undertaken for at least one year prior to reservoir drawdown, during reservoir drawdown and erosion of the sediment deposits, and until reservoir sediments are no longer contributing to the background sediment load in the Klamath River. The precise amount of time that short-term monitoring should continue is unknown because it is unknown how long it will take for the river to stop transporting reservoir sediment deposits into the river. Turbidity and dissolved oxygen should be monitored at locations within and below the hydroelectric reach using continuous/real-time sensors, and carbon, nutrients, and oxygen demand should be monitored via grab samples collected every two weeks. Continuous instream flow monitoring will be required to characterize the hydrograph before, during, and after reservoir drawdown and to assess material transport fluxes and loading, using existing USGS gage locations on the Klamath River (see SI-3). Suspended sediment samples should be collected as depth-integrated samples. Because the largest concentrations of suspended sediment are expected during high flows, suspended sediment sampling should occur during winter months and high flow periods, including collecting winter baseline data prior to dam removal and the erosion of reservoir sediment deposits. Suspended sediment sampling should also occur during the spring, summer and fall low-flow periods. Suspended sediment sampling should occur at USGS gaging stations coincident with turbidity and river discharge measurements, and sites at the mouth of the four major tributaries (Scott, Shasta, Salmon, Trinity rivers) below Iron Gate Dam should continue to be sampled to act as reference reaches.

Connection with other research and monitoring themes: Short-term water quality questions related to turbidity and suspended sediments should be addressed in coordination with geomorphic and sediment budget work. The short-term water quality monitoring question related to primary productivity and respiration should be addressed in connection with monitoring focused on primary production, algae, and cyanotoxins. Potential short-term water quality related impacts to tribal trust species (i.e., Chinook Salmon, Coho Salmon, steelhead, Pacific Lamprey, and Eulachon) should be assessed in connection with fisheries monitoring. In general, water quality monitoring questions addressing short- vs. long-term changes due to dam removal will rely upon similar monitoring data, albeit on different times scales, such that the Question 1 short-term monitoring items listed above should be addressed in connection with long-term water quality monitoring items listed below under Question 2.

Question 2: How will water quality change in the long term in response to dam removal (i.e., after the temporary effects of elevated suspended sediment from reservoir drawdown and dam removal have passed)? This overarching question is directed at understanding the differences between dammed and un-dammed river conditions, rather than addressing the effects of the temporary disturbance associated with the dam removal process, which is covered by Question 1 above.

- How will suspended sediment concentrations and turbidity change from the current dams-in condition, after substantive erosion of the reservoir sediment deposits has ceased?
- How will water temperature, dissolved oxygen, pH, conductivity, carbon, nutrients, and cyanotoxins change in response to dam removal in the Klamath River?
- How will dam removal-induced changes in suspended sediment concentrations, turbidity, water temperature, nitrogen, and phosphorus affect primary production and respiration during the summer when reach-scale primary productivity (i.e., planktonic and benthic) is elevated?
- How will changes in suspended sediment concentrations, flows, or connectivity associated with dam removal affect the fate and transport of carbon, nitrogen, phosphorus, and possible inorganic and organic contaminants?

Observations/monitoring needs: The monitoring techniques for addressing long-term water quality changes associated with dam removal are similar to those outlined in Question 1 above (short-term water quality), but the time scale differs. Baseline data are needed to compare water quality conditions before and after dam removal, including long-term changes, thus monitoring of water quality parameters via continuous/real-time sensors and discrete samples (grab or depth integrated depending on constituent) are needed for multiple years following the dam removal (length of time will depend on constituent and the impacts of dam removal on each constituent) at sites in the Klamath River, and at the reference (major tributary) sites. Because changes in water year, climate, and land use will simultaneously influence Klamath River water quality, long-term monitoring programs should be combined with special studies that seek to identify mechanisms responsible for water quality change in response to dam removal vs. other land use and water management activities. As with the monitoring needs in Question 1 above, sampling at a range of discharges including high flows, and having access to discharge data at sampling locations will be needed to calculate material transport fluxes before and after dam removal.

Connection with other research and monitoring themes: Long-term water quality questions related to turbidity and suspended sediments should be addressed in coordination with geomorphic and sediment budget work. The long-term water quality monitoring question related to reach-scale primary productivity and respiration (i.e., planktonic and benthic) should be addressed in connection with monitoring of algae, primary production, and cyanotoxins. In general, water quality monitoring questions addressing short- vs. long-term changes due to dam removal will rely upon similar monitoring data, albeit on different times scales, such that the Question 2 long-term monitoring items listed above should be addressed in connection with short-term water quality monitoring items listed above under Question 1.

Question 3: How will the upstream movement of nutrients in fish from the mainstem Klamath River to its tributaries change in response to dam removal?

- Will changes in salmon runs in response to dam removal correspond to measurable changes in nutrient concentrations (nitrogen and phosphorus species) and/or other indicators of nutrient enrichment (i.e., primary productivity, levels of marine-derived carbon and nitrogen) in tributary streams above Iron Gate Dam?
- Will changes in salmon runs in response to dam removal correspond to measurable increases in nutrient concentrations (nitrogen and phosphorus species) and/or other indicators of nutrient enrichment (i.e., primary productivity, levels of marine-derived carbon and nitrogen) in tributary streams below Iron Gate Dam?
- How will habitat connectivity created by dam removal (i.e., tributaries above Iron Gate Dam), or changes in the number of returning fish associated with restoration (tributaries below Iron Gate Dam), influence food availability and use of salmon carcasses by aquatic and terrestrial predators?

Observations/monitoring needs: Special studies should be conducted in tributary streams that will experience changes in numbers of spawning salmon in response to dam removal. Ideal streams for these studies are low-nutrient (i.e., nitrogen, phosphorus) streams, where changes associated with salmon use due to dam removal can be measured against background levels. Priority monitoring should be undertaken in tributaries between Iron Gate Dam and Keno Dam, but tributaries of Upper Klamath Lake and tributaries to the Klamath River below Iron Gate Dam also should be considered if changes to salmon spawning populations are expected in these tributaries due to dam removal. Monitoring reach-scale primary production (i.e., planktonic and benthic) before and after dam-removal induced changes in salmon spawning numbers may indicate biostimulation due to increased nutrients, and stable isotopes of carbon and nitrogen can be used to trace the influence of marine-derived nutrients in the aquatic and terrestrial food web before and after dam removal.

Connection with other research and monitoring themes: These studies should be conducted in coordination with fisheries distribution monitoring, as well as wildlife diet studies focused on tracing marine-derived nutrients in the diets of birds and other wildlife. The nutrient enrichment monitoring questions related to primary productivity should be addressed in with other algae and primary productivity studies.

Question 4: How will water temperatures change in the Klamath River in response to dam removal?

- What will the water temperature regimes be for the newly restored tributary reaches located within the prior reservoir footprints?
- What will mainstem Klamath River water temperatures be in the former hydroelectric reach, and what will be the distribution of cold-water refugia associated with groundwater spring inputs?
- How will the mainstem Klamath River water temperature regime change below Iron Gate Dam?

Observations/monitoring needs: Continuous/real-time water temperature monitoring should continue in the mainstem Klamath River below Iron Gate Dam, with higher frequency measurements in the reach between Iron Gate Dam and Beaver Creek where temperature regimes are expected to change the most in response to dam removal. Airborne thermal sensors can be used to map cold water inputs within the former reservoir reach, and a robust sensor network should be deployed within the reservoir reach and associated tributaries to monitor seasonal temperature regimes there.

Connection with other research and monitoring themes: Water quality focused questions related to water temperature should be addressed in connection with water temperature related fish disease research and fisheries habitat research.

3.2.2 Algae, Primary Productivity, and Cyanotoxins

Objectives: To document changes to algal community composition and reach-scale primary productivity (i.e., planktonic and benthic) in the Klamath River in response to dam removal, and to understand how these changes to primary production and algal communities influence water quality (i.e., dissolved oxygen, pH, nutrients, cyanotoxins), and fisheries.

Question 1: How will the community composition and distribution of planktonic algae in the Klamath River change in response to dam removal and how will this affect cyanotoxin concentrations?

- How will the elimination of phytoplankton originating in the reservoirs affect cyanotoxin distribution and concentrations in the Klamath River?
- How far downstream will planktonic algae originating in Upper Klamath Lake be measurable in the Klamath River?
- Are cyanotoxins present in the reservoir sediment deposits and, if so, will these toxins be measurable in the river during reservoir drawdown when the sediment deposits will be mobilized? How long will these cyanotoxins persist in the sediment deposits that remain in the former reservoir footprints? Can they be mobilized via dust from the reservoir sediment deposits following dam removal in measurable concentrations?
- Will the former hydroelectric reach support microhabitats of slower water allowing for phytoplankton growth?

Observations/monitoring needs: Although *Microcystis aerginosa* and other planktonic cyanobacteria that proliferate in the hydroelectric reservoirs are expected to be mostly eliminated with the removal of the reservoirs, post-dam-removal monitoring for planktonic cyanobacteria in the reservoir reach and river below the reservoirs should continue to confirm this expectation. Monitoring of cyanotoxin concentrations (microcystin and anatoxin-a) and phytoplankton species cell density estimates from the water column should continue at long-term monitoring sites for at least 3 years following dam removal from Upper Klamath Lake to the Klamath River Estuary. Monitoring for cyanotoxins associated with elevated suspended sediments and turbidity during reservoir drawdown should occur in addition to the seasonal monitoring currently underway at long-term monitoring sites. Monitoring for cyanotoxins in the reservoir sediment deposits following drawdown would also need to occur. Special studies assessing the contribution of benthic cyanobacteria to microcystin concentrations in the mainstem river will help identify whether post-dam-removal cyanotoxins are associated with transport from upstream habitat or from benthic algae. New monitoring sites should be established in the former hydroelectric reach to assess whether microhabitats of slower water are supported and in turn support phytoplankton growth.

Connection with other research and monitoring themes: Planktonic algae studies should be coordinated with water quality and public health monitoring related to algal toxin magnitudes, distribution, and source organisms, including Upper Klamath Lake studies of harmful algal blooms and Karuk Tribe and Yurok Tribe water quality monitoring in the lower Klamath River (see also SI-3).

Question 2: How will the community composition and distribution of benthic algae and macrophytes in the Klamath River change in response to dam removal and how will this affect cyanotoxins?

- What will be the community composition of benthic algae in the former reservoir reaches?
- How will macrophyte and filamentous algae distribution change in response to dam removal below Iron Gate Dam?
- How will benthic cyanobacteria distribution, densities, and toxin production change in response to dam removal?
- How will community composition of periphyton, as well as their functional status (in terms of ability to fix nitrogen), change in response to dam removal?

Observations/monitoring needs: Given expected changes in nutrient speciation, concentrations, and the timing or seasonality of nutrient transport through the reservoir reach from upstream, along with newly exposed benthic habitat under the existing reservoirs, the river's benthic algal composition and biomass could change. Surveys of benthic algae and macrophytes should be conducted in the Klamath River at sites in the Keno-JC Boyle Reach, JC Boyle-Copco reach, and between Iron Gate Dam and the estuary, following methods implemented in 2019. These surveys should be conducted in July each summer before, during, and after dam removal to assess changes in annual algae growth. Drones can be used to take photos for later assessment of macrophyte coverage. Benthic cyanobacteria monitoring sites should be established and monitored biweekly through the summer each year to assess spatial and seasonal distribution of these taxa, because benthic cyanobacteria pose a public health risk. Cyanobacterial mat samples should be analyzed for toxin concentrations (specifically anatoxin-a) at these sites. Periphyton samples should be collected and analyzed for species composition at sites between Keno Dam and the estuary to compare with previous studies of periphyton dynamics. After dam removal, newly restored fluvial reaches in the hydroelectric reach should be monitored for algal community composition and coverage.

Connection with other research and monitoring themes: Benthic algae can be important food resources and influence habitat for invertebrates and fish, thus benthic algae studies should be coordinated with food web work and habitat questions related to aquatic invertebrates and fish, including how changes in benthic algae and macrophytes could influence the invertebrate host of *C. shasta*. Benthic cyanotoxin-related questions should be addressed in connection with phytoplankton cyanotoxin-related questions since it will be important to distinguish between potential cyanotoxin sources in relation to dam removal.

