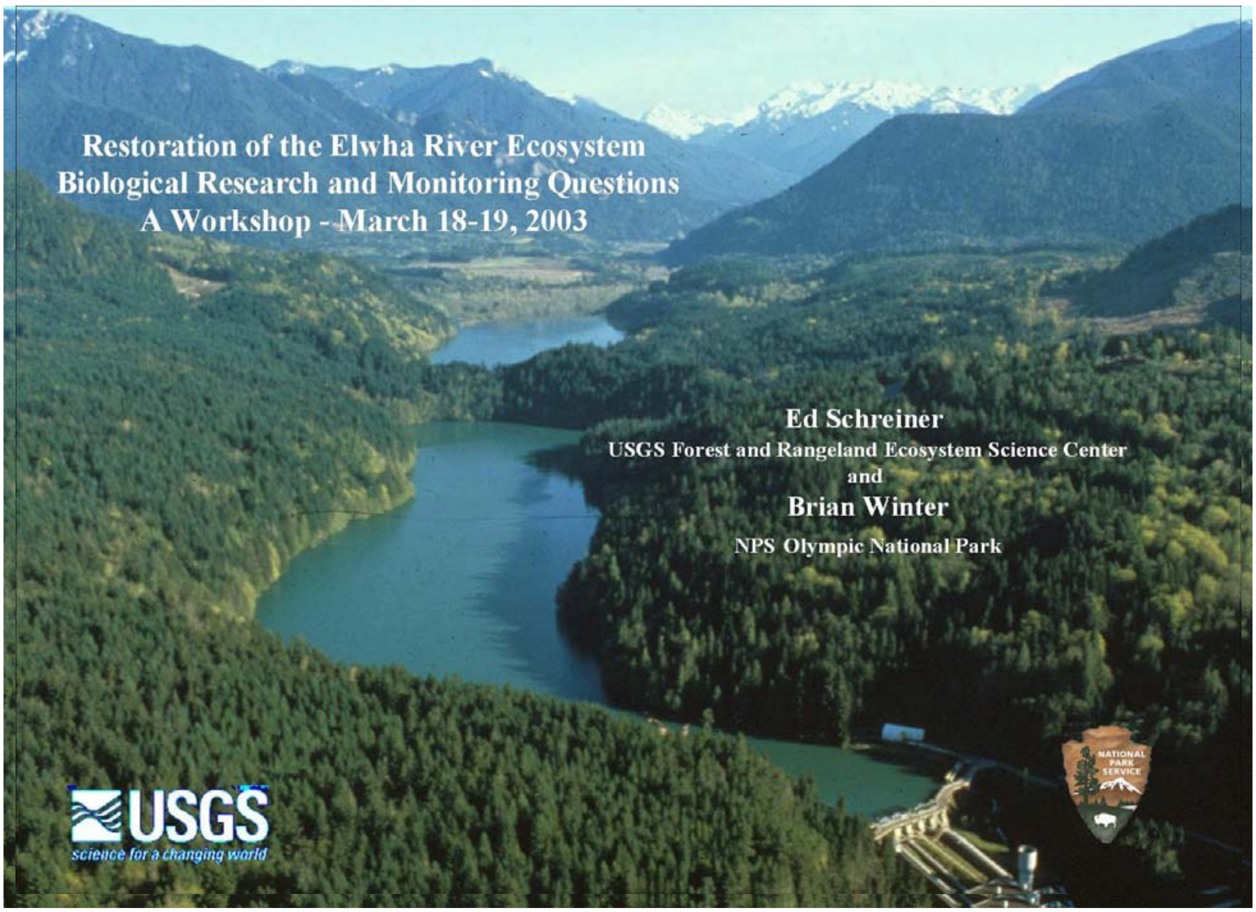
Restoration of the Elwha River Ecosystem
Biological Research and Monitoring Questions
A Workshop - March 18-19, 2003
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RESTORATION OF THE ELWHA RIVER ECOSYSTEM
RESULTS OF A BIOLOGICAL MONITORING/RESEARCH WORKSHOP:
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Introduction

The 803 square kilometer (310 mi^2) Elwha River Basin on the Olympic Peninsula, Washington State (Figure 1) is essentially pristine except it has been without anadromous fish for more than 90 years. Historically, the Elwha River was home to 10 runs of native anadromous salmon and trout; there was no month of the year when these fish were not migrating upstream, spawning, rearing, or passing juveniles out to sea (NPS 1995). Fish species utilizing the river included coho (*Oncorhynchus kisutch*), sockeye (*O. nerka*), pink (*O. gorbuscha*), chum (*O. keta*), steelhead trout (*O. mykiss*) and the famous chinook salmon (*O. tshawytscha*) that reportedly reached sizes of 45 kg (~100 lbs).

