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Abstract

Removal of two dams > 30 m from the Elwha River, on Washington State's Olympic Peninsula, can provide an unprecedented opportunity to study the geomorphic and biologic consequences of this activity. Resulting information can inform management decisions regarding Elwha resources, as well as future dam removal projects. Research and monitoring priorities for each river section (above, between, and below the dams) and nearshore depend on the location-specific effects of the dams, planned active restoration efforts, and conceptions of Elwha ecosystem dynamics. Several river section- or discipline-specific workshops were held 2001 to 2005 to describe impacts to the Elwha River, potential responses to dam removal and priorities for research and monitoring. We present conceptual models based on summaries of these workshops to provide a framework to integrate and relate studies that are currently planned or are underway. We identify the need for an organizational framework – including conceptual models, study designs, data management and integrated sample designs – for research and monitoring that will increase understanding of ecosystem response, and engender additional financial support.

Introduction

As the number of decadent dams in the United States and the awareness of the ecological cost of damming rivers increases (Poff and Hart 2002), so does the need for research on large-scale dam removal projects (Poff et al. 2003). To date, no studies of high-head (> 30 m) dam removal have been conducted in the United States (Gregory et al. 2002). Extant studies of small dam removal projects describe the potentially much less habitat altering process generated by unleashing systems with lower discharge and sediment accumulation (Doyle et al. 2005). With some exceptions (e.g., Toth 1995), available studies are short-term, qualitative, examine few system components with insufficient spatial and temporal replication (Hart et al. 2002) and describe relatively minor geomorphic change. Additionally, identifying causal pathways resulting from any dam removal process is complicated by confounding responses to simultaneously changing abiotic factors (Hart et al. 2002). Consequently, the question remains as to whether the impacts of dams are indeed reversible and by what pathways change occurs. There is evidence that ecologic changes following dam removal will be much more complex than a simple reversal of changes caused by dam construction (Auble et al. 2007). These changes will remain as an ecological legacy (e.g., Harding et al. 1998) such as that seen for Yellowstone National Park following the fires of 1988 (Gresswell 1999, Turner et al. 2003) and the eruption of Mt. Saint Helens in 1980 (Dale et al. 2005).

While several high-head dams are under review for removal (Gregory et al. 2002), removal of the Elwha and Glines Canyon dams from the Olympic Peninsula's Elwha River in Washington State will be the largest dam removal project to date in the United States. This provides an opportunity for research on removal of high-head dams and to address weaknesses and information gaps of previous dam-removal studies. With over 80% of the watershed protected from other land-use changes by National Park Service management policies, the Elwha River ecosystem is ideal for these studies. The Olympic National Park (ONP) boundary encompasses the upper portions of the Elwha River, the Lake Mills reservoir, and part of the middle river section between the dams. At this time, the Park also owns the Lake Aldwell reservoir with eventual dispensation of this area to be determined (for map, see Duda et al. 2008). The lower section of river downstream of the dams contains a mixture of private ownership and lands managed by the Lower Elwha Klallam Tribe (LEKT) and Washington Department of Fish and

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Wildlife. Portions of the estuary and nearshore are managed by Clallam County, the City of Port Angeles, and the LEKT.

Planning for research and monitoring is most effective as a collaborative effort among scientists representing many disciplines, as well as managers and other stakeholders (Poff et al. 2003). Here, we identify specific research and monitoring needed to address management concerns described during several workshops sponsored variously by ONP, U.S. Geological Survey, University of Washington and the National Park Foundation. Workshop participants represented federal agencies (i.e., ONP, U.S. Geological Survey, U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, U.S. Army Corps of Engineers, USDA Forest Service, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, U.S. Environmental Protection Agency, Pacific Northwest National Laboratory), state agencies (i.e., Washington Department of Fish and Wildlife, Washington Department of Ecology, Washington Department of Natural Resources, Puget Sound Action Team), tribal entities (i.e., Lower Elwha Klallam Tribe, Jamestown S'Klallam Tribe, Point No Point Treaty Council, Northwest Indian Fisheries Commission), local governments (i.e., Clallam County, City of Port Angeles) and academics from numerous universities, private foundations and consultants (CCMRC 2004, Schreiner and Winter 2005, Stolnack and Naiman 2005, Stolnack et al. 2005). These workshops affirmed that recovery of anadromous fish populations and trophic interactions, and restoration of the reservoirs within ONP are high management priorities. Additionally, conditions in the lower river and nearshore affect fish recovery upstream, so there is also interest in sediment effects on fish and fish habitat in these areas (Shaffer et al. 2008). Finally, it is hoped that restoration of sediment input from the Elwha River will help mitigate erosion from Ediz Hook, a spit protecting the mouth of Port Angeles harbor.