Question 3: How will rates of reach-scale primary productivity (i.e., planktonic and benthic) and nutrient limitation change in response to dam removal?

- What will reach-scale primary productivity rates be in the newly restored fluvial reaches and how will this change with time?

- How will nutrient uptake in the newly restored fluvial reaches compare to current nutrient dynamics in the reservoirs, and how will this influence nutrient availability for primary producers in the river below Iron Gate Dam?
- How will the timing of nutrient limitation shift with the elimination of the reservoirs?
- How will rates of reach-scale primary productivity change below Iron Gate Dam in response to dam removal?
- How will rates of reach-scale primary productivity and respiration affect daily dissolved oxygen and pH values and subsequent water quality exceedances in response to dam removal?

Observations/monitoring needs: Rates of reach-scale primary productivity and respiration (i.e., planktonic and benthic) can be calculated from high frequency dissolved oxygen data collected from automated sensors. The long-term water quality sensors currently operating in the Klamath River below Keno Dam should continue being operated during and after dam removal, so that daily ecosystem production and respiration can be calculated and compared to pre-dam removal rates both in years immediately following dam removal and for monitoring prolonged ecosystem recovery. Dissolved oxygen sensors should be placed in the fluvial reaches following the draining of the reservoirs so that rates of primary production can be measured in these reaches. Continued bi-weekly sampling of nutrients should occur at the dissolved oxygen sites both in the hydroelectric reach and lower river, ideally placed near current nutrient sampling sites, so that nutrient budgets can be calculated and compared to pre- and post-dam removal scenarios.

Connection with other research and monitoring themes: Reach-scale primary productivity (i.e., planktonic and benthic) influences riverine dissolved oxygen and pH levels and are influenced by light availability and changes in nutrients, thus this work should be undertaken in connection with short-term and long-term monitoring of nutrients and other water quality monitoring in the mainstem Klamath River.

3.2.3 Invertebrate Ecology

Objectives: To quantify the effects of dam removal on aquatic invertebrates in the Klamath River, including the distribution, abundance, and production of key taxa; to assess invertebrate composition and abundance as a measure of ecosystem response to dam removal; and to quantify aquatic invertebrate production and energy flow to assess changes to food webs and food available to native fish in the Klamath River.

Question 1: How will benthic macroinvertebrates in the Klamath River respond to dam removal?

- What is the pre-dam removal taxonomic composition, distribution and abundance of macroinvertebrates?
- What will the effect of the short-term impacts from the sediment pulse be on macroinvertebrates?
- How will invertebrate composition, distribution and abundance change in the Klamath River post dam removal (long-term)?
- What non-native invertebrates currently exist in the Klamath River?
- What is the current distribution of non-native invertebrate species?

Observations/monitoring needs: To assess macroinvertebrate response to dam removal, benthic sampling of invertebrates should be conducted at sites above, within, and below the hydroelectric reach. A higher density of sites closer to Iron Gate Dam will test the hypothesis that changes to invertebrate composition, distribution and abundance will be more affected immediately below the dams, and changes will lessen with distance downstream from dams. Sampling invertebrates in the 4 largest tributaries can act as references to change in the Klamath River. Sampling should be conducted before, during and after dam removal, while sites currently inundated by the reservoirs should be sampled once reservoirs are drained and continuing after dam removal to assess riverine recovery, both short-term and long-term. Continuation of these surveys should be based on invertebrate response time in other systems and based on data collected in the Klamath. Sampling invertebrates above the hydroelectric reach prior to dam removal will help identify background conditions for comparison with changes in community composition documented within the hydroelectric reach. Sampling strategies should include methods needed to sample and identify both native and nonnative mussels.

Connection with other research and monitoring themes: Benthic macroinvertebrate sampling should be conducted at geomorphic and algae sampling sites when possible to provide data that can help explain mechanisms behind changes to invertebrates in the Klamath River in response to dam removal.

Question 2: How will dam removal affect aquatic food webs and food available to native fish in the Klamath River?

- How will invertebrate food resources (i.e., algae and detritus) and energy transfer from these food resources (due to consumption and assimilation) change with dam removal?
- How will invertebrate prey for native fish be affected by dam removal?
- How will biomass and production of invertebrates be affected by dam removal?

Observations/monitoring needs: Understanding how changes to the invertebrate community influence the food resources available to native fish, and what part of the food web is responsible for these changes, requires implementing additional methods to those described in the above Question 1. At 2-4 sites, daily primary productivity, monthly secondary productivity should be assessed by season. Secondary production will require quantitative monthly sampling of invertebrates at each site, including drift samples. Stable isotopes may also be useful in answering specific questions about food resources, including identifying the importance of detrital vs. algal sources to invertebrates.

Connection with other research and monitoring themes: Primary production estimates should be conducted in collaboration with studies focused on algal growth and ecosystem primary production. Food web studies linking material fluxes among lower trophic levels should be conducted near sites with established dissolved oxygen data collection to maximize use of these data sets, and in collaboration with fisheries questions related to food availability for native fish as mentioned in the fish habitat questions.

Question 3: How will dam removal affect the distribution and abundance of native freshwater mussels in the Klamath River?

- Will mussels colonize former reservoir habitats?

- How will mussels respond to the short-term sediment pulse in the river below the dams?
- How will fish movement past prior passage barriers (i.e., the dams) promote an increase in the distribution of mussels in the upper watershed?

Observations/monitoring needs: Surveys for the distribution and abundance of mussels should be conducted prior to and following dam removal from Keno Reservoir to the Klamath River Estuary.

Connection with other research and monitoring themes: Because mussels are a culturally important food resource, surveys should be conducted in coordination with algal toxin or other contaminant studies to assess the degree that mussels accumulate contaminants differentially before and after dam removal.

3.3 Fisheries

3.3.1 Fish Disease

Objectives: Understand how restoring fish passage, opening up historic habitat, and shifting hatchery management associated with the removal of the four Klamath Hydroelectric dams will influence salmon disease dynamics in the Klamath River.

Question 1: How will the distribution of *C. shasta* and magnitude of infection risk below Iron Gate Dam change following dam removal?

- How will the distribution and abundance of pathogens change in response to flow, water temperature, sediment dynamics, and water quality changes due to a state of no dams (long-term changes)?
- How will the distribution of the invertebrate host change in response to flow, water temperature, sediment dynamics, and water quality changes due to a state of no dams?
- How will the distribution and abundance of pathogens change in response to the disturbance effect of the sediment pulse associated with dam removal (short-term changes)?
- How will the distribution of the invertebrate host change in response to the disturbance effect of the sediment pulse associated with dam removal?
- How will changes in the distribution of the fish hosts, which are expected to have lower densities immediately below Iron Gate Dam following dam removal, influence the abundance of *C. shasta* in the infectious zone, and the prevalence and intensity of *C. shasta* infections in fish below IGD?

Observations/monitoring needs: Continued monitoring and research should be conducted at established sites between Iron Gate Dam and the Klamath River Estuary. It is critical that monitoring continues to include sentinel fish exposures, invertebrate host sampling, juvenile population monitoring for disease infection rates and severity of infections, and waterborne pathogen sampling at established sites before, during, and after dam removal. Post dam removal surveys should continue beyond the sediment pulse to understand the long-term effects on *C. shasta* disease prevalence, particularly to demonstrate the range of responses to different water year types (e.g., drought vs. wet years). Additional study sites may be needed to capture changes in the river following dam removal.

Connection with other research and monitoring themes: Due to the complex, multi-host life cycle of the *C. shasta* pathogen, understanding disease dynamic changes are related to many other thematic areas of research related to dam removal, including understanding changes in sediment dynamics, water quality, food resources of the invertebrate host (carbon and algae dynamics), and fish abundance and distribution. Planning studies at similar locations and time scales has the potential to allow for data sharing and collaboration among monitoring themes, and due to established, long term study locations for *C. shasta* below Iron Gate Dam, using these sites as key study locations may enable future comparisons to data collected prior to dam removal, if these locations are deemed suitable for new studies being considered.

Question 2: How will the distribution and magnitude of *C. shasta* infection in fish change above Iron Gate Dam?

- What is the current distribution and abundance of *C. shasta* and the invertebrate host within the hydroelectric reach?
- How will the distribution of invertebrate host and *C. shasta* change after reservoirs are returned to fluvial habitats in the hydroelectric reach?
- How will the invertebrate hosts colonize and proliferate following habitat change, pulse disturbance, and flow restoration?
- What is the current distribution of *C. shasta* and the invertebrate host in potential spawning habitat above the project reach, including tributaries above Upper Klamath Lake, and how will this change as salmon recolonize these habitats?
- How will the distribution of *C. shasta* types change with dam removal; how will type I, type II and type o distributions shift with new runs of salmon entering the upper basin?
- What will be the effects from *C. shasta* (infection rates, severity of infection, and population effects) to current native fish populations above the project reach, including tributaries to the project reach and above Upper Klamath Lake, following dam removal?
- What will infection levels of *C. shasta* be to juvenile anadromous salmonids above the current location of Iron Gate Dam over time following dam removal?

Observations/monitoring needs: Surveys should be conducted in and above the project reach prior to dam removal for current distribution and abundance of the invertebrate host and for waterborne pathogen presence as a comparison for post dam removal conditions. Invertebrate sampling should be conducted at hydroelectric reach pre-dam removal sites two to four times per year, while water samples should be collected every two weeks in the spring and summer to characterize the current presence and future changes to the timing of *C. shasta* proliferation. Sites should be sampled before and after dam removal as a reference for dam removal, and choosing representative sites, including reservoir, consistently dewatered reaches, and consistently hydropeaked reaches will help describe the recolonization potential of the invertebrate host under different environmental conditions. Water sampling may provide useful baseline data describing the distribution of *C. shasta* over large spatial areas that may be recolonized by salmon following dam removal, including the project reach, tributaries to the project reach, and river sections and tributaries in and above Upper Klamath Lake. In addition to water sampling and invertebrate host monitoring, native fish populations above the project reach, including tributaries to the project reach and above Upper Klamath Lake, should be sampled for the presence of *C. shasta* prior to and following dam removal. Following dam removal, juvenile anadromous salmonids should be sampled for the presence of *C. shasta* above the Iron Gate Dam location; an optimal location for this sampling may be Keno dam.

Connection with other research and monitoring themes: As with understanding *C. shasta* dynamics below IGD, changes above IGD should also consider collaborations with water quality, food resources of the invertebrate host (carbon and algae dynamics), and fish abundance and distribution. Changes in geomorphology and sediment dynamics are especially important in this reach, thus information from teams studying physical river change is essential to integrate.

Question 3: How will fish hatchery operation changes associated with dam removal influence *C. shasta* prevalence and infection rates in the Klamath River?

- How will hatchery release survival at Fall Creek Hatchery compare to current hatchery release survival at Iron Gate Hatchery?
- How does infection of hatchery-raised fish affect the wild fish populations, and how will this change with post-dam removal conditions and hatchery operations?
- How will release timing of Fall Creek Chinook Salmon smolts differ from current release timing at Iron Gate Hatchery, based on thermal regime for incubation and early life-stage rearing, and what will be the effect to: a) C. *shasta* disease dynamics in the Klamath River, and b) survival of the hatchery fish released?
- How will the distribution and abundance of carcasses from hatchery fish spawned in the river change and what will be the effect on the infection of annelid worms from *C. shasta*?
- How will infection rates by *C. shasta* of adult salmon returning to spawn post-dam removal compare relative to current conditions?

Observations/monitoring needs: Historic records of fish disease associated with Fall Creek Hatchery operations should be compiled to inform predictions about survival of hatchery fish from Fall Creek Hatchery. Hatchery disease monitoring, downstream migrant trapping, and/or seining of fish should continue to monitor infection rates of hatchery and wild juvenile salmon. Accumulated thermal units should be compared for Fall Creek hatchery water relative to Iron Gate Hatchery water during the incubation and early life-stage rearing periods. This information should be used to compare when fish will reach the smolt stage for release (approximately 90 fish/lb) at the two facilities, the associated *C. shasta* levels in the river at these times, and the resultant expected *C. shasta* infection rates and associated mortality rates of the released fish, as well as the overall effect this will have on disease dynamics of wild fish in the Klamath River. The density of carcasses downstream of Iron Gate Hatchery should continue to be monitored and compared to the density of carcasses downstream of Fall Creek Hatchery and the current location of Iron Gate Hatchery post dam removal. Infection rates of annelid worms within and immediately downstream of these areas should also be monitored to enable pre/post dam removal comparisons. Returning adult salmon should be sampled, pre and post dam removal, to compare infection rates and severity of infection by *C. shasta,* to assess whether a change in the infection rate of smolts following release from the hatchery affects the proliferation of the *C. shasta* life cycle in the Klamath River.

