U.S. Fish & Wildlife Service

Guidelines for Monitoring and Adaptively Managing Restoration of Chinook Salmon (*Oncorhynchus tshawytscha*) and Steelhead (*O. mykiss*) on the Elwha River

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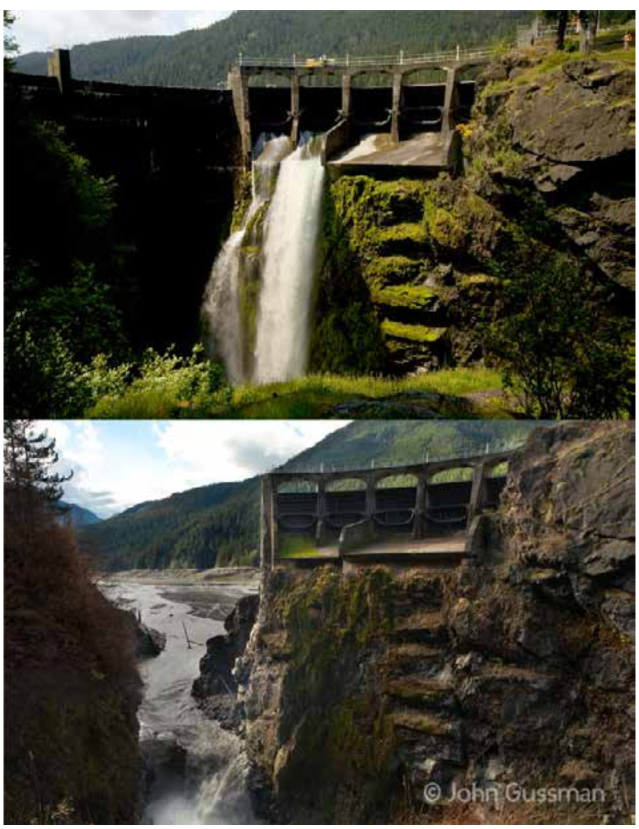

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Executive Summary

As of January, 2014, the removal of the Elwha and Glines Canyon dams on the Elwha River, Washington, represents the largest dam decommissioning to date in the United States. Dam removal is the single largest step in meeting the goals of the Elwha River Ecosystem and Fisheries Restoration Act of 1992 (The Elwha Act) — full restoration of the Elwha River ecosystem and its native anadromous fisheries (Section 3(a)). However, there is uncertainty about project outcomes with regards to salmon populations, as well as what the 'best' management strategy is to fully restore each salmon stock. This uncertainty is due to the magnitude of the action, the large volumes of sediment expected to be released during dam removal, and the duration of the sediment impact period following dam removal. Our task is further complicated by the depleted state of the native salmonid populations remaining in the Elwha, including four federally listed species. This situation lends itself to a monitoring and adaptive management approach to resource management, which allows for flexibility in decision-making processes in the face of uncertain outcomes.

The Elwha Monitoring and Adaptive Management (EMAM) guidelines presented in this document provide a framework for developing goals that define project success and for monitoring project implementation and responses, focused upon two federally listed salmon species — Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*) and Puget Sound steelhead (*O. mykiss*). The framework also should serve as a guide to help managers adaptively manage fish restoration actions during and following dam removal. The document is organized into seven sections, including an introduction (Section 1), a description of the adaptive management approach (Section 2), suggested modifications to the existing restoration strategy developed in previous Elwha River restoration documents (section 3), specific descriptions of an adaptive management framework, including establishment of goals, performance indicators, and potential adaptive management responses to monitoring information (section 4), monitoring tools and methods for use in evaluating performance and project outcomes (section 5), and brief sections on data record keeping and reporting (Section 6) and an estimated budget (section 7).

The purpose of the EMAM guidelines is to propose (1) refinement of existing goals established in previous documents (e.g., Ward et al. (2008), U.S. Department of the Interior, Department of Commerce, and Lower Elwha S'Klallam Tribe (1994)); (2) an adaptive management framework, (3) specific trigger values for relevant performance indicators that guide the adaptive management approach, (4) a specific monitoring strategy for evaluating outcomes of restoration activities; (5) a data management strategy, (6) information needed for adjusting goals when observations indicate conditions are different from anticipated. When taken together, our proposed adaptive management guidelines rely upon setting goals and objectives for each species of interest, which are monitored by relevant performance indicators and measurable trigger values that define success within each phase of the project. The guidelines themselves are arranged in a hierarchy for each species of interest. The levels of this hierarchy are goals, objectives, performance indicators, decision rules, triggers, and decisions (i.e., management/policy response).

The monitoring and adaptive management approach provided is based on monitoring several categories of performance indicators, each containing associated 'trigger' values which, when met, alters restoration activities (e.g., hatchery releases and/or strategies) through four successive restoration phases. Performance indicators proposed in these EMAM guidelines are based upon Viable Salmon Population (VSP) metrics, including abundance, productivity, distribution, and diversity (McElhany et al. 2000). Trigger values for each performance indicator are developed for four different restoration phases: ***Preservation***, ***Recolonization***, ***Local Adaptation***, ***and Viable Natural Population***. These biologically-based phases each have a set of objectives that are based on resource management scenarios, including the dam removal project itself, which change largely based on the level of active management required and the degree, if any, of resource utilization. Thus, details of prescribed management actions for each phase are based upon different needs specific to that phase.

The creation of biologically-based phases is one of the major differences between our proposed EMAM guidelines and previously presented plans for Elwha River Restoration Project management. Changed largely in response to the recommendations of the most recent of three Hatchery Scientific Review Group project reviews (HSRG 2012), the goal-oriented phases replaced the previous system of temporal changes centered around the decommissioning of the dams (i.e., before, during, and after dam removal). By focusing on outcomes associated with rebuilding salmon populations instead of an engineering schedule, the guidelines are more amenable to an adaptive management framework and the ability for management actions to influence outcomes, particularly in the periods during and following dam removal.

Trigger values for each performance indicator were generally developed using existing data from the Elwha River watershed, the Puget Sound region, or other Pacific Northwest rivers (i.e., elsewhere in Washington State, Oregon, British Columbia) modified to be relevant for Chinook salmon and steelhead recovery in the Elwha River. By meeting all of the trigger value levels for all performance indicators for a set amount of time within a management phase, the guidelines call for moving to the next phase. This next phase has a new set of trigger values for the same performance indicators. For example, upon moving from the Preservation phase to the Recolonization phase, the trigger value for intrinsic potential increases. Intrinsic potential is a pre-defined estimate of the total extent of available habitat within a watershed for adult and juvenile fish, specific to the target species and is therefore a performance indicator of spatial distribution. By the final Viable Natural Population phase, the entire intrinsic potential of the watershed is being occupied by the species of interest. For those cases when a performance indicator is not exceeding the target value for a particular phase after a certain time period, the trigger values provided in this document, as well as a series of exogenous variables, are explored that may help explain why the performance indicator is not being met. These exogenous variables include variables that are not part of the suite of performance indicators, such as hatchery production, harvest, habitat, and ecosystem indicators. In these cases where the program is stuck in a particular recovery phase, the situation could be caused by the selection of inappropriate trigger values or unforeseen environmental conditions. If the former, adaptive management would call for existing monitoring data to be used for modifying trigger values to an appropriate level. If one of the exogenous variables is found to be preventing the program moving to the next phase, then appropriate changes to management would be advised.

For each performance indicator and many of the exogenous variables, a set of monitoring tools were proposed. Data standards were also proposed for data generated by each monitoring tool. Data management, record keeping, and reporting of monitoring and adaptive management activities and results are also outlined. Management of data from the focused monitoring program and documenting the outcomes of trigger value evaluations and associated decisions from the adaptive management approach are key components of the EMAM guidelines. Without a clear history of data generated and adaptive management decisions taken by managers, the ability to learn through adaptive management breaks down. In addition to the long time period involved, another complication is the fact that the data will likely be collected by different federal and state agencies, tribal staff, and others. Having a system of reporting developed should help alleviate potential problems.

The restoration of the migration route to spawning and rearing habitats upstream of the former Glines Canyon Dam represents a great opportunity for salmon on the Olympic Peninsula. By removing two aging structures, it will be possible for all 5 species of salmon and steelhead to return to wild stretches of the Elwha River and major floodplain habitat characterized by multiple channels, as well as significant portions of numerous tributaries. Measuring the progress of restoration, from the perspective of both salmon populations and the ecosystem upon which they depend, is a great test for a collaborative team of scientists. The normally challenging conditions of working in a steep gradient, high velocity wilderness river are exacerbated by the release of millions of cubic yards of sediment that had accumulated in the reservoirs. After the first two years of the dam decommissioning process, this release has changed the ecology of the river, estuary, and nearshore habitats downstream of the dams. Our goal in developing the guidelines described is to provide a roadmap for tracking what hopefully will become a successful outcome. If successfully implemented, this information should prove useful as others begin planning for the removal, alteration, or reconstruction of dams throughout North America and elsewhere, an inevitable outcome of an aging dam infrastructure.

Acronyms and Abbreviations

ADCP	Acoustic Doppler Current Profiler
AFDM	Ash-Free Dry Mass
ANOVA	Analysis of Variance
BKD	Bacterial Kidney Disease
BO	Biological Opinion
CTC	Chinook Technical Committee
CWT	Coded Wire Tag
DFO	Department of Fisheries and Oceans
DIDSON	Dual Frequency Identification Sonar
DPS	Distinct Population Segment
DTS	Digital Turbidity Sensor
EA	Elemental Analyzer
EFRP	Elwha Fish Restoration Plan
EIBS	Erythrocytic Inclusion Body Syndrome
EIS	Environmental Impact Statement
Elwha Act	Elwha River Ecosystem and Fisheries Restoration Act, Public Law 102-495
EMAM guidelines	Elwha River Monitoring and Adaptive Management guidelines
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
FERC	Federal Energy Regulatory Commission
FHS	Fish Health Specialist
FRAM	Fishery Regulation Assessment Model
FRESC	Forest and Rangeland Ecosystem Science Center
GMR	Genetic Mark Recapture
GPS	Global Positioning System
HOR, HORs	Hatchery-origin returns. Adults returning to a stream that resulted from juveniles produced and reared in a hatchery environment
HSRG	Hatchery Scientific Review Group
IHNV	Infectious Hematopoietic Necrosis Virus
IPNV	Infectious Pancreatic Necrosis Virus
IRMS	Isotope Ratio Mass Spectroscopy
km	Kilometer
LEKT	Lower Elwha Klallam Tribe
LISST	Laser In Situ Scattering and Transmissometery
MDN	Marine Derived Nutrient
NEPA	National Environmental Policy Act
NH_4	Ammonium
NMFS	National Marine Fisheries Service
NRCS	Natural Resources Conservation Service
NO_2	Nitrite
NO_3	Nitrate
NOAA	National Oceanic and Atmospheric Administration

NOR, NORs	Natural-origin return. Adult fish returning that resulted from juveniles that were produced by adults spawning naturally in the basin
NPS	National Park Service
NTU	Nephelometric Turbidity Unit
NWFSC	Northwest Fisheries Science Center
ONP	Olympic National Park
PFMC	Pacific Fisheries Management Council
pHOS	Proportion of Hatchery Origin Spawners
PNI	Proportion of Natural Influence
pNOB	Proportion of Natural Origin Breeders
pNOS	Proportion of Natural Origin Spawners
PO_4	Phosphate
PSC	Pacific Salmon Commission
QA/QC	Quality Assurance/Quality Control
Rkm	River kilometer
RMIS	Regional Mark Information System
RMP	Resource Management Plan
ROD	Record of Decision
SAM	Strategic Adaptive Management
SGS	Spawning Ground Survey Database
SONAR	Sound Navigation And Ranging
sUS	Southern United States
TN	Total Nitrogen
TP	Total Phosphorus
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VHSV	Viral Hemorrhagic Septicemia Virus
VSP	Viable Salmon Population
WDFW	Washington State Department of Fish and Wildlife

Glossary

Adaptive Management	An iterative and flexible process of decision making for a project in order to reduce risk in the face of uncertainty, and to reduce uncertainty over time through monitoring
Biological Opinion (BO)	A formal consultation with either the U.S. Fish and Wildlife Service or the National Marine Fisheries Service regarding the effects of a Federal action on endangered species
Broodstock	Fish captured and/or kept for the purposes of propagating a species in a hatchery
Co-managers	Washington State Department of Fish and Wildlife and the Washington State Treaty Tribes whose usual and accustom grounds encompass the action area
Escapement	The number of adult fish that return to the spawning grounds
Exogenous Variables	Parameters that affect recovery but do not trigger management actions directly associated with Elwha restoration. These are used to identify factors potentially affecting the rate of recovery
Intrinsic Potential	River segments that are accessible to and provide usable and/or essential habitat for fish species addressed in this document
Lower River (or LE)	The area downstream of the former Elwha Dam location
Maximum Sustainable Yield	The point along a population growth curve that has the highest rate of growth
Middle River (or ME)	The area between the former locations of the Elwha Dam and the Glines Canyon Dam
Ocean-Type Chinook	Chinook salmon that migrate to sea during the first spring after emergence from the gravel
Performance Indicators	The parameters that define how fisheries management progresses through the restoration phases
Record of Decision	A formal decision published via a public document by a federal agency
Restoration Phase	One of four phases (Preservation, Recolonization, Local Adaptation, and Viable Natural Population) of the recovery of the Elwha River watershed. The phases are biologically based by population size, estimated carrying capacity of the watershed, watershed condition, and other parameters
Stream-Type Chinook	Chinook salmon that rear in freshwater for a year or more following emergence from the gravel
Tools	The suite of various monitoring and research methods available for monitoring performance indicators and Exogenous Variables
Trigger Values	The values for a given performance indicator that demarcate the numeric boundaries between restoration phases
Turbidity	The relative clarity of water. This is usually measured by light absorption or light refractivity. Turbidity is an indirect measure of suspended solids in water that must be calibrated for the sediment types found in the watershed
Upper River (or UE)	The area upstream of Rica Canyon. This does not include the newly exposed Lake Mills bottom and Rica Canyon since they will change dramatically in the near future
Viable Salmonid Population (VSP)	An independent population of a salmonid species that has negligible risk of extinction due to threats from demographic variation, local environmental variation and genetic diversity changes over a 100-year time frame (McElhany 2000)

1. Introduction

The Elwha River watershed hosts eight salmonid species. Three of these species, plus one other anadromous fish species, are listed under the Endangered Species Act (ESA). These species are Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*), Puget Sound steelhead (*O. mykiss*), bull trout (*Salvelinus confluentus*), and Pacific eulachon (*Thaleichthys pacificus*). Historical evidence indicates that the Elwha River was highly productive for salmonids before the construction of the two dams (Wunderlich et al. 1994; Winter and Crain 2008). The two dams, which were constructed on the Elwha River in the early 1900s limited access for anadromous species to the lower 7.9 km of the river, eliminating access to the upper 64 km of the river (Duda et al. 2008).

The 1992 Elwha River Ecosystem and Fisheries Restoration Act (The Elwha Act) (Public Law 102-495) authorized the Secretary of the Interior to acquire the Elwha and Glines Canyon dams to initiate actions required for full restoration of the Elwha River ecosystem and native anadromous fisheries. In order to achieve this goal, both dams are being removed in the largest project of its kind to date and active stock preservation and management is being undertaken as described in the project's detailed fish restoration plan (DOI 1995; DOI 1996a; Ward et al. 2008) and HGMPs developed (LEKT 2012a; WDFW 2012) and approved (NMFS 2012a) to implement this plan. As with most complex natural resource management issues, uncertainties exist regarding elements of the restoration plan, the effects of dam removal, and the response of fish populations to newly available habitat and stock restoration actions. Adaptive management is a strategy to address these uncertainties, providing the opportunity to "learn while doing" as new information becomes available through monitoring that is central to the approach (e.g., Holling 1978; Walters 1986; Roux and Foxcroft 2011).

The Elwha River Monitoring and Adaptive Management (EMAM) guidelines described herein were developed to address this uncertainty and are intended by the authors to be an extension of previous documents and technical guidance for ensuring fisheries restoration. These include the Elwha Act, the Elwha Report (DOI et al. 1994), Environmental Impact Statements (EISs) (DOI 1995; 1996a; 2005), Records of Decision (RODs) (DOI 2005), Elwha Fish Restoration Plan (EFRP) (Ward et al. 2008), and resulting HGMPs (LEKT 2012a; WDFW 2012) (Table 1). Like the EFRP, which arose from and refines the details of the legal documents (i.e., EISs, RODs), the EMAM guidelines further refines information contained in these documents as well as the EFRP. However, the EMAM guidelines focuses on ESA listed species due to time and funding limitations. This document will focus on Chinook salmon and steelhead. A separate document should be completed for bull trout in the near future. The template provided herein could also be used for other species.

The purpose of the EMAM guidelines is to propose:(1) refinement to existing goals, (2) an adaptive management framework, (3) triggers to guide adaptive management, (4) a specific monitoring strategy for evaluating outcomes of restoration activities, (5) a data management strategy, and to provide information needed for adjusting goals when observations indicate conditions are different from anticipated. To create and implement an effective adaptive management and monitoring strategy, we propose to incorporate the best available scientific methods to inform a set of management responses that will best ensure the recovery of the native anadromous salmonid stocks while minimizing the risks from the dam removal and stock preservation efforts. By further refining information developed in previous Elwha restoration documents (DOI et al. 1994; DOI 1995; DOI 1996a; DOI 2005), the EMAM guidelines sets forth the framework for adaptively managing Elwha fisheries restoration. The EMAM guidelines also set forth the conditions and schedule for reevaluating the plan and updating or altering it as new information and data become available. It is important to recognize that the EMAM guidelines serves as guidelines and is not a decision document.

Due to the complexities of Elwha River resource management (e.g., National Park, co-management of fisheries resources by state and treaty tribal interests, presence of ESA listed species) no single organization holds decision making authority for every aspect of the project. Thus, the EMAM guidelines framework can provide decision rationale while concurrently adhering to the management authorities and statutory responsibilities of the various agencies and governments involved. The EMAM guidelines were developed concurrently with the completion of the final version of the co-manager Chinook salmon and steelhead HGMPs, and the NMFS biological opinion (BO) evaluating effects to listed species of the Elwha River salmon and steelhead supportive breeding programs (NMFS 2012a). The HGMPs and BO incorporated the draft performance indicators developed during the development of these EMAM guidelines for each recovery phase as "triggers" for adjusting, and eventually, terminating the supportive breeding programs for listed Chinook salmon and steelhead. As such, the action agencies will implement supportive breeding actions described in the HGMPs, including juvenile and adult fish release levels and locations, and adult fish broodstock collection levels, in response to achievement of the specific EMAM population viability parameter triggers identified for each restoration phase. Achievement of the first tier of triggers shall direct the need to transition from the Preservation Phase to the Recolonization Phase through adjustment of supportive breeding actions. The authorized take of ESA listed fish to support supportive breeding actions runs only through the Recolonization phase of restoration, so achievement of EMAM triggers for the Recolonization Phase will delineate either the phase out points for the Chinook salmon and steelhead supportive breeding programs, or the need for re-initiation of ESA consultation if the programs are proposed for continuance.

The EMAM guidelines were also developed in consideration of fisheries affecting the Elwha River Chinook salmon and steelhead populations authorized under the Puget Sound Chinook Resource Management Plan (RMP) and the associated BO(NMFS 2011). The EMAM guidelines considered the fishery exploitation rates authorized under the Pacific Fisheries Management Council when developing the performance indicators and recovery phases in the EMAM guidelines. If adjustments to fishery exploitation rates are identified, the co-managers (state and tribes) investigate and make corrections to remedy the problem. If circumstances deviate from those considered in the ESA evaluation such that the RMP is not effective in conserving listed Puget Sound Chinook salmon or steelhead in the Elwha River basin, NMFS anticipates that the co-managers will take actions under the RMP to provide the necessary protections as per the adaptive management provisions, or NMFS may withdraw approval of the RMP under the provisions of the ESA 4(d) Rule. Recovery information collected under the EMAM guidelines will inform future fishery authorizations. The Comprehensive Plan for Puget Sound Chinook: Harvest Management Component and current co-manager fishery regulations are located online at: http://www.westcoast.fisheries.noaa.gov/fisheries/salmon_steelhead/puget_sound_fisheries.html.

The EMAM guidelines have been developed using previously released technical memos, planning documents, the EFRP (Ward et al. 2008), the Hatchery Scientific Review Group (HSRG) report on the Elwha hatchery genetic management plans (HGMPs) and EFRP (HSRG 2012), agency Biological Opinions, and relevant scientific literature to develop scientifically sound and defensible guidelines. The EMAM guidelines framework also underwent peer review by a panel of four independent scientific experts, as well as agency review by the Lower Elwha Klallam Tribe (LEKT), National Marine Fisheries Service (NMFS), National Park Service (NPS), U.S. Fish and Wildlife Service (USFWS), U.S. Geological Survey (USGS) and Washington Department of Fish and Wildlife (WDFW).

The EMAM guidelines have six major sections. Section 1 provides background of the Elwha Restoration Project and summarizes additional restoration and monitoring activities occurring in the Elwha basin. Section 2 describes the framework of the recommended adaptive management approach and defines important components and terms used throughout the document. Suggested modifications to the restoration strategy outlined in the EFRP (Ward et al. 2008) are identified in Section 3. These recommendations represent a simple selection of the multiple tools provided in the EFRP. Section 4 describes the adaptive management framework. The goals, performance indicators, decision rules, triggers, exogenous variables, and management responses are provided in this section. The processes used for developing the trigger values are also described. Adaptive management relies on assessing triggers for Viable Salmon Population (VSP) parameters. Data standards are developed for each of the triggers developed in these guidelines. Exogenous variables are developed to test assumptions and monitor hatchery production, harvest, measure habitat recovery, fish health, and overall ecosystem recovery. Data are collected to provide information to assess these exogenous variables for factors that may limit fisheries recovery. Section 5 describes the monitoring tools and proposed methods for monitoring restoration progress. Data management for data developed during monitoring and for recommendations made during the adaptive management approach is described in Section 6, along with recommended reporting. The prioritized budget for completing the monitoring activities to provide information for this adaptive management strategy is provided in Section 7.

Table 1. Federal, state and scientific review processes and associated public review and comment opportunities – on the Elwha Fish Restoration Plan and component actions (Courtesy of Tim Tynan, NMFS, Lacey, WA).

Year	Action & Review Process	Lead Agency	Actions Reviewed	Public Review/ comment period
			Federal and State Reviews	
1993	"The Elwha Report" – public review draft	NPS	Early draft of the "Fish Plan" including hatchery supplementation actions, part of the "definite plan" for dam removal under the Elwha River Ecosystem and Fisheries Restoration Act (Elwha Act).	Yes, including public meetings
1994	Draft Programmatic EIS for Elwha River Ecosystem Restoration	NPS	Fish preservation and restoration actions using hatcheries included with other actions proposed under preferred alternative to restore river to a natural condition.	Yes, including public meetings
1995	Final Programmatic EIS for Elwha River Ecosystem Restoration and ROD	NPS	Fish preservation and restoration actions using hatcheries included with other actions under final preferred alternative to restore the river to a natural condition.	Yes
1996	Draft and Final Implementation EIS for Elwha River Ecosystem Restoration	NPS	Fish preservation and restoration plan further developed and included in draft and final Implementation EISs for public review and comment.	Yes, including public meetings
2004	Draft Supplement to Final Programmatic EIS for Elwha River Ecosystem Restoration	NPS	Updated information/data for fisheries restoration plans were included in the Supplement addressing project changes (water quality mitigation).	Yes, including public meetings
2005, 2007	Shared Strategy Plan – Development, review, and approval process –Volume II – Elwha Watershed component	NMFS	Draft (2005) Elwha Fish Restoration Plan, in its entirety, included in Elwha watershed chapter for grass roots organization development, public review and SSP submittal (2005), and NMFS approval (2007).	Yes
2005	WDFW HGMP Public Review and Comment Process – (60 day notice of intent to sue settlement)	WDFW	All draft Puget Sound region hatchery plans, including HGMP for Elwha Channel Chinook program, provided for public review and comment as part of settlement with Washington Trout (now Wild Fish Conservancy).	Yes
2011	Hatchery Action Advisory Group	WDFW	NGO review of Puget Sound co-manager hatchery management plans, including all HGMPs proposed under the Elwha Fish Restoration Plan.	Yes, on going
2012	Puget Sound Hatcheries EIS	NMFS	Environmental effects of all Puget Sound anadromous salmonid hatcheries, including Elwha plans.	Yes, planned

Table 1 (continued). Federal, state and scientific review processes and associated public review and comment opportunities – on the Elwha Fish Restoration Plan and component actions (Courtesy of Tim Tynan, NMFS, Lacey, WA).

2012	4(d) Limit 6 Evaluation Pending Determination for Puget Sound anadromous salmonid hatchery programs	NMFS	NMFS pending determination regarding hatchery-related effects on listed Puget Sound Chinook salmon and Puget Sound steelhead, including Elwha plans.	Yes, planned

Year	Lead Agency	Comments
		Scientific Reviews
2001	HSRG	Preliminary review of the EFRP (ver. 08/15/00) and HSRG 2001 review of the 2000 EFRP version, as requested by the Elwha Fisheries Technical Group
2002	HSRG	Puget Sound and Coastal Washington Hatchery Reform Project – Eastern Strait. Comments on co-manager Elwha salmon and steelhead programs included in revised form in subsequent EFRP drafts
2003	NOAA NWFSC	Center review and comment on October 2003 version of the EFRP (George Pess, with input from Gary Winans and Mike Ford)
2004	HSRG	Response letter to the "Elwha Recovery Team" (from Lars Mobrand [Chair] to c/o Larry Ward) providing HSRG review comments on the revised EFRP
2005	Puget Sound TRT	Full TRT review of the 2005 draft EFRP as part of a general overall evaluation of the restoration strategy in the context of Puget Sound Chinook salmon ESU recovery planning
2006	NOAA NWFSC	NWFSC September-October 2006 peer review of the March 17, 2006 draft EFRP (Mary Ruckelshaus, Jim Myers, Phil Roni) prior to submittal of plan for publication as a technical memo by NWFSC
2008	Various agencies	NOAA Technical Memorandum NMFS-NWFSC-90 "Elwha Fish Restoration Plan" (Ward et. al 2008) – final plan collaboratively completed by a multi-agency resource management and scientific group with specific expertise on the Elwha: NPS, USFWS, NMFS NWFSC, NMFS NWR, WDFW, and Lower Elwha Klallam Tribe

2. Adaptive Management Approach

Adaptive management has been defined in many ways by many different authors (e.g., Holling 1978, Walters 1986; Lee 1999; Anderson et al. 2003; Roux and Foxcroft 2011). Common to all definitions is an acknowledgment that natural resource decisions are often made with imperfect information about highly variable systems. At the core of adaptive management is the recognition that management actions are, in effect, an experiment. Although a number of planning exercises have been undertaken for adaptive management programs, only a few have succeeded in managing through experimentation (Walters 1997). Adaptive management also explicitly calls for gathering information and monitoring of outcomes, which promotes learning and provides a mechanism to modify policy actions. Thus, at the heart of any adaptive management program is the information necessary to modify policy actions, which is provided through a focused monitoring program. This is an integral part of the overall adaptive management approach.

In a special issue describing a 10-year Strategic Adaptive Management (SAM) program for South African National Parks, Roux and Foxcroft (2011) state that a SAM framework, "provides a structured way for improving our incomplete understanding through an iterative process of setting objectives, implementing policy decisions and evaluating the implications of their outcomes for future decision making." Following this framework, our preparation of this document along with the EFRP (Ward et al. 2008) represents the first step in the adaptive management approach by identifying areas of uncertainty, setting objectives, recommending management actions, devising a method for evaluating the effects of those actions, and recommending the process for modifying future actions based on the new information obtained from focused monitoring activities.

In retrospect, the adaptive management approach followed for the Elwha Restoration Project is similar to that described for SAM by Roux and Foxcroft (2011). Similarly, the modifications that arose from Science Management Forums described by Gaylard and Ferreira (2011), which were meetings based on shared rationales that allowed technical input from scientists about the program goals, have also occurred within the Elwha process. Scientists and managers representing federal, state, and tribal entities meet regularly about Elwha River fisheries restoration activities. Outside scientific and technical review of the documents from which the EFRP (Ward et al. 2008) was derived, as well as the EFRP itself, has occurred multiple times in the past decade (Table 1). The most recent iteration by the Washington Hatchery Scientific Review Group (HSRG) (2012) supports the formalization of the planning initiated prior to that review and described herein. The HSRG is an independent scientific review panel developed by the U.S. Congress in 2000 to help reform the hatchery system in the Pacific Northwest. A primary task of the HSRG is to review all hatchery programs in Washington, such as the one described in the EFRP (Ward et al. 2008).

The SAM process can be divided into three main actions: adaptive planning, adaptive implementation, and adaptive evaluation (Roux and Foxcroft 2011). This document contributes to the adaptive planning stage by further specifying the broadly outlined plans described in the EFRP (Ward et al. 2008). We also make recommendations relative to the adaptive implementation and adaptive evaluation actions. It is critical that both the implementation and evaluation actions of the Elwha Restoration Project are adaptive, since the specific fisheries restoration strategies and the monitoring methods will occur in a highly uncertain and rapidly changing environment, particularly during the 2-3 year dam decommissioning phase and in the 3-5 years following dam removal.

Adaptive planning is used to develop a common purpose amongst stakeholders and develop a common direction. This includes the following steps: creating a vision, setting objectives, and scoping management options for meeting those objectives (Roux and Foxcroft 2011). The vision has been provided by The Elwha Act, which states the purpose of the project as "full restoration of the Elwha River ecosystem and native anadromous fisheries" (Section 3(a)). The actions necessary to meet the goals of The Elwha Act were developed through the Federal Energy Regulatory Commission (FERC), EIS process, and the associated Record of Decision (ROD) (FERC 1993, DOI et al. 1994; DOI 1995; DOI 1996a; DOI 2005). This process included public involvement (e.g., public

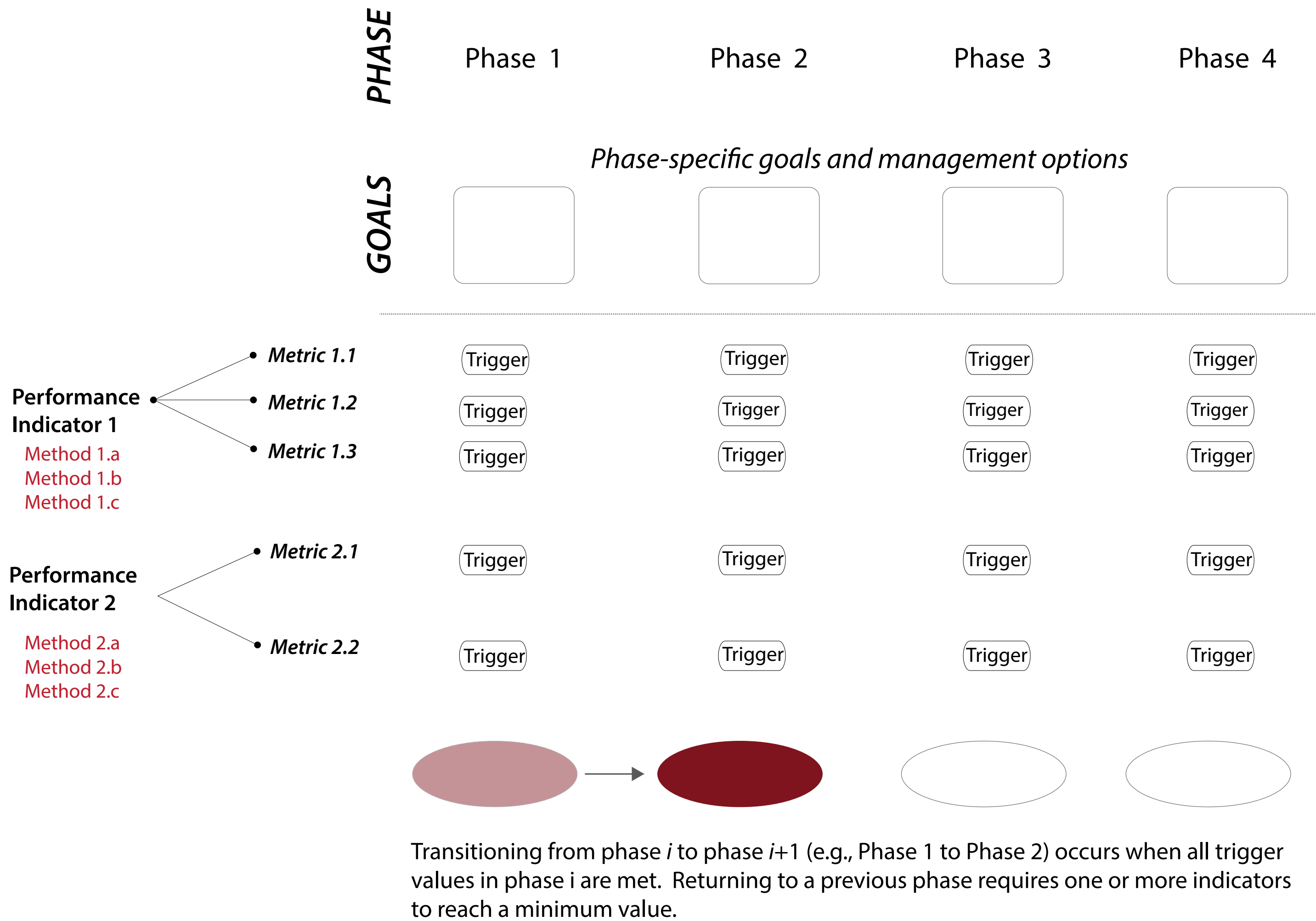


Figure 1. Conceptual example of how performance indicators (rows) will be used to evaluate whether objectives have been achieved for each restoration phase (columns). The adaptive management approach will evaluate performance indicators for each phase and move to the next restoration phase once all trigger levels for the current phase have been achieved.

meetings, comment periods) as well as federal, state, and tribal input through the FERC and EIS processes. The EFRP arose from these EISs and RODs and is a refinement of details found in these documents (DOI et al. 1994; DOI 1995; DOI 1996a; DOI 2005). The potential management options were originally developed through the EIS process, more fully described and defined in the EFRP (Ward et al. 2008), and are further refined below based on comments received from the HSRG (2012) review of Ward et al. (2008). Although the options have been refined, the general approach remains essentially unchanged from that described in the initial report to Congress (DOI et al. 1994).

Based upon the most recent HSRG recommendations (HSRG 2012), we modified goals and objectives from earlier plans to fit within a framework based on four restoration phases. Earlier plans defined the restoration phases temporally, in terms of dam removal (i.e., before, during, and after), whereas the HSRG recommended developing a biologically-based structure to monitoring and adaptive management activities. We modified their proposed four restoration phases as follows:

> **Preservation** – the period during and shortly after dam removal when elevated suspended sediment concentrations are expected, at times, to be lethal to all fish in the river, resulting in a high risk for complete loss of native fish populations and their associated genetic and life history diversity if no protective measures are taken. Beginning with the start of dam removal in 2011, this phase is currently in progress. The goal of the Preser-

vation Phase is to protect the existing genetic and life history diversity of native salmonid populations until fish passage is restored and water turbidity is determined to be non-lethal to fish in the river.

Recolonization – the period after the dams are removed, passage is restored, and fish have access to refugia from lethal suspended sediment concentrations, or suspended sediment concentrations no longer reach lethal levels expected to negatively impact fish populations. The goal of the Recolonization Phase is to ensure that salmonids are continually accessing habitats above the former dam sites with some fish spawning successfully and producing smolts.

Local Adaptation – the period during which: (1) sufficient numbers of spawning adults (e.g., meeting or exceeding minimum VSP criteria) are accessing and using newly accessible habitats above the former dam sites, and; (2) fish are successfully spawning at a rate that allows for population growth. The goal of the Local Adaptation Phase is to maintain or increase life history diversity of natural spawning populations through local adaptation to the Elwha River ecosystem until minimum levels of spawner abundance, productivity, and distribution are met.

Viable Natural Population - the period when all aspects of the previous stages are met, and viable natural populations exist that can withstand exploitation by fisheries without hatchery augmentation. The goal of the Viable Natural Population Phase is to ensure that viable natural and exploitable population levels continue once desired values for all VSP and habitat parameters have been met and hatchery programs are no longer needed to provide for protection, recovery, or exploitation.

This adaptive management approach works from broad levels to increasing levels of specificity in a hierarchical manner. The ordered levels of this hierarchy are goals, objectives, performance indicators, decision rules, triggers, and finally decisions (i.e., management/policy response). The goals and objectives for each of these different phases of restoration are provided in Section 4. Goals represent very broad statements about what we hope to achieve during each phase of restoration. Objectives are simply broad quantitative targets that test questions or hypotheses (e.g. adult abundance is increasing) that when met, will help achieve the stated goals. Performance indicators, triggers, and management responses are developed for each objective and are used to determine if the hypothesis is rejected. Performance indicators identify specific metrics to be measured by the focused monitoring program and the tools used to measure those metrics (e.g., number of spawners per spawner). We propose to monitor metrics that will result in changes to management activities (i.e., those described in Section 3 below) as well as those that will provide information regarding why the metrics are not being met (i.e., Exogenous Variables described in Section 4 below). This will allow informed decisions to be made about the potential for alternative management strategies to achieve desired goals. Overall escapement (fish that escape the ocean catch and return to the river to spawn) is an example of a performance indicator that would be used to assess an abundance objective. Triggers are the specific criteria that are used to determine if the decision rule has been met and leads to the appropriate management action. An example of a trigger would be 5,000 natural spawning adult Chinook salmon, which if all the other triggers are met, would move recovery from the Recolonization Phase to the Local Adaptation Phase (see Section 4 below for more details). An example of the changing management response would be to begin reducing hatchery production of Chinook salmon based on future returns (see Section 4 below for more details).