The workshops provided initial steps toward achieving collaboration among parties with interest in the Elwha River. Subsequent integration among agencies and scientists has continued, albeit at a lower level. Monitoring and research projects in the Elwha, at least at this stage, are primarily ad hoc and researcher-driven instead of part of a comprehensive plan (McHenry and Pess 2008, Winter and Crain 2008). Under such conditions, understanding ecosystem response is potentially compromised, and consistent funding will be hard to obtain. Having identified integration as an important need, our purpose here is to present conceptual models as a framework upon which to reinvigorate efforts at collaboration among all parties with interest in Elwha restoration. Derived from the 2001-2005 workshops, these models describe impacts to the Elwha River and how the ecosystem will respond to dam removal, together with associated priority management needs for research and monitoring.

Conceptual Models for Research and Monitoring of Elwha River Restoration

Conceptual models of ecosystems are graphic representations of interactions among key ecosystems components, processes and drivers. The processes of building and evaluating conceptual models aim to explain current understanding of ecosystem function, bring common understanding among interested parties, and clarify underlying assumptions and hypotheses. Conceptual models can include any degree of detail depending on the scope of the immediate issue. We present a general framework of models that provide context for studies reported in this issue of Northwest Science relative to management concerns.

As an overview, we first consider general consequences of the dams and planned restoration activities within each section of the Elwha River. The two dams effectively partition the river into four distinct areas experiencing different impacts, adding to the natural variability in biologic and physical processes present due to effects of gradient changes, cumulative area drained, patterns of bedrock geology and other factors (Table 1). The upper river section above Glines Canyon Dam and tributaries of the middle and upper river lack anadromous fish but are otherwise in pre-dam condition. The middle river section between the two dams lacks anadromous fish and inputs of sediments, large woody debris (LWD) and other forms of organic matter from upstream. The result is a deeply incised river channel in some areas, coarse substrates, and a less dynamic floodplain (Kloehn et al. 2008). The lower section below both dams is similarly incised, lacks sediment and organic matter inputs from upstream, but also supports hatchery-raised and wild anadromous fish. The reservoirs are extremely altered from pre-dam conditions, as the dams created a lentic ecosystem from a lotic

TABLE 1. Summary of the major direct and indirect effects of dams on sections of the Elwha River and adjacent nearshore. MDN = marine derived nutrients; NA = not applicable.

	Upper Elwha and Tributaries	Middle Elwha	Lower Elwha	Reservoirs	Estuary and Nearshore
Direct Effects—Ecological Components and Processes					
·Anadromous fish	Extirpated	Extirpated	Hatcheries	None	Reduced
·Sediment delivery	None	Reduced	Reduced	Sediment traps	Reduced from river
·Channel/Beach morphology	Pre-dam regime	Channel Incision[a] Increase particle size	Channel Incision[a] Increase particle size	Lentic	Erosion
Indirect Effects—Ecological Components					
·Resident fish	Altered community structure	Altered community structure	Altered community structure	New community structure	Altered beach spawning
·Vegetation	None	Older floodplain forest	Older floodplain forest	Elimination of floodplain habitat	Substrate changes reduce holdfast sites
·Trophic patterns	MDN-mediated trophic structure altered	MDN-mediated trophic structure altered	Lotic		Shellfish reduction
Indirect Effects—Ecological Processes					
·Succession	None	Altered floodplain dynamics, in channel wood	Altered floodplain dynamics, in channel wood	Lake shores	Beach erosion
·Large woody debris	None	Reduced and localized	Reduced and localized	NA	Reduced

[a]partial incision has occurred in some areas

one. Dam removal is expected to restore pre-dam processes to the river, with the different river segments experiencing some distinct and some similar phases (Figure 1). To facilitate restoration, ONP and the LEKT will actively re-establish vegetation in the former reservoirs and in partnership with other agencies will out-plant fish in many reaches (Table 1; see also Ward et al. *in press*, McHenry and Pess 2008, and Pess et al. 2008).

In addition to impacts within the river channel, the dams have also reduced sediment input to the Elwha estuary and adjacent nearshore areas (Table 1). These areas support eelgrass and kelp bed habitats (Warrick et al. 2008) that are important for the rearing, migration, feeding and smoltification of anadromous fish, particularly Chinook salmon and chum salmon (Healy 1982, Simenstad et al. 1982, Shaffer 2004). The estuary and nearshore habitats also are inhabited by forage fish, shellfish and other economically and ecologically important marine creatures (e.g., rockfish, halibut, herring, sea otters; Miller et al. 1980, Shaffer 2004, Simenstad et al 1979). Removal of the two dams in the Elwha River is expected to partially restore nearshore substrates and beach shape to allow eelgrass and kelp beds to re-establish. However, the Elwha is the source of only 30% of the sediments that naturally replenish the nearshore, with the remainder coming from a bluff that has been armored to protect housing and a landfill (US Army Corps of Engineers 1971). With bluff armoring in place, merely re-establishing sediment dynamics from the Elwha will likely be insufficient to fully restore estuarine and nearshore habitat (Shaffer et al. 2008).