Connection with other research and monitoring themes: Questions related to fish hatchery influence of *C. shasta* dynamics should be integrated into hatchery monitoring, as well as the monitoring of juveniles and adult salmonids within the Klamath River.

Question 4: How will other fish pathogens respond to conditions associated with dam removal and shifting fish populations in a post dam removal Klamath River?

- How will newly available thermal refugia affect the spread, distribution and prevalence of fish diseases following dam removal, including *Ichthyophthirius multifilis* (Ich), *Parvicapsula minibicornis*, and *Flavobacterium columnare* (Columnaris)?
- How will changes in temperature regimes affect the distribution and prevalence of fish diseases following dam removal, including *Ichthyophthirius multifilis* (Ich), *Parvicapsula minibicornis*, and *Flavobacterium columnare* (Columnaris)??
- How will increased spring salmon abundance influence *Ichthyophthirius multifilis* (Ich)proliferation in the Lower Klamath?
- How will dam removal influence adult salmonid migration through the lower Klamath, and how will these changes influence disease dynamics?
- How will disease brought in by salmon influence Lost River and Shortnose Suckers?

Observations/monitoring needs: Current water sampling in the Lower Klamath River, at Ishi Pishi Falls, and on the Trinity River should continue for Ich and other possible fish diseases. Increasing eDNA sites could help identify new areas of influx or lesser concentrations of Ich and other fish diseases. Areas of crowding, especially related to thermal refugia or temporary barriers should be monitored using water sampling, mobile sonar, and adult salmon pathology methods depending on the site and impact of the disease. Continuing current monitoring of fish density through the Yurok Net Harvest Monitoring Program should be augmented with additional methods for monitoring salmon densities in the lower river including increased sonar surveys in lower river pools and adding a sonar weir monitoring station. Fish density monitoring techniques should be considered at upriver sites as needed.

Connection with other research and monitoring themes: Because fish disease dynamics are commonly influenced by fish density, studies of fish distribution and abundance should be integrated into studies and monitoring of all fish disease dynamics, with special attention placed on areas of fish congregations, such as cold-water refuges.

3.3.2 Fish Abundance and Distribution

Objectives: Understand how the distribution and abundance of fish species throughout the Klamath River will shift in response to the disturbance associated with the post-dam removal sediment pulse as well as the long-term effects of restored habitat connectivity and other long-term changes to fish habitat associated with the removal of the four hydroelectric dams on the Klamath River.

Question 1: How will dam removal influence endangered Lost River and Shortnose Suckers?

- What is the current distribution and abundance of Lost River and Shortnose Suckers downstream of Upper Klamath Lake?
- How will the abundance and distribution of Lost River and Shortnose Suckers change as a result of dam removal, including movement beyond former barriers?

Observations/monitoring needs: eDNA surveys and/or population abundance surveys should be conducted before and after dam removal downstream of Upper Klamath Lake to investigate current distribution and abundance of Lost River and Shortnose Suckers below Upper Klamath Lake. Existing records of sucker distribution should be compiled and analyzed to inform pre-dam removal sampling locations and extent.

Connection with other research and monitoring themes: In some cases, monitoring and research to assess changes in distribution and abundance of Lost River and Shortnose Suckers with dam removal may be conducted with surveys assessing the movement and distribution of other fish associated with dam removal, especially in terms of eDNA sampling.

Question 2: How will dam removal influence anadromous and non-anadromous lamprey in the Klamath River?

- How will dam removal influence the distribution and run timing of anadromous Pacific Lamprey and how will we track recolonization?
- How will dam removal influence the distribution of non-anadromous lamprey in the Klamath River?
- How will changes in lamprey distribution and behavior affect salmonids?
- How will juvenile lamprey habitats improve below IGD with the influx of new sediments and with a restored sediment regime below IGD?

Observations/monitoring needs: Currently very little is being done to monitor lamprey in the Klamath River. Tribal harvest occurs in the Lower Klamath, but it is not closely monitored. For upper river monitoring, eDNA is promising but may have limitations due to the current ability to only identify lamprey to genus. Research leading to species specific eDNA techniques would lead to relatively simple survey techniques to identify lamprey distribution, while screw trapping, electrofishing and spawning surveys add more information about distribution, abundance, survival, and reproduction of all species. Traditional and sonar monitoring weirs could be used to monitor anadromous adult migration into newly established habitat upstream of the dam removal project and these techniques will likely be used for salmonid monitoring. Lamprey sampling methods are established for juveniles, but not for adults. Tribal fishing techniques (TEK, basket traps) could be used to sample adult Pacific Lamprey. Capturing anadromous adult fish downstream of the project and marking them with PIT, acoustic, or radio tags could be useful in tracking recolonization.

Connection with other research and monitoring themes: Some monitoring and research to assess changes in distribution and abundance of lamprey species with dam removal may be conducted with surveys assessing the movement and distribution of other fish associated with dam removal, especially in terms of eDNA sampling,fish trapping, telemetry studies, and sonar or traditional weir surveys.

Question 3: What will the post dam removal spawning distribution of Coho and Chinook Salmon above Iron Gate Dam be?

- What will be the spawning distribution and run timing between Iron Gate Dam and Upper Klamath Lake of Coho and Chinook?
- Where will Coho, which are only thought to have used habitats as far upriver as Spencer Creek, distribute? Will their post dam removal distribution match expectations?
- Will Chinook Salmon returning to spawn successfully enter Upper Klamath Lake?
- What will be the migration route through Upper Klamath Lake for adult salmon that successfully enter the lake?
- Where will fish reaching Upper Klamath Lake distribute and spawn?
- Will Keno and Link River Dams impede passage to adult spawners?

- To what extent will water quality conditions in the Keno Reach, Link River, and Upper Klamath Lake impact fish movement to upriver spawning grounds?

Observations/monitoring needs: Following removal of the dams, adult fish surveys should be conducted to document how fish use newly accessible habitats. Spawning ground surveys should be conducted on tributaries within the hydroelectric reach, as well as tributaries to Upper Klamath Lake, and float surveys can be conducted on the mainstem. A sonar weir monitoring site at IGD would help track adults moving up river. Remaining dams at Keno and Link River can be used as capture locations to survey adult fish migrating above the hydroelectric reach. Telemetry should be implemented on adult fish moving into and above Upper Klamath Lake to track migration routes and spawning grounds. Use of eDNA in tributaries to Upper Klamath Lake may help locate tributaries where fish are returning unnoticed and future spawning surveys should be conducted. Micro-chemical analysis of otoliths recovered from adults may help to identify the geographic areas utilized by different life stages of the fish sampled.

Connection with other research and monitoring themes: Monitoring and research to assess recolonization of anadromous salmon above IGD may be conducted along with surveys assessing the movement and distribution of other fish associated with dam removal, when methodology overlap allows for sampling efforts to be combined, such as in eDNA, sonar or traditional weirs, juvenile trapping, and some telemetry surveys. Spawning surveys in the reservoir reach should be informed by geomorphology data.

Question 4: What will the distribution and survival of rearing juvenile Coho and Chinook be following dam removal?

- What factors (physical barriers, water quality, growth potential, etc.) limit juvenile distribution in newly colonized locations?
- How will physical habitat conditions, predators, and competition limit juvenile salmon movement, and how do these differ from conditions faced in currently accessible habitats?
- What will be the survival rate of out-migrating juvenile fish in habitats upstream of Iron Gate Dam?
- How successful will juveniles be in out-migrating through Upper Klamath Lake and Lake Ewauna, and how will out-migration success vary by time of year and water quality conditions?
- How will the disease zone affect the population of out-migrating juveniles?
- How will the distribution, abundance, and survival of juvenile Coho and Chinook change in currently accessible locations below Iron Gate Dam?
- What will be the timing of outmigration for juvenile Coho and Chinook Salmon and will there be a distribution of early and late outmigrants? What will be the size class distribution of out-migrating juveniles and what will be the smolt-to-adult return rate for Coho and Chinook Salmon?

Observations/monitoring needs: Juvenile salmon surveys should be conducted in locations where spawning was known to or is expected to occur above Iron Gate Dam. Hierarchical eDNA methods can be used to identify general regions of surveys, followed by targeted snorkeling surveys of smaller scale habitat use and fish abundance. These surveys should be conducted through the hydroelectric reach and throughout the upper Klamath Basin where salmon have spawned, as well as locations throughout the Lower Klamath River where surveys currently occur. Juvenile salmon from the new Fall Creek Hatchery should be PIT tagged, and wild juvenile fish could be fin-clipped for mark-recaptured surveys involving screw traps located at downstream locations in the mainstem of the Klamath River. Downstream screw traps should be placed downstream of obstacles that are hypothesized to decrease out-migrant survival, including Upper Klamath Lake and zones of high *C. shasta* infection. Juvenile salmon should be trapped at the lower ends of Upper Klamath Lake tributaries to assess distribution and abundance. A portion of these fish should also be implanted with PIT tags and/or telemetry tags to assess movements and life history characteristics. These efforts could be coordinated with a downstream migrant trapping location at Keno Dam and other downstream locations. Yurok Tribal work on fish assemblages between Iron Gate dam and the Scott River should continue after dam removal to asses any changes in the distribution of fish (anadromous/non-anadromous, native/invasive).

Connection with other research and monitoring themes: Assessing distribution of juvenile salmonids below the dams following dam removal should be done in collaboration with physical, chemical, and biological investigations that assess factors influencing juvenile movement and survival, including water quality monitoring, monitoring of potential food resources (algae and invertebrate prey), and physical barriers. Above the hydroelectric reach, changes to the physical, chemical, and biological habitat will in general be minor compared to changes within and below dams, thus assessing these factors should be independently integrated into studies of juvenile fish distribution and survival when appropriate.

Question 5: How will steelhead spawning and rearing distribution change following dam removal?

- What will be the spawning distribution of steelhead following dam removal?
- Will winter and summer run populations recolonize the newly restored habitat?
- To what extent do resident trout populations have alleles that indicate a propensity for anadromy and for what run timing?
- What habitats will juvenile steelhead use following dam removal?
- What will juvenile survival rates be from habitats previously inaccessible to steelhead?
- Will recolonizing steelhead above Iron Gate Dam be associated with fish moving into these habitats or with rainbow trout, who are currently occupying the habitats above Iron Gate Dam?

Observations/monitoring needs: Many of the same techniques described in question 3 could also be used to track steelhead recolonization. Spawning surveys and juvenile surveys for steelhead should be conducted concurrently with surveys outlined for Question 4, above. In addition to these surveys, adult fish from below Iron Gate Dam should be tagged prior to dam removal and tracked via telemetry to observe the recolonization of fish with a pre-existing sea-run life cycle to the upper basin. Fin clips should be collected and genetic analysis conducted to assess the extent to which upper basin steelhead are associated with resident rainbow trout populations versus lower basin *O. mykiss.* Yurok Tribal work on fish assemblages between Iron Gate dam and the Scott River should continue after dam removal to asses any changes in the distribution of fish (anadromous/non-anadromous, native/invasive).

Connection with other research and monitoring themes: Surveys for steelhead spawning and rearing distribution should be coordinated with spawning and rearing monitoring for other fish species when survey timing overlaps sufficiently.

Question 6: How will dam removal influence the distribution, abundance, and movement patterns of non-native fish in the Klamath River?

- Will removal of the dams allow for increased movement of nonnative fish above Iron Gate Dam?
- Will removal of the dams allow movement of fish from upstream lotic habitats into the Klamath River below the former hydroelectric dams?
- How will Brown Trout be affected by dam removal, and will they present a competition or predation risk to native fish?