The overall adaptive management approach is described conceptually in Figure 1. Each restoration phase has several objectives, performance indicators, and associated triggers. The trigger for each performance indicator should be assessed within the appropriate time-frame (usually annually). All of the triggers within each phase of restoration must be met before moving from a lower to a higher restoration phase. Feedback mechanisms exist at each restoration phase that can result in regressing to a previous restoration phase. For example, Chinook salmon could regress from the Recolonization Phase back to the Preserva-

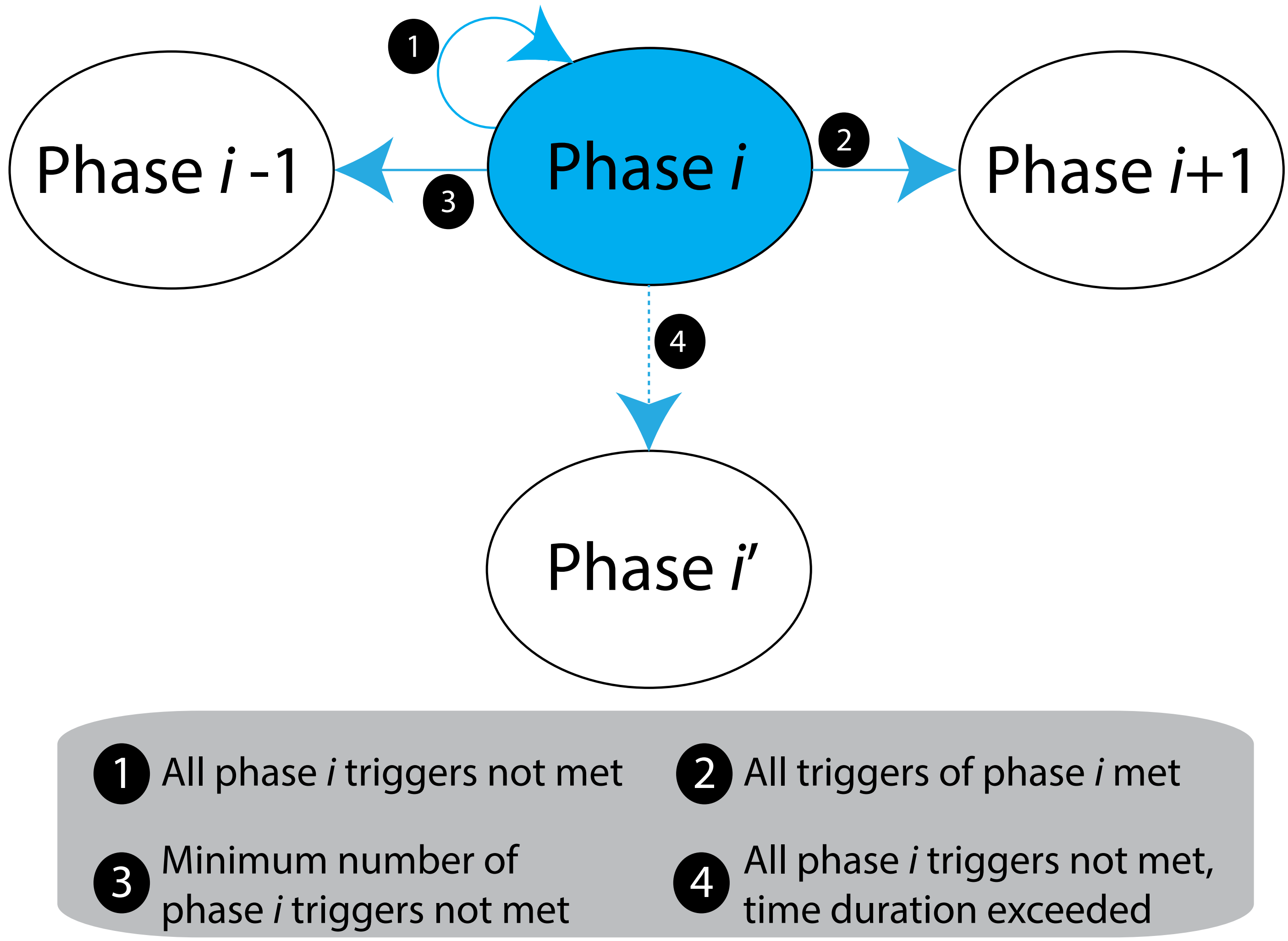


Figure 2. Conceptual model showing 4 different management outcomes (1-4) to be evaluated on an annual basis. The oval in blue is the current management phase (i). When evaluating status, the management decision could be to remain in the current phase (1), move to the next phase (2), return to a previous phase (3), or adjust the trigger values within a phase, resulting in a new set of performance indicators (denoted i') for that phase (4).

tion Phase if the geometric mean for overall escapement falls below a minimum value (i.e., trigger) for the prescribed period of time.

Four potential management responses are provided for each goal (Figure 2). First, the current management action may continue, since one or more trigger values has not been exceeded. Second, restoration moves from one phase to the next if the trigger value is exceeded for all indicators. This often results in implementing the priority management action for the new phase of restoration (see Section 3) and terminating the management action for the previous restoration phase or lowering its priority. The third scenario occurs when a pre-defined number of trigger values in an existing phase are not met for a pre-defined duration, which results in transitioning back to the previous restoration phase. For example, if the abundance and productivity triggers for Chinook salmon are not met for four years during the Local Adaptation Phase, then recovery returns to the Recolonization Phase. Thus, the trigger values and priority management actions of the previous phase are re-implemented. Alternatively, if it is determined that the trigger values selected for a particular phase are no longer valid, then the fourth management response could apply, which is the reassessment of a trigger value(s). Since each phase of restoration and associated triggers are based on a set of assumptions (see Section 4) that may or may not be accurate, there is a time limit for meeting each trigger. If the trigger is not met within this time limit, then the assumptions used to develop the trigger value are reevaluated. The time limit recommended is the dominant age at maturity for the species addressed (which is four years for both Chinook salmon and steelhead). In other words, if the system has not moved out of a particular phase within 4 years, the phase's triggers should be reevaluated (with some exceptions in the Viable Natural Population Phase). This may result in developing new trigger values or identifying other factors that are preventing the trigger value from being exceeded (e.g., a previously unrecognized limiting factor). This is, in essence, an adaptive management response. We suggest that the decision process described below (Decision Making Framework) be used to alter trigger values that were determined to be incorrect after analysis of new information.

The authors understand that triggers will likely not be met following the first four years of restoration. However, we feel that re-assessing the triggers is still a useful function since new Elwha specific information will have been collected through the monitoring suggested in this document. Simply re-assessing the triggers also does not imply that the triggers actually need to be modified.

Focused monitoring should be used to assess when trigger values have been met (see Section 5). The monitoring methods are designed to evaluate specific metrics developed during the adaptive management approach. Monitoring protocols (including the tools, methods, data analysis and interpretation) have been developed as part of these guidelines. Data management, standards, and archival systems for data collected through this work and management actions taken as a result of this work are also included in these guidelines (see Section 6). Methods may be revised in the future due to ongoing evaluation and/or the development of new techniques and technologies. However, revisions should only be done after a period of evaluation and calibration between the old and new methods, to allow data from the old and new methods to be compared to ensure they are providing the same information.

Anderson et al. (2003) described four main characteristics of adaptive decision making in the face of uncertain outcomes, which varied based on the characteristics of the ecological problem and the social context in which the management was taking place. The range of decision making was defined by the number of projects and decision points, the amount of information required to make decisions, the involvement of stakeholders, the amount of uncertainty, and the degree to which learning about the process is an explicit goal. The framework outlined in the EMAM guidelines is equivalent to the "passive" adaptive management approach outlined by Anderson et al. (2003) and summarized in their Table 2. The Elwha River dam removal project is a singular project for which ongoing monitoring is essential. Decisions are intended to be the best apparent management

Table 2. Definition of the potential restoration (management) actions used to restore salmonids to the Elwha River Basin.

Strategy	Definition
HORs from on-station releases	Returning adult fish resulting from release of progeny from hatchery or natural origin fish reared in hatchery facilities within the Elwha basin (e.g., Elwha rearing channel, Lower Elwha Tribal Hatchery). Adults returning from these on-station releases will either be brought back into the hatchery for spawning or allowed to naturally colonize the Elwha River depending on the restoration phase.
Returns from outplanted adults	Adult returns produced from adult salmonids transplanted into the upper watershed to protect them from high turbidities (Preservation Phase) or if, for some reason, they are not naturally colonizing the upper watershed (later restoration phases).
Captive brood	Fish reared to adults in captivity, spawned in a hatchery setting, and their progeny reared in the hatchery and released as on-station releases as smolts.
HORs from outplanted juveniles	Hatchery adult returns originating from hatchery juveniles (eggs, fry, or smolts) outplanted into the upper watershed.
Spontaneous colonization from NORs or HORs	Natural colonization of the upper watershed by natural origin or hatchery origin adults.
Spontaneous anadromy from resident forms	The re-establishment of an anadromous life history pattern by resident forms that have been isolated above the two dams, including rainbow, kokanee, and bull trout.

option at each decision point (e.g., transitioning among phases or re-evaluating trigger values). Quality of monitoring information (in terms of both precision and duration) is essential for success, as is continued and long-term oversight.

2.1 Decision-Making Framework

There are seven main decision points contained in these EMAM guidelines including: (1) setting the overall purpose, (2) selecting and implementing the management action (i.e., restoration method), (3) setting the goals and objectives, (4) setting the trigger values, (5) determining alternate management actions if triggers indicate they should be modified, (6) determining time frames after which assumptions (e.g., trigger values) should be assessed, and (7) determining the revised trigger values and/or assumptions, if this becomes necessary. As stated above, the overall purpose was established by The Elwha Act, which is generally a legal settlement among parties to the hydropower licensing process. The remaining tasks fall under the broad envelope of salmon management in Washington State.

Although it would be ideal to have a single party in charge of a monitoring and adaptive management plan, it is not possible in this case (or likely in any other case involving salmon in Washington State). In general, salmon management decisions in Washington State are made jointly by the WDFW and Washington State Treaty Tribes, collectively called co-managers (PSSMP 1985). Modifications to this process occur when management actions influence or involve species listed under the ESA. Further modifications occur in some cases on federal lands with specific management authority. For example, management jurisdiction of fishery resources inside the boundaries of Olympic National Park is cooperatively managed by the NPS through the Olympic National Park (ONP), LEKT, and WDFW. Specifically, NPS retains exclusive management jurisdiction of recreational fisheries within the ONP, and LEKT and WDFW have jurisdiction of fisheries outside of the park boundary. The decision making process is further complicated when species listed under the ESA are involved. In these cases, NMFS (Chinook, steelhead) and the USFWS (bull trout) have management authority. Thus, depending on the situation, WDFW, LEKT, ONP, NMFS, or USFWS could be the primary decision makers at certain points during the Elwha Restoration Project.

The fisheries restoration strategy for the Elwha was developed through the National Environmental Policy Act (NEPA) process, beginning with the Elwha Report and culminating with the 2005 ROD. The Elwha River Fish Restoration Plan technical memo (Ward et al. 2008) and these EMAM guidelines were developed cooperatively by the management agencies with assistance from federal partners, including NPS, USFWS, USGS, and NMFS. Since fisheries management within Washington State fall under the jurisdiction of the State of Washington and the Treaty Tribes (co-managers), any areas of disagreement were addressed through the state/tribal co-managers process established through the "Boldt" decision, unless the action was funded by ONP or occurred within ONP boundaries. In those cases, the ultimate decision was made by ONP after carefully considering the points raised by cooperators during discussions, and ultimately in accordance with appropriate rules and regulations. When endangered species were involved, decisions were made after consultation with the agency with management authority for the species involved (NMFS (Chinook and steelhead) or USFWS (bull trout)). In some cases, these consultations mandated specific actions. For example, the biological opinion (BO) developed by NMFS requires a certain level of hatchery production for Chinook salmon to protect this stock from extirpation during the high suspended sediment period expected during dam removal (NMFS 2006) and requires an agreed upon (NMFS and ONP) monitoring and adaptive management plan to be developed by ONP (NMFS 2012; NMFS 2012a). This monitoring and adaptive management plan was developed concurrently with this plan and is basically a subset of earlier drafts of this plan with some modifications (ONP 2013). It is expected that future decisions will continue to be made following the process described in this paragraph.

The primary role of staff from the federal agencies who are not directly involved in the decision making process is to provide technical information upon which those decisions can be based. For example, many of the scientifically defensible trigger values (see Section 4) were developed by federal staff and provided to the co-managers for review during the development of these EMAM guidelines.

3. Suggested Modifications to the Restoration Strategy

The Elwha River Fish Restoration Plan (Ward et al. 2008) identifies two main restoration approaches for stock restoration in the Elwha River: natural recolonization and artificial supplementation. Hatchery operations are assumed to be a necessary component of the preservation and restoration strategies outlined in the fish restoration plan. The use of hatcheries to preserve stocks is supported by the management responsibilities mandated by the ESA and separately by the federal-tribal-trust responsibilities of the federal government in accordance with common law determinations and treaties between the United States and the tribes. A multi-agency management group evaluated the relative risks of a no action alternative and the risks associated with hatchery operation and determined that the risks to ESA listed species were substantially greater when taking no action during dam removal than from a temporary hatchery preservation and supplementation program (DOI et al. 1994; DOI 1995; DOI 1996a; DOI 2005). These EMAM guidelines suggest revised strategies to minimize the risk from dam removal and stock preservation efforts and are generally reflected in the HGMPs submitted by the LEKT (LEKT 2012a) and WDFW (WDFW 2012), which have been approved by NMFS (NMFS 2012). One significant difference between the HGMPs and these EMAM guidelines is that the HGMPs provide management activities through the early stages of restoration (i.e., Preservation and Recolonization Phases), while the EMAM guidelines provide recommendations through all four restoration phases.

The EFRP identifies multiple strategies based on artificial supplementation, including on-station smolt releases (yearling and age-0 for Chinook); off-station smolt releases; egg, fry, and adult out-planting; and captive brood. These restoration strategies along with the natural recolonization strategies are defined in Table 2. Based on earlier recommendations from the HSRG (see Table 1), the EFRP recommends the use of a large number of approaches with associated monitoring and adaptive management to determine the most effective methods (Ward et al. 2008). Although this approach may help identify the most successful method for stock restoration, it also is more expensive and logistically difficult to implement and monitor. Based on these factors it is recommended that only one or two different approaches be used at any one time, which was also advocated in the latest HSRG recommendations (HSRG 2012). The different approaches are prioritized for each restoration phase for each species (Table 3). The use of only one or two restoration approaches at any one time will increase the probability that adequate monitoring data can be obtained to differentiate the effectiveness of concurrently applied restoration strategies, thereby allowing the use of an adaptive management approach. The continued use of a particular restoration strategy or the implementation of a new strategy will depend on feedback provided through the monitoring and adaptive management approach.

3.1 Chinook

The prioritized restoration strategies for Chinook salmon are listed in Table 3. Chinook salmon restoration during the Preservation and Recolonization phases relies on hatchery origin returns from on-station releases, whereas restoration during the Local Adaptation and Viable Natural Population phases relies on colonization and reproduction from natural-origin fish. The use of hatchery-origin fish during the early phases of restoration are based on the assumption that high turbidity during and immediately following dam removal will pose a high extirpation risk due to high mortality rates for fish left in the river. In addition, evidence from otolith data suggests that the natural spawning population in the river is not self-sustaining (WDFW, unpublished data). Thus, adult Chinook salmon should continue to be brought into the hatchery to protect the native Elwha Chinook genetic material and prevent extirpation during the Preservation and Recolonization phases. This management action is also required by the BO (NMFS 2006). The reliance on hatchery supplementation activities decreases progressively through the Recolonization and Local Adaptation Phases as Chinook abundance increases and turbidity levels in the Elwha River decrease to more natural levels.

3.2 Steelhead

The prioritized restoration strategies for steelhead are listed in Table 3. Steelhead restoration during the Preservation Phase focuses on safeguarding the broodstock either within the hatchery environment or by transporting the fish upstream into refugia streams. Broodstock safeguard relies on a captive brood program that was initiated in 2005 and returns from natural-origin returning adults (NOR) outplanted above Elwha Dam during dam removal. Hatchery produced steelhead smolts produced from the captive brood program will be volitionally released on-station. These strategies were selected to reduce the threat of extirpation from a combination of high suspended sediment concentrations expected during dam removal and low population size of native steelhead in the Lower Elwha River (45-245 from 2005-2011) (LEKT 2011). In addition to the captive brood program, adults will be transported to the Little River, above Elwha Dam, during dam de-construction to protect them from the high turbidity levels expected to occur during dam removal (i.e., "returns from outplanted adults" in Table 3). During the Recolonization Phase, the priority actions will continue to be safeguarding the broodstock in the hatchery environment or transporting them to upstream refugia if necessary. Hatchery produced smolts will continue to be volitionally released on-station; however, these numbers will be reduced as the numbers of naturally produced fish increases (explained in detail below). Both hatchery produced and naturally produced adults surplus to the needs of the hatchery program will continue to be transported above the dam sites or into tributary streams to protect them from high turbidity levels. Spontaneous colonization from the natural origin spawners will be the priority restoration strategy during both the Local Adaptation and Viable Natural Population phases, and hatchery releases will be reduced and eliminated in relation to increasing numbers of naturally produced spawners during the Recolonization and Local Adaptation Phases.

Table 3. Prioritized restoration strategies (1= highest ranked and 5 = lowest ranked) for Chinook salmon and steelhead for each phase of restoration. Cells with "na" represents methods that were not considered since they were either deemed inappropriate for that phase or not likely to be necessary (i.e., captive broodstock for Chinook).

Restoration Strategy	Restoration Phase			
	Preservation	Recolonization	Local Adaptation	Viable Natural Population
		Chinook Salmon		
HORs from on-station releases	1	1	3	na
Returns from outplanted adults	2	3	2	na
Captive brood	na	na	na	na
HORs from outplanted juveniles	3	4	4	na
Spontaneous colonization from NORs or HORs	4	2	1	1
Spontaneous anadromy from resident forms	na	na	na	na
		Steelhead		
HORs from on-station releases	na	1	3	na
Returns from outplanted adults	2	2	2	na
Captive brood	1	na	na	na
HORs from outplanted juveniles	na	na	5	na
Spontaneous colonization from NORs or HORs	3	3	1	1
Spontaneous anadromy from resident forms	4	4	4	na

4. Objectives, Questions, Performance Indicators, Decision Rules, Triggers, Exogenous Variables and Adaptive Management Response

This section lists the goals and objectives for each restoration phase along with the performance indicators, decision rules, triggers, and recommended management response used to adaptively manage fish populations and habitat during each restoration phase. The goals for each phase are provided in Section 2 above. Objectives and performance indicators for fish populations include hatchery influence (i.e., proportion of hatchery fish spawning naturally, (pHOS)) and VSP measures (abundance, productivity, diversity, and distribution). Additional exogenous variables are developed to (a) provide information regarding conditions that may limit fisheries restoration, including hatchery production, harvest, habitat (e.g., migration barriers), fish health, and ecosystem recovery, and (b) test assumptions (e.g., suspended sediments will kill all fish during dam removal). This section includes specific diagrams (Figure 3 and Figure 8) based on the generalized conceptual diagram (Figure 1) that describes the criteria needed to move from one restoration phase to the next. The adaptive management approach described in Figure 1 and further developed in Figure 3 and Figure 8 involves the assessment of each objective (rows) in each phase (columns) sequentially. The specific testable hypothesis for each objective can be developed by combining the objective, indicator, and associated triggers from Figure 3 and Figure 8. For example, during the Preservation Phase, the abundance objective measured by the natural spawner indicator (e.g., 950) can be stated as the following hypothesis: natural Chinook spawner abundance during the Preservation Phase will not exceed 950. The remaining hypotheses can be developed in a similar fashion.

As summarized in Section 2, a new restoration phase begins once trigger levels for all performance indicators in the previous phase for which data are available have been met. Failure to meet trigger levels within a given review period result in either continuing the current restoration strategy, regressing to the restoration strategy of an earlier restoration phase, or assessing the assumptions used to derive the trigger levels (Figure 2). The path selected among these three choices will depend on how long the current restoration strategy has been implemented.

4.1 The Relationship Between Trigger and Exogenous Variable Levels, Management Actions, and Moving to the Next Phase

Three general management actions that can affect fish and ecosystem restoration in the Elwha River are dam removal (i.e., barriers), increased suspended and coarse sediment transport impacts on physical habitat and aquatic ecosystem health, and the level of hatchery intervention in the recovery effort. We have identified triggers and exogenous variables for several metrics that provide information relative to performance indicators. For example, the extent of fish distribution and presence of human-induced barriers are metrics for the spatial distribution performance indicator. Triggers measure performance and, when collectively met for all performance indicators, result in changes to management actions and movement from one restoration phase to the next. Exogenous variables, on the other hand, provide information regarding why restoration is progressing as observed and do not automatically result in altered management actions directly associated with Elwha River management activities. For example, ocean harvest may impact recovery of Elwha Chinook salmon. Altering Elwha restoration strategies will not improve recovery unless ocean harvest activities are modified. Thus, this exogenous variable may result in groups associated with Elwha restoration requesting that co-managers modify ocean harvest (see harvest exogenous variable section below for details), which are outside Elwha specific jurisdiction.

Each of the above management actions has a hypothesized and actual cause and effect link to the aforementioned triggers and exogenous variables for Chinook salmon and steelhead. In addition, each management action assumes cause and effect relationships with each identified metric as well as the uncertainty surrounding that relationship. The goal of these EMAM guidelines with respect to the Elwha

Table 4. Evaluation of every year exceedance, the arithmetic mean, and the geometric mean as potential temporal trigger assessment methods, using recolonization data from the Cedar River, Washington. Mean values for the entire recolonization period were used as the Chinook (156) and coho salmon (258) 'triggers' for this evaluation. True (T) and false (F) designations in the decision columns represent the trigger values being exceeded or not exceeded, respectively. Decision cells highlighted in yellow represent movement from a lower restoration phase to a higher restoration phase, whereas red highlighted cells designate when minimum triggers were not met, resulting in restoration moving back to a previous phase.

Escapement Data[1]			Every Year Exceedence		Arithmetic Mean				Geometric Mean			
Year	Chin.	Coho	Chin. Decision	Coho Decision	Chin. 4-yr ave.	Coho 3-yr ave.	Chin. Decision	Coho Decision	Chin. 4-yr ave.	Coho 3-yr ave.	Chin. Decision	Coho Decision
2003	100	30										
2004	50	100										
2005	70	170		F		100		F		80		F
2006	200	180	F	F	105	150	F	F	91	145	F	F
2007	400	125	F	F	180	158	T	F	129	156	F	F
2008	125	300	F	F	199	202	T	F	163	189	T	F
2009	170	700	F	F	224	375	T	T	203	297	T	T
2010	190	300	F	T	221	433	T	T	200	398	T	T
2011	100	420	F	T	146	473	F	T	142	445	F	T

[1]Seattle Public Utilities, unpublished data, available at: http://www.seattle.gov/util/EnvironmentConservation/OurWatersheds/Habitat_Conservation_Plan/Species/Fish/ChinookSalmon/HCPProgress/SPU02_015446.htm

Dam removal is to link the performance metrics to the triggers and exogenous variables as well as the management actions being implemented. Potential alternative management actions can then be identified and used to aid in increasing the effectiveness and efficiency of moving from the Preservation Phase to the Viable Natural Population Phase.

An example of how triggers, exogenous variables, management actions and moving to different phases of restoration are linked together can be garnered from examining management actions described in Table 3. If spontaneous colonization from natural origin returns (NORs) and from transported adults that return to the hatchery is occurring (indicators) and is the primary source of increases in abundance, productivity, distribution, and diversity (triggers) then reductions in hatchery origin returns (HORs) from on-station releases would be warranted (management action), assuming all trigger values are met prompting a move forward to the next phase. Conversely, if HORs from on-station releases are the only fish returning (indicator) due to elevated sedimentation levels (exogenous variable) that cause NORs not to produce at a high enough level (preventing moving to the next phase), then an increase in HORs on-station releases or management activities addressing the elevated sediment levels could be a management action implemented. Linking the metrics to the triggers or exogenous variables and the actions is critical to implementing any aspect of the adaptive management guidelines.

4.2 Scientific Basis for Trigger and Exogenous Variable Levels Selected to Achieve the Objectives of Each Restoration Phase

Performance indicator triggers were developed based on available scientific results from the Elwha River, comparable watersheds and/or published information, and were made in the context of the management objectives for each restoration phase. The usefulness of each performance indicator as a trigger for the next restoration phase depends on the management objectives for the next restoration phase. Triggers are the performance indicator values assumed to prepare the fish population for the objectives of the next restoration phase. The trigger value is distinguished from the "ideal" or potential performance of Elwha River salmonids, although a

Figure 3. Performance indicators (rows) used to evaluate whether Elwha River Chinook salmon populations have achieved the objectives for each restoration phase (columns). The adaptive management approach evaluates performance indicators for each phase. Movement to the next restoration phase occurs only after all trigger levels for the current phase have been achieved.

Species: Chinook Salmon
Oncorhynchus tshawytscha

			Preservation	Recolonization	Local Adaptation	Viable Natural Population
PHASE / GOALS			*Prevent extinction and preserve the existing genetic and life history diversity of native salmonid populations until fish passage is restored and water turbidity is determined to be non-lethal to fish in the river*	*Salmonids are continually accessing habitats above the old dam sites with some fish succesfully spawning and producing smolts*	*Maintain or increase life history diversity of natural-spawning populations through local adaptation to the Elwha River ecosystem until minimum levels of spawner abundance, productivity, and distribution are met*	*Ensure that self-sustaining and exploitable population levels continue once desired values for all VSP and habitat parameters have been met and hatchery programs are no longer needed for protection, recovery, or exploitation*
Abundance	*Weir, Sonar, foot and boat surveys, aerial surveys*	**Natural spawners**	950	>950 or <4,340	>4,340 or <10,000	>10,000
		Spawner escapement duration	4 yrs	4 yrs	4 yrs	4 yrs
Managing for pHOS	*Otoliths, CWT, Scale samples*	**pNOS** (natural-origin spawner)	*	0.95	1.0	1.0
		pHOS (proportion hatchery-origin spawner)	*	0.05	0	0
Productivity	*Weir, Sonar, Spawner Surveys, Smolt trap, otoliths, cwt, harvest*	**#Juvenile migrants/female**	200	200	200	200
		#Pre-fishing recruits/spawner (h+n)	>1.56	*	*	*
		#Spawners/spawner (h+n)	>1.0	*	*	*
		#Pre-fishing recruits/spawner (n)	*	>1.56	>1.56	>1.85
		#Spawners/spawner (n)	*	>1.0	>1.0	~1.0
		Productivity trend	4 yrs	4 yrs	4 yrs	4 yrs
Spatial Distribution	*Spawner Surveys Radio-telemetry Snorkel Surveys*	**Extent**	A portion of fish accessing above Elwha Dam	Above Elwha Dam; 43% of Intrinsic Potential	Above Glines Canyon Dam; 86% of Intrinsic Potential	100% of Intrinsic Potential
		Barriers	No migration barriers exist below Elwha Dam	No 'artificial' migration barriers exist in Aldwell reach	No 'artificial' migration barriers exist in Mills reach	No 'artificial' barriers exist within Intrinsic Potential
Diversity	*Sonar, otoliths, smolt trap,*	**Stream-type proportion**	*	*	Positive trend	Stable, > Preservation Phase
		Entry timing variance	*	*	Positive trend	Stable, > Preservation Phase

prediction of potential performance is provided when possible. The one exception to this approach is the performance trigger values associated with the final phase, the Viable Natural Population Phase, in which the trigger values are the expected performance of Chinook salmon and steelhead populations in a restored Elwha River ecosystem. Triggers for Chinook salmon and steelhead are provided in separate sections below.

A time limit is recommended for determining when triggers for specific metrics are met and when they should be re-evaluated. This time limit was set as the dominant age at maturity for Chinook salmon and steelhead, which is four years for both stocks. Thus, the numeric triggers should be assessed using the previous four year geometric mean. The geometric mean was selected instead of either the arithmetic mean or exceeding a trigger value in each of four consecutive years, since it provided a more reasonable progression based on an assessment using data from re-colonizing Chinook and coho salmon in the Cedar River (Table 4). Trigger values will be re-assessed if they have not been met after the first eight years of restoration and then every four years after that to ensure the values and/or the assumptions under which they were developed are appropriate as determined by new data collected during monitoring activities.

4.2.1 Chinook Triggers

The recommended trigger values for the different Chinook indicators are listed in Figure 3. The methods for developing these triggers are listed below.

4.2.1.1 Abundance

Overall abundance is the sum of harvest, hatchery spawners (regardless of broodstock collection method) and natural spawners, which together provide information on overall stock abundance for a given year. However, for the adaptive management approach, natural spawners are considered triggers used to assess the status of a given restoration phase, while hatchery spawners (hatchery rack and brood stock collection) and harvest serve as exogenous variables (see exogenous variables sub-section below). The geometric mean for abundance must exceed the trigger levels over a four-year evaluation period. Harvest should be monitored and exogenous variables evaluated annually to ensure that harvest is not impeding recovery.

In the Viable Natural Population Phase, the natural spawner abundance indicator is the expected spawner capacity of the Elwha River ecosystem. To select a performance trigger for adaptive management, we relied on empirical data from recent studies of 25 Chinook salmon populations from Oregon to Alaska (Parken et al. 2006; Liermann et al. 2010). These studies applied a Ricker spawner-recruit function to these data sets and demonstrated that the number of Chinook salmon spawners producing maximum sustainable yield (MSY) is positively correlated with accessible watershed size and can be calculated with a few parameters (Equation 1):

Equation 1

$$S = \hat{b}\chi * e^{\ln \hat{a} + (\frac{\sigma^2}{2})}$$

Where S = Spawners that will produce maximum sustainable yield

χ = watershed area

$\hat{\alpha}, \hat{b}, \sigma^2$ = parameters calculated from regression habitat-models associated with S_{msy} in 25 Chinook populations from Oregon to Alaska (Parken et al. 2006). Parameter values for ocean-type Chinook were $\ln \hat{\alpha} = 3.52$ $\hat{b} = 0.878$, $\sigma^2 = 0.133$. Parameter values for stream-type Chinook were $\ln \hat{\alpha} = 3.89$, $\hat{b} = 0.693$, $\sigma^2 = 0.240$

The authors recognize that it would be ideal to use data for the production capacity of a system rather than MSY. However, the data and relationships are currently lacking to complete this for the Elwha River. In addition, the adaptive management approach will allow for triggers to be adjusted if it is determined that they were set to inappropriate levels in this document.

Equation 1 was applied twice, once with the ocean type parameters and once with the stream type parameters to produce separate ocean and stream type estimates. These were then summed to represent full use of the potential habitat and expression of both ocean (sub-yearling migrants) and stream-type (yearling migrants) life histories (Healey 1998). The trigger value selected was the abundance of ocean and stream-type Chinook supported by the accessible watershed size (per Parken et al. 2006; Liermann et al. 2010). For the Viable Natural Population Phase, accessible watershed size is the entirety of the intrinsic potential predicted from digital elevation model data, potential migration barriers, salmon habitat use below the dams, and salmonid habitat preferences (Pess et al. 2008). For the Preservation, Recolonization, and Local Adaptation phases, watershed size was assumed to be 9.5%, 43.4%, and 86% of the Viable Natural Population value, as determined from the intrinsic potential assessment (see below). Using equation 1, these values equate to escapement trigger values of 950, 4,340, and 10,000, for transitioning from the Preservation Phase, Recolonization Phase, and Local Adaptation Phase, to the next phase respectively.

The selected trigger levels are slightly lower than the range of estimated spawner abundance previously predicted for a viable natural Chinook salmon population in the Elwha River. Spawner capacity has been estimated to range between 17,000 (FERC 1993; DOI et al. 1994) and 31,000 (DOI et al. 1995) spawners for a non-harvested population. The EFRP additionally calculated a viable natural spawner escapement level to be 6,900 in a fished population with a 78% exploitation rate (Ward et al. 2008), corresponding to a pre-fishing abundance of 31,000 Chinook. This wide range of published values corresponds with the planning recovery targets for Elwha Chinook salmon described in the Puget Sound Chinook Recovery Plan (Puget Sound Salmon Recovery Plan 2007). The conservative escapement values selected as performance triggers are consistent with the general approach to selecting triggers adopted for these monitoring and adaptive management guidelines (i.e., preparation for the next restoration phase is not a maximum potential in a given restoration phase).

4.2.1.2 Managing for Proportion Hatchery Origin Spawners (pHOS)

Although hatcheries have been used as a stock recovery tool for years, and are proposed for use in the Elwha system, we recognize the potential deleterious effects of hatchery fish on naturally spawning populations. In an effort to limit those risks, pHOS should be monitored and managed as described in these EMAM guidelines. We focus on hatchery fish spawning naturally since the goal is for no hatchery programs in the future. In general, we follow the guidelines proposed by the HSRG for integrated hatchery programs (HSRG 2009; HSRG 2012), such as the Elwha Chinook hatchery and provisions for exceptions to the guidelines (HSRG 2009). These guidelines are as follows:

- **Maintain pHOS < 30%:** The effectiveness and efficiency of pNOB for maintaining PNI > 0.5 decreases significantly for values of pHOS > 30%. Consequently, to achieve a desired PNI > 0.5, it is much more efficient - and less risky biologically - to reduce pHOS than to increase pNOB. Increasing pNOB for high values of pHOS, as opposed to decreasing pHOS, imposes additional demographic (and potential genetic) risks to naturally spawning populations with comparatively minor increases in PNI.
- **Maintain PNI > 0.67**: For natural populations considered essential for the recovery or viability of an ESU of Pacific salmon or Distinct Population Segment (DPS) of steelhead, as those terms are defined and designated under the ESA.
- **Exceptions to the guidelines**: "Consequently, the HSRG acknowledges that some hatchery programs may be required to perform a "life support" function to prevent functional extirpation of a naturally spawning population in particular watersheds or geographic areas. Moreover, the abundance of fish representing a natural population must be sufficiently high to allow selection in the natural environment to be an effective deterministic force towards maximizing mean population fitness in view of stochastic forces. Under these exceptional circumstances, maintaining a naturally-spawning component to a hatchery-sustained population – where the number of hatchery fish spawning naturally exceeds HSRG guidelines - may be desirable for both genetic and demographic reasons." (HSRG 2009).

Although the general goal is to follow these guidelines, it will be impossible, and potentially undesirable based on HSRG (2009) for the Elwha Chinook

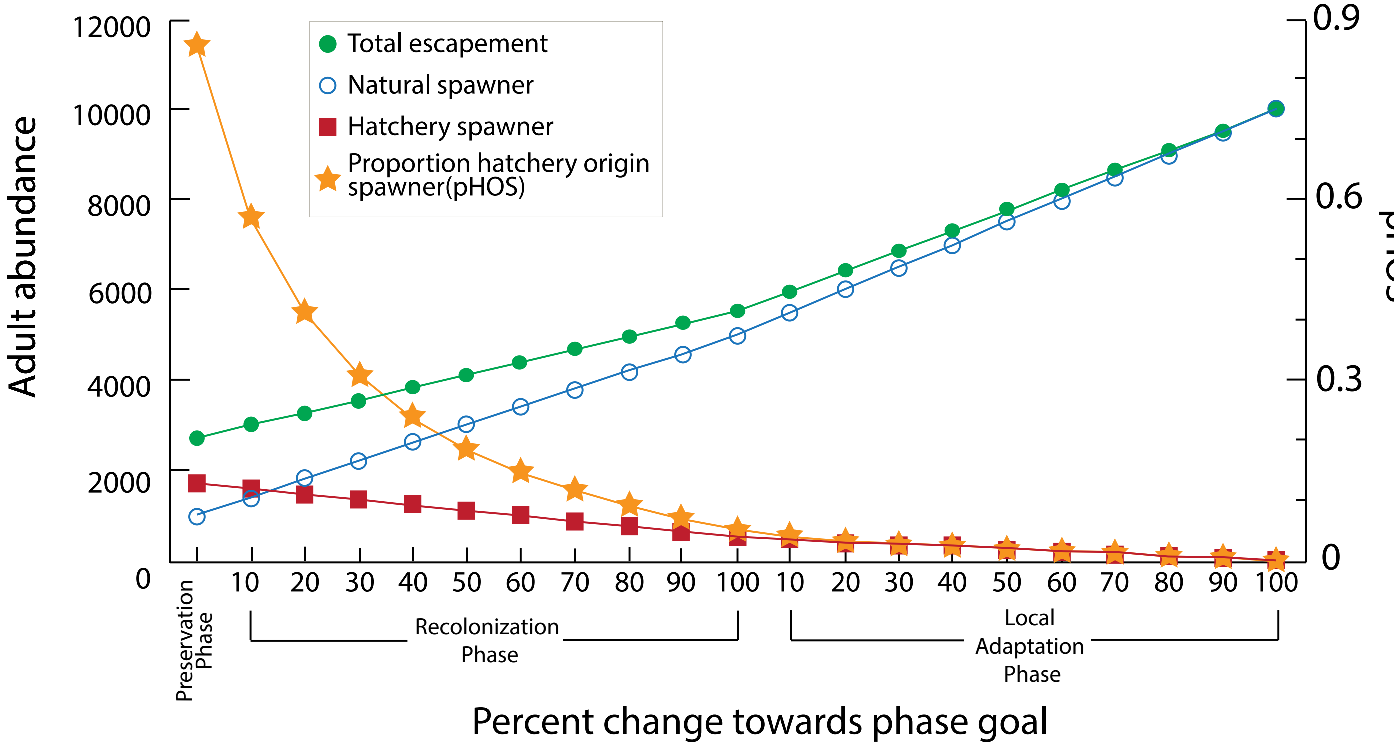


Figure 4. Conceptual diagram of Elwha River Chinook salmon abundance and proportion of hatchery-origin spawner (pHOS) through adaptive management phases. Graph shows changes in total escapement, natural spawners, number of adults used for hatchery broodstock, and associated pHOS values as restoration moves from the Preservation Phase through incremental stages of the Recolonization and Local Adaptation phases. Restoration moves from the Local Adaptation phase to the Viable Natural Population Phase once all of the triggers, including the abundance level of 10,000 adults, have been met.

program to meet these goals during the early stages of restoration. Thus, we recommend not setting pHOS or PNI goals for the Preservation Phase.

