BioOne COMPLETE

An Overview of Monitoring Options for Assessing the Response of Salmonids and Their Aquatic Ecosystems in the Elwha River Following Dam Removal

Authors: McHenry, Michael L., and Pess, George R.

Source: Northwest Science, 82(sp1) : 29-47

Published By: Northwest Scientific Association

URL: https://doi.org/10.3955/0029-344X-82.S.I.29

BioOne Complete (complete.BioOne.org) is a full-text database of 200 subscribed and open-access titles in the biological, ecological, and environmental sciences published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Complete website, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Complete content is strictly limited to personal, educational, and non - commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Michael L. McHenry[1], Lower Elwha Klallam Tribe, Fisheries Department, 51 Hatchery Road, Port Angeles, Washington 98363

and

George R. Pess, NOAA Fisheries, Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, Washington 98112

An Overview of Monitoring Options for Assessing the Response of Salmonids and Their Aquatic Ecosystems in the Elwha River Following Dam Removal

Abstract

Removal of two hydroelectric dams on the Elwha River, Washington, one of the largest river restoration projects in the United States, represents a unique opportunity to assess the recovery of fish populations and aquatic ecosystems at the watershed scale. The current project implementation does not contain sufficient funding to support comprehensive monitoring of restoration effectiveness. As a result, current monitoring efforts are piecemeal and uncoordinated, creating the possibility that project managers will not be able to answer fundamental questions concerning salmonid and ecosystem response. We present the initial elements of a monitoring framework designed to assess the effectiveness of dam removal on the recovery of Elwha River salmonids, their aquatic habitats, and the food webs of which they are an integral component. The monitoring framework is linked to the Elwha Fisheries Restoration Plan, which outlines the restoration of native stocks of salmon and relies upon a process of adaptive management. The monitoring framework includes two areas of emphasis—salmonid population recovery and ecosystem response. We provide study design considerations and make recommendations for additional monitoring efforts prior to dam removal. Based on a power analysis, we determined that a minimum of 3–11 years and up to 50 years of monitoring will be required to capture potential ecosystem responses following dam removal. The development of a monitoring plan will be a significant step forward in objectively evaluating the success of Elwha River dam removal.

Introduction

In the United States the number of aging dams nearing their life expectancies is projected to increase dramatically in the next several decades (Heinz Center 2002, Poff and Hart 2002, Stanley and Doyle 2003). Dams that are no longer economically viable or dams that have negative environmental effects will be candidates for potential removal. Over the last two decades approximately 500 dams have been removed in the United States (Pohl 2002). Most of these have been small dams (<2 m height) and only a few have been systematically evaluated for ecological responses (Stanley and Doyle 2003).

The Elwha River Ecosystem and Fisheries Restoration Act of 1994 calls for full restoration of native anadromous fish populations and their ecosystem, with dam removal having been determined to be the most effective means to achieve this goal (DOI et al. 1994, DOI 1996a). This legislation will ultimately result in the removal of the Elwha (32 m high) and Glines Canyon Dams (64 m high) between 2012 and 2014 (Duda et al. 2008). Dam removal presents a unique opportunity to assess salmon recolonization and ecosystem recovery processes. Extant populations of salmon persist in the Elwha River below the dams, providing a source of colonizers. Additionally, the majority of the Elwha River drainage is located in Olympic National Park (ONP) and is considered nearly pristine. As a result, Elwha dam removal represents a true watershed scale restoration effort (Wohl et al. 2005).

The specific mechanisms for achieving restoration of native anadromous fish populations have only recently been defined in the Elwha Fisheries Recovery Plan (Ward et al. *in press*, hereafter refered to as Recovery Plan). Efforts to recover naturally-reproducing anadromous salmon within the Elwha River basin will be achieved through the preservation of extant stocks of anadromous fish during the removal of the Elwha dams, and through rehabilitation of all anadromous fish populations following dam removal. The goals of the Recovery Plan (Ward et al. *in press*) are:

[1] Author to whom correspondence should be addressed: Email mike.mchenry@elwha.nsn.us

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

1. Re-establish self-sustaining anadromous salmonid populations in habitats of the Elwha River within 5 to 10 generations (i.e., 20 to 40 yrs);
2. Maintain the integrity of the existing native salmonid gene pools during the dam removal period;
3. Monitor pathogen distribution in fish populations before and after dam removal; and
4. Evaluate the physical and biological response of the overall ecosystem to dam removal and the return of salmon populations.

Funding for dam purchase, dam removal, and water supply protection was included as part of the Act; however, due to numerous issues (Winter and Crain 2008) funding for monitoring the ecosystem response to the removal of the Elwha River dams was not included in the Act. This has resulted in an amalgamation of individual studies that are focused upon specific questions related to dam removal and ecosystem response, some of which are published in this special issue of Northwest Science. Although a centralized monitoring plan based upon the Elwha Restoration Act has not occurred to date, there are basic questions related to objectives in the Act and the Recovery Plan that need to be addressed but will not be met by ongoing and proposed scientific studies. Because there are numerous uncertainties concerning the response of salmonids to dam removal on the Elwha (Table 1), project managers are heavily reliant on the concept of adaptive management (Lee 1993) to answer questions concerning project effectiveness. One of the central requirements of an adaptive management approach is the adjustment of project implementation, based upon data collection, so that restoration goals will be achieved.

Our intention is to focus directly on the response of fish and ecosystem components (goals 1 and 4, above) to dam removal in the Elwha River. We base this upon the recommendations outlined by Roni et al. (2005) for monitoring and evaluating the response of salmonids and their aquatic ecosystems to dam removal and ecosystem restoration. We define specific parameters that are or will be measured to a basic conceptual framework that captures some of the major hypotheses and predictions addressed in detail by other papers in this issue (e.g., Brenkman et al. 2008a, Kloehn

TABLE 1. Assumptions used in the development of the Elwha River Fish Restoration Plan (Ward et al. *in press*).

Fish Restoration Plan Assumption	Uncertainty
Sediment levels return to background levels in 2-5 yrs after dams are removed	· Assumptions and simplifications of hydrological and sediment transport models · Stabilization of reservoir sediments via revegetation efforts minimizes erosion
All native populations of salmonids survive dam removal disturbance	· 3 populations are ESA listed (threatened) and others currently have low population sizes
Recovery rates of salmon populations are steady state and immediate following dam removal	· Dam removal may initially cause salmon populations to decline in the short term · Recolonization into some areas may take longer than anticipated · Unanticipated barriers to migration may emerge · Recolonization rates may change
"Fish Windows"—where deconstruction is temporarily halted at specific times of the year—will minimize negative effects of high sediment loads to exant populations below the dams and will facilitate collection of brood stock	· Turbidity may remain high for prolonged periods during "Fish Windows" reducing ability to collect broodstock. Alternatively, salmon may avoid river outright during times of high turbidity
Hatchery supplementation will speed recovery of stocks	· Whether hatchery supplementation will allow faster recovery than natural recolonization
Monitoring will allow meaningful evaluation of management actions	· Funding levels are commensurate with requirements for data collection

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

TABLE 2. Existing status of sediment supply and migration barriers in the Elwha and Quinault Rivers. The Elwha River is divided into sections by two dams. Δ = change.

	Sediment Supply		Barriers to Migration	
Reach	Current conditions	Post dam removal Δ	Current conditions	Post dam removal fish community Δ
Lower Elwha	Unnatural	Yes	Yes[1]	No
Middle Elwha	Unnatural	Yes	Yes[1]	Yes
Upper Elwha	Natural	No	Yes[2]	Yes
Quinault	Natural	No	No	No

[1] dams block migration

[2] natural seasonal velocity barriers

et al. 2008, Morley et al. 2008, Pess et al. 2008, Winans et al. 2008, Woodward et al. 2008). Spatial and temporal scale issues are discussed as part of the study design associated with each of the parameters. How individual parameters will be measured is described in general terms, and specific references are given for existing and proposed methods. For a sub-set of these monitoring parameters we present a statistical power analysis that estimates the number of years that will be required to detect ecosystem response to dam removal. Finally, for each parameter we describe the types of metrics and data analyses that will be used to analyze trends and patterns in relation to the conceptual framework and hypotheses put forth in other papers in this issue.

A Framework for Creating General Monitoring Questions Based Upon Recovery Objectives

Our first consideration in developing a monitoring framework for the Elwha River dam removals was to clearly define working hypotheses based upon Recovery Plan goals (1 and 4) for salmonid populations and associated habitat. The effects of Elwha dam removals on salmonid recolonization, population sustainability, and ecosystem response can be addressed by two main questions: (1) What effect(s) will dam removal have on the quantity, quality and spatial extent of habitat over time? and; (2) What effect(s) will dam removal have on the abundance and distribution of salmonids over time? The development of working hypotheses for Elwha River dam removal is logically framed by existing spatial boundaries defined by the dams and the impacts from dam construction and removal (see discussion in Duda et al. 2008). These working hypotheses will predict the trajectory of ecosystem response following dam removal.