Observations/monitoring needs: Native and non-native fish distribution can be monitored before and after dam removal with screw traps, seine net monitoring, and eDNA. Existing efforts could be augmented if increased numbers of native and non-native fish are observed following dam removal. Additional monitoring sites or temporal sampling should be focused upriver near Iron Gate Dam where some non-native fish have been observed. Brown trout diet should be assessed as well as distribution and abundance to find out if they are posing a predation risk to native juvenile salmon. Yurok Tribal work on monitoring fish assemblages between Iron Gate dam and the Scott River should continue after dam removal to asses any changes in the distribution of fish (anadromous/non-anadromous, native/invasive).

Connection with other research and monitoring themes: Monitoring non-native species distribution may be combined with survey technique of monitoring other fish, including the use of eDNA, downstream migrant trapping, and seining.

3.3.3 Fish Habitat

Objectives: Understand how physical, chemical, and biological components of the Klamath River Basin will change with dam removal as related to the habitat needs and use of fish.

Question 1: What is the available tributary habitat above and within the hydroelectric reach by species and life stage?

- What habitats are predicted to be available for spawning? What proportion of those are actually used post-dam removal and how does this change over time?
- What habitats are predicted to be available for rearing and holding? What proportion of those are actually used post-dam removal and how does this change over time?
- What is the temperature regime in these tributaries and how does this affect habitat availability by species and life cycle?
- How are these habitats expected to be utilized differently among species?
- How does habitat use compare to expected use as fish gain access to these habitats?
- What are the barriers that are expected to prevent access to otherwise usable habitat?

Observations/monitoring needs: Habitat mapping of tributaries above and within the hydro-electric project reach should occur before dam removal and after to assess natural variation in potential tributary habitat. Consistent habitat typing methodologies should be employed on all streams. Course scale mapping may include geospatial analysis of existing data and newly collected drone images, while finer scale habitat mapping based on site surveys should occur on a subsample of stream reaches. Habitat typing should include geomorphic, temperature, and flow assessments. Spatially and temporally relevant temperature data should be collected using high-frequency data loggers in tributaries to capture variation that could affect fish use of habitats (i.e., daily, seasonally).

Connection with other research and monitoring themes: Assessment of tributary habitat in the reservoir reach will overlap with questions of interest from geomorphic research groups, and data from geomorphic research teams may help address these questions. Assessment of actual habitat use will overlap with questions related to fish distribution and abundance following dam removal.

Question 2: What habitat will be available and used by native anadromous fish in the Klamath River above J.C. Boyle Reservoir, in Lake Ewauna, Link River and Upper Klamath Lake?

- Where are spring-fed cold-water refuges located among river and lake habitats?
- How extensive are poor water quality zones, and how will these zones act as barriers for fish movement during different life stages?
- What Upper Klamath habitats will be available for rearing and holding by life-stage?
- How will Upper Klamath lake habitats influence life history strategies for different anadromous salmonids?
- How will habitat use by native suckers compare to habitats used by returning anadromous species?

Observations/monitoring needs: As in question 1 above, habitat mapping on large and small scales should occur throughout the upper reaches, including lake habitats, as well as a large network of temperature monitoring loggers. FLIR flights to determine locations of cold-water refugia, at both at various flows and lake levels that occur during crucial spawning and rearing periods will be useful to map temperature variation. Compiling existing data of groundwater inputs to Upper Klamath Lake will help guide the placement of new temperature sensors. Boat based surveys to collect spatially explicit coverage of dissolved oxygen data in regions of low dissolved oxygen will help identify locations of barriers associated with low dissolved oxygen conditions.

Connection with other research and monitoring themes: The study of habitat availability and actualized use by returning anadromous fish in river and lake habitats above J.C. Boyle Dam should be conducted in close association of studies of fish distribution and abundance in these same reaches. Similar methods of temperature monitoring can be used and conducted in cooperation with habitat availability monitoring in other reaches of the Klamath River.

Question 3: What habitat is available in the mainstem river within the hydroelectric reach, and how are different species and life stages expected to use these habitats?

- What habitats are expected to be available for spawning?
- What habitats are expected to be available for rearing and holding, by life-stage?
- What is the temperature regime in this area and how does it affect habitat availability by species and life cycle?
- Where are the cold-water thermal refuges above IGD?
- What is the scale of the thermal refuges (i.e., isolated to creek mouths or influencing a larger reach)?
- When and in what capacity will salmonids use these cold-water refuges?
- How are these habitats expected to be utilized differently among species?
- How does actual habitat use compare to expected use as fish gain access to these habitats?

- How do these habitats change from before to during to after dam removal, specifically in reference to the lower reaches of tributaries currently connected to reservoirs?
- What will geomorphic conditions be like (slope, sheer stress, bed movement) and how will this influence spawning habitat?
- How will geomorphology and sediment loads change over time within the hydro-electric reach, and what will be the effect to habitat?
- How long post dam removal will it take for the river to reach a state where the sediment pulse associated with dam removal is no longer influencing streambed changes and fish habitat?
- How does food availability interact with other habitat features to influence growth potential for different species and life stages, but especially during critical rearing periods?

Observations/monitoring needs: As in question 1 above, habitat mapping on large and small scales should occur throughout the reservoir reach, as well as a large network of temperature monitoring loggers. FLIR flights to determine locations of cold-water refugia, at both summer baseflow and increased flows that occur during crucial spawning and rearing periods will be useful to map temperature variation. More intensive habitat mapping should occur at tributary mouths connected to reservoirs and river reaches expected to experience extensive geomorphic change within the project reach. More intensive habitat mapping should include assessment of LiDAR data from the 2018 flights and post dam removal LiDAR should be collected to assess habitat change for the entire hydroelectric reach. During sediment erosion, higher frequency ground mapping of tributary mouths should be conducted to ensure that changes to tributary mouths are not creating barriers for fish that are detrimental to their persistence. Longer term, these tributary mouths should continue to be monitored to assess passage to these tributaries by species and life history. Follow up snorkel surveys at thermal refuges, including tributary mouths, can be used to determine utilization rates and fish behavior in these refugia.

Connection with other research and monitoring themes: Assessment of mainstem habitat availability and use in the reservoir reach will overlap with questions of interest from geomorphic research groups, and data from geomorphic research teams may help address these questions. Assessment of actual habitat use will overlap with questions related to fish distribution and abundance following dam removal. Food web studies assessing the biomass, productivity, and consumption of invertebrates by native fish should be conducted in collaboration with water quality and ecosystem studies focused on invertebrate sampling.

Question 4: How will fish habitat change in the Klamath River between Iron Gate Dam and the Klamath River Estuary following dam removal?

- How will mainstem spawning habitat be affected by the sediment pulse associated with dam removal?
- How far downstream will bed aggradation affecting spawning gravels occur?
- How will flood plain connectivity, and associated access to floodplain habitats, be affected spatially and temporally by aggradation associated with dam removal?
- How will bed particle size and associated mobility be affected by dam removal and how will this change over time?
- How many years post dam removal will sediment from the former reservoirs continue to aggregate in the river?

- After the effects of the sediment pulse have passed, how will spawning gravel availability change associated with increased connectivity to upstream sediment sources previously cut off from impoundments?
- How will creek mouth connectivity in tributaries below Iron Gate Dam be affected by sediment changes associated with dam removal?
- How will temperature regimes change in the river following dam removal?
- How will food availability for native fish in the mainstem change with changes to physical and chemical changes associated with dam removal?

Observations/monitoring needs: Existing LiDAR and bathymetry data should be analyzed to assess large-scale geomorphic conditions between Iron Gate Dam and the Klamath Estuary prior to dam removal, including changes at creek mouths and connectivity to flood plains under different flow conditions. Follow up LiDAR flights and bathymetric surveys of the entire Klamath River after dam removal would allow for comparison of major shifts in habitat. Existing temperature loggers below Iron Gate Dam should be analyzed, and new loggers placed if gaps in data exist, especially in the upper reaches of river (between Iron Gate Dam and Beaver Creek) where temperature changes are expected to be the greatest. Bed particle size should be assessed pre and post-dam removal, and over time following dam removal, to assess mobility of the bed.

Connection with other research and monitoring themes: Habitat and spawning area mapping at selected sites should be conducted before, during and after dam removal, in conjunction with geomorphology studies when possible. Food web studies assessing the biomass, productivity, and consumption of invertebrates by native fish species of concern should be conducted in collaboration with water quality and ecosystem studies focused on invertebrate sampling. Bed particle size changes and their associated mobility should be related to densities of parasite-host annelid worm colonies over time. Habitat availability should be modeled for different flow regimes post dam removal and compared to current conditions. Morphology of the river should be monitored over time post-dam removal, and used for habitat modeling, to assess changes in available habitat over time.

3.4 Riparian, Wildlife, and Upland Ecology

3.4.1 Riparian and Upland Vegetation

Objectives: Dam removal will cause large changes to the newly exposed terrestrial habitat currently inundated by the hydroelectric reservoirs and to the fluvial reaches within the hydroelectric reach that are currently subject to highly altered flow regimes. The majority of the land that will be exposed by reservoir dewatering (~85%) is upland, providing a unique opportunity for oak-juniper woodland, chaparral and native grassland restoration. Below Iron Gate Dam, sediment pulses and a subsequent return to a more natural hydrology is expected to have a significant impact on riparian ecology. Understanding how vegetation responds to dam removal will help direct specific restoration actions, both independent of and associated with the dam removal.

Question 1: How will vegetation respond to dam removal?

- How will riparian and upland vegetation recolonize the sediments left behind in the former reservoirs?

- How will riparian vegetation change in the reservoir reach in response to restored flows in non-reservoir sections currently subject to hydropeaking and very low flows?
- How will riparian vegetation below Iron Gate Dam change from sediment deposition and a return to relatively more natural flow regime?
- Will the distribution and abundance of invasive species change with dam removal?

Observations/monitoring needs: Established methods can be used to document vegetation change and invasive species abundance during and after the dam removal. Remote sensing data from satellite images, images from drone surveys, and riparian and upland vegetation transects and plots can be established to monitor vegetation development in former reservoirs and to detect changes along the banks of the river below the reservoirs. Pre-dam removal vegetation surveys of the uplands and riparian areas between and below the dams is needed to establish baseline data. Riparian vegetation monitoring should be undertaken along the entirety of the river from JC Boyle to the mouth.

Connection with other research and monitoring themes: Changes to riparian and upland vegetation will affect terrestrial wildlife habitat, as well as water quality, stream ecosystem processes, and aquatic habitat. Information about vegetation changes should be made available to wildlife and stream researchers, and in some cases surveys for riparian wildlife and vegetation may be able to be done in collaboration. Additionally, riparian and upland vegetation establishment in the former reservoirs following dam removal will influence sediment deposit erosion, thus geomorphic analysis should consider the role of riparian vegetation in sediment dynamics here.

3.4.2 Riparian and Upland Wildlife

Objectives: Understanding how vegetation and wildlife respond to dam removal will help direct specific restoration actions, both independent of and associated with the dam removal. Protecting species of concern and cultural significance requires understanding the current status of these species and a monitoring program that extends through dam removal and river recovery phases.

Question 1: How will native herbivores respond to dam removal and subsequent vegetation changes?
- How will dam removal alter beaver habitat use via alterations to riparian vegetation?
- How does expansion of critical deer winter range and migration movements change with dam removal?
- How does the expansion of available riparian habitat in the reservoir reach impact elk calving habitat and migration routes?
- How will restoration of a continuous, free-flowing river in the current hydroelectric reach impact ungulates' ability to cross from one side of the river to the other? Will the river be more or less of a barrier to movement, and how will crossing locations change?
- Do changes in hydrology affect river crossing by ungulate species below Iron Gate Dam? Is the river more or less of a barrier to dispersal post dam removal?
- What impact will herbivores have on vegetation development within the former reservoirs?

Observations/monitoring needs: Surveys for beaver using mainstem habitat should be conducted via float surveys, and con be conducted in coordination with surveys for riparian bird species and river otters (see questions 6, 8, and 9). Surveys for deer and elk in the reservoir reach, where the largest changes to upland habitat are expected to occur, should focus on pre and post habitat utilization including winter encounter surveys from roads, fecal DNA surveys, tracking movement through collar data, and aerial surveys. Surveys along the river below the dams should also include fecal DNA analyses, collaring to assess herd movements, camera traps, and aerial surveys. Impacts to vegetation can be determined using exclusion fencing, which is planned for critical riparian areas within the former reservoirs, and comparing these sites to unfenced areas.