Specific components, processes, and interactions that resource managers consider most important vary by river and intertidal segment (Figure 2) and reflect management goals. System dynamics are described in more detail in other papers in this special issue. Specific hypotheses illustrated in Figure 2 are articulated in Table 2.

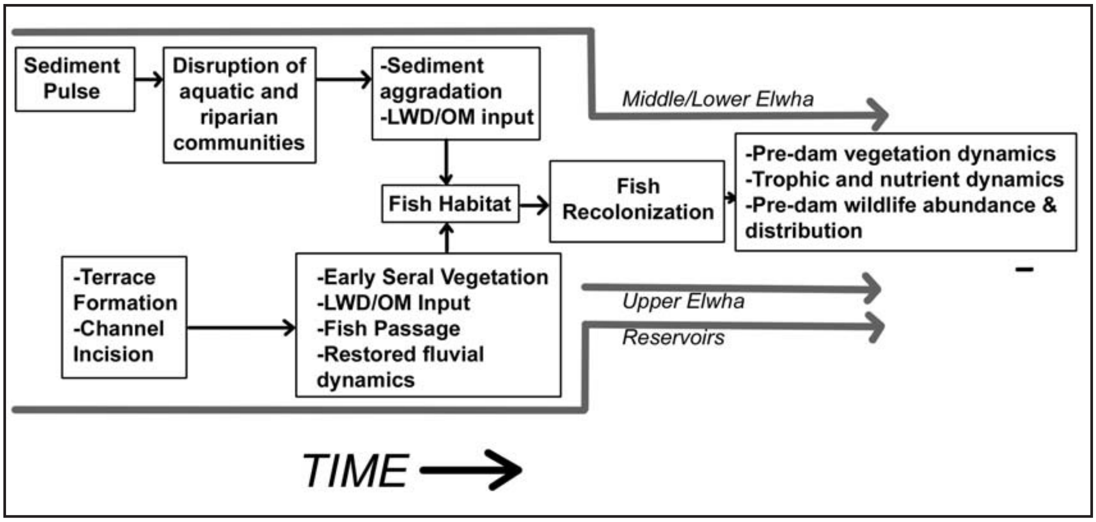

Figure 1. Paths by which different sections of the Elwha River will be restored through time. The middle/lower sections and upper section follow the same path to restoration but begin at different points. The reservoirs begin on a different path that eventually converges with the path of the river sections. LWD = large woody debris; OM = organic matter.

Designing research and monitoring around these components (Figure 2) requires careful consideration of spatial and temporal extents as well as the type of monitoring that is needed (Figure 3). Monitoring types are defined by the questions addressed and endpoints measured. *Implementation* monitoring answers how well management plans were followed (i.e., administrative endpoints such as acres of invasive species treated); *effectiveness* monitoring answers whether the management plan achieved the desired outcome (i.e., environmental endpoints such as restoration of a fish run); *validation* monitoring tests assumptions (i.e., hypotheses, models) about cause and effect (Busch and Trexler 2003, Karr and Yoder 2004). Done carefully, monitoring of restoration can provide a vital link between science and resource management, including adaptive management (Naiman et al. 1992, Stanford and Poole 1996).

Management goals vary according to spatial scale and time for achievement. At the smallest temporal and spatial scale, ONP will take direct management actions at particular sites, and monitoring projects will be used to inform adaptive management. These include monitoring the implementation and effectiveness of planting vegetation, exotic plant control, and sediment control measures during dam removal to protect a municipal water supply. These projects will occur primarily at the sites of management actions, and involve monitoring to evaluate achievement of goals such as proportion of seedlings established or suspended sediment levels (Figure 3). Goals should be established using conceptual and quantitative models that describe cause and effect relationships between initial management actions and eventual restoration. If monitoring shows that the actions fail to achieve the desired outcome, this information can support adaptive management. Management goals and target conditions have been determined for fish restoration (Ward et al. *in press*) and management of suspended sediment in municipal water supply (Randle et al. 2006), but not for other aspects of the Elwha River project.