Construction of dams on the Elwha River has dramatically reduced habitat availability and quality resulting in isolated populations of resident and anadromous fish. These populations have declined dramatically over historic levels (Pess et al. 2008). The severity of effects to the Elwha ecosystem varies by reach. The reaches below Elwha Dam (lower Elwha) and between Elwha and Glines Canyon Dams (middle Elwha) have undergone similar physical but different biological impacts, while the upper Elwha has undergone similar biological impacts but has not been physically impacted (Table 2). These reaches represent logical spatial boundaries for describing the conceptual framework to ecosystem response following dam removal.

The Lower Elwha (Estuary to Elwha Dam)

The lower Elwha River (rkm 0-8) has arguably been most impacted by the dams and will be most impacted by dam removal. Dam construction dramatically reduced the capacity of the river to transport sediment and wood from upriver sources, a necessary process for creation and maintenance of in-river habitat. The lower Elwha has also been impacted by flow manipulations, thermal alterations, and floodplain degradation from diking, logging, and channelization. This has significantly reduced the abundance of native salmonids. However, anadromous salmonids persist as fragmented populations (Brenkman et al. 2008a, Pess et al. 2008) that have retained a high degree of genetic diversity (Winans et al. 2008).

Dam removal will result in changes to aquatic habitat quality and channel morphology in mainstem and floodplain habitats in the lower Elwha due to increased rates of fine and coarse sediment transport. Increases in sediment transport will result in increased turbidity levels, stream channel

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

aggradation, and stream channel instability (Pess et al. 2008, DOI 1996b). Sediment transport modeling (USACOE 1999) suggests that aggradation of channel beds downstream of the dams will be relatively minor during the first 3–5 yr following dam removal. The initial wave of fine sediments is expected to increase turbidity and temporarily fill pools, but not significantly raise channel bed elevations (DOI 1996b). Coarse sediments stored within the dams are predicted to reach the lower Elwha after several decades, and are modeled to increase bed aggradation by about one meter, in some areas, after 50 yr (DOI 1996b). The rates and duration of turbidity generated by stored fine sediments in the reservoirs are relevant to extant downstream biological populations, and will likely affect salmonid growth and survival in the lower Elwha.

A confounding aspect of the conceptual framework with respect to salmonid response is the use of hatchery outplants. Two hatcheries (Washington Department of Fish and Wildlife Spawning Channel [WDFW] and the Lower Elwha Klallam Tribal [LEKT] Hatchery) were constructed in the lower Elwha River during the 1970s to offset losses in natural salmon production. Following dam removal these facilities will be used to provide coho salmon (*Oncorhynchus kisutch*) and Chinook salmon (*O. tshawytscha*) smolts derived from native Elwha stocks in an effort to maximize returns of adults (Ward et al. *in press*). The hatcheries will also be used to maintain and rebuild remnant populations of pink salmon (*O. gorbusha*), chum salmon (*O. keta*), and steelhead (*O. mykiss*) through the dam removal period using broodstock conservation programs. Because of their current reduced population sizes, only small numbers of these species will be moved to selected habitats (as eyed eggs in hatchboxes, fed fry, or smolts), during and immediately following dam removal (Ward et al. *in press*). The primary focus of hatchery efforts for these species will be to maintain extant populations through a period of short term negative impacts (largely sedimentation) expected following dam removal.

The Middle Elwha (Elwha Dam to Rica Canyon).

The middle Elwha (rkm 8–26) has also been impacted by a dramatic reduction of sediment and wood from upstream sources as a result of the construction Glines Canyon Dam in 1927. The dams have also submerged ~10 km (40%) of the reach in two reservoirs, resulting in broadscale shifts from lentic to lotic processes. Changes to the native salmonid assemblage in the middle Elwha have been profound due to the direct loss anadromous salmonids. The remnant fish community is now greatly simplified, consisting of rainbow trout, bull trout (*Salvelinus confluentus*), sculpin (*Cottus* spp.), and an established population of exotic brook trout (*S. fontinalis*) (Brenkman et al. 2008a). The complete loss of marine derived nutrients (MDN) from returning anadromous salmonids has likely altered food webs within the middle Elwha (Munn et al. 1996, 1998; Morley et al. 2008).

Effects of dam removal on the middle Elwha will be similar to the lower Elwha in terms of fine sediment (DOI 1996b). In contrast, stream channel aggradation will be significantly less in the middle Elwha than in the lower Elwha, primarily because sediment transport capacity is higher in the steeper middle reach (DOI 1996b, Pohl 2004, Kloehn et al. 2008). As a result, the primary impacts in this reach are likely to be short term and associated with turbidity spikes during and immediately following dam removal.

The middle Elwha will be used to test the effectiveness of hatchery supplementation over a single generation (2–5 yrs, depending on species). A single generation for each species was chosen as a point to assess the initial effectiveness of hatchery supplementation efforts. Although all native species are anticipated to use this reach (DOI et al. 1994), only Chinook salmon and coho salmon will be planted from the hatcheries in significant numbers (Ward et al. *in press*). The middle Elwha contains forested floodplain habitats with numerous side channels and is hypothesized to be quickly colonized by both natural and hatchery origin fish following the removal of Elwha Dam (DOI et al. 1994, Pess et al. 2008).

The middle Elwha also contains two large tributaries, Indian Creek and Little River, that are accessible to salmonids and will not be affected by increases in sedimentation from dam removal. These tributaries provide opportunities for recolonization experiments testing the efficacy of natural and hatchery outplanting techniques. The Little River supports a mixed origin population of resident rainbow trout, including an isolated headwater population possibly of native origin

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

(Phelps et al. 2001, but see Winans et al. 2008). Resident rainbow trout populations isolated from anadromous populations are capable of producing anadromous smolts many generations removed from their isolation above anadromous barriers (Hiss and Wunderlich 1994a, Thrower and Joyce 2004). Thus, the Little River is ideal to assess natural recolonization mechanisms by steelhead, particularly given that no hatchery outplanting is planned for the Little River (Ward et al. *in press*).

Indian Creek drains Lake Sutherland which historically supported a population of sockeye salmon (*O. nerka*). A robust population of natural reproducing kokanee (the resident form of *O. nerka*) in the lake may be producing small numbers of anadromous smolts (Hiss and Wunderlich 1994b). Dam removal will allow access by naturally colonizing anadromous sockeye salmon without hatchery supplementation (Ward et al. *in press*). In contrast, other salmon species, particularly coho, derived from hatchery outplants will be directly seeded into Indian Creek (Ward et al. *in press*). The higher proportion of low gradient channels, associated wetlands and the presence of Lake Sutherland also make the Indian Creek basin highly suitable for coho salmon recolonization (Pess et al. 2008). Thus, Indian Creek is ideal to assess coho salmon recolonization mechanisms comparing natural and hatchery supplementation methods (Ward et al. *in press*).

The Upper Elwha (Rica Canyon to Headwaters)

The upper Elwha (> rkm 26) will not dramatically change in terms of physical watershed inputs because of dam removal. Natural sediment supply from the upper Elwha River basin since 1927 (when Glines Canyon Dam was built) has averaged 146 $m^3\ km^{-2}\ yr^{-1}$ (DOI 1996b). However, similar to the middle Elwha, the salmonid fish assemblage has been greatly simplified by dam construction (Brenkman et al. 2008a). The upper Elwha River provides a potential reference reach to assess recolonization for the majority of salmonid species. We define a salmonid reference area as a section (100s of meters to kilometers) of the river where no hatchery practices are conducted for the purpose of accelerating recolonization for a particular species. However, the upper Elwha will not be a reference for all salmonid species because the Recovery Plan currently targets limited Chinook outplanting from hatchery sources in the upper watershed during the first 10 yr (Ward et al. *in press*). Natural recolonization will be the primary mechanism for other species such as coho salmon, steelhead, cutthroat trout (*O. clarki*), and bull trout. Pink salmon and chum salmon may colonize only limited portions of the upper Elwha, as stream gradient and confinement increases dramatically above ~rkm 30 (the Grand Canyon of the Elwha) and may ultimately limit their distribution (DOI et al. 1994, Brenkman et al. 2008a, Pess et al. 2008).

As none of the tributaries in the upper Elwha will have directed outplanting, they will also be considered reference areas for natural recolonization. Major tributaries in the upper Elwha include Hayes, Lillian, Lost, Goldie rivers and Long creek (Figure 1, see also Table 1, Brenkman et al. 2008a). Existing anadromous and resident populations below each dam will have the opportunity to colonize if they can successfully survive deleterious sediment impacts, by utilizing existing refuge habitats such as groundwater fed side channels and tributaries. We hypothesize that in general salmonids will respond to dam removal by establishing persistent, self-sustaining salmonid populations in the middle and upper Elwha within in one to five generations (2–30 yr) following dam removal (Pess et al. 2008).

In summary, the conceptual framework for dam removal in the Elwha River will be based upon the relative spatial location of the river reach (lower, middle and upper Elwha) as affected by past impacts (dam construction, reservoir innundation) and potential response (physical and biological inputs) to dam removal. Planned management practices, particularly the use of hatcheries to accelerate fish recolonization rates, present challenges to the development of a conceptual framework for monitoring, particularly with regards to establishing reference reaches. However, it is important to note that hatchery outplanting is limited and will be curtailed following recovery.