This recommendation is based on three factors: the current stock status, current abundance of hatchery fish and limited marking of the current hatchery program. Chinook salmon in the Elwha River have largely been maintained through the hatchery program since the 1930s and current hatchery returns far exceed natural origin returns. For example, the current escapement goal is approximately 1,700 hatchery and 1,000 naturally spawning adult Chinook salmon. This results in a pHOS value of 0.85 assuming half the naturally spawning fish were hatchery origin (would be 0.63 if none of the naturally spawning fish were of hatchery origin). This is likely the case as recent otolith data indicate that a considerable number of hatchery origin Chinook spawn naturally each year (e.g., Duda et al. 2011a). Further, the data suggests that the productivity of natural spawning adults does not replace the natural spawners (Zimmerman, WDFW, unpublished data). This situation will likely continue through the early stages of restoration since the hatchery is expected to be used to preserve the stock during the period of high turbidity associated with dam removal. This high turbidity level has resulted in the NMFS establishing egg-take goals at the current levels (3.9 million green eggs – to produce 2.5 million sub-yearlings and 0.4 million yearlings) during the high turbidity period to ensure the stock is preserved (NMFS 2006).

Our ability to manage this stock for pHOS and PNI is also limited by the fact that only a small proportion of the hatchery production is currently marked with a Coded Wire Tag (CWT) and/or an adipose fin clip. Elwha Chinook salmon are not externally marked as a conservation measure. This stock has historically not met escapement goals and therefore has not been externally marked to limit harvest in mark-selective-fisheries. Externally visible or otherwise readable marks (i.e., CWT, adipose fin clip, parentage-based tagging) that can be used to identify the origin of live fish as either hatchery or natural origin fish are required to manage pHOS and hatchery PNI values in the Elwha River. All Elwha Chinook salmon have thermally marked otoliths, but in order to read otoliths the fish has to be sacrificed (or otoliths are taken from spawned-out carcasses). Thus, due to the poor stock status and the expense required to tag all of the hatchery production (>$325,000 estimated in 2010) and the lack of parentage-based tagging (and associated cost (>$100,000/yr), we recommend not employing pHOS and PNI goals during the Preservation Phase. Parentage-based tagging at the hatchery should be explored to allow improved monitoring of pHOS and PNI in the future. However, , it is unlikely that escapement of Chinook salmon in the Elwha River could be managed to allow only natural origin fish to spawn naturally. We recommend that hatchery management be altered once restoration progresses to the Recolonization Phase to begin moving this stock toward the goals stated by the HSRG (HSRG 2009; HSRG 2012). These recommendations include reducing hatchery production as the stock begins to recover (see 4.2.2.2 below for details) to reduce hatchery influences. In addition, hatchery produced Chinook salmon could be marked using an adipose fin clip once the stock has recovered sufficiently. The ultimate goal is to have a fully natural spawning population with a pHOS of 0.

During the Recolonization and Local Adaptation Phases, the goal is to begin moving towards the ultimate goal of a population completely composed of natural spawning adults (i.e., pHOS = 0). pHOS goals during the Recolonization and Local Adaptation Phases could be obtained by significantly altering hatchery management compared to the Preservation Phase and/or through selective harvest. Hatchery production could be systematically reduced to zero during the Recolonization and Local Adaptation Phases. This could be completed by reducing the number of adults used in the hatchery broodstock proportional to overall increases in natural spawners during the previous year's return.

We recommend reducing hatchery production from 1,700 to 500 adult Chinook during the Recolonization Phase and from 500 to 0 Chinook during the Local Adaptation Phase. The goal for naturally spawning Chinook salmon during these two restoration phases is an increase from 1,000 to 5,000 and 5,000 to 10,000 during the Recolonization and Local Adaptation Phases, respectively. We propose that hatchery Chinook production would be reduced by 10% of the difference between the start and end goals of each restoration phase for every 10% increase in the difference between the start and end goal for natural spawning abundance (Figure 4). Thus, an increase from 1,000 to 1,400 naturally spawning Chinook (10% of (5,000-1,000) would result in decreasing hatchery production from 1,700 fish to 1,580 fish (10% of (1,700-500). This would result in the hatchery production goals and naturally spawning abundance goals identified for the Chinook abundance triggers. This would also result in meeting the pHOS goals of 0.05 and 0 for the end of the Recolonization and Local Adaptation phases, respectively.

Selective fishing techniques are another important tool to manage pHOS on the spawning grounds and maintain a higher proportion of natural-origin spawners in the river system. HSRG (2012) states marking of hatchery-origin fish combined with some form of selective harvest is essential for broodstock and natural population management. This suite of hatchery and harvest tools for managing pHOS and PNI allows for optimum use of all hatchery-origin fish. This technique (i.e., combination of hatchery and harvest adult management tools) has been proposed for other Chinook salmon enhancement programs in the Interior Columbia River Basin to assist enhancement programs in achieving PNI for the basin while aiding in the survival and recovery of listed Chinook salmon populations. The usefulness of this tool for managing pHOS in the Elwha River is currently limited since only a small proportion of the fish are currently externally marked to protect this critically depressed stock from being harvested in mixed stock fisheries. However, if funding was available, marking could occur to allow selective harvest on this stock to assist with managing pHOS.

4.2.1.3 Productivity

Productivity indicators recommended for monitoring include freshwater productivity (number of juvenile migrants per female spawner) and overall productivity (number of recruits per spawner). It is further recommended that these productivity indicators be monitored for pre-harvest levels, as well as the number of spawners for hatchery and naturally spawning fish combined and naturally spawning fish only to help identify where losses of productivity are

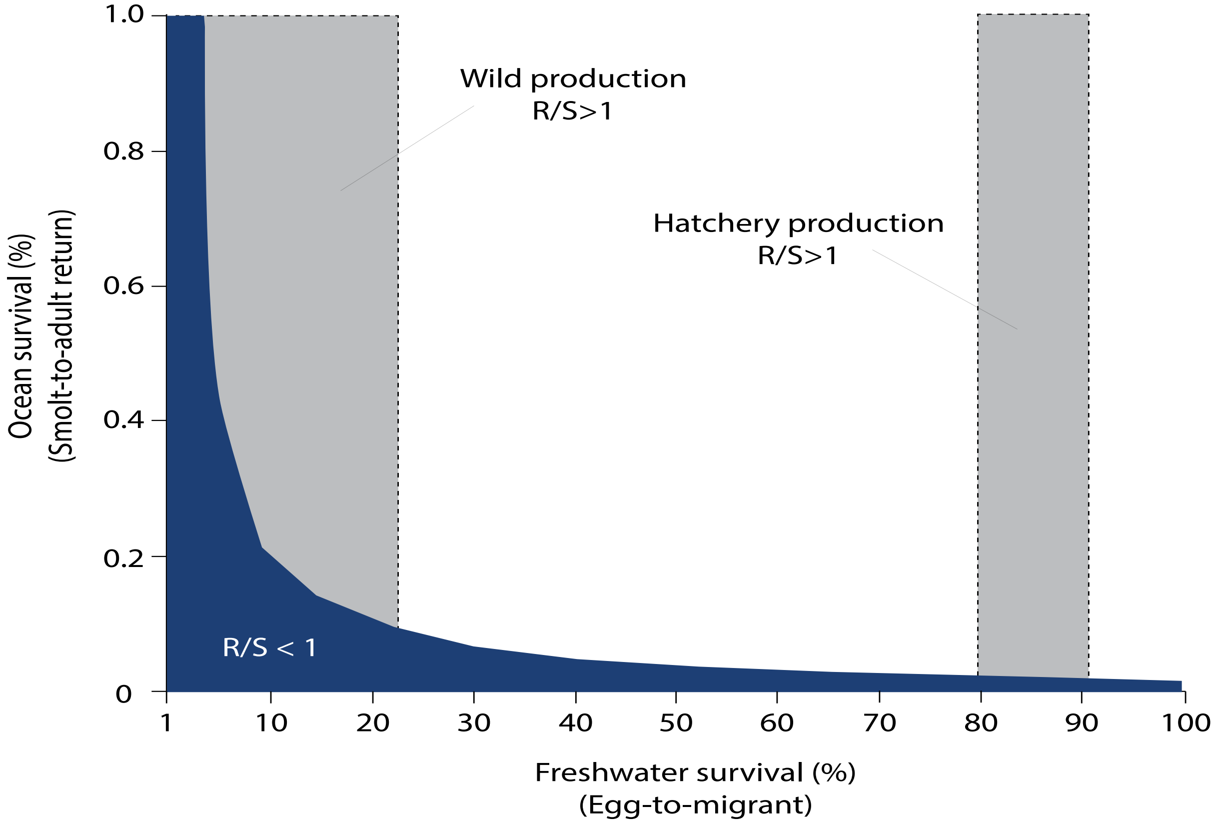


Figure 5. Conceptual graph showing combinations of freshwater and ocean survival contributing to overall stock productivity (recruits per spawner = R/S). Productivity levels required for replacement are indicated by the solid curve. Values above the curve (in gray) will result in an increasing population and those below the curve (in blue) will result in decreasing population. Gray portions of the graph delineate the range of freshwater survival for Puget Sound Chinook in wild and hatchery rearing environments. Calculations assume a fecundity of 4,650 eggs per female, which is an average value for Elwha River Chinook salmon (S. Williams, WDFW, personal communication).

occurring. Overall productivity is the product of the initial stock and survival through multiple life stages. For Pacific salmon, the most obvious partition of life stages occur between the freshwater and ocean rearing environments (Figure 5). Annual survival in any life stage can vary by at least an order of magnitude (Pearcy 1992) and the combination of all life stages over time determines trends in abundance. Hatchery production is an artificial means of inflating freshwater survival and therefore requires a lower minimum ocean survival for replacement of the parent brood. In Puget Sound, egg-to-migrant survival of natural Chinook salmon ranges from 2 to 21% (Kinsel et al. 2008; Topping et al, 2008; Kiyohara and Zimmerman 2012) compared to 80-90% egg-to-migrant survival for sub-yearling hatchery production (J. Dixon, WDFW, personal communication). As a result, ocean survival required for a viable natural spawning population is substantially higher than that required for self-sustaining hatchery spawners (Figure 5).

Between 2005 and 2011, freshwater productivity of Chinook salmon spawning naturally in the Elwha River averaged 218 (±189, or 1 standard deviation) juveniles/female. Freshwater productivity calculations were based on outmigrant estimates from the Elwha smolt trap (M. McHenry, LEKT, personal communication) and the number of females spawning naturally (http://wdfw.wa.gov/mapping/salmonscape/). The average freshwater productivity of the Elwha River during this period was comparable to other Puget Sound populations (Table 5) with similar hydrologic regimes (Beechie et al. 2006), although it was just half that of the Skagit River Chinook salmon populations (smolt trap estimates composite of all six populations). The data were highly variable, with several years of very poor productivity during the period evaluated. Unless survival in the upper Elwha basin can compensate for lower river (i.e., below the dams) and estuarine conditions, freshwater productivity is not

Table 5. Freshwater productivity (juvenile outmigrant/female spawner) estimated for Puget Sound Chinook salmon, 2005-2010 outmigration (Nisqually 2009 and 2010 only). Hydrologic regimes reflecting dominant flow patterns are Rainfall (R), Transitional (T), and Snowmelt (S) from Beechie et al. (2006).

Population	Hydrologic Regime	Ave.	Min	Max
Elwha	T	218 (189)	48	547
Dungeness	T	245 (116)	109	412
Skagit	T/S	522 (220)	269	784
Nisqually	R	131 (7.3)	126	136
Green	R	119 (79)	40	255
Cedar	R	346 (194)	181	699
Big Bear Cr.	R	187 (147)	46	494

Data sources: Juvenile smolt estimates from WDFW (M. Zimmerman) except for the Elwha R. (M. McHenry, LEKT). Number of female spawners estimated from redd survey data provided by WDFW

expected to undergo major increases throughout the restoration period. However, if decreased freshwater productivity is observed in the early years of restoration, this might cause concern for the suitability of spawning or early rearing habitat for natural production. Therefore, a performance indicator level for freshwater productivity must be maintained or exceeded in order to ensure that freshwater survival rates are high enough to support a viable population. Based on these values, we have selected a productivity trigger value of 200 juveniles per female for each of the restoration phases. This level of freshwater productivity would require an ocean survival rate of 1.56% to replace the parent spawners, assuming an ocean harvest of 36% and a 50:50 sex ratio of outmigrating smolts: 200 smolts per female* 0.5 female smolts per outmigrating smolt * 1.56%*(1-36%) = 1.

The measure of overall productivity (R/S, where R = number of recruits and S = number of spawners) should be interpreted by recruitment stage. For example, an R/S value of 1.1 to the spawning stage means the population has increased slightly from its parent brood. In comparison, an R/S value of 1.1 to the pre-ocean fishing stage on a population that is harvested at a 30% exploitation rate will result in a spawning recruitment of 0.77, meaning that the population has decreased from its parent brood. Between 2000 and 2008, exploitation rates on Elwha River Chinook salmon have averaged 36%, with 90% of the exploitation occurring in waters off British Columbia and Alaska (Table 6). Interception of Elwha Chinook salmon in the Bering Sea Aleutian Islands (BSAI) and Gulf of Alaska (GOA) groundfish fisheries were considered minimal since no Puget

Table 6. Exploitation rates of Elwha River Chinook salmon by region, 1990 to 2008. Exploitation rates are based on run reconstructions using the backwards Fishery Regulation Assessment Model (FRAM). Fishery regions are southeast Alaska (seAK), Canada (CAN), and southern United States (sU.S.).

Year	seAK	CAN	sU.S.	Total
1990	0.087	0.303	0.291	0.681
1991	0.059	0.228	0.219	0.506
1992	0.055	0.339	0.210	0.604
1993	0.060	0.220	0.173	0.453
1994	0.108	0.344	0.149	0.602
1995	0.092	0.213	0.118	0.423
1996	0.194	0.115	0.183	0.492
1997	0.123	0.142	0.131	0.396
1998	0.070	0.106	0.042	0.218
1999	0.088	0.112	0.031	0.231
2000	0.065	0.093	0.018	0.176
2001	0.062	0.097	0.033	0.192
2002	0.088	0.176	0.049	0.313
2003	0.098	0.205	0.056	0.360
2004	0.120	0.185	0.039	0.344
2005	0.155	0.206	0.027	0.388
2006	0.154	0.138	0.034	0.326
2007	0.208	0.170	0.046	0.423
2008	0.098	0.168	0.040	0.305

Sound Chinook CWTs have been observed in this fishery (NMFS 2008) and few have been observed in the GOA fishery (Balsinger 2013). This exploitation rate, which represents a noticeable proportion of the fish returning to the river, means that fisheries in waters off British Columbia and Alaska are an important portion of the productivity indicator for Elwha River Chinook salmon. Furthermore, the pre-fishing productivity indicator will help to determine terminal exploitation rates on Elwha River Chinook salmon as restoration progresses. Therefore, productivity should be measured as two indicators – pre-fishing recruit per spawner (R^o/S, Equation 2) and spawner-to-spawner (R^s/S, Equation 3 or Equation 4). Depending on the phase of restoration, this indicator may be calculated for the integrated hatchery and natural spawners combined (Equation 3 (Integrated)) or for the natural spawners only (Equation 4 (Natural)). Productivity for a given brood year should be calculated based on recruits to each age class (a). These recruits include harvest (R^{Hvst}) and spawners (R^S):

Equation 2

$$R^o / S = \frac{\sum_{a=2}^{a=6} (R_a^{Hvst} + R_a^{S})}{S}$$

R^o = Numbers of pre-fishing (ocean) recruits

S = Number of parent spawners

a = Age class

R^{Hvst} = Recruits intercepted in fisheries

R^S = Recruits that escape fisheries and return to the river to spawn.

Equation 3 (Integrated)

$$R^S / S = \frac{\sum_{a=2}^{a=6} (R_a^{HS} + R_a^{NS})}{S^H + S^N}$$

R^S = Recruits that escape fisheries and return to the river to spawn (hatchery and natural combined)

S = Number of parent spawners (hatchery and natural)

a = Age class

R^{HS} = Number of hatchery origin fish that escape fisheries and return to the river or hatchery to spawn.

R^{NS} = Number of natural spawners that escape fisheries and return to the river (or hatchery) to spawn.

S^H = Number of parent spawners (hatchery broodstock)

S^N = Number of parent spawners (natural spawning).

Equation 4 (Natural)

$$R^s / S = \frac{\sum_{a=2}^{a=6} R_a^{NS}}{S^N}$$

R^S = Recruits that escape fisheries and return to the river to spawn (natural only)

S = Number of parent spawners (natural only)

a = Age class

R^{NS} = Number of natural spawners that escape fisheries and return to the river (or hatchery) to spawn.

S^N = Number of parent spawners (natural spawning).

In order for Elwha Chinook salmon to achieve the restoration goals, spawner-to-spawner productivity (the number of returning spawners in each age class divided by the number of parent spawners) must exceed replacement ($R^s/S > 1$). Higher productivity will allow the abundance performance triggers to be reached more quickly and will provide more harvestable Chinook in the future. For the purpose of a performance trigger, we have selected a conservative value of $R^s/S > 1$ for the spawner-to-spawner productivity trigger, ensuring that the population is progressing towards the restoration goals. However, both freshwater and ocean survival are estimated following these monitoring guidelines to help identify causal mechanisms if the trigger for spawner-to-spawner productivity is not being met. The pre-fishing productivity trigger value of $R^o/S > 1.56$ (Figure 3) was selected to ensure that the recruitment of Elwha Chinook salmon abundance will increase on the spawning grounds while sustaining the current average 36% exploitation rate occurring primarily in ocean fisheries. This is assumed for all the productivity measures impacted by harvest. Harvest exogenous variables should be monitored to determine if this assumption is being met. If the exploitation rate assumption is not met, requests will have to be made to reduce harvest (through the Pacific Salmon Commission process) or the freshwater productivity triggers will have to be modified to account for increased harvest.

During the Preservation Phase, the management objective is to preserve the existing genetic and life history diversity. Hatchery production during this phase will be managed as an integrated broodstock. However, due to the lack of external marks it will not be possible to manage this in real-time and will require post-spawning assessments to determine if all the goals of an integrated broodstock have been met (WDFW 2012). All returning spawners (hatchery and natural origin) will be the earliest colonizers of the newly available habitat. Hatchery and natural origin spawners are expected to successfully produce recruits during this phase, an assumption supported by a recent study of Chinook salmon colonization above Landsburg Dam in the Cedar River, Washington (Anderson 2011). However, natural spawning success will likely be much lower than historical levels due to the high turbidity in the system and unstable river bed in and below the former reservoir reaches during and immediately following dam removal. Therefore, the productivity of natural origin stock and the integrated hatchery-natural stock should be tracked during this phase. Given the management objectives, the trigger for the Preservation Phase should be a spawner-to-spawner productivity of the integrated hatchery-natural stock greater than replacement ($R^s/S > 1$). In addition, average productivity of the integrated hatchery-natural stock pre-fishing should be greater than $R^o/S > 1.56$ to account for the average exploitation rate of 36%.

During the Recolonization Phase, the management objective is to ensure that fish are accessing habitats above the former dam sites, successfully spawning, and producing smolts from these recolonized areas of the watershed. Hatchery production should be reduced as escapement increases through this phase to relatively low production levels at the end of the Recolonization phase. The productivity of the natural stock and the integrated hatchery-natural stock should be tracked during this phase. Given the management objectives, trigger values for the Recolonization Phase should be an average productivity of natural stock to the river greater than replacement ($R^s/S > 1$) and an average productivity of natural stock pre-fishing greater than the rate ($R^o/S > 1.56$) that accounts for an average exploitation of 36%.

During the Local Adaptation Phase, the management objective is to maintain or increase life history diversity through local adaptation. The hatchery-natural composition of hatchery broodstock and natural spawners should be actively managed by reducing hatchery production to zero at the close of this restoration phase, thereby removing hatchery influence from the population (see Managing for pHOS section above). The productivity of the integrated stock (hatchery-natural combined) will decrease as the hatchery influence is removed from the population. This result is expected due to the differences between hatchery and natural freshwater productivity (Figure 5) and should facilitate local adaptation to the Elwha River. The trigger for the Local Adaptation Phase should be an average productivity of natural spawners to the river that exceeds replacement ($R^s/S > 1$) and an average productivity of natural stock pre-fishing greater than the rate ($R^o/S > 1.56$) that accounts for an average exploitation of 36%.

During the Viable Natural Population Phase, the management objective is to ensure that viable natural and exploitable population levels that do not require hatchery production are maintained. No hatchery production is planned for this phase. We expect that pre-terminal and terminal harvest will be added as a management objective during this phase and the overall exploitation rate is expected to in-

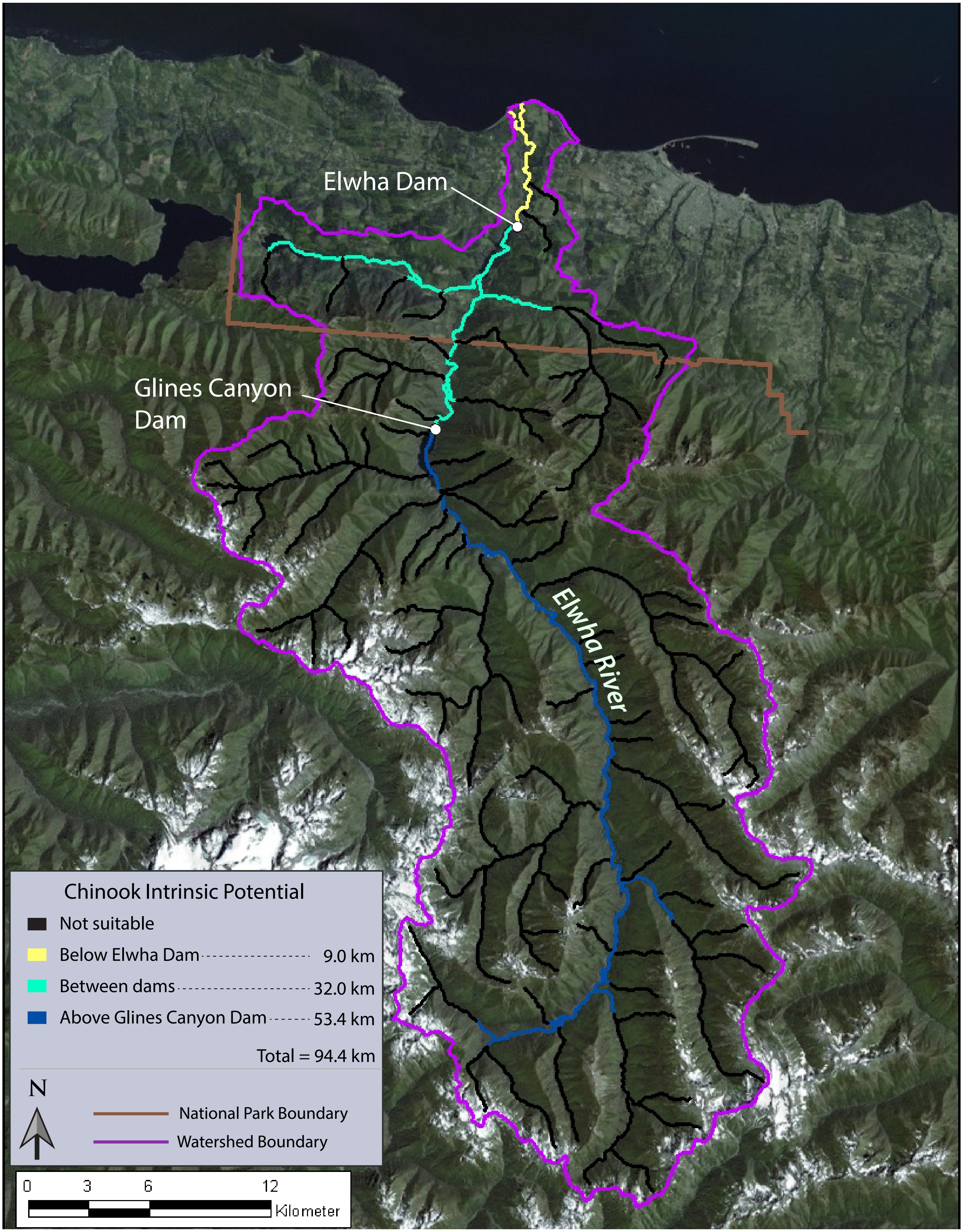


Figure 6. Intrinsic potential of Chinook salmon distribution in the Elwha River (modified from Pess et al. 2008). The colors signify sections of the Elwha River that would support Chinook salmon, whereas those river and tributary sections shown in black are either unsuitable or inaccessible (i.e., above a migration barrier).

crease. The average productivity of natural spawners to the river should be at replacement ($R^s/S \sim 1$). The harvest rate will be determined through co-manager negotiations based on other fishery objectives, but exploitation rates should reflect the average productivity of the population. The current exploitation rate cap for Southern U.S. fisheries on Elwha Chinook salmon is 10% (sensu PSIT and WDFW 2010). A $R^o/S \sim 1.85$ for natural Chinook salmon is needed to support a viable natural population with an exploitation rate of 46% (36% ocean plus added terminal). Chinook productivity observed elsewhere suggests that this rate is within the realm of realistic expectations. For example, one study of 25 Chinook salmon populations in the Pacific Northwest determined that average pre-fishing productivity (R^o/S) ranged between 1.6 and 6.3, with individual brood year values as low as 0.1 and as high as 27.3 (calculated from Liermann et al. 2010). During the Viable Natural Population Phase, exploitation rates may need to be adjusted once the productivity of the population is better understood, to ensure the population stays within the Viable Natural Population Phase.

4.2.1.4 Spatial Distribution

Trigger values were developed for spatial extent and barriers. Trigger values were developed for the extent of spatial distribution of Chinook salmon in the Elwha River for each of the four different restoration phases (Figure 3). Chinook salmon distribution could be evaluated based on the extent of potential intrinsic habitat used by spawning adults (Pess et al. 2008; NOAA Fisheries, unpublished data) and an assessment of residual migration barriers at the former dam sites and the newly exposed reservoir reaches. Although it would be preferable to use historical distribution, only anecdotal information exists regarding Chinook salmon and steelhead distribution in the watershed prior to dam construction. The spatial distribution performance indicators refer to the spatial structure of Chinook salmon and steelhead over time and emphasize spawning distribution. Although the historical distribution of Chinook salmon and steelhead within the Elwha River has not been described, it is anticipated that the species will have access to approximately 56 km of mainstem habitat and approximately an additional 40 km of tributary habitats (DOI 1996a; Pess et al. 2008).

The potential extent of spatial distribution triggers are based on a percentage of the intrinsic potential habitat used by adult Chinook salmon as developed by Pess et al. (2008) and NOAA Fisheries (unpublished data) (Figure 6). The intrinsic potential was derived from a combination of topographic data, potential migratory barriers, habitat use data from below the dams, and salmonid habitat preferences. Channel slope, channel width, and valley form were derived from topographic data using hydrologic and terrain modeling (Davies et al. 2007; Jenness 2006). Migratory barrier data was obtained from previous habitat assessments completed by Hosey and Associates (1990) and Brenkman et al. (2008b). Chinook salmon spawning habitat preferences (Groot and Margolis 1991; Montgomery et al. 1999) based on channel slope and bankfull widths were used to determine the likelihood that Chinook would spawn in different reaches available to them throughout the watershed.

Factors influencing colonization of newly accessible habitats were also considered for developing spatial extent triggers for each phase of restoration. Colonization of new habitats can be influenced by several factors including barriers, distance from the source population, population size, stray rates, and turbidity levels (Pess et al. 2008). Dam removal will remove the known artificial barriers to colonization; however, the rate of removal has varied for the two dams. Elwha Dam was completely removed by spring of 2012 and fish passage was observed during the spring and summer of 2012. However, Glines Canyon Dam likely will not be completely removed before the summer of 2014 (Brian Winter, Olympic National Park, personal communication). Thus, the removal of these two dams will influence the use of potential intrinsic habitat, since the area between the dams was available for colonization for the 2012 broodyear, whereas the areas above Glines Canyon Dam will not be accessible until the summer of 2014. This will increase the likelihood of the middle river being colonized before areas above Glines Canyon, especially given the location and size of the source population.

Salmon are expected to colonize the area above the dams relatively quickly, due to the close proximity of the source population to the available habitat (i.e., within the same watershed). However, the rate of colonization will likely vary throughout the watershed since the distance from and size of the source population will vary (Pess et al. 2008). The

Chinook salmon population available to colonize the newly accessible habitat is expected to be present in low numbers initially, but then should increase in numbers throughout the restoration process. This is due to the fact that a majority of returning adults will be removed from the river as broodstock, with their progeny reared under hatchery conditions to protect them from high turbidity levels resulting from dam removal, an activity mandated by the NMFS BO (NMFS 2006). As turbidity levels decrease and restoration progresses through the phases described in this document, proportionally fewer adults will be removed for hatchery production allowing more adults (hatchery and naturally produced) to colonize the newly accessible habitats. Thus, colonization of areas relatively close to the source population that has been maintained below the dams are expected to occur first and areas further from this source population colonized later. This colonization pattern will influence the rate of change in fish distribution during recovery.

Increased turbidity can result in increased straying, which can influence colonization of new habitats (Leider 1989). Turbidity levels in the Elwha River below Rica Canyon, located just upstream of Glines Canyon Dam will be highest just before Glines Canyon Dam is removed, with continued spikes occurring for 3- 5 years following the initiation of dam removal (DOI 1996b, Konrad 2009). The timing of dam removal (i.e., Elwha removed prior to Glines Canyon) will likely result in Little River and Indian Creek, two tributaries in the middle Elwha, being colonized first. These tributaries will not be influenced by dam removal and have relatively low turbidity water, which may increase the likelihood of these areas being colonized by adult Chinook salmon. The timing of spikes in elevated turbidities will influence Chinook distribution. If the spikes occur during migration, Chinook may move into the Little River and Indian Creek to avoid the turbidity. If not, fish may move through the Lake Mills area into upstream habitat.

There is potential for residual barriers (e.g., dam removal debris, long riffles) to occur at the former dam sites or in the reaches that develop in the former reservoirs. These potential barriers may significantly influence the recolonization of the upper watershed. Triggers to assess barriers were established for the four restoration phases based on the information described above that influence colonization. Based on this, barrier triggers for the four restoration phases were as follows:

- **Preservation** – no artificial barriers exist below Elwha Dam.
- **Recolonization** – no artificial barriers exist at the former Elwha Dam site, the Lake Aldwell reach, the Glines Canyon Dam site, or the Lake Mills reach.
- **Local Adaptation** – no artificial barriers exist within the intrinsic potential habitat.
- **Viable Natural Population** – no artificial barriers exist within the intrinsic potential habitat.

4.2.1.5 Diversity

Life history is the diversity indicator recommended for monitoring (Figure 3). Life history diversity should be represented by adult entry timing and by juvenile rearing strategies. Life history of Chinook salmon is notoriously diverse at both the juvenile and adult stage (Healey 1998). At the adult stage, Chinook salmon typically enter Puget Sound watersheds as early as June (on the spring snow melts) or as late as August or September (during summer low flows). Historically, Chinook salmon in the Elwha River are reported to have had both an early (spring) and late (summer/fall) component to river entry. At the juvenile stage, Chinook salmon typically emigrate from Puget Sound watersheds between January and August (Topping et al. 2008; Kinsel et al. 2008). A typical outmigration for Puget Sound Chinook has at least two sub-yearling peaks and one yearling peak, representing different durations of freshwater rearing (Figure 7). Yearling outmigrants are a small component of the observed freshwater production in many Puget Sound Chinook populations (M. Zimmerman, WDFW, unpublished data) and this is true in the Elwha River (Duda et al. 2011a). Additional juvenile diversity associated with estuary rearing (Beamer et al. 2005a; Campbell 2010; Volk et al. 2011) may be expected based on the quality and quantity of estuary habitat, both of which should improve over time in the Elwha River. Although adult entry timing of Chinook salmon is often linked to juvenile rearing strategies (spring ~ stream-type, summer/fall ~ ocean-type, Healey 1998), recent studies in Puget Sound have demonstrated that the correlation between adult and juvenile life histories may be more variable than previously

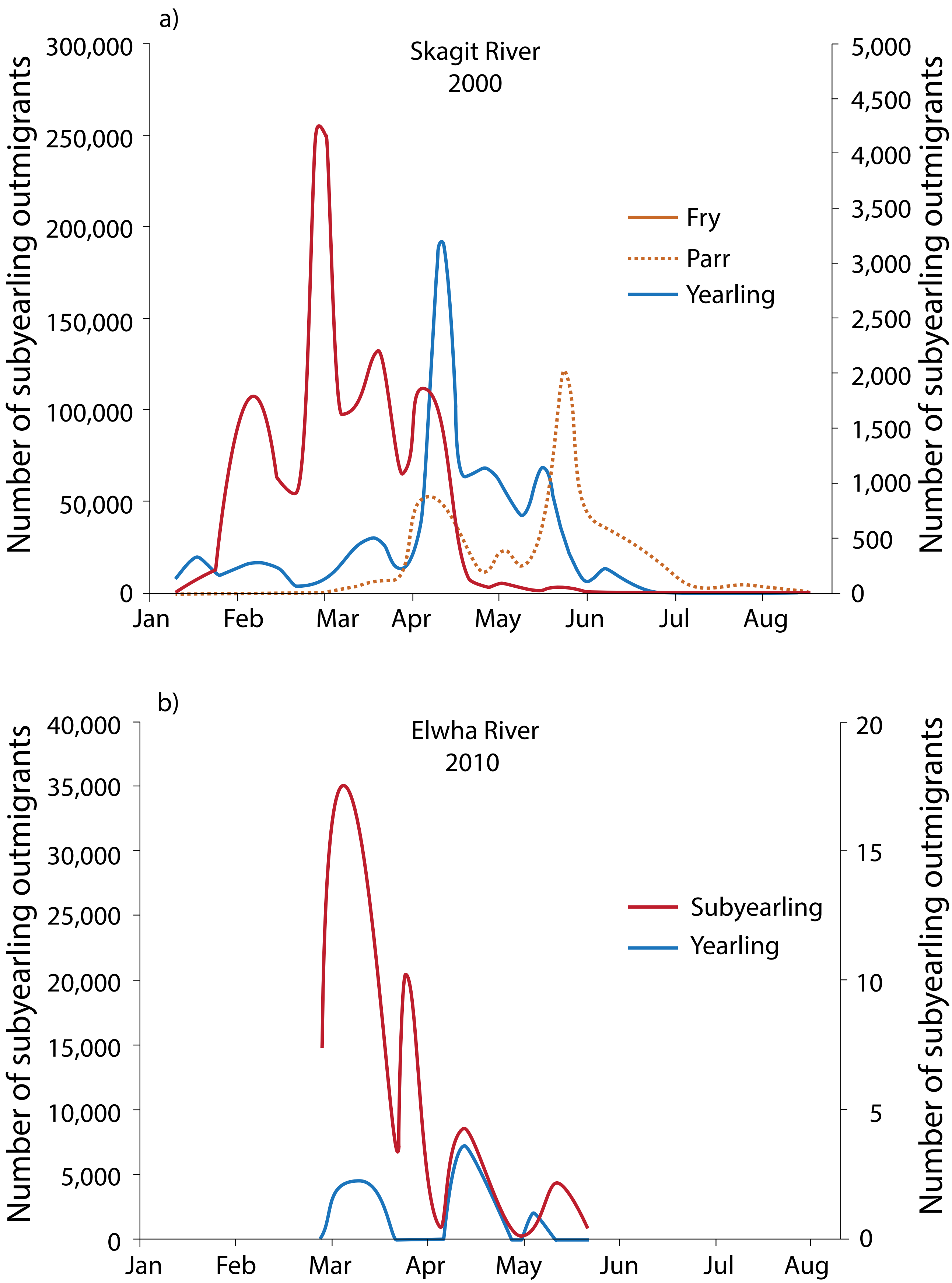


Figure 7. Life history diversity of Chinook salmon outmigrants in the (a) Skagit River and (b) Elwha River. Number of subyearling and yearling outmigrants were estimated from smolt trap catches and efficiency trials in each watershed. Subyearling migrants in the Skagit River are identified by two freshwater rearing strategies (fry <45-mm FL, parr > 45-mm FL). Yearling outmigrants in the Elwha are reported as catch because the trap is not calibrated for yearlings.

Figure 8. Performance indicators (rows) used to evaluate whether Elwha River native winter steelhead populations have achieved the objectives for each restoration phase (columns). The adaptive management approach evaluates performance indicators for each phase. Movement to the next restoration phase occurs only after all trigger levels for the current phase have been achieved. Each trigger is re-evaluated after four years if it has not been met to determine if it is accurate or needs to be adjusted.