Management goals at a slightly larger temporal and spatial scales (i.e., river segment/nearshore scale; Figures 2 and 3), reflect that the reservoirs are expected to undergo dramatic geomorphic change, as lake beds become river channels. Initial management goals are to stabilize sediments and restore vegetation on terraces and within the riparian corridor. Over the longer term, the goal is to restore fish and their habitat, wildlife, vegetation, and dynamics of sediment and organic matter. In the middle and lower reaches, the initial focus will center on effects of eroding reservoir sediments on downstream biota and water quality. Over time, the focus will shift to changes in channel morphology due to accumulation of sediments and large woody debris, and resultant effects on creation of fish habitat, and fish restoration. In the

TABLE 2. Summary of management goals, hypotheses, specific research and monitoring needs, and monitoring indicators identified by staff of Olympic National Park and attendees of research and monitoring workshops. Under monitoring indicators, "research" indicates that the associated need requires research rather than monitoring. LWD = large woody debris; MDN = marine derived nutrients.

Management Goal	Hypotheses[a]	Research/Monitoring Needs	Monitoring Indicators[b]
Re-establish self-sustaining anadromous fish populations and habitats in the Elwha River watershed and nearshore[c,d,e]	·Resident fish present above dams will compete with recolonizing salmonids for food and space	·Fish recolonization model	·Research
	·Salmon will recolonize upper river at species-specific rates and extents	·Monitoring fish distribution and abundance	·Adult and juvenile population size ·Radio-telemetry
	·Hatchery and wild salmonids will interbreed and compete for space and and food	·Fishing effort	·Commercial catch ·Recreational permits/ catch cards ·Fishermen interviews
Maintain existing salmonid genetic and life history diversity[f]	·High initial sediment loads from reservoirs will alter behavior and dynamics of existing fish populations downstream of dams ·Non-native brook trout will not threaten listed bull trout ·Sockeye salmon will reestablish from the existing stock of kokanee	·Genetics ·Life history diversity	·Behavior and genetics of tagged adults and juveniles by species ·Egg survival ·Otolith analysis
Maintain health of fish · populations[g]	Dam removal will facilitate spread of fish pathogens	Fish health and disease	·Pathogen screening ·Physiology and stress response
Restore pre-dam sediment and LWD transport dynamics[h]	·Stable floodplain surfaces will form where accumulations of LWD facilitate sediment deposition	·Channel and floodplain dynamics	·Map side channels ·Map fish habitat ·Measure riparian habitat ·LiDAR flights ·Remote sensing ·Estuarine habitat mapping ·Beach/intertidal substrate composition ·Beach elevation
Immobilize remaining reservoir sediments to minimize sediment load[i]	·Post-dam removal floodplains will move toward a dynamic equilibrium	·Develop measures of terrestrial erosion	·Research
	·Sediments from reservoirs will initially severely alter macro-invertebrate populations downstream	·Define interim and long-term landform and soils targets from reference sites	·Research
	·Prior to recruitment of sufficient LWD into channels, the river channel will change position primarily through incremental migration rather than through evulsion	·Water quality and quanity	·Discharge and stage ·Water temperature ·pH ·Turbidity

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TABLE 2. Continued.

Management Goal	Hypotheses[a]	Research/Monitoring Needs	Monitoring Indicators[b]
		·Sediment load	·Suspended sediment ·Bed load
	·Longitudinal gradients of sediment sediment texture will be maintained by hydraulic and fluvial dynamics within unconstrained reaches.	·Sediment erosion	·Repeated Bathymetric surveys ·Time lapse photography
Prevent widespread invasions of exotic plant species[j]	·Exotic species will spread from current locations to de-watered reservoir surfaces	·Current exotic species distribution ·Repeated surveys following dam removal ·Model to predict spread of invasives	·Plant surveys (focus on invasives) ·Research
Determine role of vegetation in aquatic habitats for salmon recovery	·Shade, cover, and sediment immobilization will facilitate fish recolonization	·Monitor fish habitat	·Instream structure ·Relative cover/shade ·Water temperature
On former reservoir surfaces, promote development of native vegetative communities[i]	·Plant life history traits will interact with environmental factors to influence succession pathways and rates of change	·Define interim and long-term goals from reference sites	·Research ·Permanent plots in planted areas
	·Vegetation will respond to restoration of MDN, changes in substrate, and abundance/distribution of herbivores	·Patterns of planted and colonizing vegetation	·Periodic ground surveys of reservoir sites
	·Herbivory by native ungulates and small mammals will adversely affect restoration of woody plant species	·Monitor small and medium herbivores	·Distribution and abundance patterns of herbivores
	·Soil microbial diversity will vary with texture, aeration, and litter inputs	·Describe microbial soil ecology	·Soil microbial functional and genetic diversity
Restore wildlife populations to baseline distribution and abundance (see Table 3)[k]	·As fluvial processes are restored to the formerly regulated river sections, physical and vegetative changes will effect riparian wildlife communities	·Monitor ungulate use patterns ·Monitor riparian mammals and birds (e.g., otter, mink, dipper, kingfisher)	·Movement (radio-telemetry) ·Density ·Demographics
		·Human-bear encounters	·Reports to rangers from park visitors
Determine effects of anadromous fish on trophic and nutrient structure	·C, N, and P will accumulate in floodplain and adjacent uplands as direct and indirect inputs from anadromous fish ·Trophic pathways will be restructured with cascading effects throughout the ecosystem ·Aquatic productivity will increase following dam removal for all trophic levels	·Determine baseline nutrient cycling and limits to net primary productivity	·Research ·Community composition ·Salmon carcass density ·Smolt production ·Size distribution of resident fish ·Nutrient budget by mass balance differencing

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TABLE 2. Continued.