Monitoring Design Considerations

Many study designs have been proposed for use in evaluation of watershed restoration including before-after (BA), before-after control-impact (BACI), post treatment, and various modifications of these designs such as beyond BACI (Hicks et al. 1991, Underwood 1994, Roni et al. 2005;). Any design calling for a true "control" will be

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

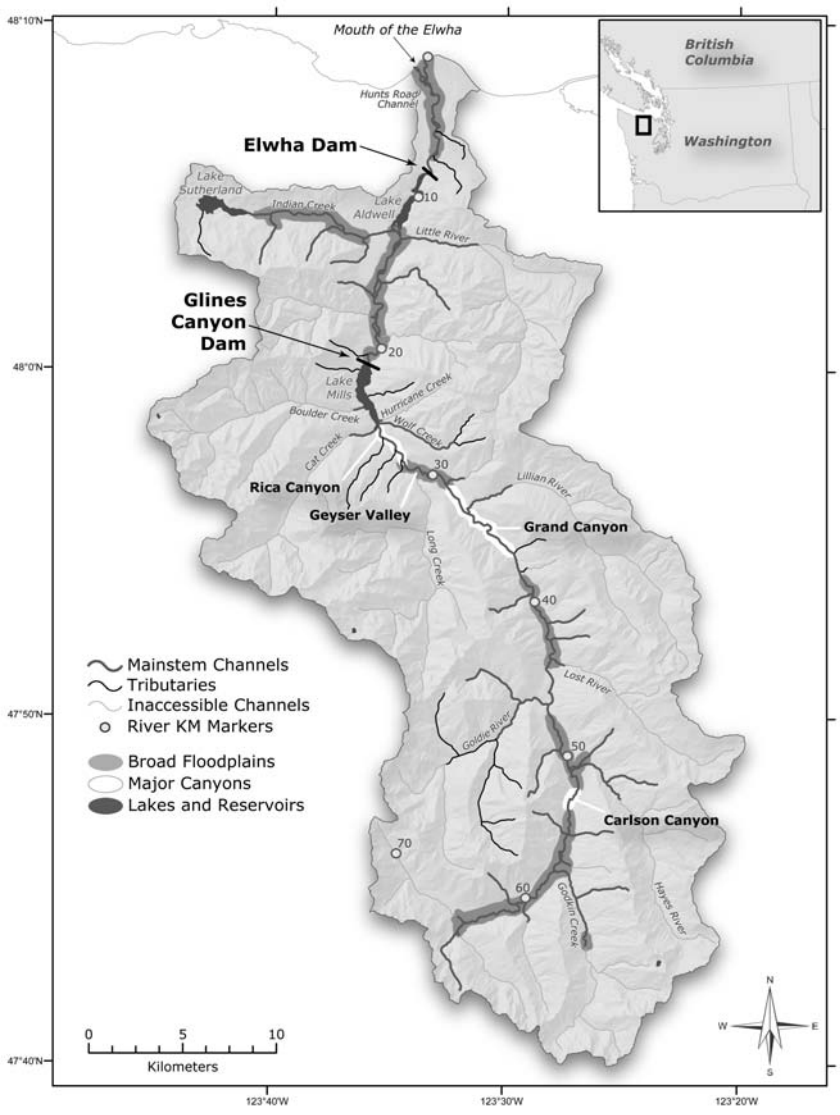


Figure 1. The Elwha River watershed. Reach boundaries are defined as lower Elwha (Estuary to Elwha Dam), middle Elwha (Elwha Dam to Rica Canyon), and upper Elwha (Rica Canyon to Headwaters).

difficult in the case of the Elwha River dam removals, because no true control watershed exists for the Elwha and no comparable dams exist in the same region of the Olympic Peninsula. Given the current availability of resources, we believe that the most appropriate study design for the Elwha River dam removal is a BA design.

Although no true control watersheds exist, we have attempted to identify potential reference watersheds or river reaches throughout western Washington based on geologic, hydrologic, and ecological variables. The goal of such reference sites is to account for variability in response variables due to factors that operate at larger scales, such as regional weather patterns or long-term climate change, which would operate independently from effects associated with dam removal. Such reference reaches could allow for the identification of larger trends in data gathered before and after dam removal.

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

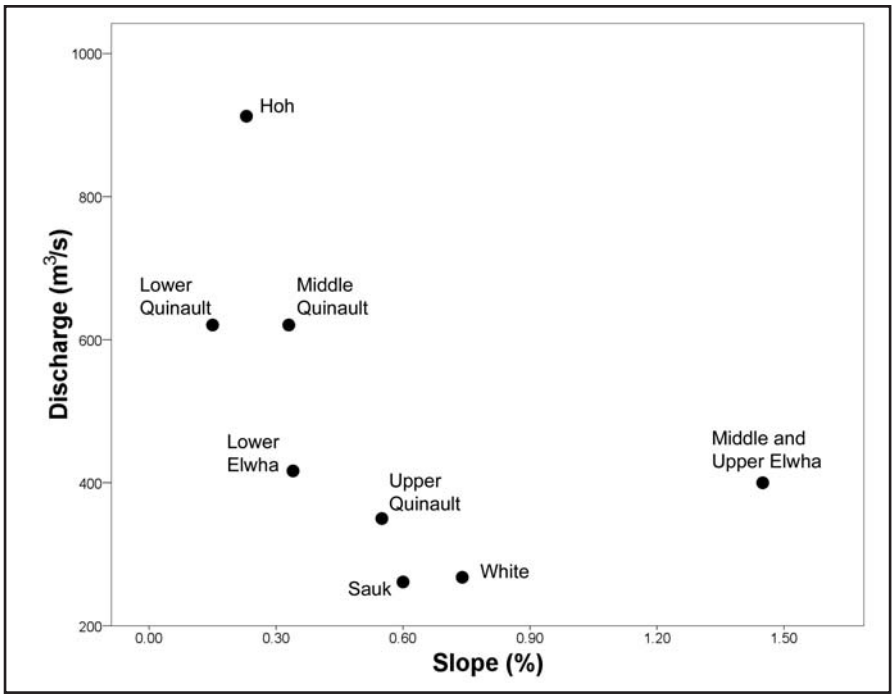


Figure 2. An example reference river selection, based upon river discharge and slope, which compares the Elwha River with other Olympic Peninsula and Puget Sound watersheds.

We examined several locations across western Washington. Based on watershed area and flow characteristics, we found the upper Quinault River to be similar to the lower Elwha (Figure 2). Additionally, both the Quinault and Elwha rivers have similar geology, geomorphic and channel characteristics (e.g., large, low-gradient meandering channels with forested floodplains), and a distribution of hydrologic regimes in each watershed (snow-dominated, transition, and rain-dominated). The Quinault River has been used as a reference reach in existing studies of invertebrates (Morley et al. 2008), river-floodplain dynamics (Kloehn et al. 2008) and fish use that will help inform the outcome of patterns in the Elwha River. It will also serve as a reference to account for large-scale environmental variability (e.g., ocean and climate conditions) that will also affect the Elwha River during and after dam removal. In addition, alluvial reaches in the upper Elwha River will provide reference reaches for reach-level comparisons of habitat quality in the middle and lower Elwha. These unimpacted alluvial reaches also provide a template for how downstream reaches functioned before dam construction.

A single reference reach may limit the ability to infer whether post-dam removal changes are due to the restoration or other factors operating at regional or global scales. However, additional reference sites can also contain high levels of natural variability between sites, as is the case when we examined other potential sites in western Washington. Thus, adding additional unsuitable reference sites could make it difficult to identify the signal of the impact (e.g., sediment) or treatment (e.g., reopening of habitat) variables. The Quinault River is a comparable site which will allow us an opportunity to identify changes due to dam removal, but in all likelihood will not allow for quantitative results to be extrapolated beyond the Elwha.

Monitoring Objectives

Re-establish Self-sustaining Anadromous Salmonid Populations

The primary monitoring objective related to the goal of re-establishing self-sustaining anadromous salmonid populations is to quantify the recolonization rate of habitats by different salmonid

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

species over time. We use two criteria to define a self-sustaining population: 1) colonizing population growth rate exceeds emigration (stray rates from the colonizing population) and immigration (stray rates from the source population); and 2) over 50% of returning adult spawners are from parents that originated from the same area (Cooper and Mangel 1998). Rates of population growth and development of self-sustaining salmonid populations above the dams will vary by species-specific tendencies to reoccupy newly opened habitats, distance from source populations, current population size, and the influence of other management practices identified in the Recovery Plan (Pess et al. 2008). For example, the introduction of hatchery fish at different life stages and in different locations throughout the Elwha River basin will contribute to species-specific spatial and temporal variability in recolonization rates. Recolonization will occur by two processes—natural recolonization and hatchery supplementation. We define natural recolonization as the establishment of self-sustaining populations without the aid of directed hatchery management techniques such as the planting of fish at specific life stages (e.g., fry or smolt). A complete discussion of how natural recolonization rates vary and how this could effect recolonization in the Elwha is provided by Pess et al. (2008).