Species: Steelhead
Oncorhynchus mykiss

		Preservation	Recolonization	Local Adaptation	Viable Natural Population
GOALS		*Prevent extinction and preserve the existing genetic and life history diversity of native salmonid populations until fish passage is restored and water turbidity is determined to be non-lethal to fish in the river*	*Salmonids are continually accessing habitats above the old dam sites with some fish successfully spawning and producing smolts*	*Maintain or increase life history diversity of natural-spawning populations through local adaptation to the Elwha River ecosystem until minimum levels of spawner abundance, productivity, and distribution are met*	*Ensure that self-sustaining and exploitable population levels continue once desired values for all VSP and habitat parameters have been met and hatchery programs are no longer needed for protection, recovery, or exploitation*
Abundance (Weir, Sonar, foot and boat surveys, aerial surveys)	Natural Spawners	<196	>196 or <969	>969 or <2,619	>2,619
	Spawner Escapement duration	4 yrs	4 yrs	4 yrs	4 yrs
Managing for pHOS (Otoliths, CWT, Scale samples)	pNOS (natural-origin spawner)	*	0.90	1.0	1.0
	pHOS (proportion hatchery-origin spawner)	*	0.10	0	0
Productivity (Weir, Sonar, Spawner Surveys, Smolt trap, otoliths, cwt, harvest)	#juvenile migrants/female	75	75	75	75
	# Pre-fishing recruits/spawner (h+n)	>1.0	> 1.0	> 1.0	> 1.0
	#Spawners/spawner (h+n)	>1.0	> 1.0	> 1.0	> 1.0
	#Pre-fishing recruits/spawner (n)	*	*	*	*
	#Spawners/spawner (n)	*	>1.0	>1.0	~1.0
	Productivity trend	4 yrs	4 yrs	4 yrs	4 yrs
Spatial Distribution (Spawner Surveys, Radio-telemetry, Snorkel Surveys)	Extent	Above Elwha Dam; 9% intrinsic poetntial	Above Elwha Dam; 37% of Intrinsic Potential	Above Glines Canyon Dam; 74% of Intrinsic Potential	100% of Intrinsic Potential
	Barriers	No migration barriers exist below Elwha Dam	No 'artificial' migration barriers exist in Aldwell reach	No 'artificial' migration barriers exist in Mills reach	No 'artificial' barriers exist within Intrinsic Potential
Diversity (Sonar, spawner surveys)	Entry timing variance	n/a - data collection	0.5 days/yr	0.5 days/yr	0.5 days/yr
	Entry timing	Fish returning in February	Fish returning in January	Fish returning in December	No change from previous

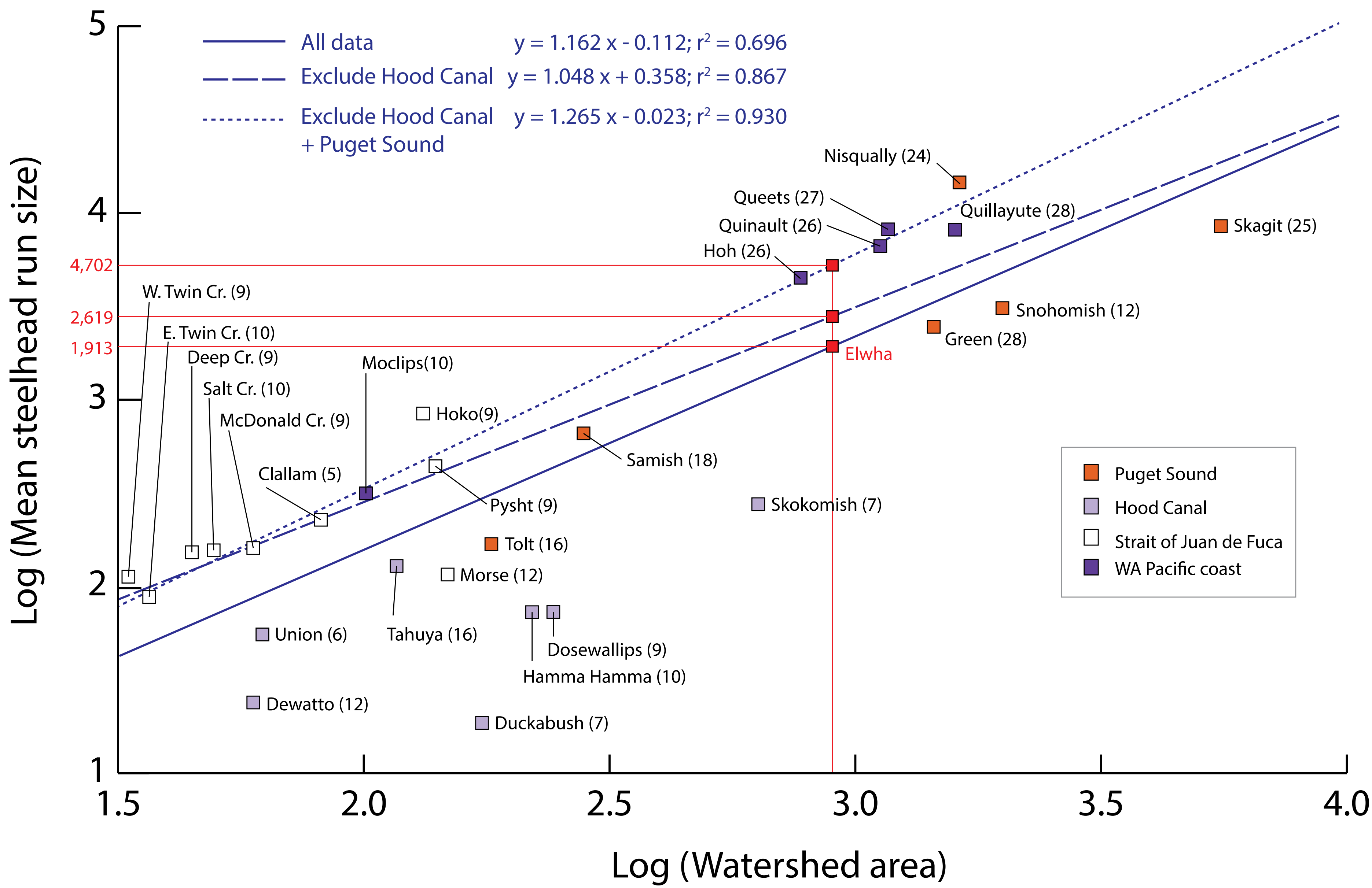
thought (Beamer et al. 2005b). For this reason, we have not linked adult entry timing and juvenile rearing when developing triggers for the life history performance indicator.

There is no clear precedent, to our knowledge, for predicting a rate at which life history strategies are expected to emerge or re-emerge. However, we expect that diversity will increase over time and that locally adapted life histories will emerge in response to newly available freshwater habitat and to replenished estuary habitat. This process is expected to accelerate during the Local Adaptation Phase when the influence of natural spawners increases and hatchery influence is reduced. Given the diversity of life histories observed for Chinook salmon in general, there are multiple potential parameters that may change over the restoration process. We have selected two components of life history diversity – proportion of stream-type Chinook (yearling migrants returning to spawn) and variation in adult entry timing – as performance indicator triggers for the Local Adaptation and Viable Natural Population Phase. For the Local Adaptation Phase, a positive trend (i.e., increased life history diversity and variation in adult entry timing) for both indicators are the proposed triggers. For the Viable Natural Population Phase, we expect that the population will stabilize with well-de-

Figure 9. Table graphic showing trends (sparklines of annual run size with colored dots corresponding to maximum and minimum run size) and average (max, min) run sizes for western Washington steelhead populations from 1977 - 2004. For the sparklines, the y-axis (run size) is scaled to a maximum value for each geographic basin (Puget Sound, Hood Canal, Strait of Juan de Fuca, and the Pacific coast), while the x-axis (time) is the same for all sparklines. Data from Scott and Gill (2008).

Basin	Watershed	Ave. Pop. Size	Max.	Min.	Run Size (1977–2004)
Puget Sound	Green	2458	3500	1368	
Puget Sound	Nisqually	3093	6870	258	
Puget Sound	Samish	660	1104	139	
Puget Sound	Skagit	8504	15862	4123	
Puget Sound	Snohomish	8140	11009	5464	
Puget Sound	Tolt	169	366	45	
Hood Canal	Dewatto	24	40	11	
Hood Canal	Dosewallips	73	99	49	
Hood Canal	Duckabush	19	36	6	
Hood Canal	Hamma Hamma	73	260	7	
Hood Canal	Skokomish	276	401	137	
Hood Canal	Tahuya	129	346	53	
Hood Canal	Union	55	73	45	
Pacific Coast	Hoh	4501	5783	2539	
Pacific Coast	Moclips	315	560	140	
Pacific Coast	Queets	8167	13086	4866	
Pacific Coast	Quillayute	14570	21615	7555	
Pacific Coast	Quinault	6640	9726	3524	
Strait of Juan de Fuca	Clallam	228	289	175	
Strait of Juan de Fuca	Deep Cr.	152	211	106	
Strait of Juan de Fuca	East Twin	88	191	55	
Strait of Juan de Fuca	Hoko	844	1239	504	
Strait of Juan de Fuca	McDonald Cr.	161	308	29	
Strait of Juan de Fuca	Morse	116	186	81	
Strait of Juan de Fuca	Pyscht	440	556	361	
Strait of Juan de Fuca	Salt	156	237	73	
Strait of Juan de Fuca	West Twin	113	188	66	

Figure 10. Linear regression relationship between log_{10} mean steelhead run size (total) and log_{10} watershed area (km) for 27 western Washington watersheds, based on data from 1977 - 2004 (see figure 9). Points depict the mean run size (number of observations) and are color coded according to geographic basin (Puget Sound, Hood Canal, Strait of Juan de Fuca, and the Olympic Peninsula coast). Values in red on the y-axis have been back-calculated to a run size for each of three regressions based on watershed area of the Elwha River. Data based on Scott and Gill (2008).



fined early and late run timing and that a consistent proportion of the returning spawners each year will have resulted from yearling smolt migrants.

4.2.2 Steelhead Triggers

The trigger values for the different steelhead metrics are listed in Figure 8. The methods for developing these triggers are listed below.

4.2.2.1 Abundance

The abundance trigger for natural steelhead spawners for each restoration phase was set by first determining the potential steelhead spawning abundance in the Elwha River. This potential abundance was set as the trigger value for the Viable Natural Population Phase. We then worked backwards to the Preservation Phase based on the proportion of habitat expected to be available during the different restoration phases and expected steelhead colonization patterns following dam removal.

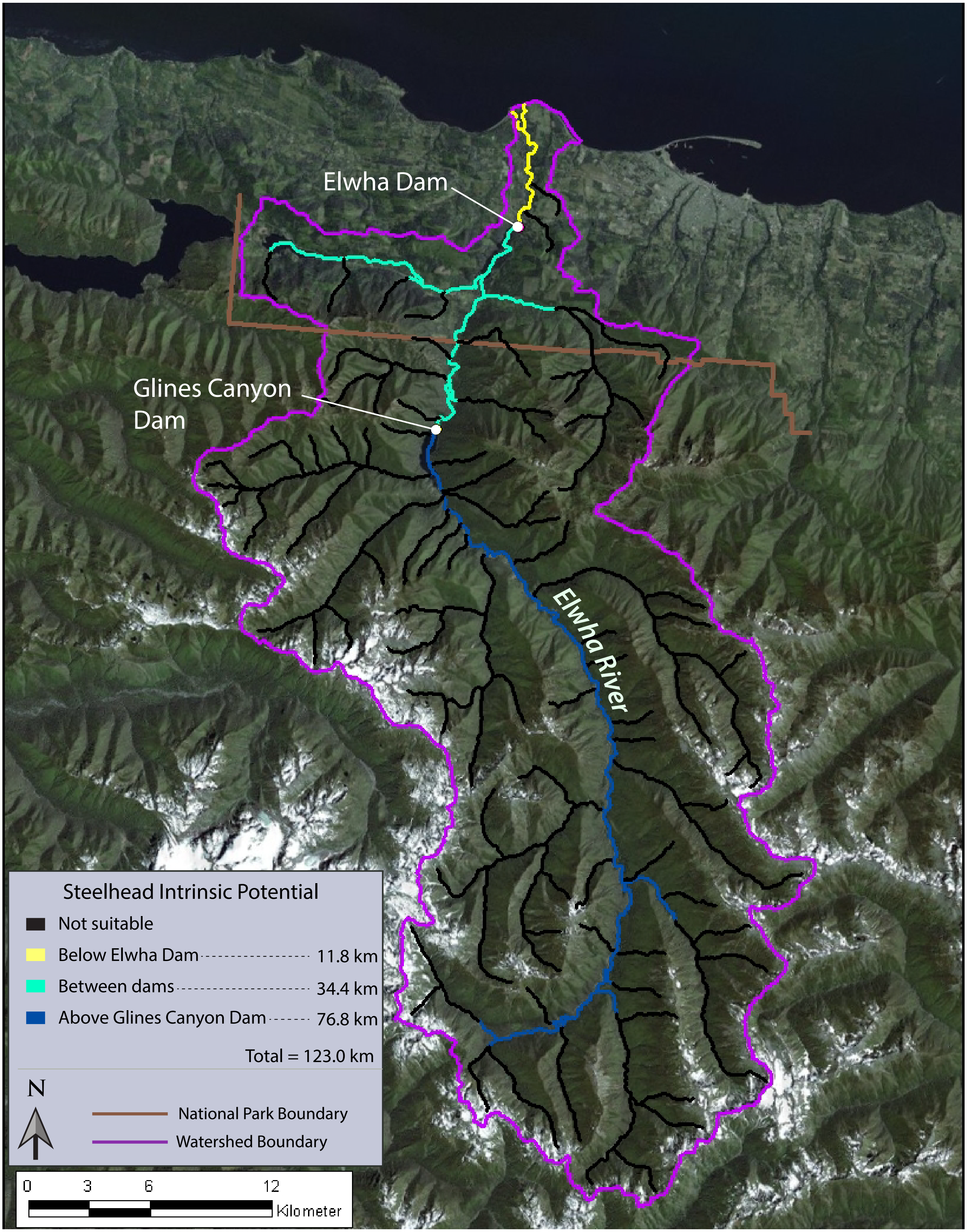
The adult native Elwha steelhead spawner abundance triggers were developed by assessing the relationship of mean adult steelhead run size against watershed area for 27 western Washington watersheds (Figure 9 and Figure 10). This was assessed using the log of both the mean adult steelhead run size and watershed area. After reviewing this relationship it became clear that the coastal and Strait of Juan de Fuca streams differed from watersheds in the Hood Canal and Puget Sound. For this reason, we assessed the relationship again after first removing the Hood Canal watersheds from the data set and then removing both the Hood Canal and Puget Sound watersheds from the data set. Removing the Hood Canal watersheds resulted in a line with a greater mean value but a similar slope. Removing both the Hood Canal and Puget Sound watersheds resulted in a line with an intermediate mean and a lesser slope. The resulting median adult steelhead abundance estimates for the Elwha were 1,913 (all data), 2,619 (minus Hood Canal), and 4,702 (minus Hood Canal and Puget Sound). We selected the intermediate value (minus Hood Canal) since the data from Hood Canal watersheds were obviously much different than the rest of the watersheds in the data set. We retained the Puget Sound data since removing both Hood Canal and Puget Sound watersheds reduced the overall data set by almost 50% and resulted in only three watersheds that were larger than the Elwha (instead of 7). This also resulted in two clumped sets of data, those for small and large watersheds, which we felt weakened the relationship. This is not unexpected since populations in larger watersheds would be impacted less by stochastic events. Thus, the steelhead abundance trigger value for the Viable Natural Population Phase was set as 2,619.

The trigger values for the remaining restoration phases were developed by multiplying the expected adult steelhead abundance in the Elwha River (as described above) by the percent of the watershed (stream length) expected to be accessible to steelhead during each phase of restoration. The length of mainstem and tributary habitat available was based on the intrinsic potential assessment summarized in Figure 11. Based on the intrinsic potential (see below for details) the amount of habitat available below the Elwha Dam site is 9 km (7.5%), between the Elwha and Glines Canyon Dam sites is 35.4 km (29.5%), and above Glines Canyon Dam is 75.4 km (62.9%). We assumed that only the area below the former Elwha dam site would be available during the Preservation Phase, which represents approximately 7.5 percent of the available habitat. Thus, the trigger value for the Preservation Phase was calculated by multiplying the overall spawning abundance estimate (2,629) by 0.075 (7.5%) to arrive at 196 natural adult steelhead. We assumed the area below Glines Canyon Dam would be available for colonization and that colonizers would access this habitat during the Recolonization Phase. This represented approximately 29.5% of the additional habitat, resulting in a total of 37% (7.5% + 29.5%) of the intrinsic potential available to steelhead during this phase. This results in an estimate of 969 natural spawners (2,619*0.37) during the Recolonization Phase. We assumed all the intrinsic potential habitat would be available during the Local Adaptation Phase and thus set the steelhead abundance trigger at full potential (2,619 natural spawners).

4.2.2.2 Managing for Proportion Hatchery Origin Spawners (pHOS)

As stated in the Chinook section above, we focus on hatchery fish spawning naturally since the ultimate goal is for no future hatchery programs once the runs have been restored. In general, the monitor-

Figure 11. Intrinsic potential of steelhead distribution in the Elwha River (modified from Pess et al. 2008). The colors signify sections of the Elwha River that would support steelhead, whereas those river and tributary sections shown in black are either unsuitable or inaccessible (i.e., above a migration barrier).



ing and adaptive management guidelines will follow the intent and specified guidelines proposed by the HSRG (HSRG 2009; HSRG 2012) for integrated hatchery programs. The HSRG recommended specific guidelines for the maintenance of the PNI and pHOS as well as when these specified guidelines would be implemented with respect to dam deconstruction.

The HSRG recommended that during the Preservation Phase, the abundance and genetic lineage of the native winter steelhead should be the primary goal in order to ensure the survival and recovery of listed steelhead due to habitat degradation during dam deconstruction (HSRG 2012). In addition, the HSRG recommended that maximizing adult returns to promote recolonization of the restored watershed during the Preservation Phase was paramount (HSRG 2012). These recommendations are based on the demographic risks being greater than potential genetic risks to the population posed by hatchery-origin fish spawning during the initial phases of restoration. Thus, although the specific guidelines for maintaining PNI and pHOS are important for later stages of restoration, no such goals are established during the initial phase because it will be more important to achieve goals associated with abundance, productivity (number of outgoing smolts), and distribution of steelhead in order to initiate overall Elwha River steelhead recovery. Once the initial phase is completed then the proceeding specified goals with respect to PNI and pHOS are pursued.

This recommendation is based on four factors: (1) the current poor status of natural Elwha steelhead, (2) current hatchery contribution to natural spawning; (3) the transition of the Lower Elwha Fish Hatchery from the early-timed (i.e., Chambers Creek steelhead) program to the late-timed native steelhead enhancement program; and (4) current monitoring tools.

Elwha River steelhead have been maintained largely through a combination of natural production and hatchery supplementation programs since the late 1950's. Despite augmentation of the early-timed stock, natural-origin returns historically have been fairly comparable to Chamber's Creek hatchery returns. For example, data from 1985-86 through 1996-97 indicate hatchery escapement averaged 309 steelhead and natural escapement averaged 333 steelhead per year (PSIT and WDFW 2010). Currently, total naturally-spawning steelhead escapement averaged 141 fish and ranged from 45 to 246 fish from 2005 through 2012 (LEKT 2012a). No data are available for the 2007-08 and 2008-09 seasons. These recent escapement estimates are uncertain due to high flows and turbidity levels from restoration efforts that have prevented implementation of spawning surveys throughout the entire steelhead return period. Despite data uncertainties, current information strongly suggests that the productivity of natural spawning adults is insufficient to support themselves (Scott and Gill 2008).

Scott and Gill (2008) estimated indices for the smolt-to-adult return (SAR) rate for winter steelhead hatchery releases in the Elwha River. The largest SAR index occurred for smolts entering the ocean in 1983 at just over 6 percent. The lowest SAR index occurred for smolts entering the ocean in 1996 at less than .05 percent. The average SAR indices have remained at low levels (under 2 percent) since 1995, where data are available. When using the winter steelhead hatchery information as a surrogate for the late-timed natural-origin population (Scott and Gill 2008), data suggests that the productivity of native hatchery spawning adults would not replace the natural spawners. This situation will likely continue or be exacerbated through the early stages of restoration unless upper watershed conditions can compensate for the lower river conditions. This uncertainty, along with the chronically low escapement, is why the hatchery will be used to preserve the late-timed native winter steelhead population during the period of high turbidities associated with dam removal.

WDFW first planted early-timed Chambers Creek steelhead in the Elwha River for recreational fishing in 1957. The Lower Elwha Klallam Tribe has conducted early-timed Chambers Creek (native to Puget Sound) hatchery steelhead releases in the river since 1977. The Lower Elwha early-timed steelhead program was initiated to provide steelhead fishing opportunity in the Elwha River, to enable exercise of tribal treaty rights, and also to serve the interests of recreational fishermen. Native steelhead production was so constrained by the presence of the dams that their populations would not support directed harvest. In November 2012, the Lower Elwha Klallam Tribe provided a letter to NMFS that they had discontinued the planting of early-timed non-native Chambers Creek hatchery steelhead in the Elwha River (Charles

2012). The Lower Elwha Klallam hatchery currently supports a late-timed native steelhead enhancement program only (i.e., captive brood program).

All hatchery steelhead have received one or a combination of the following marks for identification: (1) a thermal otolith mark (native steelhead); (2) adipose fin-clip (Chambers Creek), or (3) a coded wire tag (native captive brood steelhead progeny). Starting in release year 2015, all age-2 smolts released from the hatchery (all progeny from the native captive brood program) are expected to be adipose fin-clipped since no further (or very few returning kelts) Chambers Creek stock returns are expected. Hatchery reared broodstock should be genotyped, allowing for parentage-based tagging of both successfully returning adults and their progeny. The fact that all past Chambers Creek hatchery production is also marked with an adipose fin-clip would somewhat limit our ability to manage this stock for PNI during the Preservation Phase if so desired (which it is not). However, we expect this impact to be minimal and short-lived and should not extend into the restoration phases where management for PNI and pHOS is desired.

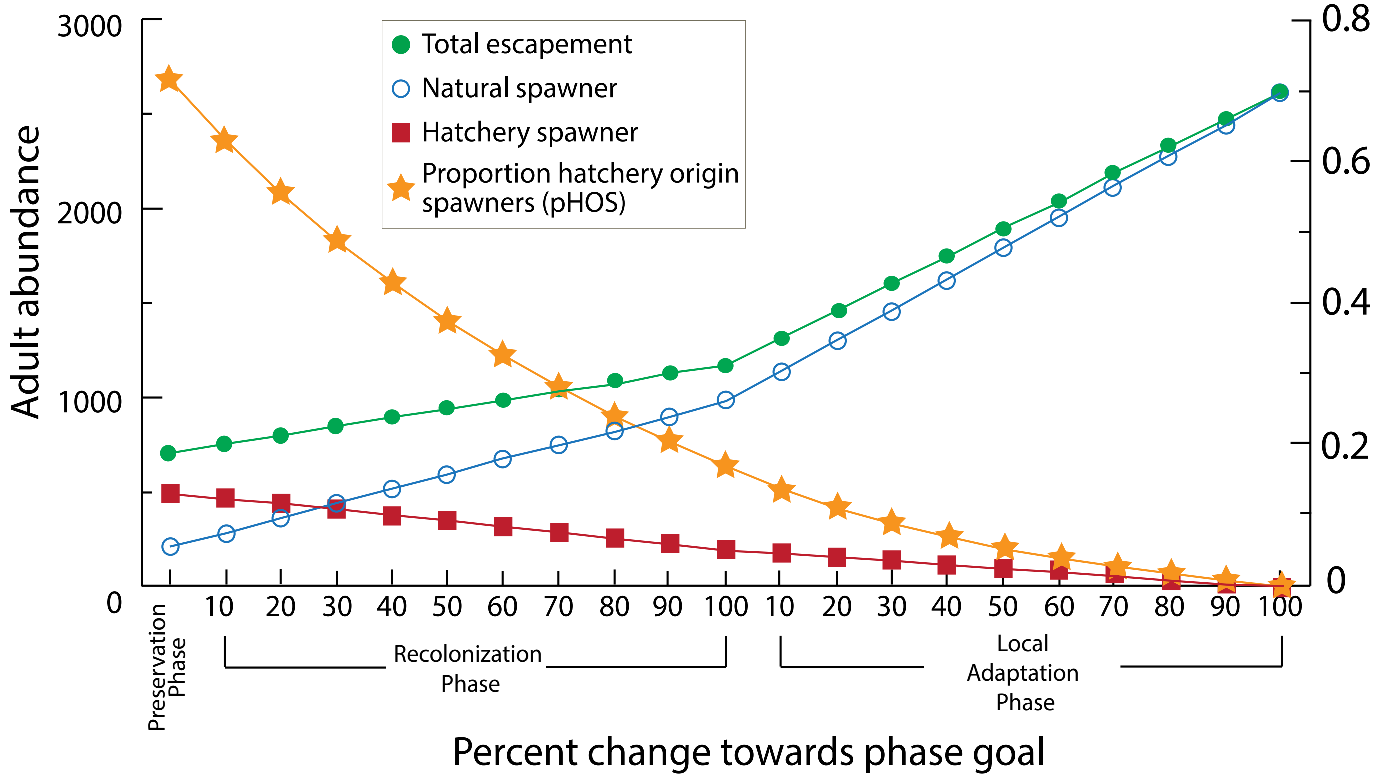
We recommend that hatchery management be modified once restoration progresses to the Recolonization Phase to begin moving this stock toward the goals stated by the HSRG (HSRG 2009; HSRG 2012) and the ultimate goal is to have a fully natural spawning population with a pHOS value of 0. The guidelines for PNI and pHOS for Elwha River steelhead are as follows:

- **Maintain pHOS < 30%**: The effectiveness and efficiency of pNOB for maintaining PNI > 0.5 decreases significantly for values of pHOS > 30%. Consequently, to achieve a desired PNI > 0.5, it is much more efficient – and less risky biologically - to reduce pHOS than increase pNOB. Increasing pNOB for high values of pHOS, as opposed to decreasing pHOS, imposes additional demographic (and potential genetic) risks to naturally spawning populations with comparatively minor increases in PNI.
- **Maintain PNI > 0.67**: For natural populations considered essential for the recovery or viability of an ESU of Pacific salmon or Distinct Population Segment (DPS) of steelhead, as those terms are defined and designated under the ESA.
- **Exceptions to the guidelines**: "Consequently, the HSRG acknowledges that some hatchery programs may be required to perform a "life support" function to prevent functional extirpation of a naturally spawning population in particular watersheds or geographic areas. Moreover, the abundance of fish representing a natural population must be sufficiently high to allow selection in the natural environment to be an effective deterministic force towards maximizing mean population fitness in view of stochastic forces. Under these exceptional circumstances, maintaining a naturally-spawning component to a hatchery-sustained population – where the number of hatchery fish spawning naturally exceeds HSRG guidelines - may be desirable for both genetic and demographic reasons." (HSRG 2009).

During the Recolonization and Local Adaptation Phases, the goal is to begin moving towards the ultimate goal of a population completely composed of natural spawning adults (i.e., pHOS = 0). The pHOS goals during the Recolonization and Local Adaptation Phases can be obtained by significantly altering hatchery management compared to the Preservation Phase. Hatchery production could be systematically reduced to zero during the Recolonization and Local Adaptation Phases by reducing the number of adults used in the hatchery broodstock proportional to overall increases in natural spawners during the previous year's return.

We recommend reducing hatchery broodstock collection from 500 to 200 adult steelhead during the Recolonization Phase and from 200 to 0 adult steelhead during the Local Adaptation Phase. The goal for naturally spawning steelhead during these two restoration phases is an increase from 196 to 969 and 969 to 2,619 during the Recolonization and Local Adaptation Phases, respectively. We propose that hatchery steelhead production would be reduced by 10% of the difference between the start and end goals of each restoration phase for every 10% increase in the difference between the start and end goal for natural spawning abundance (Figure 12). Thus, an increase from 196 to 273 naturally spawning steelhead (10% of (969-196) would result in a decreasing hatchery production from 500 fish to 470 fish (10% of (500-200). This would result in the

Figure 12. Conceptual diagram of Elwha River steelhead abundance and proportion hatchery-origin spawners (pHOS) through adaptive management phases. Graph shows changes in total escapement, natural spawners, number of adults used for hatchery broodstock, and associated pHOS values as restoration moves from the preservation phase through incremental stages of the Recolonization and Local Adaptation phases. Restoration moves from the Local Adaptation phase to the Viable Natural Population phase once all the triggers, including the abundance level of 2,619 adults (see figure 10), have been met.



hatchery production goals and naturally spawning abundance goals identified for the steelhead abundance triggers. This will move the population toward pHOS goals of 0.1 and 0 during the Recolonization and Local Adaptation phases, respectively.

Selective fishing is another important tool that could be used to manage pHOS on the spawning grounds and maintain a higher proportion of natural-origin spawners in the river system. HSRG (2012) states that marking of hatchery-origin fish combined with some form of selective harvest is essential for broodstock and natural population management. This suite of hatchery and harvest tools for managing PNI allows for optimum use of all hatchery-origin fish. This technique (i.e., combination of hatchery and harvest adult management tools) has been proposed for other steelhead enhancement programs in the Interior Columbia River Basin to assist enhancement programs in achieving PNI for the basin while aiding in the survival and recovery of listed steelhead populations. However, managers will need to consider potential hooking mortality impacts (e.g. 2–10%; NMFS 2011) to natural spawners if this management tool is used. Hatchery releases of progeny from the native captive brood program have only been tagged using CWT to this point to differentiate them from natural spawners (no marks) and Chambers Creek stock (adipose clipped). Once the last returns from past Chambers Creek stocks have occurred, adipose clipping of the hatchery releases originating from the native stock is expected to occur to allow selective fishing when warranted to manage PNI and provide harvest opportunities.

4.2.2.3 Productivity

In the absence of Elwha specific data for wild steelhead, we used long term monitoring data for smolt production and marine survival for wild steelhead from the literature (Bjornn 1969; Phillips et al. 1975; Bjornn 1978; Leider et al. 1986) and Snow Creek (Scott and Gill 2008), an Olympic Peninsula watershed draining into Discovery Bay. Marine survival ranged from 0.5 to 15% in both data sets and averaged 1.4% for Snow Creek wild-origin fish over the most recent five years for which these data are available (1999–2003). This marine survival rate indicates that at least 72 smolts per female will be necessary to maintain a consistent population of spawner-to-spawner returns. This is possible with high survival at every life stage and a literature-based average fecundity of 5,000 and intermediate to high survival for all life stages based on the Snow Creek Data (Table 7). To be slightly conservative, we use 75 smolts per female to indicate a potential for recovery.

Although 75 smolts per female are necessary for recovery, Snow Creek productivity has averaged only 60.7 smolts per female. This indicates that with ocean conditions similar to those experienced by steelhead from Snow Creek during 1999 to 2003, natural spawning and recruitment may not be sufficient to meet or exceed 75 smolts per female for wild Elwha River steelhead populations. These poor marine survival conditions coincided with significantly decreased marine survival in hatchery returns from Chambers Creek stocks in the Elwha, Skagit, and Puyallup basins (Scott and Gill 2008). Marine survival will need to be closely monitored to ensure that total productivity is sufficient to preserve and recover wild Elwha River steelhead.

No trigger values were developed for the remaining productivity metrics including number of pre-fishing recruits per spawner (hatchery and natural), number of spawners per spawner (hatchery and natural), number of pre-fishing recruits per natural spawner, and number of spawners per natural spawner, because these values depend on exploitation rates that have not yet been determined.

4.2.2.4 Distribution

As described above, the extent of spatial distribution was based on assumed habitat availability (accessible) during different restoration phases and the colonization behavior of the fish. We used unpublished information from NOAA Fisheries and Brenkman et al. (2008b) to determine the intrinsic potential for steelhead in the Elwha River. The intrinsic potential was based on channel width, gradient, and physical barriers. This resulted in the estimated

Table 7. Life stage specific survival estimates for wild steelhead based on information from the literature and Snow Creek, Olympic Peninsula, Washington. Survival is categorized as low and high, with the number of survivors to each life stage calculated for three different levels of fecundity (3000, 5000, 7000).

Life Stage	% Survival		Number of Survivors: Fecundity =3000		Fecundity =5000		Fecundity =7000		Comments
	Low	High	Low	High	Low	High	Low	High	
					Survivors Based on the Literature[1]				
Egg to emergence	0.300	0.800	900	2400	1500	4000	2100	5600	
Emergence to age1	0.060	0.250	54	600	90	1000	126	1400	
Age-1 to age-2	0.060	0.500	3	300	5	500	8	700	2-yr old smolts
Age-2 to age-3	0.060	0.500	0.2	150	0.3	250	0.4	350	3-yr old smolts
Marine survival	0.005	0.150	0.02	45	0.03	75	0.04	105	Returning adults for 2-yr old smolts
					Survivors based on Snow Creek[2]				
Egg to emergence	0.300	0.800	900	2400	1500	4000	2100	5600	
Emergence to smolt	0.034	0.162	31	389	51	648	71	907	2-yr old smolts
Marine survival	0.005	0.150	0.2	58.3	0.3	97.2	0.4	136	Returning adults

[1]Bjornn 1969; Phillips et al. 1975; Bjornn 1978; Leider et al. 1986; Ward et al. 1989; Ward and Slaney 1993
[2]Gill and Scott 2008

intrinsic potential described in Figure 11. We assumed that only the area below the former Elwha Dam site would be available during the Preservation Phase, which represents approximately 7.5% of the available habitat based on this assessment. We assumed the area below Glines Canyon Dam would be available for colonization and that colonizers would access this habitat during the Recolonization Phase, an area representing approximately 37% of the available habitat. We assumed all of the habitat would be available during the Local Adaptation Phase, but it would take time for steelhead to colonize this entire area. Thus, we simply doubled the area expected to be used during the Recolonization Phase to develop the extent of spatial distribution trigger for the Local Adaptation Phase. We expect all assessable habitats to be used during the Viable Natural Population Phase.

4.2.2.5 Diversity

Based on historical accounts (by Dick Goin, Port Angeles resident), native Elwha River steelhead were abundant in November and December and continued to enter the river through June (McMillan et al. 2012). Entry timing based on unpublished creel census data from the Elwha River (1982 - 2001, The Point No Point Treaty Council, unpublished data) summarized by McMillan et al. (2012) suggests that approximately 60% of Elwha River wild steelhead returned before March 1. However, steelhead are currently assumed to enter and spawn between February and June (Brenkman et al. 2008b). The loss of this early component of the native steelhead run is thought to be the result of fisheries for introduced Chambers Creek hatchery steelhead, which enter the river from November through January (McMillan et al. 2012). Thus, directed fisheries on the Chambers Creek stock would inadvertently intercept early timed native steelhead, thereby reducing their relative abundance and entry timing diversity (based on genetic predisposition).

Ideally, a trigger would be developed to assess mean run timing. However, detecting differences in mean run timing would be very difficult. Robards and Quinn (2002) assessed changes in summer run steelhead migration timing at Bonneville Dam in the Columbia River from 1950 through 1998 and found that the peak migration timing changed an average of 0.44 days per year during their period of evaluation. Based on this relationship and the four year temporal requirement for assessing steelhead triggers, we would established a trigger that the mean run timing (50% of the run returns by a give date) changes at a rate of 0.44 days/year which would be equivalent to 1.76 days during a four year period. Unfortunately, we likely could not detect this level of change. Based on an assessment of steelhead run timing data through Bonneville Dam on the Columbia River from 1982 to 2011, the 95% confidence interval around the four year running mean (which we would use to assess our trigger) would be 1.73 days. For this reason, we've set our diversity trigger based on steelhead appearing earlier each year, ideally fish returning in January and eventually December. The diversity triggers are fish returning in March for the Preservation Phase, February for the Recolonization Phase, January for the Local Adaptation Phase, and December for the Viable Natural Population Phase.

An additional component of steelhead life history diversity is interaction with resident trout. Steelhead frequently spawn with resident trout, and *O. mykiss* populations often exhibit partial migration in which a single, panmictic population has anadromous and non-anadromous individuals. Furthermore, even after decades of isolation above dams, resident trout descended from historically anadromous populations often retain the genetic and physiological traits of anadromy. Precise measurements of reproductive contributions by resident fish or the rate of residency vs. anadromy are difficult to achieve. Thus, we have not made these metrics formal triggers in the adaptive management plan, but rather emphasize the importance of understanding the complete array of life history diversity exhibited by steelhead. From this perspective, research approaches that address the interaction between resident and anadromous *O. mykiss* (i.e., otolith microchemistry, PIT-tag mark-recapture, genetics) provide crucial insight, and therefore are important to consider in allocation of monitoring funds.

4.2.3 Chinook and Steelhead Exogenous Variables

Exogenous variables have been set for key parameters that will provide valuable information regarding factors contributing to changes observed in our performance indicators and associated triggers, help test assumptions, and provide insight into the mechanisms of recovery or decline of the monitored species. Exogenous variables themselves will not necessarily result in changes to Elwha specific management actions, but will instead be used to provide additional information to guide management decisions. Exogenous variables have been developed for hatchery abundance and production, harvest, habitat, fish health, and ecosystem metrics. Exogenous variables should be reviewed on an annual basis as part of the routine reassessment of the EMAM guidelines.

4.2.3.1 Contribution by Hatchery Fish

Hatchery abundance for Chinook salmon and steelhead were developed as exogenous variables rather than triggers, since the ultimate goal is to restore naturally spawning populations. It would also be possible to remain in early stages of restoration even though naturally producing fish were exceeding trigger values, if for some reason the abundance of hatchery fish was failing to meet triggers values. The exogenous variable for the number of Chinook salmon spawned in the hatchery is 1,700 adults during the Preservation Phase, consistent with the number of spawners needed to produce 2.9 million hatchery Chinook (2.5 million sub-yearlings, 400K yearlings). During the Recolonization and Local Adaptation phases, the number of Chinook used for hatchery production should be reduced as the number of natural spawners increases (see section 4.2.2.2 Managing for pHOS). Therefore, the hatchery spawner abundance exogenous variable for the different phases is determined by the natural spawner abundance for each phase.

The hatchery steelhead exogenous variable is set at 500 adults during the Preservation Phase based on the hatchery production needs. This will be reduced during the Recolonization and Local Adaptation phases as the number of natural spawners increases (see section 4.2.2.2 Managing for pHOS).

4.2.3.2 Harvest Exogenous Variables

4.2.3.2.1 Chinook

The co-managers have developed and NMFS has approved under the ESA a series of joint harvest Resource Management Plans (RMP) for Puget Sound Chinook. In addition, the Puget Sound Salmon Recovery Plan relies on the harvest RMPs developed by the co-managers and approved by NMFS (NMFS 2006, NMFS 2011). Management of fisheries as described in the RMP is intended to contribute to integrated, comprehensive protection and restoration of at risk Puget Sound Chinook salmon populations, including Elwha Chinook. In addition, the RMP is intended to provide surplus fish for harvest, while minimizing the likelihood for harm to natural-origin fish populations. The RMP provides details regarding harvest actions to help recover Chinook salmon populations, including recent program modifications and measures applied to reduce the risk of harm to wild Chinook salmon while providing treaty tribal and non-tribal harvest opportunity on stronger salmon stocks (hatchery Chinook and non-listed salmon species). For each population, the RMP defines escapement exogenous variables that define the status of the population and corresponding exploitation rates consistent with the population status. For the Elwha the management objectives are:

Escapement Threshold	**Exploitation Rate Ceiling[1]**
Lower[2] <1,000	< 6% southern U.S.
1,000 < escapement < 2,900	< 10% southern U.S.
Upper: >2,900	<10% southern U.S.