Management Goal	Hypotheses[a]	Research/Monitoring Needs	Monitoring Indicators[b]
			·Primary productivity
	·Potential stream productivity varies longitudinally for all trophic levels		·Stable isotope signatures of multiple trophic levels
	·Estuary and nearshore productivity will increase		·Riparian vegetation growth, leaf chemistry

[a]Schreiner and Winter 2005
[b]Stolnack et al. 2005
[c]see McHenry and Pess 2008
[d]see Brenkman et al. 2008a
[e]see Pess et al. 2008
[f]see Winans et al. 2008
[g]see Brenkman et al. 2008b
[h]see Kloehn et al. 2008, Acker et al. 2008
[i]see Mussman et al. 2008
[j]see Brown and Chenoweth 2008
[k]See Sager-Fradkin et al. 2008

estuary and nearshore, the goal is for improved rearing and migratory habitat for anadromous fish, which may result in greater success for adult fish. Eventually, greater adult success should impact the river because greater numbers of fish may return to spawn. These changes will not necessarily be strictly sequential or concurrent throughout the Elwha ecosystem and will require effectiveness and validation monitoring.

The upper section above the dams is the least altered; best available information indicates that it includes all of its natural components except anadromous fish (Figures 2 and 3). Because this area is encompassed by a national park, there are few other stressors on the system, thus providing almost ideal conditions for research investigating the effect of anadromous fish on the trophic structure and nutrient cycling in aquatic and terrestrial forested ecosystems. Over the 30 years predicted to achieve the management goal of salmon restoration (DOI 1995), the use of validation monitoring to examine response dynamics of the upper river ecosystem to the return of anadromous fish will assist in identifying thresholds that may have bearing on effective escapement goals. Additionally, returning fish will drive interactions among other components of the system (Figure 2) making it possible to better understand ecosystem dynamics.

Considerations for Research and Monitoring of Restoration

Because so little is known about ecosystem recovery following removal of large dams, most research questions will be answered using effectiveness or validation monitoring. That is, most research questions will be answered by following trends in environmental endpoints, and comparing actual outcomes with hypotheses and models. Consequently we consider research and monitoring to be nearly one and the same for Elwha restoration.

The foundation of any monitoring program is the indicators that are monitored. Indicators were identified in the various planning workshops (Table 2), but they have not as yet been put into a conceptual framework. There are many published criteria and requirements for good indicators (e.g., NRC 2000, Dale and Beyeler 2001, Young and Sanzone 2002, Niemi and McDonald 2004) and all lists include the need for a scientific basis linking the indicator to the ecosystem. It is recommended that indicators be supported by a conceptual model, which will provide the rationale for choosing it and the interpretation of observed changes (Landres 1992, NRC 2000, Young and Sanzone 2002). While we have provided overview models, much more detail is required to support indicator selection.

Many restoration projects are hampered by lack of baseline and reference data that provide a measure of site potential and establish pre-treatment conditions (Frissell and Ralph 1998, Roni et al. 2005). Monitoring of restoration projects can address these common weaknesses by adopting a before-after control-impact (BACI) study design. According to this method, data are collected before and after the onset of restoration activities in both the treated area and an untreated, pristine reference area. The greater the number of pretreatment data collected, the better the estimate