The Recovery Plan states that natural recolonization will be allowed to occur for species or life forms that are not currently maintained by hatchery production (Ward et al. *in press*). This includes summer run Chinook salmon, cutthroat trout, bull trout, and sockeye salmon. Hatchery supplementation will be used for other species such as coho salmon and Chinook salmon, which have a long history of being raised and planted into the lower Elwha in high numbers. Populations of some species such as pink salmon, chum salmon, and winter run steelhead are currently at such low numbers (<1000, <150, and <250 returning adults, respectively) that hatcheries will be used to maintain populations during dam removal through broodstock maintenance programs that attempt to promote gene conservation. The number of hatchery salmonids planted into the Elwha River at different life stages (outplanting) in subsequent generations will be primarily based upon population rebuilding rates and to a lesser extent the availability of salmonid stocks in the lower Elwha (Ward et al. *in press*).

The combination of natural and artificial recolonization for some salmonid species confounds attempts at quantifying salmonid recolonization in the Elwha River. Various supplementation strategies will be used at different locations within the three general reaches (lower, middle, and upper Elwha). Each reach will receive different levels of supplementation: (1) single species (Chinook salmon) supplementation in the upper Elwha; (2) a temporally (e.g., 5 yr) and spatially limited multiple-species supplementation in the middle Elwha; and (3) a standard practice supplementation reach below Elwha Dam (Ward et al. *in press*).

It is understood that there is a great deal of spatial and temporal interdependence between locations in a river network due to fluvial connectivity and the ability of fish to move upstream. For example, upstream inefficiencies in nutrients and primary productivity can create opportunities and benefits to downstream recipient organisms (Vannote et al. 1980, Polis et al. 1997). Salmonids can migrate from disturbed areas and establish spawning populations following a major disturbance, resulting in population densities that were greater than prior to the disturbance (Roghair and Dolloff 2005). Thus, there will be interdependence and correlation between upstream inputs and downstream productivity in the same system or movement of the response variable of interest between control and impact reaches. The goal of having different strategies in different locations is to focus hatchery supplementation efforts into discrete areas, which may provide an opportunity to examine natural recolonization of those species with no hatchery supplementation at a preidentified scale (e.g., site, reach, and watershed) and potential areas to observe interactions between natural and hatchery produced salmonids within a given species.

One way to quantify the interactions of hatchery supplementation between these different strategies is to mark all hatchery fish released so that the origin of adults can be determined. This will also allow for the assessment of the effectiveness of hatchery supplementation toward the establishment of self-sustaining spawning populations. Initial efforts have been made to differentiate between hatchery and naturally spawning salmonids in the Elwha River. Chinook salmon from the WDFW hatchery are now thermally marked as juveniles, allowing the determination of origin through otolith analysis. Coho salmon and

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

steelhead from the LEKT hatchery are currently marked with either coded wire tags (CWT) or fin clips. An additional tool is the analysis of tissue samples, collected from adult or juvenile fish, using microsatellite DNA markers. Winans et al. (2008) are currently establishing genetic baselines for all Elwha salmonids (natural and hatchery). This information can be used to assess parentage and thus the origin of fish occupying any given habitat in the Elwha.

Recolonization Monitoring Parameters

The measurement of several parameters to enumerate fish recolonization rates, including adult and juvenile abundance, recruits per spawner, smolts per spawner, proportion of native origin returns, and survival at specific life stages (Table 3) will be necessary to adequately monitor salmonid recolonization response. In addition, the proportion of potentially habitable river network that is occupied by anadromous salmonids will be an important measure of changes in spatial distribution due to dam removal (Table 3). Large-scale disturbances that have both immediate (e.g., pulse) and long-term (e.g., press) effects can translate to changes in variation (Underwood 1994). The Elwha dam removals are an excellent example. If salmonid species survive the short-term, negative disturbance associated with increased levels of sediment and temporally unstable habitats, then large areas of newly accessible habitat may result in long-term gains at the population level. We will use adult and juvenile abundance and population productivity metrics to assess both short- and long-term changes at the population level (Table 3). These metrics will include the rate of change, mean, and variance in each parameter category. We will attempt to measure the rate of change of these parameters in occupied and newly accessible habitats to gain a watershed-scale perspective of the relative contribution of new habitats.

The general sampling approach for recolonization parameters will be a stratified sampling approach (Table 3). A stratified sampling approach uses the hierarchical nature of physical and biotic variables to identify how each variable is nested within a larger variables, and at which scale this occurs. For example, stream channel substrate is nested within several variables occurring at larger scales, including channel gradient, valley confinement, channel roughness and geology. Spatially this also incorporates the heterogeneous nature, or patchiness, of the habitat being sampled. Many of these differences are captured in the Elwha River by general habitat types such as tributary, confined mainstem, unconfined mainstem, and

TABLE 3. Fish recolonization parameters expected to be monitored before, during, and after dam removal in the Elwha River. Reach scale refers to newly opened and pre-dam removal reaches

Parameter	Scale	Statistics	Technique(s)	Frequency	Sampling Scheme
Adult-Abundance[1]	Reach and population	Mean Variance Rate of change	Spawner surveys	Annual	Stratified by habitat and using index reaches and random sampling
Juvenile Abundance[2]	Reach and population	Mean Variance Rate of change	Snorkeling Electrofishing	Seasonal and annual	Same as above
Productivity	Reach and population	Recruits per spawner	Spawner surveys	Annual	Same as above
		Smolts per spawner	Smolt traps	Annual	
Origin	Reach and population	% return	Microsatellite DNA markers	Annual	Same as above
Distribution	Reach	Proportion of newly opened habitat occupied	Spawner surveys Radio-telemetry	Annual Supplimental to surveys	Same as above

[1] Chinook salmon, pink salmon, steelhead

[2] Chinook salmon, coho, steelhead.

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

TABLE 4. Adult salmon population enumeration techniques based upon species and location. Spawner surveys are not feasible for all species and reaches due to seasonal differences in flow and visibility associated with peak spawning time of different species (Adapted from Roni et al. 2005). NA = not applicable.

Location	Chinook	Coho	Steelhead	Pink	Chum	Sockeye
Tributaries	NA	Spawner survey	Spawner survey	Spawner survey	Spawner survey	Weir counts
Side Channels	Spawner survey	Spawner survey	Spawner survey	Spawner survey	Spawner survey	NA
Upper Elwha-Mainstem	Spawner survey	Spawner survey	Spawner survey	Spawner survey	Spawner survey	NA
Middle Elwha-Mainstem	Spawner survey	Spawner survey Fish Wheel Sonar	Spawner survey	Spawner survey	Spawner survey Fish Wheel Sonar	Weir counts
Lower Elwha-Mainstem	Spawner survey	Sonar	Spawner survey	Spawner survey	Sonar	Weir counts

floodplain (Munn et al. 1998, Kloehn et al. 2008, Pess et al. 2008) measured over time at specified locations. We will attempt to include replication at specific scales such as the site or reach and to include random sampling in the overall structure of the sampling approach so as not to just focus on index reaches over time. However, due to funding constraints it is unclear how much replication and random sampling will occur and whether or not there will be balanced number of sites for each parameter category.

We will measure adult salmonid abundance by the number of returning adults. Spawner surveys will be used to determine the number of returning adults during summer, early fall, and spring when flows are typically low and clear. During these time periods, we will focus upon Chinook salmon, pink salmon, and steelhead. Spawning ground surveys of live fish, carcasses, and redds will be conducted on foot at 10–14 day intervals throughout the spawning period. Spawner surveys will include mainstem, floodplain, and tributary channels to gain comprehensive estimates of adult salmonid abundance and distribution by major habitat type. This technique has been established in the lower Elwha, but will need to be expanded into the middle and upper Elwha following dam removal. The upper Elwha presents a significant challenge, as access to roadless areas at the limit of upriver fish distribution requires multi-day (at least 5 days for the uppermost portions of the watershed) hiking in the backcountry.

Fall and winter spawning species (coho salmon and chum salmon) that return when river discharge is typically higher (and visibility lower) make traditional visual survey techniques difficult, particularly in mainstem habitats. Other sampling technologies, including a fish wheel (Meeham 1961) and sonar imaging (Moursund et al. 2003), are currently being tested on the Elwha River to ascertain their ability to estimate adult abundance. If successful, a fish wheel can be used to estimate adult population size using mark-recapture techniques. It is important to note that accurate measures of adult abundance will be challenging to obtain in the Elwha because of access, flow, and visibility issues. Table 4 summarizes the existing and projected adult enumeration techniques by species and habitat type for the Elwha River.

Radio-telemetry (High et al. 2006) will be applied to assist the determination of recolonization rates to the upper basin. This technique may be particularly useful for fall and winter timed spawners that will be difficult to enumerate using traditional counts. A series of seven monitoring antennas have been established along an upstream gradient in the Elwha River. This system is currently being used to assess bull trout and resident rainbow trout movements in the river sections above, between, and below the dams (Sam Brenkman, Olympic National Park, personal communication) as well as coho salmon (Burke et al. 2008) and winter-run steelhead behavior in the lower Elwha. Individual adult fish will be captured in the lower river and surgically implanted with radio tags to assess upstream migration rates and distances. Supplemental ground tracking and aerial overflights will be conducted in an effort to expand

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

spatial coverage of the watershed with the goal of identifying spawning aggregations.