Connection with other research and monitoring themes: Distribution of native herbivores is closely linked to vegetation, both riparian and upland, that provide habitat and food resources. Studies will benefit from cooperation with vegetation change studies. Other themes in the riparian and upland wildlife section using similar monitoring techniques, including questions related to feral cattle and horses and questions about migration barriers (Question 9) may benefit from cooperative efforts.

Question 2: How will dam removal affect non-native herbivores such as feral cattle and horses?

- How do changes in hydrology affect river crossing by non-native ungulate species? Is the river more or less of a barrier to dispersal following dam removal?
- How do feral horses and cattle impact vegetation regeneration in the reservoir reach?
- Will feral horses and cattle impact or exclude elk and deer from recolonizing the reservoir reach?
- To what extent do feral horses and cattle spread invasive species throughout the reservoir reach and the entire river corridor?

Observations/monitoring needs: Surveys should be conducted where known populations of invasive herbivores exist both pre- and post-dam removal, and to monitor the effectiveness of feral horse and cattle removal efforts during and following dam removal. Survey types will depend on the habitat occupied. Surveys to track feral ungulates can occur simultaneously with other big game surveys, including visual encounter surveys from roads, fecal DNA surveys, and aerial surveys. Collaring to assess movements is an option.

Connection with other research and monitoring themes: Questions related to feral cattle and horses have significant overlap with question 1, above.

Question 3: How do foothill yellow-legged frogs (FYLF), a species of concern in California, respond to dam removal?

- How will the sediment pulse associated with dam removal affect FYLF?
- How will the elimination of reservoir habitat and subsequent increase in riverine habitat affect available breeding habitat of the FYLF?
- How will the sediment pulse affect cobble, egg-laying habitat and the ability of FYLF to oviposit?

Observations/monitoring needs: Visual encounter surveys should be conducted for FYLF egg masses in the spring along sections of restored rivers throughout the hydroelectric reach and along the entirety of the mainstem to the river mouth. Visual encounter surveys should be conducted for FYLF egg masses in the spring along set survey reaches in high priority habitats in the Klamath River and in tributaries, with tributaries being used as controls. Further, increased use of tributaries for breeding may be expected if mainstem oviposition habitat becomes unsuitable. All amphibian surveys should be conducted before, during, and after dam removal so that post dam removal status of these amphibians can be compared to their pre-dam removal status.

Connection with other research and monitoring themes: Effects of sedimentation is a major concern for amphibians, so survey locations and timing should be informed by predictions about sediment pulses and deposition zones in the river.

Question 4: How do aerial avian insectivores, especially passerine bird species of management concern, respond to dam removal?

- How will dam removal impact nesting and foraging success of Willow Flycatchers, a state-listed endangered species in California?
- How will dam removal impact nesting and foraging success of yellow-billed cuckoos, a California state-listed endangered species and federally-listed endangered species?
- How will the sediment pulse and the expected increases in salmon populations affect food availability for American Dippers?
- How will dam removal impact nesting and foraging success of riparian songbirds more generally?
- How will dam removal affect food availability for riparian songbirds via changes to the aquatic invertebrates that provide a cross-habitat subsidy to riparian birds when they hatch?

Observations/monitoring needs: Surveys for willow flycatchers should include point counts and call surveys following state defined protocols along riparian transects in willow and alder groves at sites along the entire Klamath River corridor. Point count surveys can be conducted to include all avian species present and additional transects should be set in non-willow and alder sites to account for habitat types preferred by other avian species. Point counts will provide information about possible changes to the broader riparian bird community. Point counts should also include occurrence of American Dippers, whose response to dam removal can be further investigated through banding and repeat monitoring of body condition associated with increased salmon in the aquatic food web and blood sampling to investigate upriver marine nutrient flow. Dippers should also be documented via visual-encounter float surveys. Dipper surveys should follow methods employed on the Elwha River so that results are comparable. Studies of food availability in the riparian zone should be conducted in coordination with ecosystem studies assess the response of aquatic invertebrates to dam removal. Surveys for yellow-billed cuckoos should be conducted in expected habitat near the Klamath Estuary, where sediment is expected to deposit and affect both food availability and riparian vegetation.

Connection with other research and monitoring themes: Questions related to riparian passerines will have overlap riparian vegetation themes (habitat) and with aquatic invertebrate themes (food availability).

Question 5: How will bat species of management concern (i.e. Townsend's big eared bat, long-legged myotis, fringed myotis, long-eared myotis), known to forage in riparian habitat, respond to dam removal?

- How will dam removal impact foraging success and, occupancy and diversity of bat species in the Klamath River corridor?
- Will cross-ecosystem subsidies, in the form of marine derived nutrients from anadromous fish, be a measurable part of bat diets in the former reservoir reach, and if so, what will be the relative contribution of marine derived nutrients before and after dam removal?
- How will changes to the location and extent of riparian edge habitat and open water associated with the current reservoirs influence foraging success and, occupancy and diversity of bats in the hydroelectric reach?

Observations/monitoring needs: Bats in this region are generally insectivores and offer a view into aerial insect abundance. Surveys by human observers are difficult due to nocturnal nature and lack of vocalizations audible to humans; however, digital recording techniques coupled with computer identification algorithms makes surveying relatively simple. Set survey locations should be established in the river corridor where river noise does not interfere with detection. Surveys should be conducted in the hydroelectric reach, as well as the river below Iron Gate Dam. Bats may be used to measure changes in upriver transfer of marine derived nutrients in areas previously cut off to anadromous fish.

Connection with other research and monitoring themes: As with riparian bird species, questions related to bats will have overlap riparian vegetation themes (habitat) and with aquatic invertebrate themes (food availability).

Question 6: How do large, piscivorous, avian species of management concern respond to dam removal?

- How will dam removal impact the distribution and abundance of non-passerine species of concern, including Great Blue Heron, Golden Eagles, Bald Eagles, and Osprey both in the hydroelectric reach and below Iron Gate Dam?
- Will the elimination of reservoirs result in changes in the nesting sites of these birds associated with changes in the proximity of current nest sites to the water's edge?
- How will the elimination of reservoirs alter prey availability for piscivorous birds using the reservoirs?
- Will changes in food and nest sites affect distribution and abundance of these piscivorous birds?

Observations/monitoring needs: Monitoring for larger avian species should be conducted through visual-encounter float surveys along the river corridor, including throughout the hydroelectric reach. Monitoring of nest sites and nest success should occur before and after dam removal. Additionally, aerial surveys by helicopter or drone maybe undertaken for nests. Food web studies which assess the extent that birds currently rely on fish from reservoirs vs. flowing waters will help explain habitat selection and will inform predictions about the response of these large piscivorous birds to a restored free-flowing river and the return of salmon above Iron Gate Dam.

Connection with other research and monitoring themes: As with most wildlife related questions, understanding vegetation change is important for addresses habitat changes, especially related to nest sites. Themes related to fish abundance and distribution will help inform questions related to food availability of large, piscivorous birds.

Question 7: How do piscivorous, aquatic mammals respond to dam removal?

- How will dam removal impact the distribution, movement, and abundance of river otters in the Klamath River and its tributaries?
- How will sedimentation associated with the dam removal affect mussel and crayfish as food for otters?

Observations/monitoring needs: Monitoring for river otters should be conducted through visual-encounter float surveys along the river corridor as well as searching for otter slides and latrines where camera traps may be set up. Fecal DNA sampling at latrines can allow population counts via mark/recapture techniques, and eDNA may be useful in deciphering the river otter's range in the reservoir reach prior to dam removal.

Connection with other research and monitoring themes: Assessment of food resources should be conducted in coordination with aquatic invertebrate studies. It may be possible to conduct float surveys for river otters and use sites in combination with other aquatic or riparian wildlife float surveys.

Question 8: How do western pond turtles, a California State Species of Special Concern and Oregon State listed species, respond to dam removal?

- How will the elimination of reservoir habitat impact western pond turtle populations which currently use the reservoirs?
- How will the sediment pulse affect western pond turtle populations in the river in between reservoirs and below the reservoirs, especially in the first year following dam removal?
- What will the survival rate be of western pond turtles wintering in reservoir sediments following the year of drawdown?
- How will vegetation changes in response to dam removal affect ability of turtles to use upland breeding habitat?
- Will sediment infill of large boulder and rock interstitial spaces used as refugia affect survival of western pond turtles below the dams?

Observations/monitoring needs: Population surveys and habitat utilization surveys for western pond turtles should be conducted in the reservoir reach and below dams in the summer. Surveys should be conducted before, during, and after dam removal so that post dam removal status of turtles can be compared to their pre-dam removal status. Assessment of age distribution should be undertaken to assess breeding activity. Temperature loggers and radio telemetry units can be attached to turtle carapaces to monitor activity and track turtle river versus upland habitat use.

Connection with other research and monitoring themes: Effects of sedimentation is a major concern for turtles which use river-bottom cavities as refugia, so survey locations and timing should be informed by predictions about sediment pulses and deposition zones in the river. It may be possible to conduct float surveys for turtle in combination with other aquatic or riparian wildlife float surveys.

Question 9: How will terrestrial mammalian carnivores respond to dam removal?

- Will dam removal and changes in hydrology change the movement patterns of Humboldt Marten, resulting in changes to gene flow?

Observations/monitoring needs: Currently, the river is a semi-permeable barrier to the migration of Humboldt Marten on the Yurok Reservation, and any changes to river flows that allow more or less cross-river movement could have significant effects on population re-establishment south of the Klamath River. Camera traps at targeted locations can be used to catalog the use and movement of the above-mentioned species, while river corridor visual encounter surveys can be used to assess habitat use. Marten are being closely monitored in upland habitat areas to the northeast of the Klamath River where a relatively stable population persists and in areas of high-quality habitat to the southwest of the Klamath River where occupancy is very low and sporadic. Increases in occupancy of the high-quality habitat to the southwest of the Klamath River might indicate increased dispersal across the river at times of low flow. Conversely, lack of dispersal may indicate that the river has become more of a barrier.

Connection with other research and monitoring themes: Geomorphic surveys assessing changes to geomorphic and hydrologic conditions will inform locations to survey, while other wildlife studies concerned with how the Klamath River will become less or more of a barrier following dam removal, and specifically studies using camera traps, should be coordinated with studies of Marten on the Lower Klamath River.

3.5 Next Steps and Future Coordination

The Klamath dam removal science coordination workshop was the initiation of formal coordination around research and monitoring river ecosystem response to dam removal. This document summarizes the presentations and formal discussions of the workshop and should be considered a living document with the potential to be revised and updated as coordination efforts continue.

The focus of this first workshop was to learn about rivers response to dam removal from other rivers, how researchers have coordinated science efforts for large dam removals elsewhere, and to identify topics of research that are important in monitoring the response of the Klamath River ecosystem to the removal of dams. Discussions by natural resource professionals during the meeting and subsequent edits to the compilation of these recommendations resulted in the summaries of research needs presented in this document. Despite the summaries, informed by diverse perspectives, continued conversations are needed to refine the research priorities, details of the study plans, and to plan for continued coordination, communication, and data sharing.

Although no formal breakout groups were formed with the specific goals of prioritizing strategies for communication, future coordination, data sharing, and outreach, the need for planning around these subjects were identified throughout the workshop. Specifically, attendees expressed interest in a follow-up workshop for further coordination, as well as a science symposium. The science symposium would be a platform to present current and ongoing research and monitoring that can be used as baseline data for dam removal studies, as well as a venue to continue coordinating research and monitoring efforts. Other suggestions to facilitate continued coordination included ongoing webinars, a list serve, and a website where descriptions of projects and results could be posted. Data management and data sharing plans were also noted as needing to plan for. The logistics and frameworks of how to coordinate these structural aspects of our research and monitoring efforts should be a theme of future meetings.