[1]All southern U.S. Fisheries including those under jurisdiction of the Pacific Fisheries Management Council
[2]Represents a composite of 500 natural and 500 hatchery spawners

Thus, the exploitation rate ceiling depends on preseason forecasts for composite hatchery and natural Chinook abundance, When the preseason estimate is for less than 1,000 fish, the exploitation rate ceiling is less than 6%. When the preseason escapement estimate is for the composite run to be between 1,000 and 2,900 Chinook fisheries in Washington waters, including those under jurisdiction of the Pacific Fisheries Management Council, will be managed so that the southern U.S. (SUS) incidental exploitation rate of 10% on Elwha Chinook is not exceeded. Harvest at this level will assist recovery by providing adequate escapement returns to the river to perpetuate natural spawning in the limited habitat available, and provide broodstock for the supplementation program. The allowable preseason exploitation ceiling has been 10% in recent years, while the actual rates have been much lower (e.g., <5%; Susan Bishop, NMFS, personal communication). This information is based on post-season analyses from large geographic area influenced by the Pacific Salmon Treaty and the Pacific Fishery Management Council, from monitoring data collected for all stocks rather than specific stocks. Ocean fishing models, based on historical catch patterns are used to estimate stock specific exploitation rates. This method appears appropriate at this time since exploitation rates have been below 10% and the composite hatchery and natural Chinook escapement has been greater than 1,000 fish. Exploitation rates are expected to be 10% in the near future, but are dependent upon preseason forecasts. The co-managers and NMFS examine actual exploitation rates to ensure the RMP guidelines are met. Co-managers are expected to take action if they have not been met. Failure to remedy over harvest could lead to NMFS withdrawal of its approval per the ESA 4(d) Rule provisions (Susan Bishop, NMFS, personal communication).

The current RMP will expire in April 2014. Harvest management objectives in subsequent RMPs will be revised to incorporate new information, including updated habitat data gathered through monitoring as the Elwha watershed is restored. The EMAM guidelines will provide additional information to use in evaluating RMP objectives for the Elwha spring Chinook population. The objectives in future RMPs will then replace the exogenous Chinook harvest variables in this monitoring and adaptive management plan.

4.2.3.2.2 Steelhead

The ultimate goal is to restore naturally spawning populations of steelhead in the Elwha River. In order to track the effect of factors such as harvest, established exogenous variables are needed to examine recovery progress during the four phases of restoration. As mentioned in Section 4, exogenous variables differ from triggers in that they do not, in and of themselves, result in altered management actions. Their purpose is to provide information regarding why restoration is progressing as observed, but may result in management changes (e.g., reduced harvest).

The Lower Elwha Klallam Tribe has submitted a Tribal harvest plan to NMFS for consideration under the Tribal 4(d) Rule, proposing a tribal fishery on the early-timed Chambers Creek population during this time period. Previous analysis based on the current status of the listed steelhead population demonstrated that an average 4 percent incidental harvest rate on listed steelhead populations, similar to what is proposed for Elwha native steelhead would not appreciably reduce the likelihood of survival and recovery of ESA-listed Puget Sound steelhead (NMFS 2011). This analysis considered multiple watersheds where steelhead data were available, Puget Sound basins containing Chambers Creek hatchery programs, and degraded habitat conditions similar to the Elwha River.

The steelhead exogenous variable for harvest during the Recolonization Phase has been set at no more than a 7 percent incidental harvest rate on the native late-timed winter steelhead population. This harvest rate is based on a 1.20 annual population growth rate for natural-origin recruits post restoration efforts which translates into a population growth rate of 2.07 per generation. The proposed harvest regime, constrained to less than 7 percent harvest mortality per generation, still translates into a projected population growth rate that is greater than 2.00 per generation.

The Tribe would develop annual harvest plans that include forecasts of natural-origin and hatchery-origin returns, data and forecasting methods, projected terminal (e.g., in-river) harvest rates, an agreed-to regulatory regime for tribal fisheries, and harvest monitoring to ensure the established harvest exogenous variables are not exceeded during the Recolonization Phase (LEKT 2012d). For early-timed fisheries that would occur during the 2012-13 and 2013-14 fishing seasons, the annual harvest regime would be developed using run timing and forecasts based on hatchery brood year releases and recent return rates (i.e., survival) of hatchery-origin fish (e.g., Chambers Creek winter steelhead population). For late-timed fisheries that would occur from 2018 and beyond, adult abundance forecasting will be uncertain until several brood years (natural-origin and hatchery-origin) have returned to restored mainstem habitat. Data from the monitoring programs would inform development and refinement of forecasting, assessment efforts, and harvest management. Forecasting of natural-origin and hatchery-origin escapement will contain a high level of uncertainty until several brood years have returned to the restored habitat. Counting adults with Dual Frequency Identification Sonar (DIDSON), adults intercepted at the weir, and returns to the hatchery, augmented by surveys of key potential spawning reaches, would generate reliable estimates of escapement over time (LEKT 2012d). Beginning in release year 2015, all age-2 smolts released from the hatchery (produced from the native captive brood program) are expected to be adipose fin-clipped allowing for easy identification of returning adults for future management of PNI and pHOS. Due to limited data on the Elwha steelhead population, exogenous variables during the Local Adaptation and Viable Natural Population phases should be revisited at a later date when more information on the recovering population has been gathered to inform future decision making.

4.2.4 Bull Trout Abundance

We have not developed an exogenous variable value for Bull trout abundance. A separate document should be prepared to guide bull trout monitoring and adaptive management. Triggers and exogenous variable values specific to bull trout could be created in that document. Bull trout information should be examined when assessing management activities for Chinook salmon and steelhead to ensure that the Chinook salmon and steelhead management activities are not negatively influencing bull trout.

Bull trout abundance should also be monitored to ensure the population does not negatively impact Chinook and steelhead. Bull trout populations will overlap with Chinook and steelhead populations. Thus, bull trout will prey upon both Chinook and steelhead juveniles. Although these populations have evolved together, predation by native fish can significantly impact populations, especially in altered environments (e.g., Tabor et al. 2004).

4.2.5 Habitat, Fish Health, and Ecosystem Exogenous Variables

Data should be collected for specific habitat, fish health, and ecosystem (e.g., prey availability) metrics. These metrics will be useful to evaluate the overall health of the ecosystem and any observed changes to the VSP indicators described above and would assist managers in identifying areas of concern (e.g., water quality).

4.2.5.1 Habitat – Spawning Habitat

Quantity and Quality

Salmonid spawning habitat quantity and quality exogenous variables to monitor include particle size distribution, residual pool depth, and percent fine sediment. As large quantities of sediment stored in Lake Aldwell and Lake Mills are delivered downstream during the dam removal process, we anticipate a series of changes in spawning habitat quantity during river recovery. These include changes in streambed particle size, pool depth, and the proportion of fine sediment in riffle crests. Salmonids select spawning areas largely because of gravel size - thus changes in particle size distribution will strongly affect habitat suitability (Quinn 2005). Holding pools are also critical habitat for many spawning salmonids, and pool filling is likely to be the most obvious effect of sediment release after dam removal (DOI 1996b). Large proportions of fine sediment (intermediate particle size diameter ≤ 2 mm) in spawning gravel have been shown to decrease survival of salmonid egg to fry emergence and is thought to be a major factor limiting salmonid freshwater production and recovery (Reiser and White 1988; DeVries 1997; Malcolm et al. 2008). Based on review of the literature, we identified three habitat metrics that are relatively simple to measure and effectively convey long-term changes in habitat quantity and quality: (1) riffle crest surface particle size distribution, (2) residual pool depth, and (3) riffle crest percent fine sediment.

Our hypothesis is that the influx of sediment to the Middle and Lower Elwha will initially result in changes to pool depth and dimensions because it is expected that most new sediment will be small in size (i.e., fines) (DOI 1996b; Warrick et al. 2012; Curran et al. 2013). As the stream channel changes and eventually reaches equilibrium following dam removal, larger sediment in the form of sand, gravels and cobbles will be transported downstream and start to affect deep water areas such as pools where salmonids often stage and riffles where salmonids tend to spawn. We hypothesize that fine sediment will also accumulate in riffle areas throughout the dam removal process – initially in smaller amounts but eventually becoming part of the newly deposited gravel and cobble in the riffle crest areas. We also hypothesize that changes in streambed particle size, the depth of pool habitat and the proportion of fine sediment in riffle crests are likely to dominate in the mainstem river habitats because of the influx of sediment that will occur with dam removal. Capturing changes in the stream channel structure will thus be important to access changes in the availability of salmon holding and spawning habitat after dam removal.

4.2.5.2 Habitat - Rearing Habitat Quantity and Quality

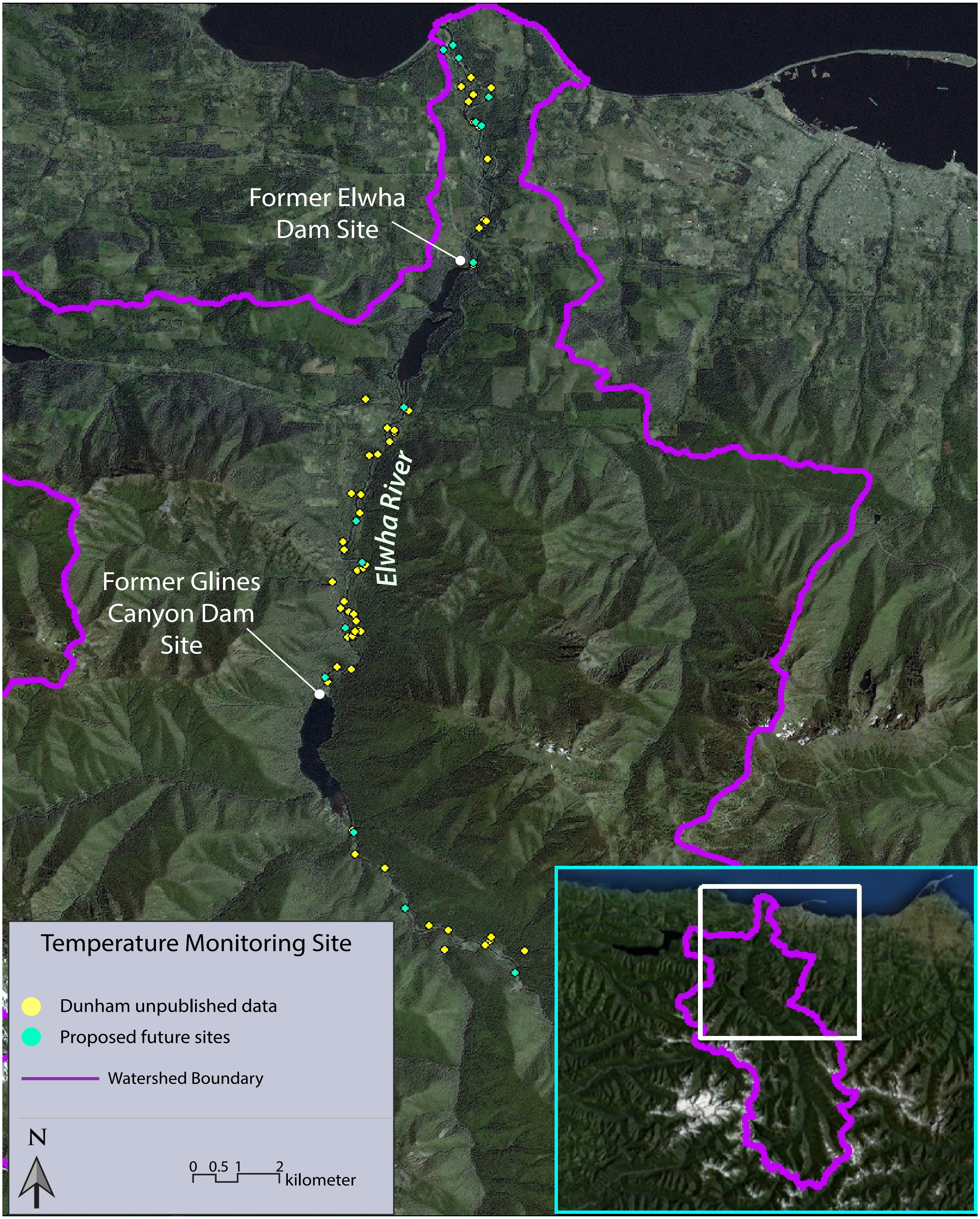
Rearing habitat quantity and quality exogenous variables to monitor include proportion of slow/shallow water habitats, residual pool depth, and habitat complexity. We hypothesize that one of the main changes that will occur in the Elwha River during and after dam removal is a reduction in substrate size and water depth due to sediment deposition, particularly along the edge of the mainstem Elwha downstream of the dams. Juvenile salmonids typically occupy relatively shallow and low-velocity areas (<1 m deep and <40 cm/s velocity; Bjornn and Reiser 1991) whether they are in large rivers (Murphy et al. 1989; Beechie et al. 2005), floodplain channels (Nickelson et al. 1992; Sommer et al. 2001), or small streams (Hillman et al. 1987). However, in large rivers such as the Elwha most of the habitat area is more than 1 m deep and velocity exceeds 40 cm/s throughout the year (Beechie et al. 2005). Therefore, most juvenile salmonids are typically found near channel margins in the mainstem Elwha, where velocities are lower and cover is more abundant, and in higher densities in Elwha floodplain channels that typically have a higher proportion of slower water and shallower habitat (Pess et al. 2008; 2012).

Floodplain channels below each of the dams, of which there are currently 66 totaling over 28 km in length, are defined as channels in the 100 year floodplain inundated with water during low and high flow periods. These channels provide important habitat for juvenile salmonids and changes in their availability or habitat complexity could impact salmon recovery. Floodplain channels may respond in one of two ways following dam removal, as sediment sinks (i.e., collect and store sediment) or as refugia. If they serve as sediment sinks, these channels will aggrade (i.e., raising the streambed level due to sediment deposition). This will result in lost depth and reduced substrate size, and potentially elimination after dam removal. If this is the case, the combined effect of mainstem and floodplain channel habitat changes the Elwha River downstream of the two dams will be a significant reduction in the proportion of slower water habitats available in the near- (years) and long-term (decades). The alternative hypothesis is that some floodplain channels may serve as refugia for salmonids from high flows and turbidity, thereby playing a particularly important role in salmon recolonization. In this case, the overall reduction in the proportion of slower water habitats available below the dams will be much less than if they serve as sediment sinks.

We hypothesize that one of the main changes that will occur in the Elwha River during and after dam removal is a change in habitat quality along the Elwha's mainstem channel margins and floodplain channels. Juvenile salmonid rearing habitat quality typically is defined by the type of cover (e.g., wood, substrate type, vegetation, undercut banks), substrate size (e.g., sand, gravel, cobble, boulder), velocity (Shirvell 1990; Fausch 1993), and associated depths of the general habitat type, regardless of stream size (Bustard and Narver 1975; Shirvell 1990; Beechie et al. 2005). Differences in habitat quality do affect the densities of juvenile salmonids, but this varies considerably by species (Bisson et al. 1988). For example, coho salmon select low velocity over cover when given a choice (Shirvell 1990; Fausch 1993) and have higher growth and survival rates in low-velocity habitats (Kruzic et al. 2001). In contrast, steelhead parr prefer low-velocity locations that are adjacent to faster water and have overhead cover (Shirvell 1990; Fausch 1993). Density patterns associated with habitat quality differences typically reflects the suitability of salmonid body forms to different focal velocities and feeding strategies (Bisson et al. 1988; Beechie et al. 2005). Thus, habitat quality changes to slower water areas are important because the microhabitat preferences in depth, cover, and velocity can vary among salmonid species, reflecting differences in body size and morphological adaptations (Beechie et al. 2005). Edge habitat and floodplain channels may aggrade, lose depth, and have a reduction in substrate size during and immediately after dam removal. This change in habitat quality will have corresponding effects on juvenile salmonid density, and subsequent effects on growth, movement, and survivorship, which will likely vary by species.

4.2.5.3 Water Quality - Stream Temperature

Figure 13. Map showing sites previously monitored (yellow circles) for surface water temperature of the Elwha River by USGS (J. Dunham, unpublished data) and proposed sites for future monitoring by the Lower Elwha Klallam Tribe (blue circles).



A single stream temperature water quality exogenous variable is proposed for monitoring: proportion of days above identified limits (Chapter 173-201A WAC). Pre-project summer water temperature conditions have been adequately characterized in the Elwha River. Multiple data sets have been collected over space and time on the Elwha River dating to the early 1990s. Stream temperature was monitored in the Elwha River drainage between 1992-96 and 1998-2002 and again in 2004 by the Lower Elwha Klallam Tribe (McHenry 2002, unpublished data). During the first period of monitoring temperature, patterns were broadly assessed on the relative effects of dams on annual temperature regimes at three points on the Elwha River (above, between, and below the dams). The results of this monitoring showed that summer water temperatures generally increased by 2-4 °C in a downstream direction.

In the 1998-2002 data sets, monitoring sites were expanded and designed to assess temporal and spatial variability in different mainstem and side-channel habitats. These data showed that temperature conditions were more complex than previously thought. Peak summer water temperatures in free flowing reaches of the Elwha River above Glines Canyon Dam rarely exceeded 15 °C and averaged 10-13 °C in the summer. Peak and diurnal temperatures increased dramatically within the middle reach between Elwha and Glines Canyon Dam, and water temperatures exceeding 20°C were recorded in two summers. The relative increase varied with summer air temperature and ranged from 3-7 °C by year. In the lower river, additive increases in peak temperature of 1.5-2.0 °C were measured in two years, while no significant change was measured in three other years.

There was also finer scale structure in the temperature data. For example, Lake Aldwell provided a thermal buffering effect immediately below the dam, primarily through leakage of cool water at the base of the dam. This appeared to moderate the peak water temperature of water delivered from the middle to lower reaches of the Elwha. However, temperatures in the lower river were highly variable depending upon location and year. Air temperature, flow, and channel morphology affected peak temperatures to a greater degree than water withdrawals or groundwater influences. Water temperatures exceeding 20°C occurred in dewatered side-channels during low flow years.

In anticipation of dam removal, water temperature monitoring plans were altered to answer the question: How will water temperatures in the mainstem Elwha River change in a longitudinal direction? To answer this question 15 sites were selected in the mainstem river between river mile 0.5-19.6 (Figure 13). In addition, NOAA researchers plan on reoccupying a subset (~ 25) of the stream sites where thermographs were deployed by USGS/FRESC in 2007 (Jason Dunham, unpublished data) (Figure 13). These sites should be selected in tributaries, and side channels to supplement the mainstem sites listed in Figure 13. By collecting data in the mainstem, tributaries and side channels before and after dam removal, determining how the removal of the two dams influence mainstem Elwha temperature will be possible, since controls for monitoring other environmental changes that may occur (e.g., increased air temperature) are also being monitored.

4.2.5.4 Water Quality - Turbidity

The proposed turbidity water quality exogenous variable is the proportion of time above identified limits. The deconstruction of high dams (> 30 m high) storing large amounts of fine sediment (~27 million m^3) is predicted to dramatically increase suspended sediment to severe and potentially lethal levels during and immediately following removal (Konrad 2009; Warrick et al. 2012; Curran et al. 2013). Chronic elevated suspended solids can displace juvenile salmonids (Bisson and Bilby 1982), reduce feeding and growth rates (Sigler et al. 1984; Berg and Northcote 1985), impair physiological processes, increase stress (Carlson 1984; Berg and Northcote 1985), and can be lethal at high levels (Stober et al. 1981; Newcombe and McDonald 1991). Monitoring suspended sediment levels before, during, and after dam removal therefore has implications for understanding how suspended solids might influence the behavior and physiology of juvenile salmonids in the Elwha River basin.

One way to estimate the level of suspended solids is to measure turbidity. Turbidity is a measurement of the relative clarity of a liquid, and expresses the degree to which organic and inorganic materials suspended in water cause light rays to be scattered and absorbed (ASTM 2003). Although turbidity is often closely related to suspended sediment concentrations, it is not identical. In addition to sediment concentrations, turbidity measurements are affected by the sizes and color of particulate (and dissolved) matter (Anderson 2006). Turbidity is also sensitive to factors such as light source and bubbles in the water column. Measuring suspended sediment concentrations accurately can be relatively time intensive, particularly when it is necessary to take multiple measurements across different floodplain habitats and over different flow stages. We recommend instead to measure turbidity as a relative index of habitat quality influenced by suspended sediments. A drawback in measuring turbidity is the difficulty in extrapolating studies of suspended sediment effects on biota to particular turbidity levels. However, turbidity itself also directly impacts biota via effects on photosynthesis and dissolved oxygen levels (Davies-Colley and Smith 2001).

We reviewed the literature on the influences of turbidity on juvenile salmonid behavior, physiology, and survival, with a focus on the most abundant species in the Elwha River basin: rainbow trout/steelhead, coho, and Chinook salmon. We focused on juvenile salmonids because they are more sensitive to suspended solids than adults (Bash et al. 2001). Some results were gleaned from a literature review by Bash et al. (2001), while others were derived from individual studies.

Turbidity levels up to 150 NTU (Nephelometric Turbidity Units) influence salmonid species differently. For example, juvenile Chinook salmon exposed to 1-810 NTU displayed their highest feeding rates at 18-150 NTU (Gregory 1993). In contrast, there is evidence that juvenile rainbow trout/steelhead and coho salmon may feed less, grow more slowly, and be displaced by turbidity levels from 40-70 NTU (Sigler 1980; Bisson and Bilby 1982; Sigler et al. 1984; Berg and Northcote 1985). However, the influence of turbidity on juvenile salmonids behavior, feeding, and mortality varies with background turbidity levels (Muck 2010).

Determining lethal turbidity levels is more challenging. Once suspended sediment levels exceed 500–1000 mg/L for at least 96 consecutive hours, there is evidence of reduced survival and death in juvenile rainbow trout (Campbell 1954), coho, and Chinook salmon (Stober et al. 1981). However, because suspended sediment cannot be directly converted to NTU, it is difficult to predict whether such levels will be sustained on the Elwha. Nor are the suspended sediment levels considered potentially lethal consistent within or among species. Noggle (1978) found that lethal turbidity levels for coho at 96 hours ranged from 1,200-35,000 mg/L. In addition, Newcombe and McDonald (1991) found that only 50% of steelhead smolts perished at 19,364 mg/L and that only 60% of juvenile Chinook salmon perished at 82,000 mg/L.

Erosion of the accumulated sediments in the Lake Aldwell (lower dam) and Lake Mills (upper dam) deltas is expected to be a major short-term impact to river sections below the dams, the estuary complex where the river meets the Strait of Juan de Fuca, and the nearshore ecosystem from Freshwater Bay to Ediz Hook. Earlier studies of the reservoir sediment composition (Czuba et al. 2011 and references therein) suggest that 85% of this material is silt, sand, and clay in Lake Mills (95% in Lake Aldwell), some of which will be readily transported during and immediately following dam removal (Warrick et al. 2012; Curran et al. 2013). Based upon a 1995 reservoir draw down experiment in Lake Mills, extremely high fine sediment concentrations (up to 30,000-50,000 ppm) are expected in the Elwha River for 3-5 years, depending on climatic conditions (especially rainfall).

4.2.5.5 Fish Health

After the removal of two dams, natural and hatchery produced fish are expected to recolonize historical habitats in the Elwha River. Fish populations that were previously isolated by the dams will interact and potentially transmit pathogens. Despite many potential benefits of dam removal, the interaction between potamodromous fish upstream of the dams and recolonizing anadromous salmonids poses fish health risks. Fish populations in the Elwha River can potentially be exposed to a greater number of a given pathogen or to a pathogen to which the population has not been previously exposed. This exposure may result in transmission and amplification of pathogens, which can lead to disease.

The comprehensive monitoring program should include assessments of fish diseases in the state and tribal hatcheries and throughout the Elwha River. Such information on fish diseases after co-mingling of natural and hatchery fish can be compared to existing baseline pathology from the basin (Brenkman et al. 2008a). A total of 13 species of parasites, six species of bacteria, and three viruses were recorded in Pacific salmonids in Elwha hatcheries since 1988. The most routinely observed diseases and their etiological agents in recent history are bacterial kidney disease (BKD), bacterial cold water disease, and erythrocytic inclusion body syndrome (EIBS), which is caused by a toga-like virus. Other fish pathogens have been detected over time, but less frequently (see Table 2 in Brenkman et al. 2008a).

4.2.5.6 Ecosystem Response

There are many possible options available to evaluate ecosystem responses to dam decommissioning on the Elwha River. Because salmon and the aquatic ecosystem both figure prominently in the restoration project, measuring the response of benthic primary and secondary producers is particularly relevant. In medium and large rivers (≥ 4th order), primary production by periphyton is a major food source for higher trophic levels (Thorp and Delong 2002). Secondary producers (e.g., aquatic invertebrates) in turn serve as a major food source for fish and strongly influence nutrient cycling and primary productivity (Merritt and Cummins 1996; Wallace and Webster 1996). Understanding the dynamics associated with reintroduction of anadromous salmonids and the nutrient subsidy provided to their spawning habitats and surrounding ecosystems is an important component of ecosystem response (Duda et al. 2011c). Our monitoring thus far has focused on tracking periphyton and benthic invertebrate density and taxonomic composition in river sections upstream and downstream of the Elwha dams and linking these patterns to fish use with study of nutrient dynamics and juvenile salmonid diet (Morley et al. 2008).

4.2.5.6.1 Ecosystem Response - Primary and Secondary Productivity

Primary and secondary productivity exogenous variables proposed for monitoring include periphyton density, algal density, microbial community, diatom taxonomic composition, invertebrate density, and invertebrate taxonomic composition. Sediment is a primary driver of habitat quality and community structure for benthic invertebrate and periphyton communities (Minshall 1984; Waters 1995). The depletion of sediment through sequestration in the reservoirs has played a role in the structure of downstream aquatic communities (Morley et al. 2008). The release of large quantities of sediment during and following dam removal (Czuba et al. 2011) will also change the benthos and likely affect downstream community structure and function. The rapid response and recovery that periphyton and benthic invertebrates typically display following disturbance are well suited to capturing ecological response to these dam removal impacts (Shannon et al 2001; Doyle et al. 2005). There are also several existing benthic invertebrate data sets that have been established in the Elwha River prior to dam removal (Li 1990; Munn et al. 1996, Morley et al. 2008; Duda et al. 2011b).

Existing research teams propose to sample either semi-annually or quarterly at a rotating subset of index sites (Table 8). Sampling at multiple times throughout the year will allow the data to better capture natural seasonal variation, and thus better detect ecosystem changes over the course of dam removal and river recovery. Prior to dam removal, 52 index sites distributed approximately every two river kilometers (Rkm) from the river's mouth to its headwaters were established (Morley et al. 2008; Duda et al. 2011c). River kilometers measure distance from the mouth of a river upstream. Sampling locations within a given 2 Rkm reach were selected to coincide with side channel complexes and tributary junctions so that multiple habitat types could be sampled in proximity. To this existing set of pre-dam-removal sites, new sites should be added as appropriate (e.g., newly forming floodplain habitat in former reservoir areas).

Pre-dam-removal monitoring served the important purpose of standardizing data collection protocols, coordinating field collections among multiple collaborators, and incorporating detailed metadata to facilitate data sharing. To maintain comparability between datasets, post-dam-removal monitoring closely follows protocols for primary and secondary productivity detailed in Morley et al. (2008) and for nutrient dynamics described in Duda et al. (2011c). The pool of response metrics should be expanded wherever possible.

4.2.5.6.2 Ecosystem Response - Nutrient Dynamics

Table 8. Ecosystem response metrics that could be used to help identify ecological changes post Elwha River dam removal. Annual costs are estimated in FY13 dollars and the tools and estimates should be reviewed annually.

Category	Indicator	Tools	Methods	Current Lead	Frequency	Annual Cost estimate	Limitations
Primary productivity	Periphyton density	Rock cobble sampling	Gravimetric AFDM	NOAA, USGS	Semi-annually	$21,000	Standing crop only; highly variable
	Algae density	Rock cobble sampling	Chorophyll-a via flourometry	NOAA, USGS	Semi-annually	Included in above	Standing crop only, funding ends 2014
	Microbial community structure	Rock cobble sampling	Biolog microtiter system; PCR analysis of functional + genetic diversity	None	Semi-annually	unknown	lack of funding; no current expertise
	Diatom taxonomy	Rock cobble sampling	Slide-mount; ID to genus or species	NOAA, USGS	Semi-annually	$18,500	No funding, samples archived
Secondary productivity	Invertebrate density	Benthic slack net sampling	Invertebrate enumeration and measurement	NOAA, USGS	Semi-annually	$21,000	Standing crop only; highly variable
	Taxonomic composition	Benthic slack net sampling	ID to lowest practical taxonomic level	NOAA, USGS	Semi-annually	$15,000	Funding ends in 2014
Nutrient dynamics	Total N, Total P, NO_3, NO_2, NH_4, PO_4	Water grab samples	Continuous flow Alpkem RFA/2, persulfate digestion	NOAA, USGS	Semi-annually	$10,300	Daily point estimate only
	δ^{15N}, δ^{13C} stable isotopes	Plant and animal tissues across multiple trophic levels	Isotope ratio mass spectroscopy with elemental analyzer	USGS, NOAA	Semi-annually	$36,000	No funding
Fish diet	Prey selectivity	Gastric lavage	Prey enumeration and measurement	NOAA, USGS	Quarterly	$28,750	Funding ends 2014
	Invertebrate density	Drift net sampling	Invertebrate enumeration and measurement	NOAA, USGS	Quarterly	$5,150	Highly variable, funding ends 2014
	Taxonomic composition	Drift net sampling	ID to lowest practical taxonomic level	NOAA, USGS	Quarterly	$15,500	Funding ends 2014

Nutrient dynamic exogenous variables proposed for monitoring include total nitrogen and phosphorous, dissolved NO_3, NO_2, NH_4, PO_4, and tissue $\delta^{15}N$, $\delta^{13}C$. The focus of food web research in the Elwha River has been on changes in nutrient dynamics following recolonization by anadromous salmonids. With the majority of their body mass obtained at sea, adult salmon return to freshwater spawning grounds enriched with marine-derived nutrients (MDN). These MDN influence the productivity and ecology of freshwater ecosystems via deposition of carcasses, gametes, and excretion of waste when salmon complete their life cycle (Gende et al. 2002; Schindler et al. 2003). Pre-dam-removal water chemistry analyses indicate that the Elwha is oligotrophic, but estimates of future salmon returns could increase annual nitrogen and phosphorous loading (Munn et al. 1999; Duda et al. 2011a,c). Tracing the movement and magnitude of MDN inputs into freshwater and riparian ecosystems is frequently done with stable isotope analysis - a technique that relies upon measuring the isotopic ratio of carbon and nitrogen heavy stable isotopes (which are more prevalent in marine environments) to their lighter counterparts (Fry 2006).

4.2.5.6.3 Fish Diet

Prey selectivity is the only exogenous variable monitored for fish diet. Information on fish diet will provide an important link between primary and secondary productivity and fish use data (such as density, distribution, and growth). To better link these datasets, NOAA fisheries researchers and colleagues began collecting diet information on juvenile *Oncorhynchus mykiss* (steelhead and resident rainbow) at a subset of established study sites in the summer of 2010. Their focus has been limited to this species since it was present both above and below the Elwha Dam, and because of funding limitations. Expanding this sampling to include all salmonid species to examine diet overlap and the partitioning of prey resources between resident and newly colonizing anadromous species, would be beneficial in the future.

4.3 Data Standards for Performance Indicators

Data standards provide a benchmark for data quality. On the Elwha River, data standards are needed to ensure that the derived indicator values are useful for management decisions during the restoration process. The monitoring data standards recommended for the adaptive management of Elwha River restoration were based on NOAA's monitoring guidelines for salmon and steelhead populations listed under the ESA (Crawford and Rumsey 2011). These guidelines emphasize sampling designs that provide unbiased and precise estimates for each measured parameter (indicator). Below we recommend data standards for the performance indicators outlined in the EMAM guidelines. The type and frequency of field surveys and sample analyses described in this plan (see Section 5) were selected in order to have a high likelihood of achieving these standards. In some cases, logistical constraints may prevent the data standards from being achieved; however, this outcome should be an exception and not a rule for monitoring data collected on the Elwha River.

Bias and precision of the estimates are two considerations for any sampling design (Hansen et al. 2007). Bias has generally been defined as the difference between the true value and the expected value of a population attribute (Cochran 1977). Significant bias can occur when sampled units differ from those in the entire population or when efficiency varies among sampling units (Hansen et al. 2007). Precision, on the other hand is the likelihood that the estimate of an attribute is close to the true unknown value of the attribute (Hansen et al. 2007). The precision of an estimate is influenced by the variability of the measured attribute, the number of observations collected, and the sampling design (Hansen et al. 2007). In general, the number of samples required to attain a desired precision increases with the variability of the attribute being measured (Hansen et al. 2007).

4.3.1 Abundance

4.3.1.1 Chinook and Steelhead

The goal of the abundance estimates is to obtain an unbiased estimate with specified precision. To derive an unbiased estimate of adult spawner abundance, the study design must either include a complete census count or sample a representative portion of the population and expand those counts to the entire population. Abundance of hatchery spawners is an example of a census count. For the natural spawner abundance, a complete census is unlikely and thus will rely on sampling a representative portion of the population and expanding those data to the entire population. The precision of Chinook and steelhead adult spawner abundance estimates should be measured by the coefficient of variation (CV), which is the ratio of the standard deviation to the mean. The goal is to have an estimate with a CV < 15%.

SONAR (sound navigation and ranging) counts are by nature a "census" but they must be partitioned (rather than expanded) by species composition. The expansion of fish or redd counts will require a study design that ensures the expansions are unbiased and have an associated measure of uncertainty (precision). Mark-recapture, probabilistic sampling of index reaches, and area-under-the-curve are all sampling designs that will meet these criteria when properly implemented (Schwarz and Taylor 1998; Parken et al. 2003; Parsons and Skalski 2010).

We propose to use DIDSON to estimate natural Chinook salmon and steelhead spawner abundance. We also recommend that genetic mark-recapture methods (Young et al. 2012) be considered in the future to estimate natural Chinook salmon spawner abundance once the method has been validated. We do not propose the genetic mark-recapture method for steelhead since it is unlikely that an adequate sample could be obtained for a genetic-mark-recapture method for this species.

DIDSON estimates can be derived as described in section 5. DIDSON estimates provide a reliable estimate (e.g., Cronkite et al. 2006; Dunbar and Pfisterer 2004), assuming one knows species composition. Few other species currently migrate in significant numbers relative to Chinook salmon during their spawning migration (Mayer et al. 2011). However, pink salmon are expected to migrate in large numbers in the future. We propose to use the mixed model developed by Liermann et al. (2012) to separate these species in DIDSON estimates. Weekly gillnet surveys are also recommended to provide additional information on species composition and to validate the model by Liermann et al. (2012).

Mark-recapture study designs provide unbiased estimates if the assumptions of the estimator are met (Seber 1973). Monitoring studies must address these estimator assumptions and adjust for violations of these assumptions. For example, the Petersen estimator for a closed population assumes that:

1. The population is closed (i.e., the population size is the same over time with no recruitment or losses);
2. Marked and unmarked fish have the same probability of being caught ((i.e., all fish have the same probability of being caught in the second sample, the same probability of being marked in the first sample, or marked and unmarked fish mix uniformly);
3. Marking does not affect fish behavior;
4. No marks are lost, and;
5. All marks are detected upon recapture.

Figure 14 provides guidelines for field sampling needed to achieve the recommended precision standard (CV < 15%). The precision of an estimate derived from a mark-recapture study design is determined by the number of fish caught in the first and second sample period relative to the total population abundance. In the case of genetic mark-recapture, each second sample (i.e., smolt) contains two "captures" and zero, one, or two "recaptures". Bailey's modification to the Petersen estimator is based on a binomial distribution and sampling with replacement. Therefore, the number of smolts needed in the second sample is half the number of "captures" needed to meet the data standard CV < 15%.

4.3.2 Managing for pHOS

4.3.2.1 Chinook

The goal for estimating Chinook salmon pHOS is an estimate with a 95% confidence interval of ± 6% (absolute value). The number of otolith and CWT samples will determine uncertainty in the estimated proportion of natural (or hatchery) spawners. Figure 15 provides guidelines for field sampling in order to achieve the recommended precision standard for pNOS/pHOS (± 6%). Figure 15 characterizes uncertainty using the half interval size of a 95% confidence interval, assuming the assumptions of the binomial distribution are met (i.e., samples are identically and independently distributed). Wilson's score confidence interval was used based on the recommendations of Agresti and Coull (1998).

To estimate total natural origin spawners (or hatchery origin spawners), uncertainty in the otolith/CWT data and the genetic mark recapture data need to be included. Figure 16 demonstrates the interaction between the number of genetic samples (juvenile and adult) used to estimate abundance and the number of adult otolith samples used to estimate pNOS/pHOS. Uncertainties in the two quantities were assumed independent allowing for a simple calculation of the total variance. In order to meet the data standard CV < 15%, different combinations of genetic and otolith analyses could be used depending on available funds (e.g., otolith $ < genetic $) and ability to collect juvenile and adult samples in the field.

4.3.2.2 Steelhead

The goal for estimating steelhead pHOS is an estimate with a 95% confidence interval of ± 20 percent (absolute value). The number of CWT samples will determine uncertainty in the estimated proportion of natural (or hatchery) spawners. As shown in Figure 15, the number of samples required to achieve the recommended precision standard for pNOS/pHOS for Chinook (± 6%), is unlikely for steelhead due to reduced population size, the difficulty associated with sampling during their return timing, and the remoteness of the area in which they will spawn. The uncertainty described in Figure 16 will also be required for steelhead; however, this uncertainty would be associated with the DIDSON estimates only.

4.3.3 Productivity

4.3.3.1 Chinook and Steelhead

The data standard goals for estimating juvenile recruits, proportion in different age classes, pNOS, and pHOS for Chinook and steelhead are as follows:

- Chinook
  - Juvenile recruits will be an unbiased estimate of juvenile migrant abundance with a precision value of CV < 15%.
  - Proportion of adults in each age class will be estimated with a 95% confidence interval of ± 6% (absolute value).
  - Proportion of hatchery and natural spawning adults will be estimated with a 95% confidence interval of ± 6% (absolute value).
- Steelhead
  - Juvenile recruits will be an estimate of juvenile migrant abundance with a low confidence interval and CV.
  - Proportion of adults in each age class will be estimated with a small confidence interval.
  - pNOS and pHOS with an unknown CV (dependent on sampling methods).