Repeatable spatial and temporal monitoring of juvenile abundance using snorkeling techniques at stratified (e.g., mainstem, floodplain, and, tributary habitats within the lower, middle, and upper Elwha) index areas as well as in randomly sampled locations will be an important technique for monitoring response of Elwha fish communities. Snorkeling provides non-invasive, reasonably precise estimation of abundance (Thurow et al. 2006). Juvenile fish population estimates conducted over different reaches of the river can be used not only to monitor recolonization of habitats, but changes in fish community structure over time. This will be particularly important in the middle and upper Elwha, where fish communities are currently dominated by resident rainbow trout and bull trout (Brenkman et al. 2008a). As anadromous species move into these areas, community structure is anticipated to change, as seen in other Pacific Northwest watersheds where recolonization has occurred (Brenkman et al. 2008a, Anderson et al. *in press*).

Snorkel surveys are considered an appropriate tool to use in the Elwha because the natural variability between units, seasons, and years can be quite high (Pess et al. 2008). Having high natural variability means that sampling greater habitat area increases the precision of mean density estimates relative to the trade-off of increasing observation error, which can typically be larger with snorkel surveys relative to other techniques such as electrofishing. Regardless of the technique utilized both observation and process error will be quantified in order to detect trends following dam removal. The biggest drawback with using snorkel surveys will occur during and immediately after dam removal when turbidity levels are high and visibility will be low. During these periods, other methods such as electroshocking (Connolly and Brenkman 2008) and seining will be utilized to obtain juvenile population estimates in mainstem habitats.

To assess changes in salmonid productivity, we will monitor smolt abundance using traps including rotary screw traps in the mainstem and fence weirs in floodplain channels and tributaries. Currently a 2.45 m diameter rotary screw trap is used in the lower Elwha (rkm 0.5) between February and June to sample smolt outmigration rates and timing. The screw trap has been fished annually since 2005, sampling a small proportion of the flow during peak outmigration periods. This has allowed for the estimation of smolt production for several salmon species including Chinook, coho, pink, and chum. The trap will be used in combination with adult enumeration to provide estimates of productivity such as the number of smolts produced per spawner. Additional smolt trap sites will be established following dam removal to monitor production from newly accessible portions of the watershed. Of particular importance will be an additional mainstem site that would measure output from the upper Elwha watershed and in the large middle Elwha tributaries (Indian Creek and Little River). Smolt traps will also provide a convenient means of collecting fish for genetic analysis, fish health screening, and tagging.

Evaluating Physical and Biological Ecosystem Responses

Dam removal on the Elwha River will release large volumes of stored sediment that will, over the short term, affect ecosystem productivity in the downstream reaches, estuary and nearshore. As sediment levels stabilize following dam removal, populations of anadromous fish will colonize upstream reaches increasing nutrient availability for freshwater ecosystems after nine decades of absence. Dam removal also restores natural hydrologic conditions (flow, temperature) and other critical habitat forming processes (large wood transport). Additionally, two reservoirs will be drained and exposed sediments on the reservoir bottom will be revegetated through natural processes (Brown and Chenoweth 2008) as well as supplemental revegetation (Chenoweth et al. *in press*). Sedimentation due to dam removal and subsequent habitat degradation, the restoration of natural watershed processes, habitat expansion, and increases in nutrient availability focus the Elwha River ecosystem recovery monitoring efforts on four areas: (1) habitat and food web response to the release of stored sediment in the middle and lower Elwha; (2) food web response to salmon recolonization in the middle and upper Elwha; (3) the recovery of reservoir reaches as forests recolonize exposed reservoir sediments; and (4) responses of the river delta and nearshore ecosystem to release of stored sediment. We emphasize one and three and note that Elwha food web response (Morley et al. 2008) and the nearshore

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

monitoring efforts are developing simultaneously (e.g., Schwartz 2005, Warrick et al 2008; see also Shaffer et al. 2008).

Habitat Response to the Release of Stored Sediment

Measuring the response of fish habitat to the release of stored sediment will focus on the mean, variance, and rate of change in habitat quantity and quality (Table 5). We will monitor spawning gravel beds in mainstem and side-channel habitats in the lower and middle reaches (including the reservoirs), where the greatest changes are anticipated as a result of dam removal. In addition there will be reference sites in the lower portion of the upper Elwha (e.g., Geyser Valley), and the Quinault reference reach in order to gain a quantitative estimate of variability in available spawning area for each habitat type. Spawning gravel aggregations are defined as gravels (16–64 mm) and cobbles (64–128 mm) that exceed 3.0 m^2 in surface area for larger salmonids, and 1.5m^2 for smaller salmonids (Bjornn and Reiser 1991, Beechie and Sibley 1997). These areas will be located and mapped using GIS. This technique has been used to map changes in Chinook spawning aggregations in the lower Elwha (McHenry et al. 2007).

We will monitor changes to the bed surface and subsurface in order to quantify changes in spawning habitat quality over time (Table 5). Large increases in the supply of fine sediment will affect quality of salmon spawning habitats and may be visually obvious in the bed surface material (Roni et al. *in press*). These can be evaluated by surface pebble counts or a measure of embeddedness (e.g., Potyondy 1989). More subtle changes in fine sediment delivery to channels can be monitored by changes in the subsurface material, which may not be obvious on the bed surface (Young et al. 1991).

We propose to visually estimate substrate size and embeddedness in every potential spawning area, and to conduct pebble counts (Wolman 1954) in every 10th habitat measured (Roni et al. *in press*). We will analyze changes in D_{50} and the proportion of substrate that is sand or finer (< 2 mm) over time. Annual summer surveys are initially recommended for all spawning habitat quality and quantity metrics, though periodic (every other year or third year) may be more feasible. We also propose to monitor subsurface fine sediment (< 0.85 mm) using bulk sampling techniques (Schuett-Hames et al. 1999) in selected areas of the Elwha River. Emphasis will be placed on habitats in the lower and middle reaches (including exposed reservoir surfaces following dam removal). Areas in the upper

TABLE 5. Candidate ecosystem monitoring parameters that could be collected before, during, and after dam removal in the Elwha River. Reach scale includes newly opened and pre-dam removal reaches.

Parameter	Scale	Statistics	Technique	Frequency	Sampling Scheme
Habitat response to release of stored reservoir sediment	Reach/watershed	Mean Variance Rate of change	Gravel mapping	Annual	Stratified and including index reaches and annual randomly located sites
	Reach/watershed	Mean Variance Rate of change	Embeddedness	Annual before and every 3 yrs following dam removal	Every 10th habitat sampled
	Reach/watershed	Mean Variance Rate of change	Sub-surface sediment sampling	Same as above	Stratified and including index reaches and randomly located sites
	Reach/watershed	Mean Variance Rate of change	Census of pool depths	Annual	Stratified and including index reaches and randomly located sites
Reservoir reach recovery as forest recolonize exposed reservoir sediments	Reach	Mean Variance Rate of change	see list above	Annual	Complete census

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Elwha represent potential reference conditions of unimpacted spawning habitat.

An additional area of emphasis will be the effect of dam removal on the quality and distribution of rearing habitats in the Elwha River. Habitat measurements will focus on the quantifying the amount, location, and condition of habitat types, especially in regards to the parameters related to sediment and wood supply, which are expected to change following dam removal (Table 5). Field measurements will include parameters sensitive to changes in sediment supply such as habitat unit type and area, residual depth of pools, variation in bed material grain size, and size and abundance of wood debris (Beechie et al. 2005). One example of this is change in residual pool depth. Holding pools are a critical habitat for most spawning salmonids, and pool filling is likely to be the most obvious effect of sediment release after dam removal (Roni et al. *in press*). Repeated surveys of thalweg profiles or channel cross sections can indicate changes in bed elevation variability (Madej 1999), but these methods are expensive and yield little information directly relevant to holding pools or spawning habitat. Measurement of residual pool filling is a direct measure of changes in holding habitat quality, but the method is relatively time consuming to apply over a large area. Measuring changes in number of pools or residual pool depth is more efficient than other techniques because surveys can be conducted rapidly (Beechie et al. 2005), and the information obtained is a direct measure of holding habitat availability and quality. Hence, we propose to monitor residual pool depths in all pools in accessible mainstem reaches, and record locations of pools with GPS. Pools will be identified and measured by floating the mainstem and walking the floodplain channels on an annual basis. Because we expect the location of many bedrock pools to remain stable following dam removal, we will track changes in depths of individual pools over time. Because some pool locations will shift frequently with channel migration and movement of wood debris jams, we will also compare frequency distributions of residual depths in each reach over time.

Dam removal also restores the natural fluvial transport process for large wood to the lower and middle reaches of the Elwha. These reaches have been historically depleted of in-channel wood and their riparian forest sources (Johnson 1997, McHenry et al. 2007). Annual surveys of in-channel wood snags and accumulations (jams) have been established in the lower Elwha (below Elwha Dam) since 2001 (McHenry et al. 2007). Surveys involve measurement of individual piece characteristics (e.g., species, size) as well as geographic location. These provide useful information on the quantity and quality of large wood and its function for habitat forming processes. This wood budgeting approach also provides information on rates of recruitment, longevity, and movement. These surveys will be repeated at 5 yr intervals in the lower Elwha. Expansion of the wood budget to include the middle Elwha would also be an important priority.