Acknowledgments

This workshop and the resulting research and monitoring suggestions was made possible by the participation of the many fisheries and water quality professional from throughout the Klamath Basin and beyond who gave their time and expert knowledge to the networking and planning efforts documented here. Funding for the workshop was provided by an anonymous foundation. Chauncey Anderson from the USGS Oregon Water Science Center assisted with workshop planning, provided conceptual understanding of the region-specific context of the Klamath Dams, and contributed significant edits to this document. Researchers with experience documenting river recovery in other large dam removals, including, Jennifer Bountry, Joshua Chenoweth, Jeff Duda, George Pess, Andie Ritchie, and Thomas H. Williams traveled long-distance to present their scientific findings and to give advice for how to coordinate the research and monitoring associated with large dam removals. Mark Bransom, Chief Executive Officer for the Klamath River Renewal Corporation presented the current state of the dam removal process and answered the many questions that researchers and managers had concerning dam removal times and project details. Many meeting participants further contributed to review of this document and assisted in the transfer of meeting breakout-group recommendations from the meeting into the text herein, including, Julie Alexander, Eli Asarian, Jennifer Bountry, Nate Bradley, Mark Buettner, Emily Cooper, David Gaueman, Jacob Kann, Leanne Knutson, Jessie Moravek, Maia Singer, Desiree Tullos, Chris West, Scott Write, and others.

SI-1: Klamath River Fisheries, Water Quality, and Dam Removal Resources

Organization/Group/Agency	Web Address	Summary of Resources
Klamath River Renewal Corporation	http://www.klamathrenewal.org/	Dam removal background and links to regulatory documents
Klamath Tribal Water Quality Consortium	https://klamathwaterquality.com/	Water Quality Reports and Memos (Mid and Lower Klamath)
Klamath Basin Monitoring Partnership	http://www.kbmp.net/	Maps, monitoring data, water quality and fisheries reports, news, and meeting information
Integrated Fisheries Restoration & Monitoring Plan	https://kbifrm.psmfc.org/	Information about the IFRMP, document library
PacifiCorp Klamath River	https://www.pacificorp.com/energy/hydro/klamath-river.html	Dam stats, KHSA information, Water quality reports and data
OSU Myxozoan Parasite Research Group	https://microbiology.oregonstate.edu/content/disease-effects-wild-populations	Information about salmon disease (background, methods, monitoring, and data)
Bureau of Reclamation, Klamath Basin Area Office	https://www.usbr.gov/mp/kbao/	Operating plans and biological assessments related to water supply in the Klamath Basin
CA Dept. of Fish & Wildlife; Klamath/Trinity Program	https://nrm.dfg.ca.gov/documents/ContextDocs.aspx?cat=KlamathTrinity	Links to annual reports focused on salmonid monitoring studies
US Geological Survey	https://or.water.usgs.gov/projs_dir/klamath_dams/#	USGS Klamath Basin Mapper showing real time gauges
US Geological Survey, Oregon Water Science Center	https://www.usgs.gov/centers/or-water/science/upper-klamath-basin-studies?qt-science_center_objects=4#qt-science_center_objects	Links to USGS reports, data, and maps related to Upper Klamath Basin water quality, fish ecology and hydrology
US Geological Survey, Oregon Water Science Center	https://or.water.usgs.gov/proj/keno_reach/	Project description and links to USGS reports related to water quality monitoring and modeling of the Keno Reach
Arcata Office of the National Fish and Wildlife Service	https://www.fws.gov/arcata/fisheries/default.htm	Description of monitoring activities, news and reports related to Klamath River Fisheries
California-Nevada Fish Health Center	https://www.fws.gov/canvfhc/CANVReports.html	Publications related to fish health monitoring in the Klamath River
Yreka Fish and Wildlife Office	https://www.fws.gov/yreka/klamrest.html	Archived documents related to Klamath Restoration, including the original EIS/EIR and Secretarial Determination Overview Report
USGS Dam Removal: Synthesis of ecological and physical response	https://www.usgs.gov/centers/powell-ctr/science/dam-removal-synthesis-ecological-and-physical-responses?qt-science_center_objects=0#qt-science_center_objects	Publications synthesizing the current state of ecological and geomorphic knowledge of river response to dam removal

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SI-3: Current monitoring activities in the Klamath Basin Relevant to Dam Removal

Agency	Monitoring Activity	Location	Frequency	Start
DOC - NOAA - NMFS - NWFSC - Fish Ecology - Watershed Program	Restoration benefits of beaver dam analogs in the Scott River	Scott River	Seasonally	Do not know
The Klamath Tribes	Water quality and temperature monitoring	Upper Basin (Above JC Boyle Reservoir)	Varies	Early 1990s
The Klamath Tribes	Fish population monitoring	Upper Basin (Above JC Boyle Reservoir)	Throughout the year	Early 1990s
The Klamath Tribes	Instream flow monitoring	Upper Basin (Above JC Boyle Reservoir)	Continuous	Early 1990s
Humboldt State University (Ward lab)	Assessment of tributaries for Coho Salmon production	Klamath River (Reservoir Reach), Tributaries Below Iron Gate	Monthly May to Sept	2018
Humboldt State University (Ward lab)	Tributary Coho Salmon tagging	Tributaries Below Iron Gate Dam	Monthly year round	2011
CA Dept Fish and Wildlife	Coastal Monitoring Program	Klamath River below Iron Gate, Tributaries Below Iron Gate, Estuary, Coastal Wetlands, or Near Shore	Annually	2000
CA Dept Fish and Wildlife	FRGP project monitoring	Klamath River below Iron Gate Dam, Tributaries Below Iron Gate Dam, Shasta and Scott Rivers and their tributaries	Project by project implement ation	enacted with FRGP
ODEQ, Klamath Falls	UKL Harmful Algal Blooms	Upper Basin (Above JC Boyle Reservoir)	Twice Monthly	2016
ODEQ, Klamath Falls	UKL Phosphorus Sampling	Upper Basin (Above JC Boyle Reservoir)	Weekly	2021
University of Montana	Benthic algae and aquatic plant surveys	Klamath River below Iron Gate Dam	1/year	2019
University of Montana	Benthic cyanobacteria surveys	Klamath River below Iron Gate Dam	summer, opportunist ically	2018
University of Montana	Ecosystem Primary Production and Respiration	Klamath River below Iron Gate Dam	Daily May-Oct	2007
Karuk Fisheries	Spawning Surveys below Iron Gate Dam	Klamath River below Iron Gate Dam	Between Oct and Dec.	2001
Karuk Fisheries	Water temperature monitoring	Klamath River below Iron Gate Dam, Tributaries Below Iron Gate Dam	Varies	2003

Agency	Monitoring Activity	Location	Frequency	Start
Karuk Fisheries	Klamath River Coho Salmon Ecology Studies	Klamath River below Iron Gate Dam, Tributaries Below Iron Gate Dam	All year	2008
Oregon State University, Bartholomew Lab	Waterborne abundance of the myxozoan parasite Ceratonova shasta	Upper Basin (Above JC Boyle Reservoir), Klamath River below Iron Gate Dam	UB once a year, LB weekly all year	UB 2010, LB 2006
Oregon State University, Bartholomew Lab	Sentinel fish exposures *(C. shasta)*	Upper Basin (Above JC Boyle Reservoir), Klamath River below Iron Gate Dam	2-4/year	2004
Oregon State University, Bartholomew Lab	Annelid sampling (distribution and ecology; *C. shasta*)	Upper Basin (Above JC Boyle Reservoir), Klamath River below Iron Gate Dam	Once each season	2004
Oregon State University, Bartholomew Lab	Distribution and density of *C. shasta* myxospores in adult salmon carcasses	Klamath River below Iron Gate Dam		2018
UC Berkeley; Dept. of Environmental Science, Policy & Management	Agroecosystem Condition Assessment	Klamath River below Iron Gate Dam, Tributaries Below Iron Gate Dam	May and August	2018
UC Berkeley; Dept. of Environmental Science, Policy & Management	Elk ecology and Management	Klamath River below Iron Gate Dam, Tributaries Below Iron Gate Dam	October to June	2018
UC Berkeley; Dept. of Environmental Science, Policy & Management	Klamath Basin Tribal Food Security Assessment	Basin-wide survey	Survey was conducted once, from ~2014-2017	~2014
Karuk Water Quality Program	Baseline discrete grab sampling	Klamath River below Iron Gate Dam	March-Dec	2005
Karuk Water Quality Program	Baseline discrete grab sampling	Tributaries Below Iron Gate Dam	March-Dec	2005
Karuk Water Quality Program	Continuous Monitoring	Klamath River below Iron Gate Dam	Year Round	2005
Karuk Water Quality Program	Continuous Monitoring	Tributaries Below Iron Gate Dam	May - Oct	2005
Karuk Water Quality Program	*C. shasta* Monitoring	Klamath River below Iron Gate Dam	Year Round	2005
Karuk Water Quality Program	Public Health Sampling (microcystin)	Klamath River below Iron Gate Dam	June to Oct	2005

Agency	Monitoring Activity	Location	Frequency	Start
Karuk Water Quality Program	Nutrient collection	Klamath River below Iron Gate Dam	March-Dec	2005
Karuk Water Quality Program	Nutrient collection	Tributaries Below Iron Gate Dam	March-Dec	2005
Yurok Fisheries and YTEP	Klamath River Carcass Survey	Klamath Below Iron Gate	Weekly/Oct-Dec	1-Oct
Yurok Fisheries and YTEP	*C. shasta* monitoring eDNA	Klamath Below Iron Gate	Weekly/Mar-Oct	1-Mar
Yurok Fisheries and YTEP	*C. shasta* monitoring Fish	Klamath Below Iron Gate	Weekly /Jun-Aug	1-Jun
Yurok Fisheries and YTEP	Ich monitoring projects	Klamath Below Iron Gate	Weekly /Jun-Oct	15-Jun
Yurok Fisheries and YTEP	Thermal refugia monitoring	Klamath Below Iron Gate	Weekly /Jun-Sept	15-Jun
Yurok Fisheries and YTEP	Juvenile salmonid outmigrant trapping	Klamath Below Iron Gate	Daily/Mar-Jul	1-Mar
Yurok Fisheries and YTEP	Coho ecology studies	Klamath Below Iron Gate	Year round	
Yurok Fisheries and YTEP	Water temperature monitoring	Klamath Below Iron Gate	Hourly/Mar-Dec	1-Mar
Yurok Fisheries and YTEP	Water Quality Monitoring (temp, sp. Cond., pH, DO%, DO mg/L, BGA, Turbidity)	Klamath River below Iron Gate Dam	Every 15 minutes, year round	Nov-18
Yurok Fisheries and YTEP	Water Quality Monitoring (temp, sp. Cond., pH, DO%, DO mg/L, BGA)	Klamath River below Iron Gate Dam	Every 30 minutes, May-Oct.	2001
Yurok Fisheries and YTEP	Sediment Accretion Klamath River Estuarine Wetlands	Estuary, Coastal Wetlands, or Near Shore Ocean	Every few months Adapted to high flows	2019
Yurok Fisheries and YTEP	Hydrology monitoring	Tributaries Below Iron Gate Dam	Year round	2002
Yurok Fisheries and YTEP	Water Quality & Hydrology monitoring (temp, sp. Cond., pH, DO%, DO mg/L)	Klamath River South Slough	Every 15 minutes, year round	2018
Yurok Fisheries and YTEP	Water Quality Monitoring (temp, sp. Cond., pH, DO%, DO mg/L)	Tributaries Below Iron Gate Dam	Monthly	2015
Yurok Fisheries and YTEP	Water Quality Grab sampling	Klamath River below Iron Gate Dam	Monthly, Mar-Dec	2004
ODFW	Genetic characteristics of *O. mykiss* throughout the Klamath Basin prior to dam removal	Basin-wide	1/year	spring 2019
ODFW	Assessment of potential Coho Salmon habitat in Spencer Creek - HSU/ODFW	Tributaries in the Reservoir Reach	1/year	summer 2019
ODFW	Characteristics of resident fishes in Spencer Creek - HSU/ODFW	Tributaries in the Reservoir Reach	1/year	summer 2019