The abundance of juvenile migrants could be estimated using a single trap mark recapture study design (Volkhardt et al. 2008). Juvenile migrants would be released above the trap on a weekly basis throughout the outmigration period to test the assumption that all fish have an equal probability of being caught over time. If this assumption is violated, the data could be stratified by time or flow periods with homogeneous capture rates (e.g., Kiyohara and Zimmerman 2012). For days when sampling is not completed (e.g., high flows, trap repair), an estimate of catch could be accounted for by interpolating adjacent catch periods or using comparative outmigration curves from the neighboring Dungeness River (Topping et al. 2008). Based on comparable juvenile trap studies in Puget Sound, a CV < 15% should be attainable with this study design for Chinook salmon. However, based on the difficulty of sampling and therefore expected low trap efficiencies for outmigrating steelhead, estimates of juvenile steelhead outmigrants will most likely have large confidence intervals for a mainstem trap. For this reason, we propose the use of additional traps in small tributaries of Indian Creek and Little River where we expect to have a CV <15%.

The estimate of adult recruitment relies on the sum of total recruits (natural or integrated hatchery-natural) by age class over consecutive return years. Scales could be used to determine proportion of adults from each age class. The number of scale samples needed to estimate the proportion in a given age class can be approximated from Figure 15 by substituting the number of scales from natural (or hatchery) origin fish into the x-axis of this plot (otoliths (n)). Because both natural and hatchery produced fish are present in the system, sampling

Figure 14. Graph showing the number of samples (marks in adults and captures of smolts) sufficient to estimate population size with a coefficient of variation (CV) of 15% based on NOAA's monitoring guidelines for salmon and steelhead populations listed under the Endangered Species Act (Crawford and Rumsey 2011). The different lines represent different assumed population sizes.

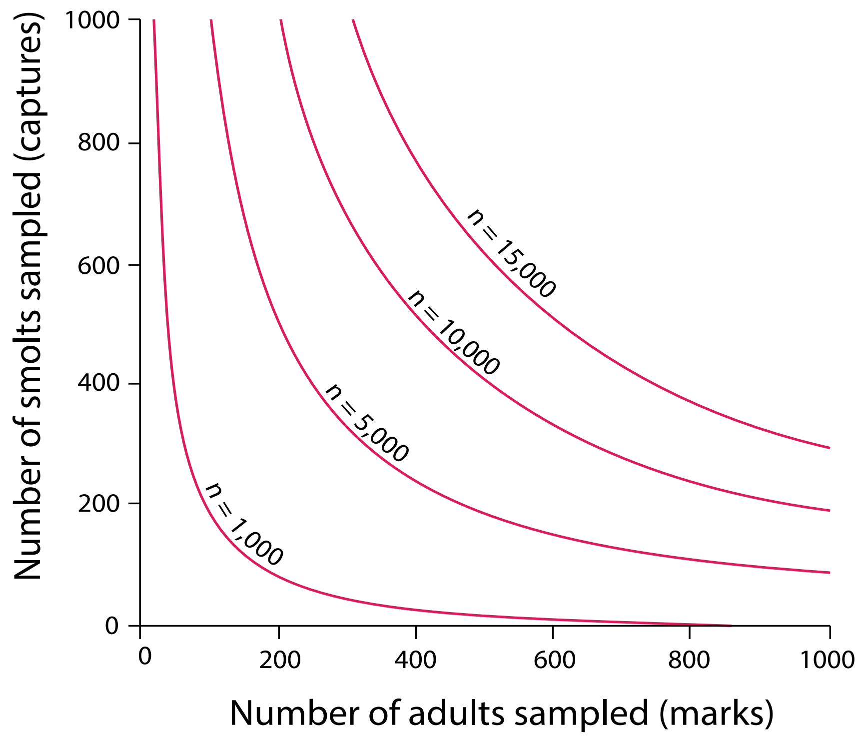


Figure 15. The half interval size for a 95% confidence interval for the proportion of natural (or hatchery) origin spawners based on the otolith sample size. The different lines represent three different assumed proportions (p).

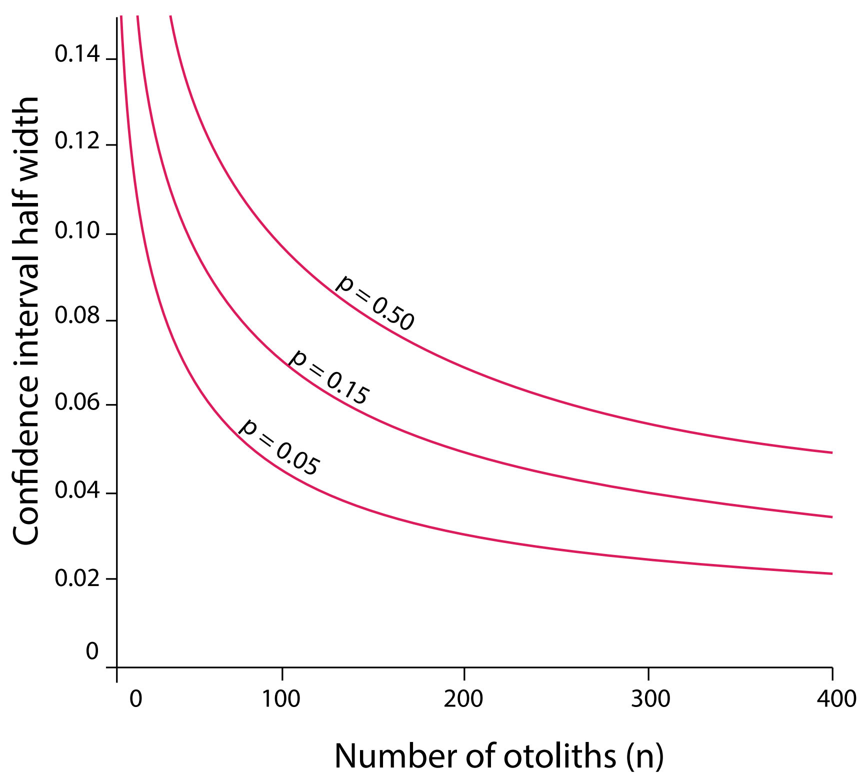
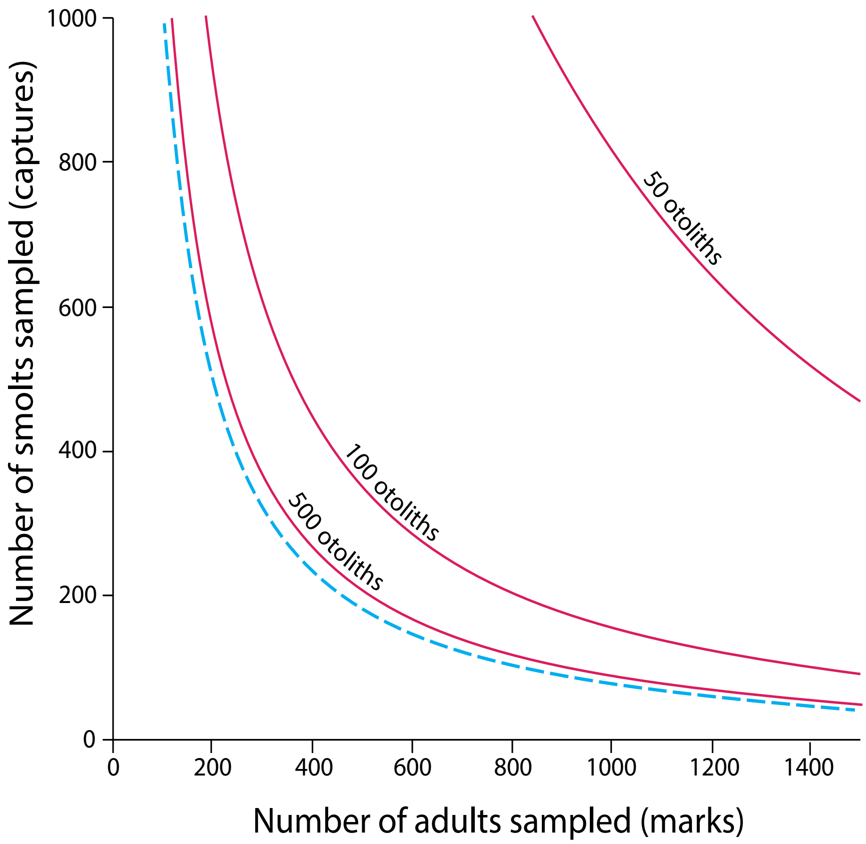


Figure 16. Figure showing the relationship between the number of adults marked and the number of smolts captured in a mark-recapture program, assuming a coefficient of variation in hatchery spawners of 15%. The more otoliths that are sampled, the fewer adults and smolts need to be sampled at the mark-recapture stage. The lowest line (blue dashed) represents the case where there is no uncertainty in pHOS. Total spawners and proportion hatchery origin spawners (pHOS) were assumed to be 5000 and 0.5, respectively, for this illustration.



estimates must also account for how many fish must be sampled to obtain the desired number of natural (or hatchery) origin fish. To achieve the age composition data standards for natural origin recruits only, otolith and/or CWT samples analyzed for fish origin must exceed the sampling recommended to meet the pHOS data standards alone (see above). For example, if the proportion of age-3 spawners is 15%, then approximately 60 scales are needed to meet the data precision standards. If pNOS is 5% (pre-dam-removal level for Chinook), then 1,200 otoliths/CWTs must be analyzed to ensure that a sample of 60 scales from natural origin recruits will be obtained. As a result, obtaining an adequate number of scale samples to achieve data standards for natural origin Chinook and steelhead recruits will be difficult in the early years of restoration. These data standards would be more easily met in the Local Adaptation and Viable Natural Population phases, when pNOS for Chinook is expected to steadily increase from 20% and 100% and the productivity trigger shifts from the integrated hatchery-natural stock to the natural stock alone.

Data does not currently exist for steelhead pNOS and pHOS in the Elwha River since hatchery fish produced from the native broodstock have not yet returned to the watershed (first returns from the captive brood program occurred in 2013). With the small extant population size, unknown number of hatchery raised native steelhead returning to the watershed, and high turbidity levels, recovery of sufficient numbers of carcasses will be difficult for determining age structure of NOS and pNOS/pHOS, particularly in the earlier phases of restoration. As a result, obtaining an adequate number of scale or otolith samples to achieve data standards for steelhead will be difficult in the early years of restoration, although it is expected these data standards will be met more easily in the Local Adaptation and Viable Natural Population phases.

Hatchery produced Chinook and steelhead are marked in multiple ways in the Elwha River. A small proportion of hatchery Chinook salmon in the Elwha River are adipose fin-clipped and marked with CWTs, while all are otolith marked. All hatchery produced steelhead are marked using either CWTs or adipose fin-clips. Steelhead produced from the captive brood program have been marked using CWTs with no adipose fin-clip. Chamber Creek steelhead have adipose fin-clips but have not been marked with CWTs.

Sampling for productivity in tributaries (e.g. Little River and Indian Creek) may provide more precise estimates for steelhead within the Elwha watershed and provide an index for productivity. Net sampling, smolt trapping, foot surveys, and carcass recovery will be more effective in these areas, allowing us to establish smaller confidence intervals and CVs. These data may then be extrapolated to apply to the rest of the Elwha River watershed and used to estimate productivity parameters for the broader population, potentially enhancing the power of our results. Sampling the tributaries requires the assumption that they are representative of the Elwha system as a whole. Although productivity in the tributaries may be a bit higher than throughout the entire watershed, the estimate will likely be more reliable than the estimate obtained from mainstem sampling which would likely have extremely large CVs due to poor sampling efficiency associated with the large river.

4.3.4 Diversity

4.3.4.1 Chinook

The data standard goals for Chinook diversity were set to determine the proportion of stream-type Chinook salmon with a 95% confidence interval of ± 6% (absolute value).

The number of scale samples needed to meet the data standards for the life history diversity (proportion of stream-type Chinook) will vary according to the proportion of this life history type in the population. The proportion of stream-type Chinook (low to none during pre-dam-removal monitoring) may increase to 30% of the returning spawners over time. The number of samples needed to meet the data standards can be approximated from Figure 15 by substituting the number of scale samples onto the x-axis in the place of otoliths (n) of the figure and following the lines for p = 15% and p = 50%.

4.3.4.2 Steelhead

The data standard for assessing the entry timing of steelhead into the Elwha River is a probability of accurately detecting entry timing of 0.53. This data standard was developed based on the factors influencing the likelihood that steelhead entry timing would be accurately detected. The probability that steelhead entry timing will be detected depends on the date the DIDSON starts sampling (P_f, probability that the start date is before the entry timing), the amount of the total data set reviewed (P_d, the probability that the data set containing a passing steelhead is sampled), the amount of time the DIDSON is operational during the sampling period (P_t, the probability that the DIDSON is operational), the presence of other steelhead sized species (e.g., coho and chum) in the system (P_s, the probability that the passing fish is a steelhead), and the efficiency of the DIDSON unit and observers in detecting fish presence (P_e, the probability that a passing fish is detected by the DIDSON unit and the observer(s) assessing the data). The probability of detecting steelhead entry timing will be multiplicative based on the probabilities of each of the factors described above.

$$P(D) = P_f*P_d*P_t*P_s*P_e$$

$$P(D) = 0.53 = 1*1*0.7*0.95*0.8$$

Some of these probabilities can be controlled and some cannot. Those factors that can be controlled should be held to a probability as close to 1 as possible.

The factors that can be controlled include the start date for DIDSON sampling (P_f) and the amount of the total data set that is reviewed by observers (P_d). Despite the possibility of freshets, we have assigned a probability of 1 to P_f because we are confident that the DIDSON sampling could start early in December, which is the earliest likely arrival of steelhead. The amount of the total data set reviewed by observers is easy to control: we recommend that all the data be viewed until the first steelhead is detected, resulting in a P_d of 1.

Factors that cannot be controlled, and in some cases estimated, include the amount of time

Table 9. Tools and methods useful for monitoring the abundance of Elwha River Chinook salmon and steelhead. Differences for steelhead are noted in parenthesis (). Annual costs are estimated in FY13 dollars and the tools and estimates should be reviewed annually.

Abundance Indicator	Tools	Method	Sampling Area	Extent of Tributary Sampling	Period of Monitoring	Sampling Frequency	Leads	Data Mgt.	Annual Cost	Limitations
Harvest	Ocean catch reporting (not done)	Backwards FRAM model	seAK, Can, U.S. Fisheries	na	Jan. – Dec.	Daily	WDWF, DFO, ADFG	CTC, none	na	Unknown accuracy or precision
	Terminal area catch reporting	User catch reports	All river areas open to fishing	na	Jul. – Oct.	Daily	WDFW, LEKT	WDFW, LEKT	na	Reliance on accurate user reporting
Broodstock	Broodstock collection	Count	Near WDFW hatchery	None	Sep.	Daily	WDFW	WDFW	na	Low visibility downstream dam sites
Hatchery rack	Hatchery rack returns	Count	WDFW, LEKT, Morse Cr. hatchery facilities	None	Jul. – Oct. (Dec. – Jun.)	Daily	WDFW, LEKT	WDFW (LEKT)	na	na
Spawning escapement	Foot surveys (redd, live count)	Area under the curve	Mouth to Glines Canyon powerhouse site	Bosco Cr. upstream to Long Cr.	Aug. – Oct. (Dec. – Jun.)	every 7-10 days	WDFW, LEKT, ONP	WDFW, LEKT	$33,333	Low visibility downstream dam sites
	DIDSON Sonar	Count[1]	~Rkm 2	None	Dec. – Oct.	Daily	NOAA, LEKT	NOAA, LEKT	$200,000 for 2 sites	Species identification and composition limited
	Weir	Count	~Rkm 6	None	Jul. – Oct.	Daily	WDFW	WDFW	$281,000	Trap aversion
	Adult and juvenile sampling[2] (none)	Parentage genetic mark-recapture (none)	Entire watershed	All	Jan. – Oct.	Daily	WDFW, LEKT	WDFW, LEKT	$67,000	Getting representative sample of entire juvenile outmigration
	Aerial redd surveys	Peak count	Rkm 0 to rkm 65	TBD	Aug. – Sep. (Dec. – Jun.)	1-2 flights (7 flights)	ONP	ONP	$2,000 ($5,000)	Low visibility downstream dam sites
	Boat surveys (redd, live count)	Count; redd life measure	Rkm 0 to 25	None	Aug. Oct.	Weekly	WDFW	WDFW	$33,333	Low visibility downstream dam sites

[1]With bootstrapping to fill in missing hours or days
[2]Weir, carcass surveys, or gill netting for adults; smolt trap for juveniles

Table 10. Tools and methods useful for monitoring the annual hatchery contribution to Elwha River Chinook salmon and steelhead. Differences for steelhead are noted in parenthesis (). Annual costs are estimated in FY13 dollars and the tools and estimates should be reviewed annually.

Indicator	Tools	Method	Sampling Area	Extent of Tributary Sampling	Period of Monitoring	Sampling Frequency	Leads	Data Mgt.	Annual Cost	Limitations
pNOS, pHOS	Carcass sampling, weir, surveys	Thermal otolith mark interpretation	Elwha River	Represen-tative	Jul. – Oct. (Dec. – Jun.)	Weekly	WDWF, LEKT, ONP	WDFW	$8,800 for lab analysis	Clarity of thermal mark
		CWT recovery/ reading (CWT and adipose fin detections)	Elwha River (Elwha River + tributaries)	Represen-tative	Jul. – Oct. (Dec. – Jun.)	Weekly	WDFW, LEKT, ONP	WDFW, RMIS (LEKT)	na	Tag loss

Table 11. Tools and methods useful for monitoring the productivity of Elwha River Chinook salmon and steelhead. Differences for steelhead are noted in parenthesis (). Annual costs are estimated in FY13 dollars and the tools and estimates should be reviewed annually.

Productivity Indicator	Tools	Method	Sampling Area	Extent of Tributary Sampling	Period of Monitoring	Sampling Frequency	Leads	Data Mgt.	Annual Cost	Limitations
Freshwater productivity	Smolt trap	Thermal otolith mark interpreta-tion	Near mouth (Indian Cr./Little R.)	None (partial)	Jan. – Aug.	Daily	LEKT	WDFW	$60,000	Truncated deployment due to hatchery releases (trap efficiency)
	Spawner escapement	See Table 9	Entire watershed	All	Jan. – Jun.	Daily	WDFW, LEKT	WDFW, LEKT	See Table 9	Representative sample of entire outmigration
Spawner recruit per spawner	Carcass sampling, Weir, foot and boat surveys	Thermal otolith mark interpreta-tion	River, hatchery	Represnen-tative	Aug. – Oct. (Dec. – Jun.)	Weekly	WDFW, LEKT, ONP	WDFW SGS (LEKT)	$45,000 for analysis	Clarity of thermal marks
		CWT (CWT and adipose fin detection)	River, hatchery	Represen-tative	Aug. – Oct. (Dec. – Jun.)	Weekly	WDFW, LEKT, ONP	WDFW RMIS (LEKT)	na	Tag loss
		Scale analysis	River, hatchery	Represen-tative	Aug. – Oct.	Weekly	WDFW, LEKT, ONP	WDFW	na	Clarity of scale annuli
	Spawner escapement	See Table 9	River, hatchery	Represen-tative	Aug. – Oct. (Dec. – Jun.)	Weekly	WDFW, LEKT, ONP	WDFW	na	See Table 9
Pre-fishing recruit per spawner	Ocean catch reporting	Backwards FRAM (not done)	seAK, CAN, U.S. Fisheries	na	Jan. – Dec.	Daily	WDFW, DFO, ADFG	CTC	See Table 9	Unknown accuracy or precision
	Terminal area catch reports and sampling	User catch reports	All rivers open to fishing	na	Jul. – Oct. (Dec. – Jun.)	Daily	WDFW, LEKT	WDFW, LEKT	See Table 9	Rely on accurate user reporting
	Hatchery rack return	Count	WDFW, LEKT, Morse Cr.	None	Jul. – Oct. (Dec. – Jun.)	Daily	WDFW, LEKT	WDFW	na	na
	Broodstock	Count	Near WDFW hatchery	None	Sep.	Daily	WDFW	WDFW	na	Low visibility
	Carcass sampling, weir, surveys	Otoliths, CWT, Scales	River, hatchery	Represen-tative	Aug. – Oct. (Dec. – Jun.)	Weekly	WDFW, LEKT, ONP	WDFW, LEKT, ONP	See above	na
	Spawner Escapement	See Table 9	Entire watershed	All	Jan. – Oct. (Dec. – Jun.)	Daily	WDFW, LEKT	WDFW, LEKT	See Table 9	Representative sample of entire juvenile outmigration

Table 12. Tools and methods useful for monitoring the diversity of Elwha River Chinook salmon and steelhead. Differences for steelhead are noted in parenthesis (). Annual costs are estimated in FY13 dollars and the tools and estimates should be reviewed annually.

Indicator	Tools	Method	Sampling Area	Extent of Tributary Sampling	Period of Monitoring	Sampling frequency	Leads	Data Mgt.	Annual Cost	Limitations
Life history diversity	Carcass sampling, gillnetting, weir, foot and boat surveys	Scale analysis	River, hatchery	Represen-tative	Jul. – Oct.	Weekly	WDWF, LEKT, ONP	WDFW	na	Clarity of scale annuli
	DIDSON sonar	See Table 9	Rkm 2	None	Jul. – Oct. (Dec. – Jun.)	Daily	NOAA, LEKT	NOAA, LEKT	See Table 9	Difficult to ID species and composition
	Weir	Count	Rkm 6	None	Jul. – Oct.	Daily	WDFW	WDFW	See Table 9	Trap aversion
	Gillnet	Species Composition	Lower river	None	Jul. – Oct. (Dec. – Jun.)	Weekly	WDFW, LEKT	WDFW	See Table 9	Low numbers

the DIDSON will be operational (P_t), the observation efficiency (P_e), and the presence of other steelhead sized fish species in the system (P_s). Based on previous Elwha sampling, we estimate that the DIDSON will be operational 70% of the time ($P_t = 0.7$), with outages due to freshets, power outages, and other unforeseen issues. DIDSON units and data observers have been shown to be relatively precise and therefore have a high probability of detecting a fish when present (Holmes et al. 2006; Coyle and Reid 2012; Pipal et al. 2012). Based on results from these studies, we set $P_e = 0.8$.

Assigning a probability to observed fish actually being steelhead and not another species (P_s) is problematic, and will change throughout the year as the numbers of coho and chum salmon decline from December through February. We assigned a probability of 0.95 to this based on the recommendation that weekly sampling (i.e., weir, gillnet) be completed to determine species composition near the DIDSON. Obviously, if a steelhead is caught during gillnet surveys it can be assumed that at least one of the fish observed in the DIDSON was a steelhead.

As a result of this probability exercise, we conclude that it is important to maximize the probabilities for factors under control because some factors are not under control. Thus we recommend: a) DIDSON is installed in early December, b) all DIDSON data are reviewed until the first steelhead is observed, and c) weekly sampling be used to determine species composition of fish near the DIDSON.

4.3.5 Distribution

4.3.5.1. Chinook and Steelhead

Data standards were developed to adequately identify the extent of adult Chinook salmon and steelhead distribution and barriers present in the system. Adult distribution could be assessed using tools identified for assessing spawner escapement and distribution, including foot surveys, aerial surveys, and boat surveys (Table 9), along with radio-telemetry surveys.

The data standard for accurately determining Chinook and steelhead distribution is expected to be near 100% for the mainstem and lower river tributaries (i.e., Indian Creek, Little River). These data standards were developed assuming a combination of foot, boat, and aerial spawner surveys, and radio-telemetry surveys would be completed to assess distribution. Given this, the probability of detecting overall distribution is the combined probability of detecting distribution during spawner surveys and radio-telemetry surveys (i.e., the probabilities are additive rather than multiplicative as in the entry timing situation above). It was assumed that the observer efficiency of the spawner surveys would be 76% and 18% for Chinook and steelhead, respectively and that the efficiency of radio-telemetry surveys would be 87% for both fixed stations and aerial surveys. Adding the probabilities from the spawner surveys and telemetry ($0.76+0.87 >1$; $0.18+0.87 >1$) results in a combined probability of 100% for detecting fish Chinook and steelhead distribution. It also allows the assumptions made in this section to be evaluated during data collection, which is highly recommended so the exact level of uncertainty can be determined.

Observer efficiency during spawner surveys can be influenced by time of season, turbidity, discharge, channel confinement, gradient, species, stream habitat, and water depth (Shardlow et al. 1987; English et al. 1992; Korman et al. 2002). Efficiency estimates for the spawner surveys were developed based on data reported in the literature (Solazzi 1984; Trouton 2004; Gallagher et al. 2010). For Chinook salmon, we relied upon observer efficiency values reported by Solazzi (1984) and Trouton (2004), who reported observer efficiencies of 76.1% and 96%, respectively. Given the larger size of the Elwha River and the difficulties associated with surveying the upper watershed, we selected the lesser value (76%) reported by Solazzi (1984) as the probability that Chinook salmon distribution would be accurately assessed (i.e., fish observed) using spawner surveys. Observer efficiency estimates were much less for steelhead; reported as 18% (Gallager et al. 2010).

Efficiency estimates for the radio-telemetry surveys were developed based on Wertheimer et al. (2003). Detection efficiencies for radio-tagged kelts passing Columbia River dams ranged from 66% to 96% (averaged 86.8%). The mean value was used as the efficiency value for all telemetry data since no other efficiency information could be found. It is recommended that the efficiency of both fixed stations and aerial surveys be assessed to ensure the data standards specified here are met or adjusted as necessary.

5. Monitoring Tools and Objectives

This section outlines the tools and methods proposed for use to measure performance indicators and to meet the data standards suggested herein. This section also highlights the spatial extent of sampling, period and frequency of sampling, and lead roles of each entity. Performance indicators include those described for the VSP monitoring that could be measured for Chinook salmon and winter steelhead. Although not generated as part of these guidelines, VSP monitoring should also occur for coho salmon, chum salmon, sockeye salmon, and pink salmon. Bull trout should be covered in a separate document. Performance indicators are also identified for testing the assumptions associated with the restoration strategies as well as for habitat, fish health, and ecosystem objectives associated with the restoration process. In this section, we define "tools" as the means of gathering data and "methods" as the analysis or estimator used to derive the indicator measure. Every method, therefore, relies on one or more tools to acquire data.

The size, complexity, and other physical characteristics of the Elwha River (particularly access in roadless areas, visibility in the water column, and safety during high flows) as well as the limited resources available, impose substantial constraints on the different approaches to estimating the performance indicators. Therefore, a combination of approaches will be necessary in many cases to estimate the performance indicators.

Visibility is a major constraint on the effective use of survey tools. High flows and decreased visibility occur naturally throughout the Elwha River and its major tributaries during winter freshets and spring snowmelt, temporarily reducing the effectiveness of visual survey techniques (e.g., live counts or redd counts). In response to controlled releases of sediment during dam removal and erosion occurring on the newly exposed reservoir soils following dam removal, this issue will be exacerbated in the reaches downstream of the reservoir sections and will occur during all months of the year. It is unknown how long poor visibility conditions will persist in the Elwha River due to dam decommissioning. Therefore, visual survey techniques alone will not be an effective means of measuring salmon and steelhead spawning in the reaches downstream of the reservoir sections (below Rkm 25) and salmon and winter steelhead spawning distribution throughout the watershed (those spawning during winter freshets and snowmelt).

A second constraint to monitoring performance indicators in the Elwha River is river access. The vast majority of the basin, including approximately 75% of the mainstem and floodplain reaches, lacks road access. Thus, tools that are facilitated by vehicle access (such as visual foot surveys) will be costly and impractical for a substantial portion of the watershed (> Rkm 25) and alternative tools such as aerial redd surveys, snorkel surveys, or fixed radio-telemetry stations may be preferable.

Lastly, the protected status of three ESA listed salmonid species in the Elwha River – Chinook salmon, steelhead, and bull trout - limits the potential tools used to quantify abundance, productivity, distribution, and diversity. Fish handling, sampling, and tagging provide valuable biological information but the benefits of this information must be weighed against the potential fish health consequences. Furthermore, other terrestrial species that are ESA listed (Spotted Owls and Marbled Murrelets) constrain other aspects of working on fish populations, mostly related to noise associated with aircraft engines.

Based on these logistical constraints, many of the performance indicators will require the combination of multiple tools. Regardless of the life stage, habitat type, or watershed performance indicator, the use of multiple methods brings up the same general question – can performance indicators be reliably derived by combining different tools and methods? If not, are there analytical techniques that allow for comparison between methods measuring the same performance indicator?

5.1 Abundance

5.1.1 Chinook

Abundance is the sum of harvest, hatchery rack returns, broodstock collection, and spawner escapement (Table 9). Hatchery rack returns and broodstock collection are census counts whereas harvest and spawning escapement numbers must be estimated using a combination of tools and methods.

Harvest is the sum of interceptions in the southeast Alaska, Canadian, and southern U.S. (SUS) fisheries. Terminal harvest in the Elwha River has been minimal over the last decade (Table 6 – Section 4) and is currently curtailed due to an agreed upon 5-year fishing moratorium associated with dam removal. Any future terminal harvest should be tracked using Fish Tickets (commercial) and Catch Record Cards (sport) currently used by co-managers to report catches in terminal area fisheries. Ocean harvest of Elwha Chinook salmon is estimated with the backwards FRAM (Fishery Regulation Assessment Model) as part of the annual review by the Chinook Technical Committee of the Pacific Salmon Commission (PSC). Exploitation rates are estimated by the FRAM based on fishery catches and stock escapement in a given year and the ocean distributions of that same stock over the model base period. Although CWT recoveries may generally be used for estimating exploitation rates, recoveries from Elwha Chinook in recent years have been too low to derive reliable estimates (P. McHugh, WDFW, personal communication).). NOAA has low confidence in the Elwha River FRAM estimates at this time. The data provided in the model is dated, contains a conglomerate of life histories (i.e., fingerling and yearling), and cannot be supported by recent year CWT recovery analysis because there haven't been sufficient numbers of fish released with adipose fin-clips and/or CWTs for many years. Thus, the estimates for southeast Alaska and Canada may be biased high but the SUS fishery values are accepted as the best exploitation estimates available at this time (L. LaVoy, NOAA, personal communication).

Spawning escapement will be challenging to estimate for Elwha Chinook and a number of tools and methods will be useful (Table 9). We propose different suites of methods during the Preservation, Recolonization/Local Adaptation, and Viable Natural Population phases. The use of DIDSON SONAR is recommended to estimate Chinook salmon and steelhead abundance during one or more of the restoration phases and is therefore described here in detail.

Single beam sonar systems have been used to enumerate fish migration in rivers since the early 1960's. Similar technology is still being used to measure escapement in a number of commercial fisheries in Alaska (Westerman and Willette 2003; Dunbar and Pfisterer 2004; Dunbar 2001, 2003; McKinley 2002), and Canada (Levy et al. 1991, Cronkite et al. 2006). More recent sonar technology has greatly improved counting accuracy by incorporating multiple high frequency beams, producing "movie" quality images while also providing detailed data on several other fish characteristics including direction of travel, range, length, and swimming speed (Belcher et al. 2001, 2002). Most imaging sonar-based salmon escapement estimation on the west coast of North America is based on DIDSON.

Several studies have been conducted relating DIDSON counts of adult salmon derived from DIDSON imaging systems to other enumeration methods such as weir passage (Holmes et al. 2006), visual counts (Enzenhofer et al. 1998, Maxwell and Grove 2007), and mark-recapture (Cronkite et al. 2006, Holmes et al. 2006); and DIDSON counts have consistently been found to have little error compared to the more traditional methods. It is important to note; however, that most of the practical and research applications of DIDSON have been focused on large salmon runs that transpire over the course of only a few short weeks, and employ large technical staffs and operating budgets to produce their results (e.g. Lilja et al. 2008). In the Elwha River, attempts would be made to enumerate a protracted run of Chinook over a few months.

A DIDSON 300LR multi-beam imaging SONAR has been tested in the Elwha River (Denton 2012). It has been deployed at a long range, low frequency setting. The DIDSON includes a high resolution large lens that has been set out to 40 meters due to the size of the river. The DIDSON has typically operated from December until the first high spring flows, typically the end of February or beginning of March. The DIDSON has then been re-deployed as soon as flows recede, which may be after the migration and spawn timing of the steelhead. During this entire period of operation either a picket weir fence has been installed to shunt fish towards the DIDSON or eight 10 foot resistance panels have been placed on a substrate rail directly downstream from the DIDSON, forcing upstream migrating fish to pass at least 4 meters in front of the transducer (see Tobin 1994 for a rough approximation of the design of these panels). The method depends upon the location and site specific needs to maximize the probability of capturing the fish on the DIDSON image.

The first 20 minutes of each recorded hour is typically analyzed for fish passage (Lilja et al. 2008). These counts are then simply multiplied by three to obtain hourly passage numbers (Lilja et al. 2008). Raw imagery is transformed into an echogram which is used to identify possible targets that could then be visually confirmed from the raw imagery data. This process eliminates the need for reviewing frames that do not contain moving targets, greatly reducing the amount of time necessary to review recorded imagery (see Denton and Liermann 2011 for a full description of this procedure). Each target that is deemed a fish is then categorized into one of three length classes in an effort to capture the range of possible fish sizes present in the Elwha River. In addition, each target is categorized into one of three observer confidence categories to provide a composite of qualitative information that can affect the ability to accurately record the passage of a fish, such as image quality, speed of fish passage, and distance of passage. Final fish passage analysis and passage numbers are based solely on fish that ranked as the largest length class and the best observer confidence ranking. If no imagery is recorded for a period of time, for whatever reason, then an estimate is made by simply averaging the daily fish passage for the week before and the week after the gap and applying that daily rate to each day during the recording gap. There typically is no estimate of fish passage when floods preclude recording. Over the last several years the DIDSON has recorded steelhead sized fish migrating everyday past the site of operation. Upstream counts have been estimated during this time period. As turbidity levels remain high into the summer Chinook season and the DIDSON emerges as the primary enumeration tool, we recommend moving the DIDSON to the Hunt Road Side Channel to take advantage of the narrower channel and lower flows.

Preservation Phase: Chinook spawning in the Preservation Phase will be concentrated below the former Elwha dam site. Two methods - genetic mark recapture and DIDSON estimates - should be used simultaneously to estimate total watershed escapement during this phase. The use of two methods is recommended to ensure that a reliable estimate is obtained. Both of these methods are designed to produce unbiased estimates of known precision. Neither method relies on visual surveys and are, therefore, well matched for the expected turbidity of the lower Elwha River. DIDSON should be located as close to the mouth of the river as possible and will use the method described in Denton and Liermann (2011). Weekly gillnet surveys should be completed in conjunction with DIDSON to provide species composition estimates necessary to develop species specific estimates. Genetic mark recapture (GMR) is a parentage based analysis similar to the approach of Pearse et al. (2001) with the exception that we are proposing an inter-generational application of this method. This method has been successfully used by WDFW on the Coweeman, Stillaguamish, and Green Rivers. The GMR method genotypes a subset of the spawners (live releases from the weir and/or gillnet surveys and carcasses recovered during stream surveys) and a subset of the juvenile outmigrants (captured at the smolt trap). The parental genotype is the "mark" and the mark to unmark ratio in the second sample (smolt trap) is used to expand the mark in the first sample (genotyped adults).

Recolonization and Local Adaptation Phases: Chinook spawning distribution during the Recolonization and Local Adaptation phases will be expanding through the Aldwell and Mills reaches (i.e., the former reservoirs) of the Elwha River. Therefore, tracking escapement into these portions of the watershed will be important during these phases. The methods used to estimate escapement should be designed to inform both the escapement and the spatial distribution performance indicators. Total escapement should be measured using either a DIDSON count at the river mouth or GMR. The usefulness and reliability of these two methods should be evaluated during the Preservation Phase and a single method selected for the Recolonization and Local Adaptation Phase. Escapement above the former Lake Aldwell reach should be measured with a DIDSON estimate and will use the method described in Denton and Liermann (2011). Aerial surveys during peak spawn timing may also be used to assess overall distribution and relative abundance in different areas of the watershed.

Viable Natural Population Phase: In this phase, Chinook spawning should have reached its maximum extent in the watershed and water clarity is expected to improve. Cost effectiveness of the estimation method is a primary consideration during this phase and used to establish a long-term monitoring method. The use of parallel methods (i.e., both intensive and cost effective) is recommended until an adjustment factor for the cost effective method can be reliably determined. The intensive method should be either a DIDSON estimate at the river mouth or GMR and should be consistent with the total escapement method selected during the Recolonization/ Local Adaptation phases. The cost effective method should include a combination of aerial surveys during peak spawning and stratified foot surveys in side channel, tributary, and mainstem habitat. The distribution of redds/km in the foot surveys should be used to expand the distribution information gained from the aerial surveys. An adjustment factor for this redd-based estimate should be developed using the DIDSON or GMR estimate depending on which is deemed more reliable during the Preservation Phase.

5.1.2 Steelhead

As with Chinook, adult steelhead abundance is the sum of harvest, hatchery rack returns, broodstock collection, and spawner escapement. Spawner escapement will be challenging to estimate for steelhead. In contrast to Chinook, fewer methods are proposed due to expected low abundance, which limits the usefulness of GMR. We propose different suites of methods during the Preservation, Recolonization/Local Adaptation, and Viable Natural Population phases.

Preservation, Recolonization, and Local Adaptation Phase: A two-pronged approach is recommended for enumerating Elwha River steelhead,, including traditional redd and foot surveys combined with live and dead counts of adult steelhead and DIDSON SONAR estimates in the mainstem as described above. Redd and foot surveys should be utilized in parts of the Elwha where visibility allows these surveys to be completed. To this point, redd survey efforts have been concentrated on tributary habitats such as the Little River and Indian Creek. Weekly redd surveys have been conducted during the course of the spawning season to determine the location and timing of adult steelhead spawning activity. Current areas of emphasis include the Little River and Indian Creek, several side channels in the middle Elwha River (from Glines Canyon Dam downstream to the former Elwha Dam site), and the WDFW Hatchery outflow channel in the lower Elwha River. Surveys have typically begun mid-April and continue until mid-July due to noted later spawning steelhead that utilize the Elwha. In some years, redd counts can start as late as May because visibility in Little River and the side channels is too poor for visual surveys in April. Surveys have been conducted once per week at sites except when conditions do not allow for it, such as poor visibility in the side channels. Stream conditions are also identified during surveys. Specifically, stream flow is visually described as: low, moderately low, moderate, moderately high, or high. Stream visibility has been described as: excellent, very good, good, fair, or poor.