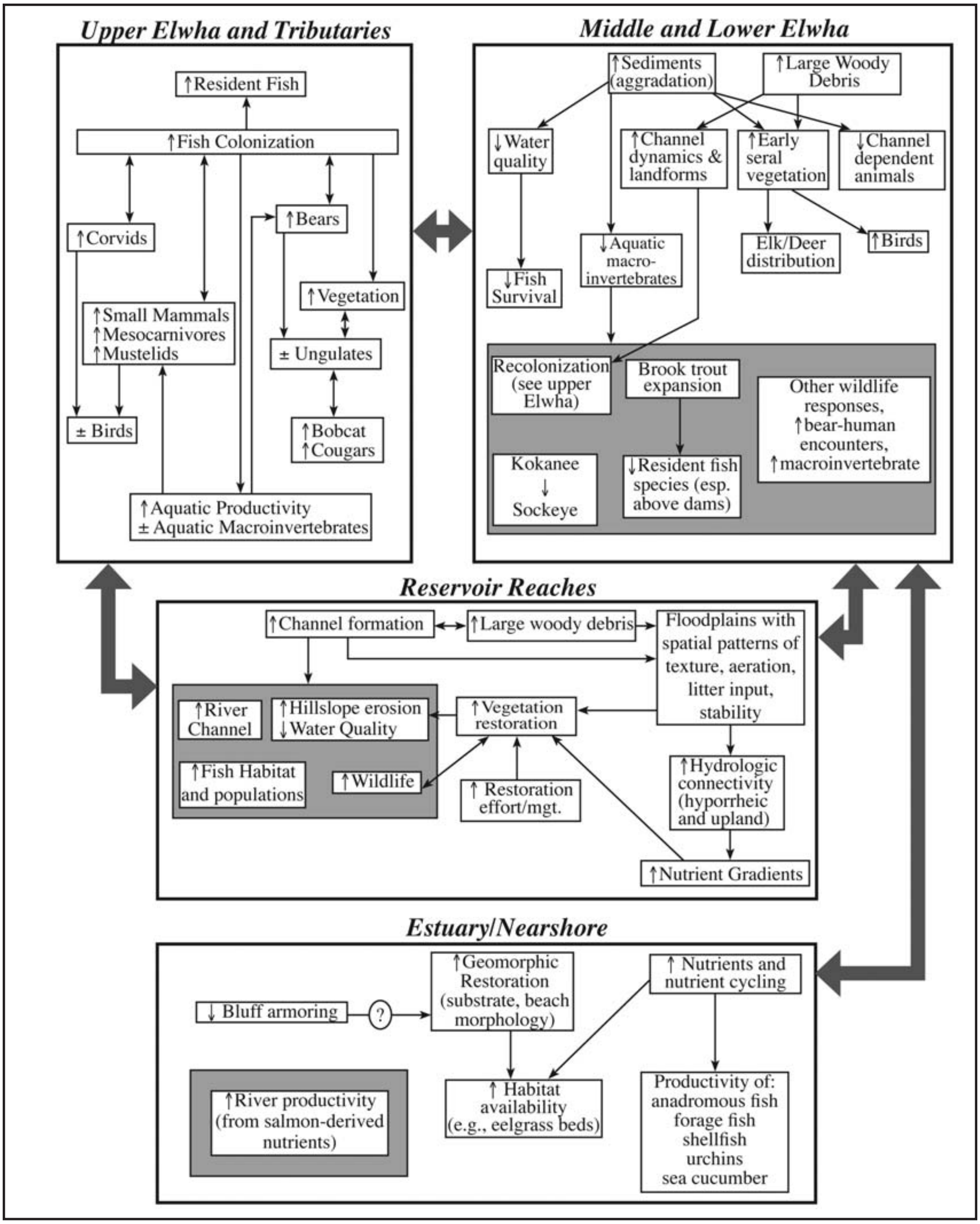

Figure 2. Hypothesized results of dam removal on three sections of the Elwha River: above both dams and tributaries throughout (Upper Elwha and Tributaries), below one or both dams (Middle Elwha and Lower Elwha), the reservoirs currently behind each dam (Reservoirs), and the Elwha estuary and associated nearshore area (Estuary/Nearshore). Arrows in boxes indicate increase (↑), decrease (↓), or unknown (±) change in component; components with no arrow are not expected to change in abundance, at least in the short term; arrows between boxes indicate causal links. Thick grey arrows indicate potential for transport of exotic plants and animals, diseases/pathogens, sediment, large woody debris, wildlife, plant propagules, fish, and nutrients. Grey boxes indicate components with a lagged response time.