Removal of Elwha and Glines Canyon Dams exposes ~324 ha of former reservoir surface to fluvial processes. This ~10 rkm of river reaches will be initially devoid of vegetation and subject to high rates of sediment transport from the reservoir surfaces, where the bulk of sediments have accumulated since dam construction. Initially, channel instability is likely to be high, with harsh and unstable conditions of spawning and rearing habitats for both resident and colonizing fish. The exposed reservoir surfaces will require extensive revegetation efforts and a restoration and monitoring plan has been prepared to accomplish this goal (Chenoweth et al. *in press*). Current planned monitoring for the reservoir surfaces focuses on vegetative responses only (Chenoweth et al. *in press*).

We propose to implement intensive survey efforts within the newly exposed reservoir surfaces following dam removal. These areas are likely to highly dynamic during peak sediment transport periods with unstable braided channel morphology. Analysis of historic aerial photographs and existing bathymetry indicates that both reservoirs were formerly unconstrained alluvial valleys dominated by island braid channels (DOI et al. 1994, Chenoweth et al. *in press*). We will use both remote sensing and *in situ* data collection techniques described throughout this paper to asses changes in physical and biological habitats (Table 5).

Ecosystem Study Design Considerations

River and floodplain habitats are dynamic, creating a shifting mosaic of terrestrial and aquatic habitats (Stanford et al. 2005). Sampling strategies must therefore accommodate channel movement across the floodplain by allowing sample locations to move between years. We stratify habitats into

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

three general types (e.g., floodplain, mainstem, and tributary) and will sample each type throughout a given study reach for each sample year. In this way, we will represent all habitat types in each year regardless of channel movement. Within each general habitat type we will identify more specific habitats at the site scale (e.g., pool, riffle, and glide) and develop a sample design to assure that sampling of ecosystem components broadly represent both specific and general habitat types. We will then sample attributes in the same locations so that we can document changes over space and time (e.g., periphyton, benthic invertebrates, fishes are sampled every n^{th} pool and riffle within a side channel). We will couple this field sampling design with channel mapping to characterize spatial and temporal trends in each ecosystem parameter at the site, reach, and watershed scale. This sampling design will allow results to be scaled up from the site to characterize each reach in aggregate.

Power Analysis

One of the key components to the Elwha monitoring effort is to link the objectives, study design, and monitoring parameters to expected outcomes. To address these fundamental monitoring questions, we used a power analysis to examine the number of years required to detect statistically significant change, given different effect sizes (i.e., magnitude of change before and after dam removal) in a sub-set of the parameters described above (Figure 3). *A priori* power analyses such as these are an important, yet often overlooked, step in identifying the level of effort, amount of time, and consequently overall cost necessary for restoration monitoring. Specifically, we determined how many years of post-dam removal data would be needed in order to detect a zero to four-fold (i.e., 0 to 400 %) effect size, 95% of the time (alpha = 0.05), with a power of 0.80 (i.e., type II error = 0.20). We assumed a before-after-control-impact

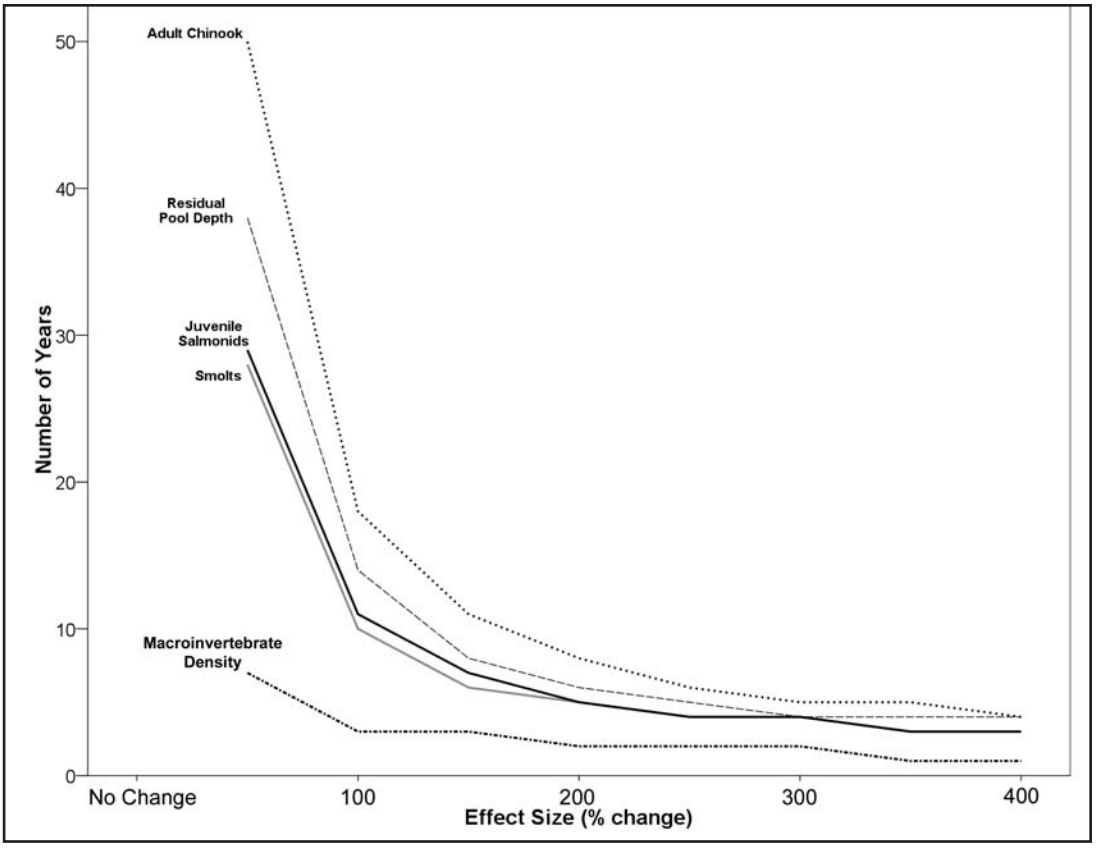


Figure 3. Power analysis results for select Elwha River monitoring parameters showing the number of years required to detect 50% to 400% effect sizes, 95% of the time, with an alpha of 0.05.

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

(BACI) design for each parameter and examined a range of effect sizes.

The parameters chosen for this exercise, and likely to be part of a final monitoring plan, include adult salmonid population size, juvenile salmonid fish density, the number of outmigrating Chinook smolts, residual pool depth, and benthic invertebrate density. We identified a "control" or reference reach for each parameter and have between 2–10 yrs of before (pre-removal) data for each. Reference data for juvenile fish density, residual pool depth, and invertebrate density were from reaches in the Quinault River where we will continue to sample following dam removal. Reference data for adult Chinook salmon and pink salmon populations come from the Dungeness River, the nearest large river system in the Strait of Juan de Fuca. The correlation in the population size estimates for each species between the Elwha and Dungeness populations is over 0.80. These data will also be collected following dam removal. No reference data was available for outmigrating Chinoook salmon smolt counts, so we used data from Elwha River chum salmon as a proxy. Effect size examined for each parameter was in increments of a one-fold (100%) increase. We used a range of 0 to 400% based on changes seen in other watershed-scale restoration actions and salmonid response (Solazzi et al. 2000). The between-year variance for each metric was calculated by using time series data for each variable.

The number of years needed to detect a statistically significant change varied considerably among parameters (Figure 3). Adult Chinook salmon required the greatest amount of time, ranging from 7 to 50 yrs, depending upon the effect size. It will take a little over a decade (two generations) to detect a significant difference in Chinook population size following dam removal, assuming a 250% increase, which is comparable to other reach and watershed-scale responses by salmonids (Roni and Quinn 2001, Solazzi et al. 2000). The amount of time required to detect significant differences in invertebrate density was the shortest at 1–7 yrs. Juvenile salmonid density and the number of outmigrating smolts showed similar time frames between 3 and 28 yrs, while the amount of time required to detect change in residual pool depth was 4 to 38 yrs. Assuming an average effect of 250% for the five parameters tested here, 3 to 11 yrs of monitoring will be needed to capture a statistically significant signal because of the removal of the Elwha River dams. The number of years required to identify a change in any of the preceding parameters was qualitatively similar in shape if the alpha was increased from 0.05 to 0.10 or higher, however the number of years to detect a change decreased.

Data Analysis

Data analysis of before and after data sets can be both relatively straightforward and complex depending upon the model used. Several authors have suggested simple graphical methods over a purely statistical approach (see Roni et al. 2005 for a review of the literature). Thus we will rely upon exploratory graphical analysis to discern trends in parameters before and after dam removal and between control and treatment reaches. We will then use parametric tests such as a t-tests and ANOVA to compare before and after fish abundance and redd density throughout the watershed and among reaches. Changes in distribution and frequency will initially be examined using a chi-square tests (Zar 1999).

One key component to analysis of any of the preceding variables will be to examine changes in variation as well as changes in means by quantifying the components of variation (Underwood 1994, Larsen et al. 2004). Several approaches exist for such analyses including maximum likelihood analysis, a nested analysis of variance, and trend detection analysis (Underwood 1994, Larsen et al. 2004). The key to each of these analyses will be to examine and quantify the variation between years, among locations, and their respective interactions in order to help identify the relative importance of any change due to the treatment. The type of ANOVA analysis will be a function of the number of sites, replicates, time intervals, and locational differences for each of the preceding metrics.