Agency	Monitoring Activity	Location	Frequency	Start
ODFW	Life cycle monitoring of salmonids (video/capture weir, juvenile downstream trap, spawner/redd surveys)	Klamath River (Reservoir-Reach), Spencer Creek	Weekly spring-fall	spring 2020
ODFW	Feasibility study for the monitoring of fisheries from Keno Dam to stateline.	Klamath River in the Reservoir Reach	Weekly spring-fall	spring 2020
ODFW	Limiting factors of Klamath juvenile *O. mykiss* in the Sprague River	Upper Basin	Weekly spring-fall	spring 2019
ODFW	Adfluvial spawner/redd surveys in tributaries of Upper Klamath Lake	Upper Basin	Weekly fall-spring	2011
ODFW	Habitat use, energetics, thermal physiology of *O. mykis*s - OSU/ODFW	Klamath River between J.C. Boyle Reservoir and Keno Dam	Year-round	2017
ODFW	Habitat use, movement ecology, foraging ecology, life-cycle functions of *O. mykiss* - OSU/ODFW	Upper Basin	Year - round	2016
ODFW	Riverscape-level distribution of juvenile *O. mykiss* on the Sprague River - OSU/ODFW	Upper Basin	Year - round	2019
USGS	Stream gaging	All, except KHP tributaries and Estuary	Continuous /Real Time	Varies
USGS	Real-time WQ monitoring (incl. Turbidity)	All, except KHP tributaries and Estuary	Continuous /Real Time	2018 & 2019
USGS	Suspended Sediment Sample Collection	All, except KHP tributaries and Estuary	Continuous /Real Time	2018 & 2019
USGS	Sediment Source Analysis (aka "Fingerprinting)	All, except KHP tributaries and Estuary	Recon only	fall 2018
USGS	Intensive Geomorphic Analysis	Klamath River below Iron Gate (10 short reaches) to estuary,	~2x each reach before dam removal	fall 2018
USGS	Estuary Sediment Characterization	Estuary	1/year	fall 2018

SI-4: Summaries of Invited Speaker Presentations

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The San Clemente Dam on the Carmel River on California's central coast was removed in November 2015. At 32 meters high, it was one of the tallest dams yet removed in the U.S. and the largest removal in California; in addition, it is the largest dam removal in a Mediterranean hydroclimatic setting to date. Besides the dam's seismic hazards, the dam's demolition removed a barrier and an inefficient fish ladder, which had long limited both the upstream and downstream movement of ESA-listed steelhead, and the downstream movement of wood and coarse sediment. The scale of construction for this removal was unprecedented in the Western U.S. because, unlike previous dam removals in the Pacific Northwest, the removal of San Clemente Dam included the construction of a re-route channel that bypassed two-thirds of the reservoir sediment. The Carmel River was re-routed through a ridge that separated it from a tributary, San Clemente Creek, creating a new confluence with that tributary 700 m upstream from the former location, allowing only sediment in the furthest upstream third of the reservoir to became available for natural transport by the river.

The Carmel is a small (650 km^2), steep watershed dominated by chaparral vegetation and oak savannah, typical of the central California coast. The Carmel watershed's Mediterranean climate is characterized by dry, foggy summers and infrequent, large winter rainstorms, unlike the climate found in the Pacific Northwest where recent dam removals have occurred. Fires episodically impact the upper watershed and sediment dynamics in the river. The main driver of habitat-forming processes in rivers of this region is the interplay between infrequent large winter rainstorms that trigger landslides coupled with high runoff and peak flows when most sediment movement occurs.

Between 2013 and 2017, we conducted a before-after/control-impact (BACI) study to examine impacts of the dam removal on steelhead and their stream habitat. These efforts focused on physical processes and on *O. mykiss* response in 10 reaches selected for monitoring. These study reaches included nine impact reaches: one in the upstream portion of the former reservoir (above the re-route channel), one immediately downstream of San Clemente Dam, and seven additional reaches in the approximately 30 km between the dam site and the river mouth. A "control" reach was several hundred meters upstream from the former reservoir. During the course of the sampling from 2013 to 2017, the region experienced an exceptional drought with extremely low flow conditions, including more than a year when the Carmel River surface flows did not connect to the ocean (2014). Added to this were large fires in 2015 and 2016 in the upper watershed, and the extreme high flow events in 2017. The third year following dam removal (2017) saw a highly energetic series of floods, including four 2-year floods, two 10-year floods, and one 30-year flood—all within six weeks and each lasting no more than two to three days. This combination of drought and flooding conditions over this period provided a unique opportunity to observe the region's habitat-forming processes after a major dam removal in very dissimilar water years.

To evaluate physical processes we measured river channel topography and bed sediment grain size once per year in each reach to track the evolution of channel shape (morphology) and bed habitat composition. During the relatively dry winter immediately following dam removal (2016), we observed sediment deposition in the 3 km immediately downstream of the re-route channel, with new sand and gravel accumulating in formerly deep pools. Effects of the dam removal were also observed in the area immediately upstream of the re-route channel during winter 2016, with the river downcutting more than a meter through former reservoir sand and gravel that had accumulated since the 1920s. However, the floods of 2017 brought much greater change: when high flows receded, the sediment pulse had reached all the way downstream to the river mouth, with new sediment deposited in every study reach downstream of the former dam location. The floods introduced new gravels to riffles and pool tail outs in reaches downstream of dam. The abundance of large wood downstream of the dam location also increased following the floods. The sediment and wood inputs resulted in more, and more complex, channel habitats. The river channel in the old reservoir reach had widened five-fold, creating an entirely new flow path through the reservoir deposits. These responses differed from those measured in previous large dam removals, as in no previous example had exceptionally high flows followed so soon after dam removal.

We also sampled *O. mykiss* at four reaches before and after dam removal. We found significant variability in fish abundance in the reaches examined, which is common for Pacific salmonids, and likely reflects of the natural variability of such populations. Against this backdrop of dramatic environmental variability, one would predict fluctuations in fish abundance, diversity of habitat available, habitat use, and fish growth. And indeed the size distribution of *O. mykiss* in the reaches surveyed did vary over the course of the study. In the impact reaches, we observed an increase in the breadth of fish sizes and age classes as these areas of the stream shifted from rather simple, static habitats to much more dynamic and diverse habitats. Untangling the changes resulting from the drought, fires, dam removal, and extreme flow events is difficult, but clearly the absence of the dam starting with the sampling in the fall of 2015 allowed the reservoir reach and the reaches downstream of the former dam to experience sediment and channel changes that would not have occurred with the dam in place.

Early indications from our data and other observations are that 1) adult steelhead and Pacific Lamprey pass through the re-route channel and access areas upstream of the former San Clemente Dam, and 2) increased size variability of *O. mykiss* in the sampled reaches after dam removal is consistent with observations in more complex and diverse habitat conditions where previously very simplified habitat existed. We also observed in fall 2017 that *O. mykiss* rapidly colonized the new habitat in the re-route channel. However, as with other dam removals, understanding the response of anadromous Carmel River fish populations will require more than just three years. Carmel River steelhead typically have a generation time of four years, and habitat response in the Carmel River is extremely dependent on events such as high flows, as shown in the first three years since the removal. Expectations of the recovery time scale should be measured both in generation time of steelhead and the temporal dynamics of the physical/ecological processes of the watershed and region.

Dams, with or without fish passage, block or constrain much more than fish, including important habitat-forming processes on downstream reaches. Regardless of whether we consider the Carmel River in a Mediterranean climate or the Elwha River in the temperate rainforest of the Olympic Peninsula, the physical and ecological processes that form the habitat template for salmon and steelhead are not static. Restoring the connections within a watershed reduces constraints on physical and ecological processes, allowing dynamic habitat features such as connected floodplains, wood and gravel delivery downstream, and constant rearrangement of sediment, wood, and stream channels. Restoring these and other non-static features of stream systems provides a diverse habitat that allows for future expression of life-history diversity of salmon and steelhead.

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Salmonid response to the removal of the Elwha River dams

Entities who are working on salmonid monitoring in the Elwha River – Lower Elwha Klallam Tribe, Washington Department of Fish and Wildlife, Olympic National Park, National Oceanic and Atmospheric Administration, U.S. Fish and Wildlife Service, the U.S. Geological Survey, the Bureau of Reclamation, the University of Washington, Washington State University, K. Denton and Associates LLC, and Trout Unlimited

Worldwide stream and watershed restoration efforts cost billions annually. These projects are typically local-scale activities that, in some cases, do not have a measurable effect on ecosystem function or services. One ecosystem restoration technique that can have a large-scale effect is dam removal. This single action allows for the re-connection of ecosystem processes such as upstream and downstream organism movement, the rapid transformation from lentic to lotic conditions in former reservoirs, rapid shifts in community structure and food webs, and accelerated habitat creation through sediment deposition. We present results from the Elwha River, where the largest dam removal ever undertaken resulted in ecosystem changes, focusing on salmonid response to dam removal.

The release and subsequent downstream transport of tens of millions of metric tonnes of sediment from former reservoirs has resulted in the transformation and rebuilding of estuarine and riverine habitats. Short-term changes due to large changes in sediment supply resulted reductions in the egg to fry survival stage for Chinook Salmon, but they recently rebounded. During and post dam removal, Chinook Salmon fry outmigration averaged 46,715 (S.D. 21,344), however in 2019 the Chinook Salmon fry outmigration estimate increased to over 500,000, suggesting the major short-term sediment impacts have diminished. The resumption of free passage for aquatic organisms has re-established anadromous fishes to areas that have been void of such species for 100 years, prompting rapid increase in spawning nests in the newly colonized river sections, an increase in salmonid life history diversity, and new species.

The majority of salmon redds now occur above both former dams, averaging over 1,400 known redds per year. There has also been a “re-awakening” of life history types for bull trout (i.e. more anadromy), Coho Salmon (age 0 fry migrants), Chinook Salmon (1+ juvenile life stage), and steelhead (now both winter and summer). The “re-awakening” of summer steelhead, is likely owing to the harboring of alleles for run timing in up-river resident *O. mykiss* populations. We have also seen new species such as Pacific Lamprey at all life stages, also indicating a positive response. Thus, salmonids and non-salmonids, are adapting to the local environmental conditions in the newly connected habitats, resulting in increasing abundance trends as well as life history diversity. We hypothesize these trends will continue for the next 10 plus years. Our results demonstrate the critical importance of maintaining longitudinal connectivity for proper functioning of watershed processes and ecosystem services.

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Ecological responses to dam removal on the Elwha River: highlights and lessons learned

Two fundamental goals of the Elwha River dam removal project are the restoration of anadromous salmonid runs and the freshwater ecosystems that support them. Research suggests that river ecosystems—when given the opportunity—can recover after dams come down. Importantly, the trajectory of ecological recovery can be predicted. Given each river’s unique history, surrounding land use, regional setting, and size of dams, it is reasonable to expect that ecological responses to each dam removal will differ. However, the physical and biological processes that govern how ecosystems respond to dam removal are similar, particularly when drivers and responses are segregated into upstream, within reservoir, and downstream reaches. Using empirical studies and established theories about how rivers work provided a framework for identifying these shared physical and biological processes and creates a template for predicting how the ecology of a river responds to dam removal. We recently developed a set of conceptual models that elucidate these shared physical and biological processes. These models can help resource managers, river restoration practitioners and other stakeholders identify the major factors likely to control ecological responses to future dam removals. By identifying the most important factors involved with ecosystem response, this approach should also help scientists predict ecological outcomes and identify which variables should be monitored.

Of fundamental importance to restoring connectivity via dam removal is the ability for fish to pass through the site where the former dam stood. Establishing the presence of fish upstream of former dam locations, including in tributaries, is necessary to evaluate project success. Once such presence is verified, additional detailed studies and methods can be used to show how functional recolonization is happening, including spawning and rearing of fish in upstream reaches and how this effects overall population productivity. Tracking the rate and extent of recolonization can be challenging in a wilderness river like the Elwha, as current techniques applicable in the easily accessible frontcountry (e.g., sonar, screw traps) are untenable in the roadless backcountry. We developed a collection of species-specific molecular markers for use in qPCR amplification of aquatic environmental DNA (eDNA). We targeted 11 fish species, sampled from 2014 – 2017 across 58 river kilometers at 10 frontcountry and 15 backcountry sites from both the Elwha River (n=15) and its tributaries (n=10). The application of species-specific molecular markers was effective at documenting the passage of migratory fish species past both the Elwha and Glines Canyon dams, as well as the timing and extent of recolonization.