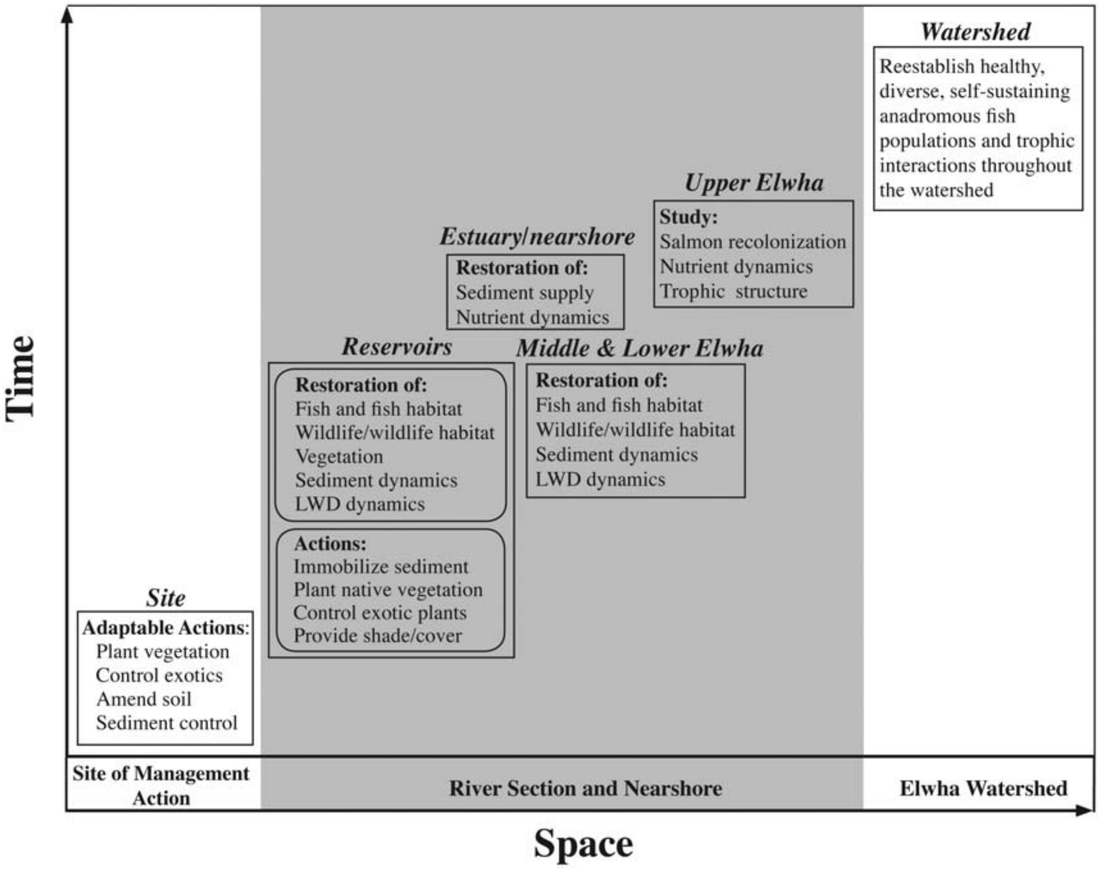

Figure 3. Spatial and temporal extents of management goals. Indicators of spatial extent on the x-axis are categorical variables, therefore difference in spatial scale within category is not intended to be represented. Management goals listed in the lower sub-box within "reservoirs" are expected to be achieved before those in the upper box. Reservoirs are expected to begin changing before the other sections, with the upper section changing most slowly.

of natural variation in treated and control sites (Frissell and Ralph 1998). The biggest impediment to this approach from a design perspective is the difficulty in finding reference sites (Block et al. 2001, McHenry and Pess 2008). There are no perfect controls in field studies, and pristine sites of any kind are challenging to locate. Nevertheless, it is important to find the best reference sites possible (Minns et al. 1996). Even if no data are collected before the treatment, comparing an area after treatment with an untreated reference area is a reasonable option. If no reference sites can be found, a before-after (BA) design will describe the outcome of a treatment better rather than a poorly controlled BACI design (Roni et al. 2005). The lack of reference sites can sometimes be addressed by using mechanistic models (Shugart 1989).

Possibilities for location of reference sites assessing various responses to Elwha dam removal can be found elsewhere within the Elwha basin and on the Olympic Peninsula (Table 3). None of the potential reference sites are ideal because environments and ecosystems of the Olympic Peninsula vary depending on aspect, geology, climate, elevation, and land management objectives (McHenry and Pess 2008). Consequently, available controls will depend on the objectives and variables of each research or monitoring project. For example, monitoring of large woody debris dynamics in the middle reach of the Elwha should probably use areas dominated by old-growth Douglas-fir (*Pseudotsuga menziesii*) of reasonably similar climate. This might include the upper Sol Duc River but not the Hoh River where floodplains are predominantly Sitka spruce (*Picea sitchensis*)

TABLE 3. A subset of research and monitoring topics and associated potential reference sites for comparison to the Elwha River (See also McHenry and Pess 2008).