Summary

The removal of dams on the Elwha River offers a unique opportunity to evaluate the effects of dam removal and subsequent recovery of formerly productive aquatic ecosystems that supported large populations of anadromous salmonids. Although intentional dam removal of this magnitude has never been attempted before, it could become more common as the nation manages an increasingly aging system of dams. In the western United States alone, dams on California's Ventura (Matilija)

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

TABLE 6. Summary of past and ongoing Elwha River biological monitoring studies relevant to dam removal.

Topic	Methods	Years	Reference
Nearshore benthos	Diver quadrats along transects	1995	Seavey and Ging 1995 USGS planned for 2008
Macroinvertebrates	Hess Sampling - riffles	1992–1997	Munn et al. 1996 Munn et al. 1998
	Slack sampling – riffles	2004–2006	Morley et al. 2008
Salmon escapement	Adult/Redd counts	1984–present	Hiss 1995 WDFW and LEKT unpublished data
Smolt outmigration	Rotary screw trap	2005–present	LEKT unpublished data
Estuary characterization	Fish seining, invertebrate sampling, habitat mapping	2006–2008	LEKT, in progress
Nearshore fish use	Beach seining, surface trawling	2005–2007	NOAA, WDFW in progress
Periphyton	AFDM and chlorophyll a	2004–2006	Morley et al. 20008
Water chemistry	Standard techniques	1997 2004–2006	Munn et al. 1998 USGS/NOAA unpublished data
Fish movement	Radio-telemetry in lower Elwha River by adult Coho	2005–2006	Burke et al. 2008
Fish movement	Acoustic-telemetry of outmigrating Chinook and coho salmon	2005	U. of Idaho and LEKT
Fish movement	Radio-telemetry in Elwha River watershed by bull trout and rainbow trout	2006–present	NPS
Juvenile fish assemblage	Snorkling, electrofishing	1984–present	Pess et al. 2008 Connolly and Brenkman 2008 Unpublished studies by LEKT, ONP, USGS, and NOAA
Fish genetics	Microsatellite DNA, electrophoresis	1983–present	Reisenbichler and Phelps 1989 Phelps et al. 2001 Winans et al. 2008 LEKT in progress
Fish disease	ELISA and PCR screening	1988–present	Brenkman et al. 2008b
Temperature	continuous recording thermograph	1994–present	LEKT, ONP unpublished data Connolly and Brenkman 2008

and Washington's White Salmon (Condit) are currently being considered for removal. In 2007 a dam on the Sandy River, Oregon was removed. We have discussed components of a watershed scale monitoring plan designed to evaluate the effects of dam removal on existing salmon populations and the food webs and habitats of which they are an integral part. Portions of this plan have already been initiated. However, there remains a major challenge in scaling the project to the entire basin. Long term funding outlooks are uncertain for the existing monitoring efforts (Table 6) as well as the monitoring outlined herein. If resources to implement the long-term monitoring strategy are unavailable, then it is likely that a piecemeal monitoring strategy will be implemented. As a

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

result, managers will be limited in their ability to evaluate the success or failure of dam removal in relation to the goals and objectives identified in the Elwha Fisheries Recovery Plan.

Acknowledgements

Numerous individuals and agencies have contributed to the development of concepts in this paper through their participation in the recovery planning effort including P. Crain, R. Elofson, B. Freymond, G. Ging, D. Morrill, D. Poon, R. Peters, R. Reisenbichler, A. Shaffer, T. Tynan, L. Ward, B. Winter, and B. Wunderlich. The authors wish to thank three anonymous reviewers for their constructive and thought provoking comments. The authors also wish to thank number of scientists who have volunteered their time and resources to give life to this plan: C. Peery, N. Wright and C. Boggs (University of Idaho), S. Morley, H. Coe, T. Bennett, K. Fresh, K. Kloehn, B. Burke, K. Frick (NOAA), J. Ganzhorn (Peninsula College), J. Duda, P. Connelly (USGS), M. Elofson, E. Sampson, R. Moses, M. Beirne, and R. McCoy (LEKT).

Literature Cited

Anderson, J. H., P. M. Kiffney, G. R. Pess, and T. P. Quinn. *In press*. Distribution and growth of juvenile coho salmon (*Oncorhynchus kisutch*) during colonization of newly accessible habitat. Transactions of the American Fisheries Society.

Beechie, T. J. and T. H. Sibley. 1997. Relationships between channel characteristics, woody debris, and fish habitats in northwestern Washington streams. Transactions of the American Fisheries Society 126:217-229.

Beechie, T. J., C. N. Veldhuisen, D. E. Schuett-Hames, P. DeVries, R. H. Conrad, and E. M. Beamer. 2005. Monitoring treatments to reduce sediment and hydrologic effects from roads. *In* P. Roni (editor) Methods for Monitoring Stream and Watershed Restoration, American Fisheries Society, Bethesda, MD. Pp. 35-65.

Bjornn, T. C. and D. W. Reiser. 1991. Habitat requirements of salmonids in streams. *In* W. R. Meehan (editor), Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society, Special Publication 19, Bethesda, MD. Pp. 83-138.

Brenkman S. J., G. R. Pess, C. E. Torgersen, K. K. Kloehn, J. J. Duda, and S. C. Corbett. 2008a. Predicting recolonization patterns and interactions between potamodromous and anadromous salmonids in response to dam removal in the Elwha River, Washington, USA. Northwest Science 82 (Special Issue):91-106.

Brenkman, S. J., S. L. Mumford, M. House, and C. Patterson. 2008b. Establishing baseline information on the geographic distribution of fish pathogens endemic in Pacific salmonids prior to dam removal and subsequent recolonization by anadromous fish in the Elwha River, Washington. Northwest Science 82 (Special Issue):142-152.

Brown, R. L. and J. Chenoweth. 2008. The effect of Glines Canyon dam on hydrochorous seed dispersal in the Elwha River. Northwest Science 82 (Special Issue):197-209.

Burke, B. J., K. E. Frick, R. E. Moses, and M. L. McHenry. 2008. Movements by adult coho salmon in the lower Elwha River, Washington. Northwest Science 82 (Special Issue):119-127.

Chenoweth, J., S. A. Acker, J. Lapp, M. McHenry, and R. W. Olson. *In Press*. Lake Mills and Lake Aldwell revegetation and restoration plan. Elwha River Ecosystem Restoration Project. Olympic National Park, Port Angeles, WA.

Connolly, P. J. and S. J. Brenkman. 2008. Fish assemblage, density, and growth in lateral habitats within natural and regulated sections of Washington's Elwha River prior to dam removal. Northwest Science 82 (Special Issue):107-118.

Cooper, A. B. and M. Mangel. 1998. The dangers of ignoring metapopulation structure for the conservation of salmonids. Fisheries Bulletin 97:213-226.

Department of the Interior (DOI), Department of Commerce, and Lower Elwha S'Klallam Tribe. 1994. The Elwha report: restoration of the Elwha River ecosystem and native anadromous fisheries. Port Angeles, WA.

Department of the Interior (DOI). 1996a. Elwha River ecosystem restoration implementation, final environmental impact statement. NPS D-271A. Department of the Interior, National Park Service, Olympic National Park, Port Angeles, WA.

Department of the Interior (DOI). 1996b. Sediment analysis and modeling of the river erosion alternative. Elwha Technical Series, PN-95-9, Bureau of Reclamation, Pacific Northwest Region, Boise, ID.

Duda, J. J., J. E. Frelich, and E. G. Schreiner. 2008. Baseline studies in the Elwha River ecosystem prior to dam removal: introduction to the special issue. Northwest Science 82 (Special Issue):1-12.

Heinz Center. 2002. Dam Removal: Science and Decision Making. The H. John Heinz III Center for Science, Economics, and the Environment, Washington DC.

High, B., C. A. Peery, and D. H. Bennett. 2006. Temporary staging of Columbia River summer steelhead in coolwater areas and its effect on migration rates. Transactions of the American Fisheries Society 135:519-528.

Hicks, B. J., J. D. Hall, P. A. Bisson, and J. R. Sedell. 1991. Responses of salmonids to habitat changes. *In* W. R. Meehan (editor), Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society, Special Publication 19, Bethesda, MD. Pp. 483-518.

Hiss, J. 1995. Elwha River chum salmon (*Oncorhynchus keta*): Spawner survey and escapement estimate, 1994-1995. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia, WA.

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Hiss, J. M. and R. C. Wunderlich. 1994a. Salmonid availability and migration in the middle Elwha River system. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office. Olympia, WA.

Hiss, J. M. and R.C. Wunderlich. 1994b. Status of kokanee salmon (*Oncorhynchus nerka*) in the Lake Sutherland Basin and prospects for sockeye salmon restoration. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia, WA.

Johnson, P. R. 1997. Elwha River historical narrative. Unpublished Report, Olympic National Park, Port Angeles, WA.

Kloehn, K. K., T. J. Beechie, S. A. Morley, H. J. Coe, and J. J. Duda. 2008. Influence of dams on river-floodplain dynamics in the Elwha River, Washington. Northwest Science 82 (Special Issue):224-235.

Larsen D. P., P. R. Kaufmann, T. M. Kincaid, and N. S. Urquhart. 2004. Detecting persistent change in the habitat of salmon-bearing streams in the Pacific Northwest. Canadian Journal of Fisheries and Aquatic Sciences 61:283-291.