Redds are identified as disturbed areas in the stream bed where gravels were overturned. Each redd should be identified with a distinct GPS location (latitude and longitude) and number. They should also be marked with a flag that includes the redd number for the individual stream, date, surveyor initials and the distance (m) and direction to the redd from the flag (e.g., 1; 11/21/11; CGO and SK; L 2 m). All old redds should recorded in a field book from the previous surveys. In addition to redds, live and dead spawning *O. mykiss* should be counted and classified by sex (male/female) and life history (steelhead/resident rainbow trout) based on size (resident rainbow trout < 20" in length), degree of darker coloration, and presence of numerous spots below the lateral line (as described in McMillan et al. 2007). The redd data can be analyzed several ways. First, redd counts can be delineated by date for all sites combined to describe the timing of redd construction. Second, the spatial distribution of redd counts could be mapped. Next, the total number of alive and dead winter steelhead observed during the surveys can be described and delineated by sex and life history. Lastly, the number of winter steelhead females per redd can be calculated.

Viable Natural Population Phase: Methods used to assess adult steelhead abundance could be the same as those described for Chinook salmon above, except that GMR will not be used.

5.2 Managing for pHOS

5.2.1 Chinook and Steelhead

The proportion of natural origin spawners (pNOS) and proportion hatchery origin spawners (pHOS) in the overall Chinook salmon and steelhead escapement should be estimated. The PNI should be estimated for the hatchery stock (HSRG 2009). PNI is a function of the pNOB and pHOS:

Equation 5

$$PNI = \frac{pNOB}{pNOB + pHOS}$$

The origin of Chinook salmon returning to the Elwha River could be determined using a combination of two tools - CWTs and thermal otolith marks (Volk et al. 1990; Duda et al. 2011b) (Table 10). As discussed above, few Chinook salmon in the Elwha River are adipose fin clipped to protect them from mark-selective fisheries, since escapement has been extremely low and expected to be impacted by the large volumes of sediment released from dam removal. A positive reading for either a CWT or an otolith thermal mark is assumed to be hatchery origin and a negative is assumed natural origin. A positive reading then allows for the decoding of the CWT or thermal mark to determine hatchery of origin, brood year, age, and other information such as release strategy. Information acquired from CWTs and otoliths will depend on field collections of a spatially and temporally representative sample of carcasses from both the river and the hatchery.

The origin of steelhead can be determined by adipose fin clips and CWTs. Native steelhead are unmarked. The Chambers hatchery stock received an adipose fin clip, while the progeny of the native Elwha captive brood program have been marked with CWTs through 2013. However, the tags used are simple agency wire and therefore do not include sufficient information to determine when they were released. Thus, we will be unable to determine brood year and age of adult steelhead from these groups using CWTs. Once the Chambers Creek hatchery stock is eliminated, the progeny from the native Elwha captive brood program can be marked with only an adipose fin clip and this will occur in 2015. As with Chinook, information acquired from CWTs will depend on field collections of a spatially and temporally representative sample of carcasses from both the river and the hatchery.

5.3 Productivity

5.3.1 Chinook and Steelhead

Productivity indicators measure the recruitment to a particular life stage divided by the number of parent spawners. Tools and methods used to estimate spawning escapement (Table 9) and origin (Table 10) are described above. Tools and methods used to estimate recruitment to three life stages - juvenile migrant, pre-fishing adults, and adult spawners – are described below.

Freshwater productivity is the freshwater production (number of juvenile migrants) divided by the number of parent spawners (Table 11). Freshwater production for Chinook should be monitored using a smolt trap near the river mouth and a mark-recapture study design. Freshwater production for steelhead should be monitored at the smolt trap near the river mouth used for Chinook and at two tributary traps, located in Indian Creek and Little River. The smolt traps should be operated for as much of the outmigration period as possible. Missed fishing periods during high flows or large releases of hatchery Chinook (river mouth trap only) should be recorded by time period so that missed catch can be estimated and incorporated into the total estimate. Efficiency trials to calibrate the smolt traps should be conducted on a weekly basis. A subsample of Chinook and steelhead should be measured to assess freshwater growth and assign outmigrant age class. Scales should be collected to assign age class, as needed. A Petersen estimator, appropriate for a single trap design, should be used to calculate freshwater production for Chinook salmon (Volkhardt et al. 2007). This method should be used at all three traps for steelhead.

Spawner-to-spawner productivity is the number of returning spawners in each age class divided by the number of parent spawners. Tools and method used to estimate spawning escapement (S) are presented in Table 9. Sampled spawners in each return year should be identified by age and origin and assigned to parent brood year. Recruitment by age class and origin should be estimated by expanding the sampled proportions of the spawners to the entire abundance of natural spawners for a given return year. Spawner-recruits (R^s) are the sum of all returning spawners assigned to a particular parent brood year. In the Preservation and Recolonization phases, the trigger for this indicator should be calculated for the integrated (combined) hatchery and natural spawners (Preservation) and the natural spawners alone (Recolonization). In the Local Adaptation and Viable Natural Population phases, the trigger for this indicator should be calculated from natural spawners only.

Pre-fishing recruits-per-spawner is the pre-fishing abundance divided by the number of parent spawners. Pre-fishing abundance is the sum of harvest (R^{Hvst}), hatchery rack returns (R^{Htch}), broodstock collection (R^B), and natural spawners (R^S) in each return year. Tools and method used to estimate spawning escapement (S) and the number of recruits (pre-fishing $R^O=R^{Hvst}+R^{Htch}+R^B+R^S$) are described above (Table 9). Recruitment by age class and origin should be estimated by expanding the sampled proportions of spawners to the entire abundance of spawners for a given return year. In the Preservation and Recolonization phases, the trigger for this indicator should be calculated from the integrated (combined) hatchery and natural spawners. In the Local Adaptation and Viable Natural Population phases, the trigger for this indicator should be calculated for natural spawners only.

Estimates of productivity require both origin and age determination. Hatchery or natural origin of Elwha River Chinook is determined through the presence of a CWT or otolith thermal mark, and the presence of a CWT or adipose fin clip for steelhead, as described above. For unmarked fish, scale analysis is used to estimate brood year, freshwater age, ocean age, and rearing strategy. If a yearling life history is assigned to a sample, an estimate of hatchery or natural would be given; if a sub-yearling life history is given, no corresponding hatchery or natural classification would be noted (left blank). All scale age assignments are recorded with the Gilbert-Rich ageing notation (Gilbert 1912; Rich and Holmes 1928). For example, an adult Chinook sampled in the fall of 2010 and aged as a 4_1 would be sub-yearling Chinook that migrated to the ocean sometime in 2007 and assigned to a brood year (parental spawner) of 2006. When possible, a comparison of the three methods of age and brood year assignments should be conducted to validate the measure.

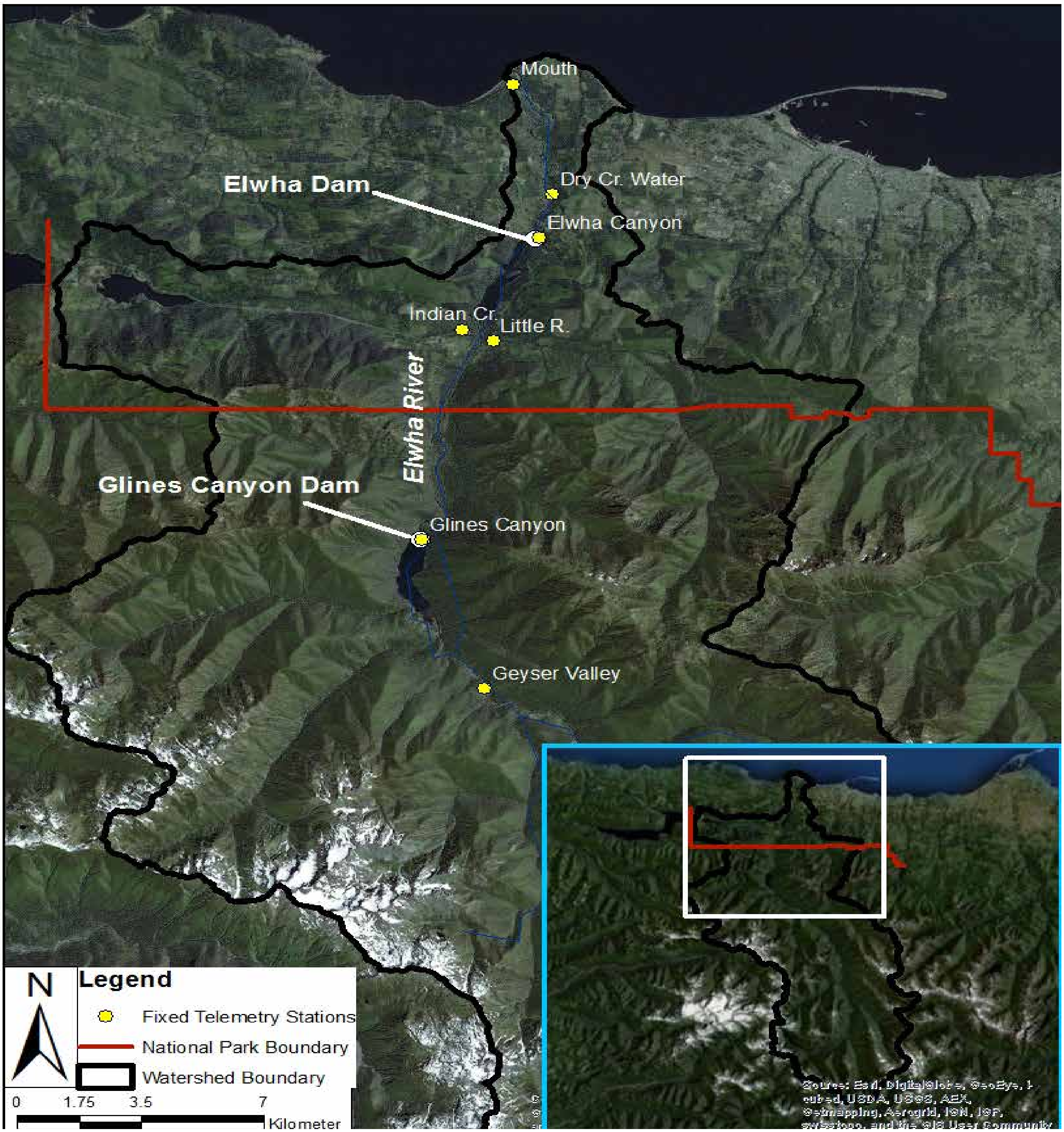
5.4 Spatial Distribution

The lack of easy access to much of the watershed, which limits the tools available for abundance estimates, will also influence the ability to assess fish distribution and barriers. A subset of the tools identified to assess annual abundance (Table 9) could also be used to assess distribution and barriers along with radio-telemetry. Foot, boat, and aerial redd surveys would be particularly useful in some cases, while radio-telemetry would be more useful to assess distribution and barriers in other locations (e.g., upper watershed). Foot surveys could be used to determine adult distribution in middle and lower reach areas accessible by vehicle or short hikes. These data could also be used to determine efficiency of aerial surveys. Adult Chinook salmon spawner surveys will occur spatially from Chicago Camp to Geyser Valley during the beginning, middle, and end of the spawning season, which we assume to be early September, mid-September, and early October based on observations below the former Glines Canyon Dam site. Adult Chinook salmon spawner surveys below the former Glines Canyon Dam site will occur every 7-10 days from August through mid-October following traditional spawner survey techniques. Adult steelhead spawner surveys will be conducted in tributaries below the Glines Canyon Dam site and Geyser Valley from May until the end of July.

Aerial surveys would allow an estimate of the upper extent of Chinook salmon and steelhead spawning distribution and the relative abundance of Chinook salmon and steelhead throughout the watershed. Data from aerial surveys could be compared to concurrent foot and/or boat surveys in the Middle and Lower River to allow sampling efficiency of the aerial surveys to be assessed. Several surveys should be completed using multiple 'passes' by separate crews in some reaches during both foot and aerial surveys to evaluate observer efficiency.

Aerial surveys, likely via helicopter, should be completed multiple times during the spawning season if feasible. These surveys should be completed from the former Glines Canyon Dam site to Chicago

Figure 17. Potential locations for fixed radio-telemetry stations for assessing fish distribution and movement in the Elwha River during and following dam removal.



Camp. Chinook surveys should occur in September with a sufficient number of surveys to surround peak spawning. Steelhead surveys should occur once a month from May to July. These surveys should be coordinated with foot surveys to allow the efficiency of the two methods to be compared.

Radio-telemetry could be used to obtain more detailed information regarding the distribution of Chinook salmon and steelhead in the basin. Adults captured during weekly gillnet surveys could be externally tagged with radio-tags and released to continue upstream. Fifty Chinook salmon and steelhead each year, for total of 200 fish of each species during their 4-year run cycle, should be tagged to provide a reasonable (90%) representation of these species' distributions. This sample size falls within the median range of tags used in published studies from 1998-2007, and should therefore provide an adequate samples size to address the questions specified (Cooke and Thorstad 2012).

Tracking will be completed using fixed arrays, aerial tracking and manual tracking. An array of up to seven fixed stations located from near the mouth of the river to the upstream end of Rica Canyon would allow broad scale distribution monitoring (Figure 17). These arrays will be developed to run continuously. Aerial surveys should be completed at least once a month between the former Glines Canyon Dam site upstream to Chicago Camp to determine finer scale distribution. Manual tracking should occur weekly downstream of the former Glines Canyon Dam site and the Geyser Valley area.

One must calculate tag detection efficiencies in telemetry studies to account for tagged fish that might not be detected during sampling to ensure that an unbiased estimate of biological data has been obtained (Melnychuk 2012). We recommend that the detection efficiencies of each tracking methods be assessed. For fixed stations, this should be completed by periodically dragging a tag through the channel at different distances from the fixed site to allow the proportion of known tag transmissions detected to be identified for different distances from the receiver. The detection efficiencies of mobile and aerial surveys should be assessed by periodically deploying test tags in known locations and assessing how many of the tags are detected by 'blind' surveyors (i.e., individuals that did not deploy the test tags). In addition, data from fixed, mobile, and aerial surveys should be compared to determine how often tagged fish near the fixed stations are detected and/or missed by each method.

These tools and methods collectively would allow us to identify any potential barriers at the former dam sites and/or within the reservoir reaches. If barriers are suspected, foot surveys should be completed in the reach of concern to identify potential barriers. Snorkel surveys likely will not be possible below Rica Canyon during the early phases of restoration due to high turbidity.

5.5 Diversity

To accurately measure Chinook salmon and steelhead diversity, samples used for analysis need to be spatially and temporally representative of the observed spawning distribution (see Spatial Distribution in Section 5.4).

The proportion of stream-type Chinook spawners (yearling outmigrant life history) could be based on scales collected from Chinook intercepted during weekly gillnet surveys or at the weir and during stream surveys. Entry timing of Chinook salmon could be assessed with DIDSON, weekly gillnet surveys, and weir interceptions. Both methods are recommended until their limitations are understood and can be accounted for (see Table 12).

5.6 Habitat Assessment

A number of tools and methods have been developed to assess changes in habitat quantity and quality (Table 13). These methods can be broadly divided into three habitat categories, spawning habitat (quantity and quality), rearing habitat (quantity and quality), and water quality. Tools and methods used to assess habitat (Table 13) are described below.

5.6.1 Spawning Habitat Quantity and Quality

Particle size distributions and residual pool depths are two suggested variables proposed for measuring spawning habitat quantity. The tools used to derive these indicators are pebble counts and mainstem residual pool depth. Streambed particle composition is quantified for "full spanning" riffles us-

Table 13. Habitat metrics that could be used to help identify changes in the quantity and quality of aquatic habitat in the Elwha River pre and post dam removal. Annual costs are estimated in FY13 dollars and the tools and estimates should be reviewed annually

Category	Indicator	Tools	Methods	Area	Period of monitoring	Sampling Frequency	Leads	Data Mgt.	Annual Cost	Limitations
Spawning habitat quantity	Particle size distribution	Pebble counts	Quantify % spawnable area by species	Riffle crests in LE, ME, and portions of UE	Low flow (Aug. – Sep.)	Annual	NOAA	NOAA	$15,500	Does not account for all spawnable areas
	Residual pool depth	Surveys	Cumulative distribution of pool depths	Mainstem in LE, ME, and portions of UE	Low flow (Aug. – Sep.)	Annual	NOAA	NOAA		
Spawning habitat quality	% fine sediment	Bulk sampling	Quantify % bed <2mm	Riffle crests in LE, ME, and portions of UE	Low flow (Aug. – Sep.)	Annual	USFWS	NOAA	$62,000	Does not account for all spawnable areas
Rearing habitat area	% of slow/ shallow water	Remote sensing, habitat surveys, longitudinal profiles	Quantify amount of slow water rearing habitat	Floodplains in LE, ME, and portions of UE	Low flow (Aug. – Sep.)	Bi-Annual	BOR, LEKT, NOAA	NOAA, BOR	$15,500[1]	Will not include all possible habitats
Rearing habitat quality	Residual pool depth, habitat complexity	same as above	Variation in pool depth and/or changes in cover	Floodplains in LE, ME, and portions of UE	Low flow (Aug. – Sep.)	Annual	BOR, LEKT, NOAA	NOAA, BOR	$15,500[1]	Will not include all possible habitats
Water quality	Temperature	Temp. sensors	% of time above exogenous thresholds	LE, ME, and portions of UE	Continuous	Hourly	LEKT	LEKT, NOAA		
	Turbidity	Optical sensors	% of time above exogenous thresholds	USGS Gages	Continuous	15-min intervals	USGS	USGS	$31,000	Only 2 locations on mainstem; funding ends Oct. 2016
		Optical sensor	% of time above exogenous thresholds	14 locations in LE and ME	daily	1 per day	NOAA	NOAA	$21,000	Daily point estimates; funding ends 2014
		CTD, turbidity, surface elevation	% of time above exogenous thresholds	Estuary (n=4)	Continuous	15-min intervals	LEKT, USGS	USGS		
		Optical Sensors	% of time above exogenous thresholds	2 tripod deployments in nearshore	Continuous	15-min intervals	USGS	USGS	$21,000	
		Suspended sediment conc.	Calibrate turbidity to suspended sediment load	Mainstem at USGS diversion station 12046260	Flow dependent	Intermittent	USGS	USGS	$31,000	

ing this tool. A full spanning riffle is a riffle crest that spans the entire wetted width of the stream at the time of sampling prior to fall salmon spawning. Full spanning riffles are typically associated with the front end of large, transverse gravel bars (Lisle 1982).

Streambed particle size should be measured at every full spanning riffle in the Middle and Lower Elwha. These riffles are typically located in the tail out portion of the pools where depth is measured. The extent of the riffle crest is determined by creating two transects – one upstream and one downstream – at a point where the water is 0.2 m deeper than the minimum riffle crest depth. Total riffle area is then measured. Pebble counts (100 particles measured along the B axis of a rock) are then conducted along each transect because salmon spawning is hypothesized to occur in those locations. Pebble counts quantify the substrate within a given area and include the distribution of streambed particle sizes. Data collected at each site includes location, widths, depths, and particle size distribution.

In addition to the Middle and Lower Elwha sites, reference sites in the lower portion of the Upper Elwha (e.g., Geyser Valley) and a reference reach of the Quinault River are useful for before-after comparisons. The purpose of these reference sites is to gain a quantitative estimate of variability in available spawning area for each habitat type. The Quinault was chosen based on an analysis of stream channel slope and average annual discharge across six potential reaches (McHenry and Pess 2008).

To capture the change in pool depth, NOAA researchers have utilized a proven method that quantifies the residual pool depth of each mainstem pool in the Middle and Lower Elwha. The longitude and latitude of each pool should be recorded with a GPS and the area and residual depth of each pool measured in accessible mainstem reaches. It is assumed that pebble counts and residual pool depths will be sensitive enough to the changes in particle size and depth to capture the change due to the anticipated large-scale change in sediment supply from dam removal.

Annual data from before and after dam removal could be compared to understand the variation in individual streambed particle size and pool depth prior to dam removal. The cumulative distribution of pool depths should be examined using the Kolmogorov-Smirnov statistic. In addition, the within year variation between sites should be compared at the reach (Middle Elwha, Lower Elwha) and site (upstream versus downstream side of riffle crests) scales.

Attempts should be made to link the stream bed particle size data with fish size data in order to estimate the percent spawnable area for all salmon that inhabit the Elwha River. Several sources of data could be used for this analysis, including stream bed particle size and the body size of spawning female salmon (Wooster et al. 2009). To do so, some basic assumptions need to be made regarding spawnable area for salmonids. First, a salmon spawning redd is assumed to be limited by a maximum moveable stream bed particle size, the size of the female salmon, and flow conditions. Second, salmon spawning redds are assumed to decrease with an increase in the amount of "immovable" particles. Third, while salmon are expected to utilize many different habitats for spawning, the majority of spawning is assumed to occur where the tail out of a pool transitions into riffle areas (Quinn 2005).

The Lower Elwha Klallam Tribe has collected spatially specific spawning data for Chinook salmon (2005 – 2011) and steelhead (2006 – 2011) for the entire river downstream of Elwha Dam. This will enable the comparison of existing spawnable area data to predicted spawnable area by examining Chinook and steelhead redd locations over time. This will allow the identification of the proportion of Chinook and steelhead that spawn in the riffle crest areas relative to other areas in the Lower Elwha. Fish data from hatchery spawners, weir captures, and carcass surveys could be used to estimate the average and standard deviation body mass of female Chinook and steelhead (assuming that female size in past years will be representative of female size in future years). Equation 6 determines the fraction of the sediment that is immobile (i.e., cannot be moved by spawning females) as follows:

Equation 6

$$\text{Fraction immobile} = a+b*(g\ (SD)/D84^{1.5})+c*BM1$$

where;

a = 0.94 ± 0.05

b = -280 ± 30.0

c = - 0.078 ± -0.07

g (SD) = geometric standard deviation in mm

D84 = the 84% of the stream bed particle size in each location

BMI = average body mass index of salmon; for example Chinook = 5.41 ± 0.06 (g/mm)

The percentage of spawnable habitat at each riffle crest is calculated as the total spawnable area of the riffle crest size minus the percent immobile fraction of substrate in the riffle crest.

Percent fine sediment (less than 2 mm) would be the indicator used to assess spawning habitat quality. Bulk sampling of sediment would be an effective tool for gathering fine sediment data. Volumetric (bulk) sediment samples could be collected at a sub-set (approximately one-third) of mainstem riffle-crests in the Upper (Geyser Valley), Middle, and Lower Elwha to quantify the proportion of fine sediment in riffle crest substrates. Additional samples could be collected from side channel habitats in these three reaches. Samples should be collected at the upstream and downstream end of each of these side channels to account for longitudinal variability. These data would be compared to data collected prior to dam removal, with the exception of the upper river sites, which were not sampled prior to dam removal.

Three samples should be collected at each mainstem site, generally at the left bank, right bank, and center locations in relation to flow in the riffle crest. This may not be possible in some cases, which would result in samples being collected from only one bank at the up, down and mid-riffle crest portion of the site. Samples could be collected behind a four-sided plywood shield, which is a modification of a system designed by Bunte and Abt (2001). The shield isolates the sample area from moving water and prevents the loss of fine materials. This shield would isolate an area of approximately 0.7 m^2 (±0.04), from which a sample of approximately 0.5 m^2 could be extracted. The surface layer (defined as the depth that individual particles representing the 84th percentile streambed particle size D84 penetrated into the bed), should be removed and taken back to the lab for processing. Samples would be removed by hand and/or shovel and placed into a canvas mining bag for processing in the lab. Large particles (i.e., >2 kg) that will be difficult to transport could be set aside and weighed in the field after drying on a tarp during sample collection. Water samples (0.5 - 1 L) should be collected immediately before and after bulk sample collection to determine background suspended sediment levels (before sample) and capture fines dislodged and suspended in the water column during sample collection (after sample).

The coarse sediment (those in the canvas bag) and fine sediment samples (water bottle samples) should be processed following standard procedures in the lab. Coarse material should be dried, sieved and weighed. Samples should be sieved into size classes corresponding to the Wentworth "powers of two" scale (e.g., 0.0625, 0.125, 0.25, 0.5, 1.0, 2.0, 4, 8, 16, 32, 64, 128 mm). Water samples should be filtered through dried glass filters to determine the weight of fine sediment suspended in a given volume of water. This information would be used to calculate the weight of suspended fines for the entire volume of water behind the plywood shield. This weight would be added to the smallest Wentworth particle size category and would be used along with the data from the coarse substrate analysis to generate a complete particle size distribution for the surface layer. Annual data before and after dam removal could be compared to understand the variation in fine sediment levels at the riffle crest scale. In addition, within year variation could be compared between sites at the reach (Middle Elwha, Lower Elwha) and site (upstream versus downstream side of riffle crests) scale.

5.6.2 Rearing Habitat Quantity and Quality

Surveys should be conducted on the mainstem and floodplain channels in the Upper, Middle, and Lower Elwha, with data collected on the following six habitat types for the main stem Elwha: pools, riffles, and glides in mid-channel and bank edges, bar edges, and backwaters along the channel margins. Due to limited resources and over 200 km of mainstem and floodplain channel, only a subset of the river will likely be sampled during a given year. To date, this approach has been coupled with other efforts (e.g., Brenkman et al. 2012) to provide a complete baseline habitat inventory of the vast majority of the Elwha mainstem and floodplain over the last decade.

We have defined habitat type as a unit with similar physical characteristics such as water depth, velocity, and stream substrate size. Pools are defined as low velocity, deep water areas that have a defined entrance and exit point that is shallower than the deepest part of the habitat unit (Bisson et al 1988). Riffles are defined as shallow water areas with moderate to fast velocity and typically have depths shallow enough that substrate protruded from the streambed and is exposed outside of the flow (Bisson et al. 1988). Glides are defined as moderately shallow to deep water that have a consistent depth to the unit at the entry and exit point of the habitat unit (Bisson et al. 1988). The boundary between edge and mid-channel units is a visible current shear line, the edge units having lower velocity (Beechie et al. 2005). Banks have a vertical, or nearly vertical shore; bars have a shallow, low gradient interface with the shore; and backwaters are partially enclosed, low-velocity areas separated from the main river channel (Beechie et al. 2005).

For the mainstem surveys, data should be collected on habitat unit average width, maximum depth, and residual or minimum depth. Each unit is typically identified spatially to compare differences in location, as well as differences in habitat area and depth. Habitat quantity is defined as the aggregation of similar habitat units, whereas condition is the quality of habitat units such as depth, dominant and subdominant streambed particle size, and the amount of in stream cover associated with a habitat unit. Basic descriptive statistics for the mainstem should continue to be developed to gain a better understanding of existing habitat extent. Before, during, and after dam removal habitat type and total area per habitat type should be compared to examine changes in the proportion and distribution of slower water habitat such as pools and all edge habitats. A similar analysis would be conducted for all floodplain channels in the portions of the Upper Elwha, and the entire Middle and Lower Elwha.

For floodplain channels, the same basic habitat characteristics as main stem habitats should be documented throughout the Elwha River watershed. This includes the change in habitat type (pool, riffle, glide), quantity (amount of each habitat type), and condition (depth, substrate, and cover) in the Elwha in order to gain a better quantitative understanding of the spatial and temporal variability in slower water habitats associated with this landform.

Basic descriptive statistics will also be developed for floodplain channels in the Upper, Middle, and Lower Elwha, to better understand existing versus future habitat extent and structure. Spatially explicit KMZ files (Google Earth) of all floodplain channels in the Elwha River have been created to better understand before, during, and after dam removal locations for these biologically and physically important habitat types.

Mainstem habitat quality should be assessed by measuring the availability of different primary and secondary habitat types, cover, and substrate. Primary habitats (those that encompass the entire channel width) should be classified as pool, glide, run, and riffle. The surface area of each primary habitat unit should also be measured. Secondary habitats (those unique hydraulic habitats near the channel margin that encompass at least 20% of the channel width) should also be tallied for each primary unit. In addition, the surface area of any slow-water habitats such as eddies or depositional habitats should be measured.

Cover within each primary unit should be classified broadly as single pieces of large wood (minimum dimensions), large wood accumulations, small wood accumulations, vegetation (live aquatic and terrestrial vegetation within the water column), and rock (i.e., cobble size or greater). Each cover element should be measured for surface area.

Substrate size within each primary unit should be classified as the number of unique areas of specific size as well as percent substrate composition within the unit. Substrate sizes should be classified as sand/silt, gravel, cobble, or boulder. Each area of unique and relatively uniform substrate size (i.e., 70% of unit has a single substrate size) within the habitat unit should be classified by size and measured for surface area. This information should be compiled to estimate the percent substrate composition for each habitat unit.

In a subset of the floodplain channels in the Upper, Middle, and Lower Elwha River, longitudinal profiles could be conducted to gain a more quantitative understanding of thalweg profiles and corresponding habitat condition before, during, and after dam removal. Longitudinal profiles have been identified as a useful tool to assess and monitor fish habitat in wadable streams, in part because they can improve the accuracy and precision of channel and pool measurements (e.g., Bauer and Ralph 2001; Mossop and Bradford 2006). Longitudinal profiles involve surveying the streambed elevation along the deepest portion of the stream (the thalweg) to produce a two-dimensional, longitudinal profile of streambed elevations (Mossop and Bradford 2006). Depressions or deep points in the profile typically represent pools or deeper habitats with low velocity during low flow periods, while crests in the profile represent riffles (Mossop and Bradford 2006). Longitudinal profiles can also provide important quantitative measures of stream channel morphology (e.g., stream channel gradient) and fish habitat quality (e.g., variation in pool depth), while still being independent of flow conditions (Lisle 1987; Bauer and Ralph 2001; May and Lee 2004; Mossop and Bradford 2006). Longitudinal profiles have also been used for national long-term monitoring projects such as the United States Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program (EMAP) for thousands of small streams (Kaufmann et al. 1999). In addition, metrics from longitudinal profiles, such as residual pool depth, the difference between the elevation of the deepest point in a pool, and the elevation of the riffle crest immediately downstream (Lisle 1987), have been correlated to important fish metrics such as juvenile salmon survival and density (Mossop and Bradford 2006; Pess et al. 2011). Longitudinal profiling is thus a quantitative technique that has a relatively low measurement error, is insensitive to differences in observers and flow conditions, can occur across all habitats in a reasonable amount of time, and is simple and easy to explain to new crews. Repeated surveys of longitudinal profiles can indicate changes in bed elevation variability (Madej 1999), which we hypothesize are particularly important for measuring response to dam removal because we expect downstream increases in sediment and wood supply to substantially alter the channel bed profile.

Methods should follow standard surveying techniques (Harrelson et al. 1994) and the longitudinal profile survey methods described in Madej (1999) and Mossop and Bradford (2006). The crew should be three people consisting of a surveyor, rod person, and data recorder. Surveying the entire side channel should be attempted, but in some cases it will not be possible due to large logjams that create obstructions. Surveys typically begin and end at riffle crests, which are the highest location in a riffle. Streambed elevation is measured using a laser range finder (e.g., Laser Technology Inc.'s Impulse Laser Rangefinder) and stadia rod at systematic intervals (i.e., every 1 to 2 times the wetted channel width), as well as every break in slope. Both horizontal distance and vertical distance are read from the laser range finder. Floodplain channels with more variation in the stream bed typically result in more data points due to more breaks in slope.

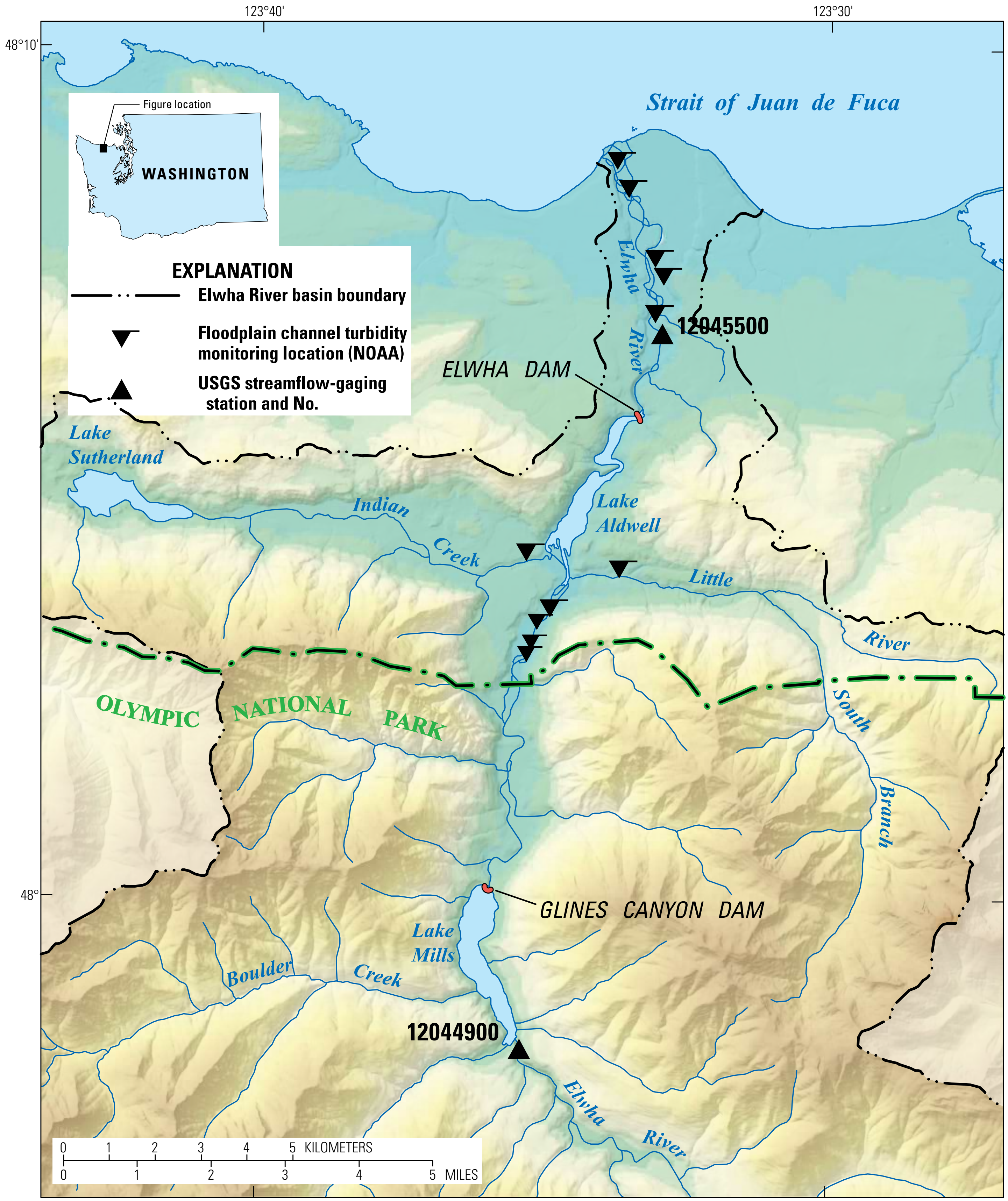
Several general metrics can be calculated from the longitudinal profile data. These include: (1) proportion in residual pool (the total length of the profile in residual pools divided by the total length surveyed (Madej 1999; Mossop and Bradford 2006), (2) total number of pools, (3) the average maximum residual pool depth, (4) the variance in maximum residual pool depth, and (5) the maximum pool depth (maximum residual pool depth in the profile). Delineation of residual pools, calculation of the statistics, and plotting should all be performed by an appropriate statistical software package, such as the R statistical programming language (R Development Core Team 2011). Profile metrics should be compared across river section, season, and channel type (tributary or floodplain channel). These metrics, combined with information on the dominant and subdominant particle size for each point, will allow determination of spatially explicit changes in habitat quality over time in floodplain channels. In addition, longitudinal profiles can be compared between locations and time periods to assess the spatial and temporal heterogeneity of stream morphology.

5.6.3 Water Quality

5.6.3.1. Stream Temperature

Temperature monitoring in tributary and side channel sites should continue with a continuous recording thermograph (HoboTemp Pro) deployed at each site. Each thermograph could be housed in a length of PVC tubing and secured using aircraft cable and cable clamps. Pre-dam removal data has been collected from 2009-2011. All thermographs were re-

Figure 18. Locations of turbidity measurements in the mainstem (USGS) and tributary/floodplain channels (NOAA) in the Elwha River watershed.



Base map from USGS National Elevation Data
Projection: Universal Transverse Mercator Zone 10,
10 meter resolution

moved in the fall of 2011 to download data. Post-dam removal data collection began in the spring of 2012 and will continue until at least 2015.

5.6.3.2 Turbidity

The U.S. Geological Survey, in cooperation with the National Park Service, is monitoring turbidity levels of the mainstem Elwha River at two locations with stream-flow gaging stations (#12044900, Elwha River above Lake Mills; #12046260, Elwha River at Diversion) using an array of on station monitoring equipment. In addition to the standard Digital Turbidity Sensor (DTS-12) suitable for low to moderate suspended sediment levels, there are also Acoustic Doppler Current Profiler (ADCP) and Analite Turbidity Sensor instrumentation on station for the high concentration turbidity range. In addition to turbidity, the mainstem river water is being sampled for suspended sediment concentration and particle size distribution, which will allow the calibration of the turbidity data to compute a time-series of suspended-sediment concentration and load at the downstream diversion site (Curran et al. 2013; see also Rasmussen et al. 2009).

A monitoring program was also initiated to track turbidity in the mainstem Elwha River, several floodplain channels, and two tributaries. The objectives were to: quantify turbidity levels before, during, and after dam removal across different habitat types; quantify the variation in the turbidity at different flow stages; and review the existing literature on the effects of turbidity on juvenile salmonids to better understand the potential impacts of the elevated levels of turbidity resulting from removal of the Elwha River dams.

For coastal environments, similar turbidity measurements are being collected with automated sensors in the estuary and the nearshore. In both the eastern and western portions of the estuary, the LEKT is operating three YSI 600 OMS multiparameter probes that are measuring conductivity, depth, temperature and salinity (see Magirl et al. 2011), as well as turbidity in NTU. In the coastal zone, turbidity and sediment transport are expected in both a buoyant plume and via hyperpycnal flow along the seafloor (Warrick et al. 2011). The expected long-term deployment of multi instrument, benthic sampling tripods occurred just off shore (summer 2012) and to the east and west of the river mouth (December 2010). These instrument packages measure water properties (conductivity, temperature, depth, salinity), turbidity (optical and acoustic), currents (speed and direction), and waves (direction). They also take regular photographs of the seafloor.