Research/Monitoring Need	Reference Location
Riparian use by mammals and birds	Lower Sol Duc River, South Fork Skokomish River, Lower Dungeness River
Ungulate distribution, abundance and habitat utilization patterns	Bogachiel River, Sol Duc River
Large woody debris dynamics	Skokomish River, Bogachiel River, Upper Dosewallips River
Bear-salmon interactions	Rivers on the northwest Olympic Peninsula
Benthic macroinvertebrates	Rivers on the northwest Olympic Peninsula, south Fork Skokomish River, lower Sol Duc River, lower Dungeness River, Quinault River (see Morley et al. 2008)
Fish recolonization and recovery	Quinault River (see Pess et al. 2008)

and precipitation is approximately double that of the Elwha. On the other hand, for studies of bear-use of riparian corridors in the upper reach of the Elwha, control areas may have to include the Hoh and Quinault Rivers because anadromous fish are currently present, even though the difference in vegetation may have an effect on bear distribution. The best control area for nearshore monitoring is offshore from the Dungeness River mouth, approximately 16 km to the east near Sequim.

The spatial sample frame of restoration research and monitoring should recognize that ecosystems are hierarchically nested structures in time and space (Frissell and Ralph 1998). In aquatic systems, habitat units are nested within reaches; reaches are nested within valley segments; and valley segments are nested within watersheds. The rate of controlling dynamics slows as spatial extent increases. This structure calls for a likewise nested, hierarchical approach to monitoring, with functional controls at several spatial scales (Frissell and Ralph 1998, Minns et al. 1996, Poole et al. 1997). The hierarchical approach to restoration monitoring has rarely been applied and perhaps never in the Pacific Northwest (Imhoff et al. 1996).

In addition to hierarchical nesting, co-location or coordination of sample frames among studies of different resources will likely provide more information for the same cost. For example, co-located information about riparian vegetation, wildlife behavior and fish carcass abundance would provide greater understanding of system dynamics than the same studies located independently.

Full implications of restoration management actions in the Elwha River will likely require a long time to evolve because the time scale of ecosystem response to perturbation is proportional to the size of the ecosystem, habitat diversity (Trexler and Busch 2003) and size and intensity of the disturbance. Short-term changes at this scale may be misleading because it may be hard to differentiate effects of management actions from natural variation. For example, macroinvertebrate density and richness following a dam removal in Oregon did not immediately respond to dam removal, but over time responded to reservoir erosion (Stewart 2006). However, changes at smaller spatial scales such as the outcomes of local management actions may be easier to detect in shorter time. Bryant (1995) suggested that pulsed monitoring is an effective temporal design for restoration monitoring. He advocates that monitoring should include extensive long-term surveys repeated at intervals of 10-15 years, interspersed with intensive short-term 3-5 year studies focused on specific questions.

Needs for Information and Coordination

Resource management staff members of ONP have five priority information needs related to removal of the dams on the Elwha River, all of which can be addressed by monitoring (see also McHenry and Pess 2008):

- Fish restoration success throughout the river relative to species and source (i.e., hatchery, natural, or wild);
- Role of LWD and other types of organic matter in shaping fish habitat in reservoirs and lower reaches;

- Response of wildlife, vegetation, and other ecosystem components to restoration of anadromous fish in the middle and upper reach;
- Response of ungulates, birds and small herbivores to early seral vegetation in middle, lower and reservoir reaches;
- Response of estuary and nearshore habitats to increased sediment from the river.

Additionally, monitoring is required to support adaptive management (Table 2). Some of these needs are being met, including baseline data collections for some topics. Other needs are for integrated, long-term research and monitoring following dam removal. Our conceptual models and list of potential indicators is a first step towards developing the plan. In the near future, resource managers must develop refined models for indicators and prioritize the indicators as a basis for selecting a feasible number. They must also identify restoration targets for ecosystem components other than fish and sediment, and develop a sample frame for all indicators. These activities will be less effective if undertaken independently by each interested party.

Development of a common framework to evaluate, prioritize and coordinate the many goals associated with this large restoration project is a potential role of the Elwha Research Consortium. An intellectual framework could be built by coordinating more detailed conceptual and quantitative model development to integrate hypotheses supporting research and monitoring needs for agency management, and those of other research projects. An important aspect would be to address spatial and temporal hierarchies inherent in the results of large-extent restoration projects. An organizational framework would include integrating research through coordination of sample designs, and co-location of data collection among research and monitoring projects. Additionally, there is a need for data management, project-wide data standards, information management, protocols, and coordinated reporting (Conquest and Ralph 1998).

Sustaining support for long-term monitoring will be a daunting challenge due to the low priority generally given to monitoring of restoration (Frissell and Ralph 1998, Roni et al. 2005) and evidenced by the fact that no money for monitoring was included in the appropriation supporting the Elwha River dam removal project (Winter and Crain 2008). Nevertheless, this challenge must be addressed because this project is an unprecedented research opportunity, many research questions cannot be answered with a short-term effort, and the information can be used to improve the success of other anticipated dam removal projects. Long-term monitoring is the most practical and effective way to assess restoration and to document recovery. An intellectual and organizational framework including data management and reporting will form a strong platform from which to justify funding for necessary monitoring.

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