Lee, K. N. 1993. Compass and Gyroscope: Integrating Science and Politics for the Environment. Island Press, Washington, DC.

Madej, M. A. 1999. Temporal and spatial variability in thalweg profiles of a gravel-bed river. Earth Surface Processes and Landforms 24:1153-1169.

McHenry, M., G. Pess, T. Abbe, J. Goldsmith, M. Liermann, R. McCoy, S. Morley, and R. Peters. 2007. The Physical and Biological Effects of Engineered Logjams (ELJs) in the Elwha River, Washington. Interagency Committee for Outdoor Recreation, Salmon Funding Recovery Board, Olympia, WA.

Meeham, W. R. 1961. Use of a fishwheel in salmon research and management. Transactions of the American Fisheries Society 90:490-494.

Morley, S. A., J. J. Duda, H. J. Coe, K. K. Kloehn, and M. L. McHenry. 2008. Benthic invertebrates and periphyton in the Elwha River basin: current conditions and predicted response to dam removal. Northwest Science 82 (Special Issue):179-196.

Moursund, R. A., T. J. Carlson, and R. D. Peters. 2003. A fisheries application of a dual-frequency identification sonar acoustic camera. ICES Journal of Marine Science 60:678-683.

Munn, M. D., M. L. McHenry and V. Sampson. 1996. Benthic macroinvertebrate communities in the Elwha River basin, 1994-95. U.S. Geological Survey Open File Report 96-588, Tacoma, WA.

Munn, M. D., R. W. Black, A. L. Haggland, M. A. Hummling, and R. L. Huffman. 1998. An assessment of stream habitat and nutrients in the Elwha River basin: implications for restoration. U.S. Geological Survey, Water Resources Investigations Report 98-4223, Tacoma, WA.

Pess, G. R., M. L. McHenry, T. J. Beechie, and J. Davies. 2008. Biological impacts of the Elwha River dams and potential salmonid responses to dam removal. Northwest Science 82 (Special Issue):72-90.

Phelps, S. R., J. M. Hiss, and R. J. Peters. 2001. Genetic relationships of Elwha River *Oncorhynchus mykiss* to hatchery origin rainbow trout and Washington steelhead. Washington Department of Fish and Wildlife, Olympia, WA.

Poff, N. L. and D. D. Hart. 2002. How dams vary and why it matters for the emerging science of dam removal. BioScience 52:659-668.

Pohl, M. M. 2002. Bringing down our dams: trends in American dam removal rationales. Journal of the American Water Resources Association 38:1511-1519.

Pohl, M. 2004. Channel bed mobility downstream from the Elwha dams, Washington. The Professional Geographer 56:422-431.

Polis, G. A., W. B. Anderson, and R. D. Holt. 1997 Toward an integration of landscape and food web ecology: the dynamics of spatially subsidized food webs. Annual Review of Ecology and Systematics 28:289-316.

Potyondy, J. P. 1989. Cobble embeddedness as an effectiveness monitoring tool. *In* U.S. Forest Service (editor), Proceedings of the National Soil and Water Monitoring Workshop, Watershed and Air Management, U.S. Forest Service, Washington, DC. Pp. 91-98.

Reisenbichler, R. R. and S. R. Phelps. 1989. Genetic variation in steelhead trout (*Salmo gardneri*) from the north coast of Washington State. Canadian Journal of Fisheries and Aquatic Sciences 46:66-73.

Roghair, C. N. and C. A. Dollof. 2005. Brook trout movement during and after recolonization of a naturally defaunated stream reach. North American Journal of Fisheries Management 22:777-784.

Roni, P., M. McHenry, G. Pess, and T. Beechie. *In Press*. Evaluating changes in salmon spawning habitat and spawners in the Elwha River following dam removal. *In* D. Sear, P. DeVries, and S. Greig (editors), Salmon spawning habitat in rivers: physical controls, biological responses and approaches to remediation. American Fisheries Society, Bethesda, MD.

Roni, P., M. Liermann, C. E. Jordan, and E. A. Steel. 2005. Steps for designing a monitoring and evaluation program for aquatic restoration. *In* P. Roni (editor), Methods for Monitoring Stream and Watershed Restoration, American Fisheries Society, Bethesda, MD. Pp. 13-34.

Roni, P. and T. P. Quinn. 2001. Density and size of juvenile salmonids in response to placement of large woody debris in western Washington and Oregon streams. Canadian Journal of Fisheries and Aquatic Sciences 58:282-292.

Seavey, F. and G. Ging. 1995. Marine resources of the Elwha River estuary, Clallam County, Washington. Unpublished report for the National Park Service, U.S. Fish and Wildlife Service, Olympia, WA.

Schuett-Hames, D., B. Conrad, M. McHenry, P. Peterson, and A. Pleus. 1994. Salmonid spawning gravel composition module. Timber, Fish and Wildlife Ambient Monitoring Manual, TFW-AM9-94-001, Northwest Indian Fisheries Commission, Olympia, WA.

Schwartz, M. 2005. Beach geomorphology at the Elwha River delta in connection with removal of the Elwha and Glines Canyon Dams. Report to the Lower Elwha Klallam Tribal Council, Port Angeles, WA.

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Shaffer, J. A., P. Crain, B. Winter, M. L. McHenry, C. Lear, and T. J. Randle. 2008. Nearshore restoration of the Elwha River through removal of Elwha and Glines Canyon dams: an overview. Northwest Science 82 (Special Issue):48-58.

Solazzi, M. F., T. E. Nickelson, S. L. Johnson, and J. D. Rodgers. 2000. Effects of increasing winter rearing habitat on abundance of salmonids in two coastal Oregon streams. Canadian Journal of Fisheries and Aquatic Sciences 57:906-914.

Stanford, J. A, M. S. Lorang, and F. R. Hauer. 2005. The shifting habitat mosaic of river ecosystems. Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie 29:123-136.

Stanley, E. H. and M. W. Doyle. 2003. Trading off: the ecological effects of dam removal. Frontiers in Ecology and the Environment 1:15-22.

Thrower, F. P. and J. E. Joyce. 2004. Effects of 70 years of freshwater residency on survival, growth, early maturation and smolting in a stock of anadromous rainbow trout from southeast Alaska. American Fisheries Society Symposium 44:485-496.

Thurow, R. F., J. T. Peterson, and J. W. Guzevich. 2006. Utility and validation of day and night snorkel counts for estimating bull trout abundance in first- to third-order streams. North American Journal of Fisheries Management 26:217–232.

Underwood, A. J. 1994. Spatial and temporal problems with monitoring. *In* P. Calow and G. E. Petts (editors) The Rivers Handbook, Hydrological and Ecological Principles, Vol. 2, Blackwell Scientific, London, UK. Pp. 101-123.

U.S. Army Corps of Engineers (USACOE). 1999. Water control infrastructure: National inventory of dams (CD-ROM). Federal Emergency Management Agency, Washington, D.C.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushman. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130-137.

Ward, L., P. Crain, B. Freymond, M. McHenry, D. Morrill, G. Pess, R. Peters, A. Shaffer, B, Winter, and B. Wunderlich. *In Press*. Elwha River Fish Restoration Plan Developed Pursuant to the Elwha River Ecosystem and Fisheries Restoration Act, PL 102-495. NOAA Technical Memorandum NMFS-NWFSC#, Seattle, WA.

Warrick, J. A., G. R. Cochrane, Y. Sagy, and G. Gelfenbam. 2008. Nearshore substrate and morphology offshore of the Elwha River, Washington. Northwest Science 82 (Special Issue):153-163.

Winans, G. A., M. McHenry, J. Baker, A. Elz, A. Goodbla, E. Iwamoto, D. Kuligowski, K. M. Miller, M. P. Small, P. Spruell, and D. Van Doornik. 2008. Genetic inventory of anadromous Pacific salmonids of the Elwha River prior to dam removal. Northwest Science 82 (Special Issue):128-141.

Winter, B. D. and P. Crain. 2008. Making the case for ecosystem restoration by dam removal in the Elwha River, Washington. Northwest Science 82 (Special Issue):13-28.

Wohl, E., P. L. Angermeier, B. Bledsoe, G. M. Kondolf, K. MacDonnell, D. M. Merritt, M. A. Palmer, N. L. Poff, and D. Tarboton. 2005. River restoration. Water Resources Research 41:1-12.

Wolman, M. G. 1954. A method of sampling coarse river-bed material. Transactions of the American Geophysical Union 35:951-956.

Woodward, A., E. G. Schreiner, P. Crain, S. J. Brenkman, P. J. Happe, S.A. Acker, and C. Hawkins-Hoffman. 2008. Conceptual Models for Research and Monitoring of Elwha Dam Removal—Management Perspective. Northwest Science 82 (Special Issue):59-71.

Young, M. K., W. A. Hubert, and T. A. Wesche. 1991. Selection of measures of substrate composition to estimate survival to emergence of salmonids and to detect changes in stream substrates. North American Journal of Fisheries Management 11:339-346.

Zar, J. H. 1999. Biostatistical analysis. Prentice Hall, Upper Saddle River, NJ.

Downloaded From: https://complete.bioone.org/journals/Northwest-Science on 29 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use