To better understand the response of the aquatic ecosystem to Elwha River dam removal, we conducted a long-term study of the aquatic food webs before, during, and after dam removal. Anticipating large-scale changes in some reaches downstream of the dams due to the massive amounts of stored reservoir sediments expected to be released, we focused upon estimating food web effects by measuring periphyton, benthic invertebrates, and fish consumers (largely resident and juvenile forms of *O. mykiss*). In order to track possible changes to the food web from marine derived nutrients provided by salmon, we also are measuring stable isotope ratios in several taxa. Sampling occurred in mainstem, side channel, and tributary sites downstream, between, and upstream of the dams, as well as tributaries that served as no dam removal controls for comparative purposes. During and following dam removal, we also established sites in river sections emerging within the former reservoir reaches of Lake Aldwell and Lake Mills. At each sample location, we seasonally sampled periphyton standing crop, benthic invertebrate density and drift, and fish diet, as well as bed substrate composition and water chemistry. Highlights from this work are presented, including the changes in total phosphorous concentration during dam removal, a decrease in the density of invertebrates during dam removal, and a shift in species composition favoring dipterans during the high sediment load period during dam removal. In the years following dam removal, many of the changes seen during dam removal returned or approached levels seen prior to dam removal, suggesting that the river recovers from dam removal induced changes within a few years, a pattern seen in other projects that measured the same metrics. Macroinvertebrate drift was also lower during dam removal in the lower Elwha, but not in the middle Elwha. The decline was buffered as fish transitioned their diet to favor terrestrial sources of food (either adult forms of aquatic macroinvertebates, or terrestrial-origin taxa), which allowed for them to achieve similar levels of energy density as pre-dam removal levels.

There are many lessons to be learned from the Elwha experience that could be applied to the upcoming project on the Klamath River. Experience from the Elwha suggests that collaboration networks, among federal, state, tribal, academic, and NGO partners will be key to establishing a robust science portfolio. The advantages of such collaboration include increasing the resources available to study the outcomes of dam removal, both in terms of the duration and density of information generated. It also fosters coordinated multidisciplinary studies, which can expand the scope and complexity of the scientific questions being addressed. Reinforcing and reinvigorating the collaborations will arise from communicating the scientific results to multiple audiences, including the Klamath research community, the greater scientific community, and the public. Having regular information exchanges, including dedicated science symposia and pre-field work coordination meetings, was an effective tool in the Elwha to keep researchers abreast of each other's work, foster internal and external communications about results, and identify potential cost savings and/or conflicts (especially for fieldwork). Working in parallel with strategies for communicating within the scientific community will be strategies for making scientific findings public. There will be a great deal of interest in the results coming out of the Klamath and having a plan for managing requests for media, project tours, and speaking requests will be a great benefit.

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Revegetation of the Elwha Reservoirs

This presentation highlighted results and lessons learned from six years of the revegetation of two large reservoirs after the removal of Elwha and Glines Canyon dams and how it might inform revegetation of the Klamath Reservoirs after dam removal. The goal of the Elwha revegetation program was to minimize invasive species establishment in the newly exposed surfaces, restore ecosystem processes and accelerate forest development.

Dam removal on the Elwha dewatered two large reservoirs, exposing 721 acres over a period of three years from 2011-2014. Historic environmental records on the Elwha reveal a mild climate with average high temperatures in the summer reaching only into the lower 70s (degrees Fahrenheit) with an average annual rainfall of 55 inches that predominately occur in the fall and winter months. The environment in the Klamath watershed where the dams are present is considerably hotter (average highs in the low 90s in the summer) and drier (only 22 inches of rain each year, mostly falling in fall and winter). Typical vegetation surrounding the Elwha reservoirs is dense conifer forests. Forests are critical to most ecosystem processes and to a healthy watershed supporting salmonid species. In contrast to this, the vegetation surrounding the Klamath reservoirs are dominated by chaparral communities with oak-juniper woodlands and riparian forests.

The sediments that accumulated in the Elwha reservoirs were characterized by texture for the purposes of revegetation. A little over half of the sediments in the Elwha were fine-textured. The fine sediments varied in composition but tended to be mostly silt-sized particles (75-82%) followed by clay-sized particles (15-18%) with occasional fine sand present (0-10%). The other predominant sediment texture present in the Elwha was coarse sediment, representing just under half of all sediment exposed by dam removal. At the start if dam removal, the coarse sediments were predominately stored in the Lake Mills reservoir delta. The slow drawdown of the Glines Canyon Dam redistributed the coarse sediments from the delta into the entire valley bottom of the former Mills reservoir, creating artificial terraces 20-60 ft above the floodplain that compose one-third of the post drawdown landscape and are outside of the active floodplain. The sediments in the Klamath reservoirs are all fine textured and highly variable in the particle sizes, with, in some samples, substantially more clay-sized particles (17-78%) generally less silt (13-49%) and more fine sand (5-56%).

Multiple growth trials in the sediments were conducted prior to Elwha dam removal to determine species performance. All studies indicated that woody species would struggle to germinate and establish on the fine sediments and grass species would perform well. A seed bank study suggested there would be a sparse seed bank of wetland species in the fine sediments that may initiate some revegetation post dam removal. The revegetation plan for the reservoirs called for an adaptive monitoring approach using the dam removal period to experimentally plant a diverse array of native woody species and seed herbaceous forbs and graminoids. Permanent vegetation monitoring plots were established throughout the two reservoirs to direct adaptive management and provide scientific data for analysis to assist future dam removal projects. The plots were surveyed once annually from 2012-2017. Planted native woody plants were tagged to assess survival and performance in the fine and coarse sediments. A total of 324,794 native plants were planted from 2012-2017. A total of 6,558 lbs of native forbs and graminoids were seeded.

The slow drawdown of the fine sediments in the former Mills reservoir was over a period of 13 months, providing seed dispersal from a diversity of species to naturally colonize the new surfaces. The slow drawdown also provided ample moisture to new seedlings, boosting natural seedling establishment. The seed bank of wetland species was more prominent than initial studies suggested, resulting in an herbaceous layer of sedges (*Carex* species) and rushes (*Juncus* species) forming in all upland landforms covered in fine sediments and persisted for several years despite the dry summer conditions. Wind-dispersed seed from deciduous trees common to riparian plant communities germinated and established during drawdown. The combination of wetland herbaceous plants and riparian deciduous trees establishing on upland landforms was a novel plant community type for the Elwha. Typical early seral communities in the Elwha would consist of conifers and dry upland shrubs and herbaceous plants. Overall vegetation cover developed rapidly on the fine sediments, reaching mean cover of over 95% in the third growing season (2014). Timing of drawdown influenced the composition of deciduous trees, with sites exposed in May and June dominated by cottonwoods (*Populus balsamifera*) and willows (*Salix* species) while sites exposed earlier (November-March) were dominated by red alder (*Alnus rubra*). Planted species performed exceptionally well, with an average survival rate of 92% in the fine sediments after one year. Trees and shrubs that performed poorly in the pre-dam removal plant trials had high survival rates and excellent performance in the dewatered reservoirs. Planting increased species richness and species composition. Seeding native herbaceous species significantly reduced non-native plant frequency.

Plants were less successful on the coarse sediments. Natural regeneration of native species was nearly non-existent. The survival of planted species was high during drawdown but declined over time and was low in all plantings that occurred post-drawdown. Seeding herbaceous species was effective and significantly reduced bare ground compared to unseeded sites. Riverbank lupine (*Lupinus rivularis*) was a key species to bare ground reduction in the coarse sediments.

The Elwha dam removal project provided insight into vegetation development after dam removal that may be relevant to the Klamath Project. Plant performance on fine sediments defied pre-dam removal expectations. Sediment texture is more variable and generally finer in the Klamath (more clay). Natural regeneration was substantial in the Elwha. Drawdown timing matters. Initial plant communities unusual and developed novel species compositions on upland landforms dominated by natives. However, there are profound differences in sediment texture, climate and species availability between Elwha and Klamath. A robust monitoring program is critical to adaptively manage revegetation of reservoirs after large dam removals.

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Elwha River Restoration Reservoir Sediment Story

This presentation highlighted results and lessons learned from six years of an interagency, adaptive sediment management program for the removal of Elwha and Glines Canyon dams. The presentation focused specifically on reservoir sedimentation response to dam removal with a brief overview of the dam removal project. The Elwha River Restoration Project removed Elwha and Glines Canyon dams to restore access to over 70 miles of historical fish habitat blocked by the dams. Dam removal also honored the Federal trust relationship to the Lower Elwha Klallam Tribe by recovering sacred sites at Elwha Dam and Lake Aldwell and revitalizing cultural traditions. Dam removal also restored the river ecosystem including restoring fish migration and natural sediment and wood load from the dammed reaches downstream to the ocean. Elwha Dam, completed in 1913 at river mile (RM) 4.9, was a 108-ft high concrete gravity dam that formed Lake Aldwell with an original storage capacity of 8,100 acre-ft and power capacity of 14.8 megawatts. Glines Canyon Dam, completed in 1927 at RM 13.6, was a 210-ft high concrete arch dam that formed Lake Mills with a storage capacity of 26,000 acre-ft at the time of removal and a power capacity of 13.3 megawatts (40,500 acre-ft when first built). Over the 98 years that one or two dams were in place, all the natural incoming coarse sediment load and about three-fourths of the fine sediment load was trapped in the reservoirs. At the time of removal, both reservoirs contained 27 million yd^3 of sediment that was approximately 50% coarse and 50% fine sediment with wood and litterfall intermixed. After dam removal, the new landscape in the former reservoirs includes remnant sediment terraces formed during drawdown. Sediment impacts from dam removal are diminished within the restored ecosystem. Landscape evolution started as the river incised (lowered through vertical erosion) into reservoir delta sediments after each 15-ft increment of dam removal and reservoir drawdown. The river in both the former reservoirs reached the valley bottom as evidenced by exposure of pre-dam tree stumps, historical photographs, and pre-dam topography. After dam removal, several floods increased the width of the new floodplain as the river laterally eroded into terraces exposed during drawdown. Terraces with compacted fine sediment were more resistant to erosion (cohesive). Meander bends formed and the rate of lateral migration across the landscape slowed. A wide active channel and new floodplain is now present through both former reservoirs, bounded by the valley walls in some places and in others by terraces of remaining reservoir sediment. Both reservoirs are now in the last phase of landscape evolution with vegetation flourishing on hillslopes and becoming established in portions of the new floodplain. Large wood is playing a role in forming new islands in the floodplain. It is impossible to know when the last segment of reservoir sediment will erode. As of September 2017, river erosion resulted in about two-thirds of the reservoir sediment being released into the downstream river (71% of Lake Mills and 50% of Lake Aldwell sediment). Only 14% of the original reservoir sediment volume is still potentially erodible in future floods (2.4 million yd^3 and 1.3 million yd^3 in Mills), but erosion would be spread out over many decades. In years without floods such as water year 2017, minimal terrace erosion occurred. In February 2020, a flood occurred that eroded intermittent areas of the “potential to erode” segments in Lake Aldwell, confirming prior predictions. Real-time monitoring, open and collaborative communication and data sharing, and the ability to quickly respond to adaptive management needs were all important to making the program a success.

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Elwha and Glines Canyon dam removals: river, delta, and shoreline response

The Elwha and Glines Canyon dams impounded about 28 million cubic yards of sediment in Lake Mills and Lake Aldwell. Removal of these dams represented the largest dam removal and managed sediment release in U.S. history, with roughly a 20-year supply of coarse sediment and a 5-year supply of fine sediment released from October 2012 to March 2013 alone. Monitoring changes during dam removal presented a significant challenge due to limited monitoring resources, the large area affected by dam removal (approximately 16.5 river miles with an average valley width of about 3000 ft) and the near-real-time need for data from both reservoir and river reaches for adaptive project management decisions. A rapid-deployment, low-cost method was developed to collect aerial imagery and generate orthoimagery and digital elevation models (DEMs) of the Elwha River during removal of Elwha and Glines Canyon dams. Orthoimage resolution allowed identification and measurement of features such as individual logs and sediment texture differences. Data were used to determine maximum inundation/erosion width, map banklines and evolution of depositional and erosional features, and to evaluate significant features affecting river morphology such as logjams and channel braidedness. The temporal frequency of flights made it possible to compute bank erosion rates, meander migration rates, and the evolution of potential hazards.