The presence of the Elwha and Glines Canyon dams delineate three distinct river sections: the lower 8 km of river below the Elwha Dam (elevation 0-30 m), the middle 14 km of river between the two dams (elevation 60-120 m), and the upper 50 km of river above the Glines Canyon Dam (elevation 170-1300 m). All point sample turbidity measurements have and should continue to be collected in the Lower and Middle Elwha where sediment stored in the deltas of Lake Mills and Lake Aldwell will be released following dam removal. To examine spatial variability in turbidity, measurements are and should be collected as daily point measurements (once per day) in the mainstem Elwha River, floodplain channels, and tributaries. Specific long-term monitoring locations were

Table 14. Description of mainstem and floodplain channel sites and locations where daily portable turbidity measurements are taken and the date when sampling was started.

Site	Location[1]	Type[2]	Date
Sonar Hole	LE	MR	12/8/2010
Boston Charlie	LE	GW	12/8/2010
SC7	LE	SW	12/8/2010
Sonar SC	LE	GW	12/8/2010
SC Hunt Rd(@high bank)	LE	SW	12/8/2010
SC1 (head)	LE	SW	6/1/2011
SC1 (mouth)	LE	SW	6/1/2011
Altaire Campground	LE	MR	12/8/2010
ONP Boundary Channel	ME	SW	12/8/2010
Madison Cr. SC	ME	GW	12/8/2010
SC27	ME	Combo	6/1/2011
SC28	ME	Combo	6/1/2011
Little R.	ME	TR	12/8/2010
Indian Cr.	ME	TR	12/8/2010

[1]Location in the Elwha waterhsed; LE=downstream of former Elwha Dam and ME=between two former dams.
[2]Water source for site; MR=Mainstem Elwha R., GW=groundwater, SW=surface water, Combo = GW+SW, TR = tributary.

selected based on accessibility, distance downstream from the dams and connectivity to the mainstem (e.g., water source for floodplain channels). Seven long-term monitoring sites are located in the Lower Elwha and seven in the Middle Elwha. Six of the seven lower river sites are in floodplain habitats and one is located in the mainstem. In the upper river, four of the sites are located in floodplain habitats, one in the mainstem, and two in tributaries (Figure 18; Table 14).

All daily point turbidity measurements could be taken with a McVan Instruments Analite NEP160 series microprocessor-based portable turbidity meter with a submersible sensor for instantaneous readings. This meter is designed to operate with both a 90° probe (compliant with International Organization for Standardization method 7027) for turbidity levels < 3,000 NTU and a 180° retro-scatter probe for turbidity levels up to 20,000 NTU. All readings are recorded in NTUs.

5.7 Fish Health

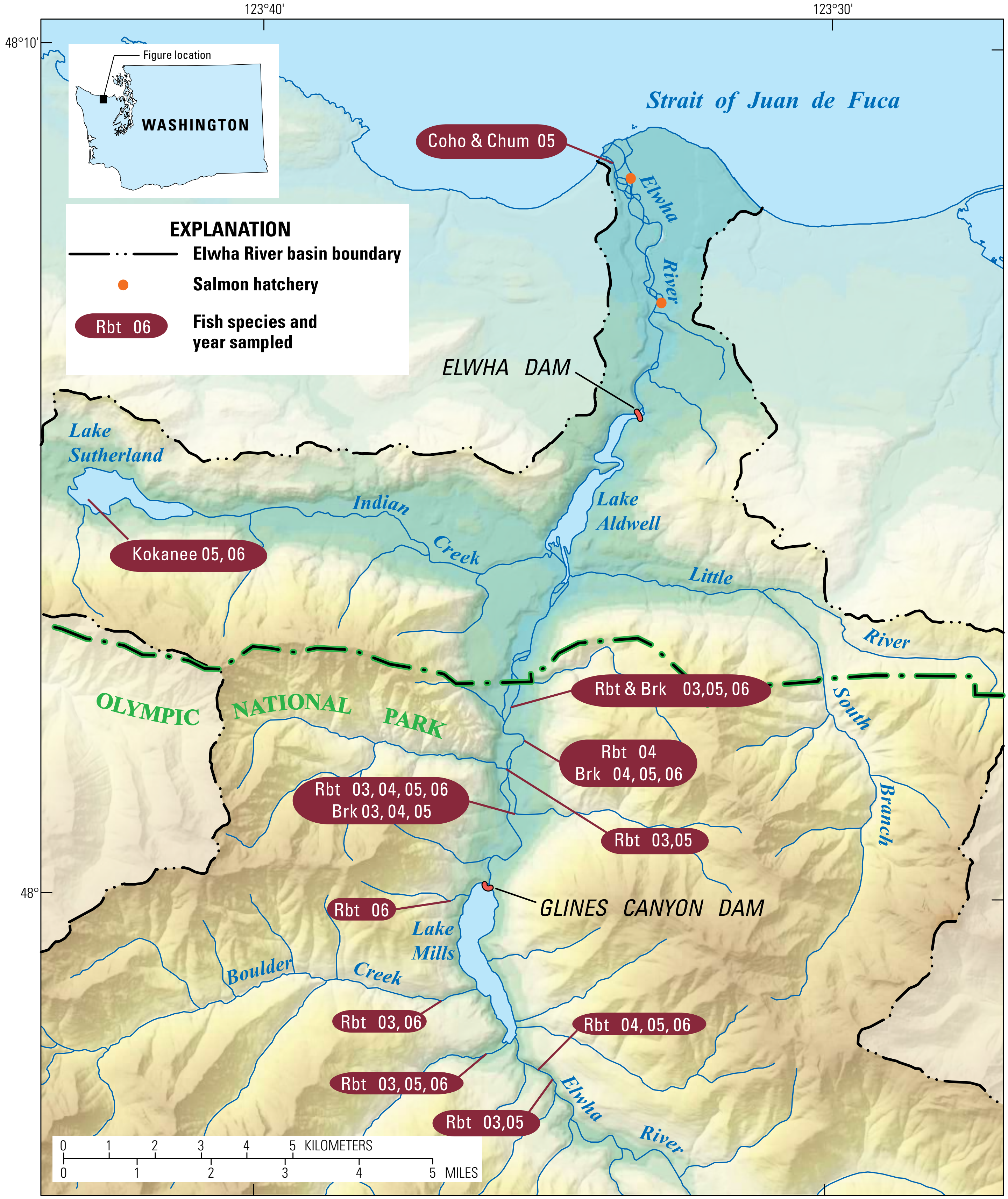
The salmonid community in the Elwha Basin is comprised of wild, natural, hatchery, and non-native fish. Downstream of the former Elwha Dam site, hatchery programs currently raise Chinook, coho, fall chum, and pink salmon and winter steelhead and information regarding these programs can be found in the species specific HGMPs (WDFW 2012; LEKT 2012a, 2012b, 2012c; LEKT and WDFW 2012). The interaction between fish upstream of the dams and recolonizing anadromous salmonids, including hatchery-origin spawners, poses fish health risks. Fish populations in the Elwha River can potentially be exposed to a greater number of a given pathogen or to a pathogen to which the population has not been previously exposed. This exposure may result in transmission and amplification of pathogens, which can lead to disease.

Both WDFW and LEKT operate hatcheries in accordance with The Salmonid Disease Control Policy of the Fisheries Co-Managers of Washington State (Anonymous 2006; WDFW 1998), which requires monitoring of returning adults at spawning and routine monitoring of their offspring in the hatcheries. The purpose of this policy is to promote fish health and to prevent the transfer of pathogens among watersheds. Regular monitoring of fish health at the WDFW and LEKT hatcheries has occurred since 1976 and 1978, respectively. Fish health is monitored on a daily basis by hatchery staff and at least monthly by a Fish Health Specialist (FHS) from WDFW or NWIFC. Hatchery personnel carry out treatments prescribed by the FHS (HSRG 2012). Procedures are consistent with the Co-Manager's Fish Health Policy (WDFW 1998). It is expected that this monitoring will continue as long as the hatcheries are operating.

A total of 13 species of parasites, six species of bacteria, and three viruses have been recorded in Pacific salmonids in Elwha hatcheries since 1988 (see Table 2; Brenkman et al. 2008). The most routinely observed diseases and their etiological agents in recent history were erythrocytic inclusion body syndrome (EIBS), bacterial kidney disease (BKD), and bacterial coldwater disease. In past years, losses of adult Chinook due to the parasite *Dermocystidium* sp. were occasionally excessive and approached 30% from fish at the trap and in the Elwha River (HSRG 2012). From 2003 to 2006, five salmonid species from the Lower, Middle, and Upper Elwha River and tributaries were tested for bacteria (n=684), viruses (n=943), and *Myxobolus cerebralis* (the causative agent of whirling disease) (n=740). The only target pathogen found was *Renibacterium salmoninarum* (the causative agent of BKD), and was detected in five salmonid species in each segment of the river. There have been no detections of infectious hematopoietic necrosis virus (IHNV), infectious pancreatic necrosis virus (IPNV), and viral hemorrhagic septicemia virus (VHSV) as of January 2013 (Marcia House, Pathologist with the Northwest Indian Fisheries Commission, personal communication). However, yearly surveys of kokanee salmon in Lake Sutherland, within the Indian Creek sub-basin, revealed a newly described myxozoan parasite. The new species of Sphaerosporid myxosporean, *Sphaerospora elwhaiensis* sp. n., was described from kidney samples. Infection with the parasite was detected in 45% of 177 kokanee examined over 5 years (Jones et al. 2011).

To date, IHNV has been detected in other nearby coastal watersheds of the Olympic Peninsula, but has not been detected in hatchery or wild fish in the Elwha Basin. However, IHNV could be introduced by anadromous salmonids that recolonize the Elwha River. The introduction of IHNV to salmonid populations exposed by the removal of dams has the potential to lead to disease outbreak (Brenkman et al. 2008a). With the larger goal of restoration of viable

Figure 19. Locations in the Elwha watershed where baseline data on fish pathogens were collected by Brenkman et al. (2008) and that will be monitored following dam removal.



Base map from USGS National Elevation Data
Projection: Universal Transverse Mercator Zone 10,
10 meter resolution

natural fish populations, there is a need for a comprehensive monitoring program (Brenkman et al. 2008a).

Data collected following dam removal could be compared to data collected prior to dam removal, including data from the fish hatcheries and field data collections (Brenkman et al. 2008a). Fish health monitoring at hatcheries within the Elwha Basin and at hatcheries used to rear Elwha fish (e.g., Morse Creek, Sol Duc) should be monitored following standard fish health procedures (WDFW and WWTIT 1998) by WDFW and LEKT. Regular monitoring of the health of the fish raised at the WDFW and LEKT hatcheries has occurred since 1976 and 1978, respectively. Both WDFW and LEKT operate hatcheries in accordance with The Salmonid Disease Control Policy of the Fisheries Co-Managers of Washington State (WDFW and WWTIT 1998), which currently requires monitoring of returning adults at spawning as well as routine monitoring of their offspring while they are raised at the hatcheries. Brenkman et al. (2008a) also collected natural origin fish throughout the Elwha River.

Additionally, annual monitoring of fish pathogens should occur in the Lower, Middle, and Upper Elwha River to better understand pathogen distribution as recolonization of the watershed commences. A regular monitoring program for fish pathology should be conducted to test for the presence and distribution of bacteria, viruses, and *Myxobolus cerebralis*. The primary emphasis should be on Pacific salmonids. These surveys should be compared with baseline conditions found prior to dam removal at the 11 locations previously sampled by Brenkman et al. (2008a) (Figure 19).

Laboratory analysis of fish from the Elwha River (outside the hatchery facilities) should be regularly conducted to determine presence of regulated pathogens, including IPNV, IHNV, and VHSV. Additional analysis to determine the presence of other possible pathogens such as *R. salmoninarum, M. cerebralis, Aeromonas salmonicida* (the causative agent of furunculosis), and *Yersinia ruckeri* (the causative agent of red mouth disease) should be conducted into the future. Detailed information regarding standardized laboratory procedures for these pathogens is provided in National Wild Fish Health Survey (NWFHS) Laboratory Procedures Manual (Puzach 2006).

5.8 Ecosystem Response

In addition to directly monitoring the size, diversity, and viability of salmonid populations, it is also important to study the responses of the ecosystems upon which salmon depend. Because of the large changes expected in the areas downstream of the dams, as well as the changes that the salmon themselves will have on the ecosystem (e.g., from marine derived nutrients, bioturbation of spawning gravels, interactions with predators and scavenger communities), estimating the response of the aquatic ecosystem is vital. In particular, an important component to be studied is the direct and indirect effects of high sediment levels on biological food webs and the role that ecosystem changes may play in the recovery of Elwha fish populations. These studies are critical, as the effects of dam removal are expected to continue for 3-5 years depending on flow conditions (Konrad 2009, DOI 1996b).

5.8.1 Primary and Secondary Productivity

As in past studies that established baseline levels prior to dam removal (Morley et al. 2008), stream macroinvertebrates could be collected from the benthos of riffles (where densities and diversity are typically highest) using a Slack sampler placed at five random locations within an index site. These samples should be pooled and sub-sampled such that up to 600 invertebrates will be identified at each site. All numeric counts should be converted to density based on sample area and the proportion of each sample processed. For a sub-set of samples, invertebrate head-capsule width should also be measured to calculate species biomass densities. Analysis of taxonomic structure could be done with a variety of univariate and multivariate approaches, including using the PRIMER statistical software package (Clarke and Gorley 2006) to assess change in macroinvertebrate assemblages and to relate these changes to any measured habitat or environmental variables (for example, see Morley et al. 2008). The unpicked portion of each invertebrate sample should serve as a sample pool for stable isotope analysis (see "nutrient dynamics" below), which can be used to assess changes in the marine nutrient signature due to recolonization or rebuilding of salmon populations (Duda et al. 2011c). Similar work measuring responses of macroinvertebrate communities could be conducted in the estuary of the Elwha River, but would require different sampling methods (Duda et al 2011b).

Periphyton represents the bulk of autotrophic primary production occurring in aquatic environments and primarily consists of algae and cyanophyta, but with significant bacterial and fungal constituents. As in past studies documenting baseline conditions (Morley et al. 2008), periphyton should be sampled from five rock cobbles collected adjacent to each of the invertebrate samples mentioned above. Periphyton should be scrubbed and rinsed from each cobble, pooled into one sample and homogenized. From this combined slurry, 15 ml should be stored on ice for microbial analyses and another 30 ml preserved for diatom taxonomic analysis—should funding allow. From the remaining periphyton sample, 10-30 ml should be filtered onto three 47 - mm glass-fiber filters for analysis of stable isotopes, chlorophyll a concentration, and ash-free dry mass (AFDM). Chlorophyll a specifically measures the algal component of periphyton whereas AFDM is a measure of total periphyton biomass (Steinman and Lamberti 1996). Diatom samples should be archived until funding can be found for taxonomic analysis—a process that will involve species and genus-level identification of slide-mounted samples by a professional taxonomist with expertise in regional diatoms. If a collaborator can be identified, microbial samples should be analyzed for functional and genetic diversity.

5.8.2 Nutrient Dynamics

The Elwha River and its tributaries, like many other watersheds in the Pacific Northwest, have previously been shown to be nutrient-poor oligotrophic waters (Munn et al. 1999, Duda et al. 2011c). In order to assess changes to nutrient status of the Elwha, water samples should be collected in acid washed bottles from index site for analysis of total nitrogen (TN), total phosphorus (TP), nitrate (NO_3), nitrite (NO_2), ammonium (NH_4), and phosphate (PO_4). Samples should be held on ice after collection and frozen in the laboratory prior to analysis by an accredited laboratory. For stable isotope analyses, tissue samples should be collected from multiple trophic levels: macroalgae, periphyton, benthic invertebrates, and salmonids. Tissues should be preserved in the field in ethanol, and freeze-dried and pulverized in the laboratory. Homogenized tissues should be analyzed for stable isotopes using an elemental analyzer (EA) coupled with isotope ratio mass spectroscopy (IRMS). Water chemistry and stable isotope data should be analyzed with a two-way ANOVA (or analogous non-parametric techniques, as appropriate) with river section (above and below dams) and year (before and after dam removal) as fixed dependent variables.

5.8.3 Fish Diet

The possible changes to food web structure and function during and following dam removal could have implications for the bioenergetics of juvenile fish in the Elwha River. As part of an assessment to changes in fish diet and growth, fish could be sampled at suitable sites using a combination of electrofishing and seining, concurrent with other fish sampling events whenever possible to minimize disturbance. When conducting diet and growth analysis, all fish should be anesthetized, identified to species, weighed to the nearest 0.1 g, and measured to the nearest 1 mm. For juvenile salmonids > 55 mm fork length, diet information could be collected from up to 10 individuals per species using non-lethal gastric lavage. This technique involves flushing the stomach cavity with water, preserving the regurgitated contents in ethanol, and identifying all taxa to the lowest practical taxonomic level under microscopy. Head-capsule measurements should also be taken for each prey item to calculate the relative abundance of different prey items on a numeric, weight, and caloric basis. After a suitable period of recovery, all fish should be returned to the habitats from which they were collected.

Concurrent with fish sampling events, 1-3 drift nets (determined by channel width) could be placed at the upstream end of each index site to capture invertebrate prey resources available to downstream fish. Nets should be left in place from 30-60 minutes depending on flow conditions. The contents of all drift nets should be pooled for a given site, preserved in ethanol, and processed in the same fashion as for benthic invertebrate samples. Densities should be determined based on the portion of the sample processed and the total volume of water passing through the nets—determined by sample time, water velocity, and net area. Multivariate analyses in PRIMER or various statistical methods could be used to examine what prey resources juvenile salmonids utilize relative to what is available, diet overlap between species, and how these patterns differ by habitat type, season, and time after dam removal.

5.9 Additional Monitoring and Restoration Activities

This document outlines monitoring and adaptive management guidelines related to the restoration of anadromous salmonids in the Elwha watershed. The plan was written with an understanding that anadromous fish restoration is only one part of the overall restoration program and associated monitoring. This section briefly summarizes additional restoration and monitoring activities occurring in the basin, particularly those that are directly and indirectly relevant to salmon restoration. However, the list below is not comprehensive.

5.9.1 Revegetation

Once dam removal was nearly completed, dewatering of the Mills and Aldwell reservoirs exposed approximately 800 acres of former hillslope and floodplain habitats along seven miles of newly recreated river channel. Revegetation of the former reservoirs is critical to restore habitat forming processes and is necessary to stabilize accumulated sediment that will be stored on hill slopes and terraces, and therefore, available to river transport. The overall revegetation effort for Elwha restoration is included in the overall project budget and is guided by the Elwha Revegetation Plan (Chenoweth et al. 2010). The revegetation plan's goals, broadly stated, are to establish native vegetation communities and to accelerate natural succession toward older vegetation communities. Implementation of revegetation activities is co-managed by Olympic National Park and the Lower Elwha Klallam Tribe who lead revegetation efforts on the former Mills and Aldwell reservoirs, respectively. Revegetation began in 2004 and initially focused on control of exotic vegetation adjacent to project areas, collection of native seeds to be used in Elwha revegetation, construction of a greenhouse/nursery facility to propagate native plants used in revegetation and seed amplification with the Natural Resources Conservation Service (NRCS) facility in Corvallis, Oregon. Revegetation efforts accelerated beginning in the fall of 2011 with reservoir drawdowns and dam removal. In the winter of 2012, the first plantings of native trees and shrubs occurred on the former Mills reservoir. These efforts will accelerate over the next four years and culminate with the eventual planting of 400,000 native trees and shrubs and over 5,000 pounds of native grass seed. Monitoring plans are under development and will be used to modify and refine planting actions. At this time, revegetation efforts are funded through 2016. Project managers are seeking additional funding to extend these efforts.

5.9.2 Habitat Restoration

Habitat restoration efforts complementary to dam removal have been led by the Lower Elwha Klallam Tribe, and have been concentrated on floodplain habitats in the lower river downstream of the former Elwha Dam site. To date, these efforts include the construction of 33 engineered logjams between river mile 1.0-2.5, additions of large wood to four side-channels, removal of four relict push up flood control dikes, planting of 25,000 native trees and shrubs in areas disturbed during construction or dike removal, and control of non-native vegetation. The Tribe constructed 14 additional logjams between river miles 2.5-3.5 in 2012-2013 and may construct two other jams in 2014. Future restoration is being considered for Little River and Indian Creek and includes wood additions and culvert barrier corrections; however, these efforts are currently unfunded. Additional restoration efforts are also being analyzed as dam removal proceeds and are focused on the estuary and dewatered Aldwell reservoir. The Elwha estuary has been severely degraded over its history by diking and channelization (Duda et al. 2011a). The Aldwell reservoir, which was logged prior to filling, appears to lack large wood and may be an excellent candidate for engineered logjams.

5.9.3 Suspended Sediment

Suspended and bedload sediment transport are being monitored in real time by BOR, NPS, and USGS as part of the sediment monitoring and adaptive management activities of the Elwha dam removal project (Randle et al. 2012; Randle et al. 2010). Additionally, changes in reservoir and river bed elevation as well as water surface elevation are monitored through time, as is sediment erosion from the reservoirs, floodplain deposition, and volumetric changes in the river mouth and adjacent shoreline. Information on particle size distribution of suspended, bedload, and deposition sediment is maintained. Regular aerial photogrammetry occurs on weekly- to monthly intervals depending on hydrology and flight conditions. Data from these monitoring activities are incorporated into predictive models which are updated on a regular basis. Data collected resides with the BOR and the individual investigators. Additional monitoring details are described by category below.

Fine sediment transport is being monitored by measuring water column turbidity in the mainstem Elwha River (Curran et al. 2013), floodplain and tributary channels, the estuary, and marine waters to the east and west of the river's mouth in the Strait of Juan de Fuca. NOAA is taking daily spot turbidity measurements from 14 floodplain channel and tributary sites downstream of the two dams. Turbidity is also being collected with three optical data loggers in the east and west portions of the Elwha River estuary and by sensors mounted on multi-instrument tripods on the seafloor to the east and west of the river mouth (Warrick et al. 2011).

At all sampling locations, turbidity is being used as a surrogate measurement for suspended sediment concentration (SSC) - the fraction of material that is held in suspension in the water column. The continuously collected flow and turbidity data is calibrated with water sample derived suspended sediment concentration to provide total estimates of sediment flux (see Warrick et al. (2012) and Curran et al. (2013)) for estimates of flux during the time period of Elwha Dam removal). Turbidity can also be influenced by organic material and other suspended solids. However, SSC measurements are collected at several locations in the river and nearshore by automated samplers, and regular discharge-calibrated equal-width increment measurements are collected by USGS from the pedestrian bridge near the ESWI facility to calibrate USGS sensors deployed at gage #12046260 and provide data on particle size distribution of suspended sediments (Curran et al. 2013).

The USGS is operating optical turbidity sensors on the mainstem of the Elwha River upstream and downstream of the two dam removal locations, and trying to maintain a sensor between them as well, at gaging station "Elwha River at McDonald Bridge" (#12045500). The USGS gaging station "Elwha River above Lake Mills" (#12044900) provides near-natural background turbidity values of the mainstem Elwha River, although it is slightly influenced by accumulated sediment in the canyon, which is expected to rapidly flush during the project. The USGS "Elwha River at Diversion" gage downstream of the Elwha Dam (#12046260) is indicative of conditions downstream of the two dam removal sites. USGS hydrologists also collect regular discharge-calibrated equal-width increment measurements from the pedestrian bridge near the ESWI facility and the Altair Bridge on Olympic Hot Springs Road to calibrate USGS sensors deployed at gage #12046260 and #12045500 respectively, and to provide data on particle size distribution of suspended sediments in the water column at various flows.

Coarse sediment transport is monitored in real time by a series of bedload impact sensors deployed across the ESWI weir at the upstream end of the engineered riffle, just below USGS gage #12046260. These sensors are calibrated by repeat bedload sampling conducted at a variety of flows just upstream of the weir. Additional coarse sediment monitoring includes monthly to quarterly sediment sampling for grain size distribution at various locations from Lake Mills to the river mouth where recent sediment deposition has occurred.

River bed and water surface elevation longitudinal profiles from Rica Canyon to the river mouth are measured by repeat surveys conducted with RTK GPS, depth sounder, acoustic Doppler current profiler (ADCP) and total station at least quarterly, with profiles in reservoirs collected at least monthly. Bed elevation profiles are also collected quarterly for river sections between and below the former reservoir reaches. Continuous river stage is recorded at 30 minute increments in 25 cross sections from Glines Canyon Dam to the river mouth.

Sediment erosion from both reservoir reaches is mapped and measured on weekly to monthly intervals by aerial photogrammetic surveys depending on hydrology and weather. Aerial surveys provide accurate digital surface models of reservoir regions, and 10-15 cm resolution ortho-imagery of channel conditions from Rica Canyon to the river mouth, including bar, riffle, and pool areas, changes in grain size (cobble, gravel, sand, and silt have different texture), and wood distribution.

Bureau of Reclamation models reservoir erosion of fine and coarse sediment and suspended sediment concentrations in the river based on a series of hydrologies to predict the range of suspended sediment concentration response that can be expected in various scenarios, both for drawdown schedules and for potential flood timing. A model for coarse sediment transport in the river is being developed and calibrated with longitudinal profile and stage/discharge data to better predict channel bed elevation response to coarse sediment released from the reservoir. Both of these models are regularly adjusted with data collected from the field.

6. Data Management, Record Keeping, and Reporting

Management of data from the focused monitoring program and documenting the outcomes of trigger evaluations and associated decisions from the adaptive management approach should be key components of these monitoring and adaptive management guidelines. This difficult task is made more difficult by the fact that data will likely be collected by different federal and state agencies, Tribal staff, as well as different divisions within the same agencies.

In an effort to centralize data from multiple sources, monitoring data from all projects related to performance indicators and triggers should be housed in the Elwha Master Database. Data from secondary projects, which are not directly associated with performance indicators and triggers that may provide inference regarding mechanisms influencing recovery, may also be added to this master database. As indicated in the budget section, there should be a dedicated individual responsible for creating, maintaining, and performing quality assurance/quality control (QA/QC) on the database. The master database could be maintained by NOAA/NMFS, since they have already initiated its development based on several monitoring projects they have undertaken. They have also added data from several other projects from other agencies, so this is well underway. However, this effort will lag behind without dedicated funding as monitoring activities progress.

Project managers from different agencies should be responsible for providing metadata and raw data in electronic (Excel or Access) format to the database manager on a bi-annual basis. Metadata, established and developed by each project manager, should consist of project title, purpose, contact information, conditions of use, site description, project summary, methods (including any analysis procedures), and metric definitions. Raw data files sent to the data manager should have gone through first level quality control by the managing agency. This should include, but is not limited to; ensuring accuracy between paper and electronic copies of the data and correcting or eliminating any unreliable or erroneous values. Secondary quality control should be performed by the database manager, and should include an assessment of the consistency between the raw data received and its eventual format in the Elwha Master Database.

This system would ensure adequate backup of data to prevent data loss. The Elwha Master Database will likely be housed on the NOAA/NMFS internal network server, which is backed up regularly. In addition, the data manager should back-up the database on an external drive on a bi-weekly basis. The original electronic data files sent to the data manager should be retained by the project manager as a secondary backup. In addition, original and copied field sheets should be retained by the project manager. Web access to the database may be developed if it is deemed appropriate.

The data manager and project managers should collectively maintain data maps that outline the relationships among the different data sets as well as their relationship to the adaptive management approach. We plan to develop data maps outlining the relationships among the different data sets and their relationship to the adaptive management approach.

An important component of a long-term adaptive management is record keeping, including archival of trigger values and decisions made throughout the process (Medema et al. 2008). The purpose of these records is to provide transparent documentation of the entire process that resulted in specific management actions. This would allow future managers to understand why specific management decisions were made that has led up to the current management strategy. We propose to develop a database to track monitoring data and develop a yearly summary similar to that described in (Table 15). This database will contain the specific questions used to develop the adaptive management objectives above (Figure 3) and will list the desired trigger value, the actual value obtained from monitoring, the data source (e.g., report reference), and the associated response. These records should be archived at the Elwha Project Management Office and on the NOAA/NMFS internal server in association with the Elwha Master Database and/or the USFWS.

A summary report should be generated annually that provides information regarding the management actions implemented, differences between the prescribed and actual management actions (e.g., failure of hatcheries to meet production goals), trigger values for the performance indicators and exogenous variables, quality of the data used to assess the triggers, and recommended future management actions based on this information. Essentially, these annual reports will provide the history of management actions, monitoring data, and adaptive management actions. This level of reporting will be necessary to allow others to carry this process along in the future, which will be required since the expected recovery time of the system will span multiple manager careers.

Table 15. An example, using hypothetical data, of how performance indicator values would be tracked through time, for Chinook salmon starting with the preservation phase of the Elwha River restoration project at the start of dam removal (2011). For most performance indicators, the trigger value is met for all years, with the exception of Number of Spawners/Spawner (H+W), which does not meet its trigger value until 2017. So, under this scenario, during 2017 all of trigger values for the preservation phase would be met and the project would move into the next phase (recolonization).

Indicator	**Indicator Values by Year**						
	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Abundance							
Number of wild spawners	1000	1200	800	1100	1200	1400	1100
Spawner escapement duration (years)	na	na	na	Yes	Yes	Yes	Yes
Managing for pHOS							
pHOS	*No indicator values for these metrics during preservation phase*						
pNOS							
PNI							
Spatial Distribution							
Extent[1]	>Rkm 8	22% IP	30% IP	60% IP	62% IP	60% IP	65% IP
Barriers[2]	0	0	0	0	0	0	0
Diversity							
Stream type proportion	*No indicator values for these metrics during preservation phase*						
Entry timing variance							
Number of Alleles	0 change	0 change	0 change	0 change	0 change	0 change	0 change
Expected heterozygosity	0 change	0 change	0 change	0 change	0 change	0 change	0 change
Productivity							
Number of juvenile migrants/female	200	100	150	201	202	210	250
Number of pre-fishing recruits/spawner (H+W)	>1.56	1.00	1.40	1.60	1.60	1.56	2.00
Number of spawners/spawner (H+W)	>1.0	0.8	0.8	0.9	1.0	0.7	1.2
Number of pre-fishing recruits/spawner (W)	*No indicator values for these metrics during preservation phase*						
Number of spawners/spawner (W)							
Productivity trend (years)	na	no	no	no	no	no	Yes

[1]Given in terms of intrinsic potential (IP)
[2]Number of barriers downstream of former Elwha Dam site

7. Budget

The overall budget for completing 10 years of monitoring as described in Section 5 to facilitate the adaptive management approach described in Section 4 is $15.9 million (Table 16). This is equivalent to approximately $1.4 to $1.8 million per year and includes a 3% per year inflation rate during this period. A total of approximately $6.7 million has been identified for this monitoring thus far. Identified funding has either been provided by the different agencies as in-kind contributions, through external funding sources (e.g., Federal Caucus of the Puget Sound Partnership), or through the NMFS BO (NMFS 2012). These dedicated funds have also been identified in Table 16, along with the funding deficit necessary to complete the monitoring and adaptive management as described. The costs associated with each indicator category for 2013 is provided in Figure 19.

Partial funding for the described monitoring and associated adaptive management activities will be covered by NPS through Reasonable and Prudent Measures (RPMs) identified in the BO (NMFS), which lists the NPS's funding for monitoring (ONP 2013). A total of $6.7 million dollars will be provided for monitoring (~$6.5 million) and fish relocation efforts ($~160,000) (Table 16). This funding will be provided over 10 years beginning in 2013. This funding is provided for specific tasks; however, they can be used for additional tasks if the specified tasks are somehow funded through another funding source.

The funding deficit for the proposed monitoring activities in these guidelines is approximately $9.2 million for 10 years or approximately $0.92 million per year. No funding has been identified to continue the monitoring after 2022. However, it is very likely that recovery will only be in the Recolonization or Local Adaptation Phases by this time. Thus, additional funding will need to be secured to continue the monitoring and adaptive management approach after 2022.

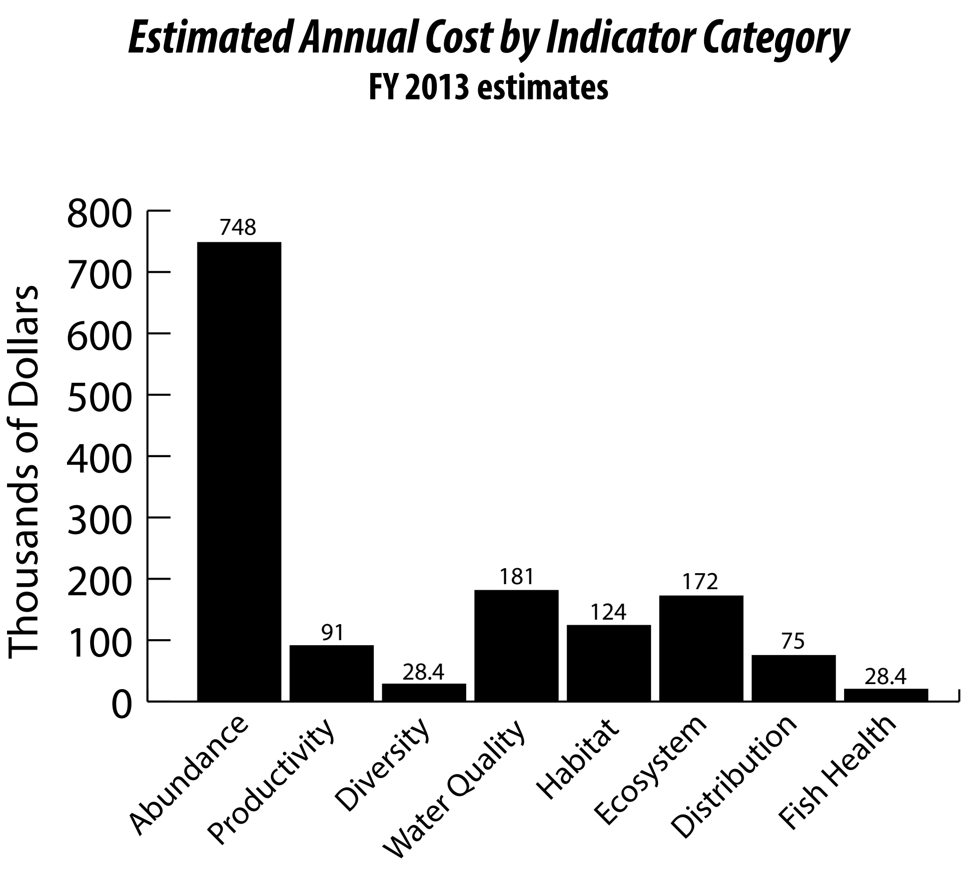


Figure 20. Estimated annual monitoring costs for the different indicator categories (e.g., Figure 2) during 2013.

Table 16. Annual cost estimates, current funding availability, and funding deficit associated with different monitoring tools for 2013. Costs are also specified for species/task (Ch – Chinook, Sth – steelhead, Hab – habitat, EV – Exogenous Variable).

Task	**Tools**	**Species/ task**	**Annual cost**	**2013 Funds available**	**Deficit**
Abundance	Parentage, Genetic Mark Recapture	Ch	$67,000	$0	$67,000
	Boat surveys (redd, live count)	Ch, Sth	$33,333	$33,333	$0
	Foot surveys (redd, live count)	Ch, Sth	$33,333	$33,333	$0
	Snorkel surveys	Ch, Sth	$33,333	$33,333	$0
	Broodstock collection	Ch, Sth	$5,200	$0	$5,200
	Weir/adult capture	Ch	$281,000	$100,000	$181,000
	Hatchery rack return	Ch, Sth	$10,000	$0	$10,000
	Smolt trap	Ch, Sth	$60,000	$60,000	$0
	DIDSON sonar	Ch, Sth	$280,000	$280,000	$0
	Aerial redd surveys	Ch, Sth	$5,000	$5,000	$0
pHOS	Otolith mark interpretation - for pHOS	Ch	$4,400	$0	$4,400
	Otolith mark interpretation - for pNOS, pHOS	Ch	$4,400	$0	$4,400
Productivity	Otolith mark interpretation	Ch	$31,000	$0	$31,000
Diversity	Scale analysis	Ch, Sth	$1,000	$0	$1,000
	Number of Alleles	Ch, Sth	$9,300	$0	$9,300
	Heterozygosity	Ch, Sth	$9,300	$0	$9,300
Distribution	Radio-telemetry	Ch, Sth	$75,000	$75,000	$0
Fish health	Wild fish surveys	Sth	$20,000	$20,000	$0
Habitat	Spawning habitat quantity - pebble counts	Ch, Sth	$15,500	$0	$15,500
	Spawning habitat quality - bulk sediment samples	Ch, Sth	$62,000	$0	$62,000
	Rearing habitat area	Ch, Sth	$15,500	$0	$15,500
	Rearing habitat quality, residual pool depth, etc.	Ch, Sth	$31,000	$0	$31,000
Water quality	Portable turbidity meter	Ev	$21,000	$0	$21,000
	Turbidity, gage optical sensor	Hab	$31,000	$30,000	$1,000
	Turbidity to suspended sediment load	Ev	$31,000	$30,000	$1,000
	Nearhsore tripods-turbidity	Ev	$21,000	$20,000	$1,000
	CTD in estuary	Ev	$25,750	$25,000	$750
	Water temperature sensors	Ev	$51,500	$0	$51,500
Ecosystem	Invertebrate taxonomy	Ev	$15,500	$0	$15,500
	Periphyton and algae biomass	Ev	$21,000	$0	$21,000
	Invertebrate density	Ev	$21,000	$0	$21,000
	Fish food availability	Ev	$21,000	$0	$21,000
	Fish diet	Ev	$28,750	$0	$28,750
	Microbial community structure	Ev	$0	$0	$0
	Total N, Total P, NO_3, NO_2, NH_4, PO_4	Ev	$10,300	$0	$10,300
	Diatom taxonomy	Ev	$18,500	$0	$18,500
	Marine-derived nutrients (Stable isotopes)	Ev	$36,000	$0	$36,000
	Habitat/Ecosystem SUBTOTAL		$477,300	$75,000	$402,300
	Total Cost per year		$1,439,899	$820,000	$694,000

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