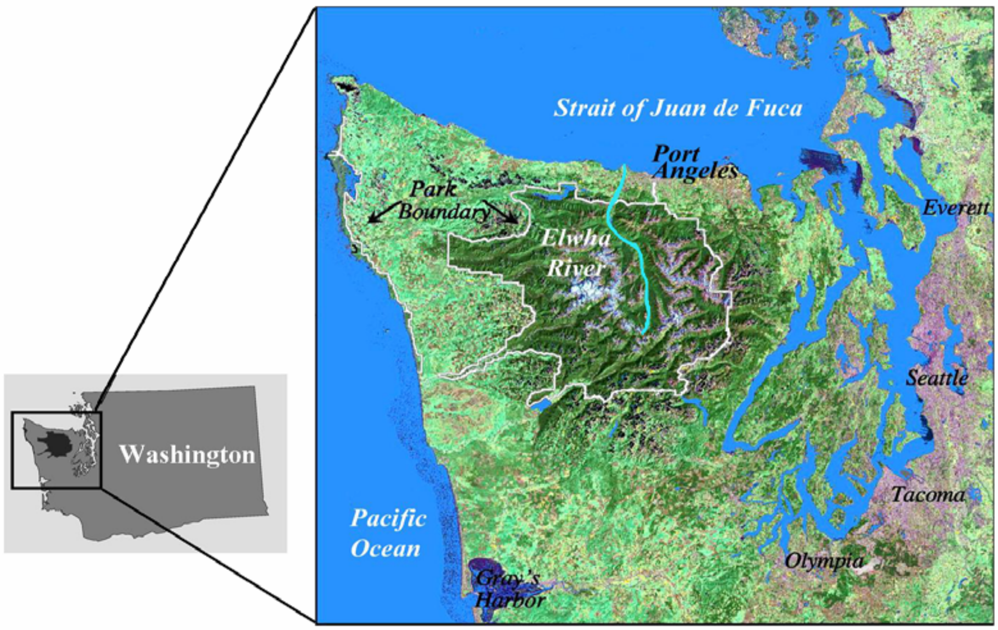

Figure 1 Location of Olympic National Park and the Elwha River relative to Washington State. The park boundary shows clearly in this LANDSAT image: light green represents primarily second growth forest, dark green represents primarily old-growth forest and shades of pink represent urban development (image courtesy of Roger Hoffman, Olympic National Park)

Construction of Elwha Dam (Figure 2) from 1910 to 1913 without provisions for fish passage at river kilometer 9.1 (5.7 mi) eliminated anadromous fish from over 130 km (80 miles) of mainstem and tributary habitat, limiting salmon and steelhead to the river below the dam. Glines Canyon Dam (Figure 3) was constructed from 1925 to 1927 about 15.8 km (9.8 mi) upstream of Elwha Dam. The two reservoirs, Lake Aldwell and Lake Mills, inundate over 9 km (5.5mi) of riverine habitat, trap all coarse sediments (i.e., sand, gravel, cobble) and woody debris transported from the upper river, diminish nutrient transport downstream, and increase downstream water temperatures that exacerbate fish diseases such as *Dermocystidium salmonis*, which has resulted in intermittent high mortalities of the remaining chinook salmon. The lack of coarse sediment transport has resulted in substrate downstream of the dams that is too large for spawning, an unnaturally stable and less diverse riparian zone, an estuary reduced in diversity and in size by about 0.9 km^2 (0.5 mi^2), and a change in near shore beach communities from those dependent on sandy bottoms to those able to exploit rocky substrates (NPS 1995).

Figure 2. Elwha Dam and Lake Aldwell

In 1992, Congress enacted the Elwha River Ecosystem and Fisheries Restoration Act (PL 102-495) directing the Secretary of the Interior to fully restore the Elwha River ecosystem and native anadromous fisheries. The National Park Service has determined that only the removal of two dams will result in full restoration (NPS 1995). The long-anticipated removal of the two dams is currently scheduled to commence in 2008. Removal of these dams and subsequent restoration work will constitute the single largest endeavor of this kind ever attempted.

Figure 3. Glines Canyon Dam and Lake Mills

Collecting scientific data prior to removal of the dams is critical to assess the effects of dam-removal. Granted, baseline data already exists with respect to anadromous fish in one sense, because there are none upstream of the dams. However interpretation of post dam-removal studies of stream productivity, marine derived nutrients, resident fish, vegetation, and wildlife requires a pre-dam removal baseline or results will be uncertain. In some cases, all that is necessary is to establish a pre dam-removal starting point, (e.g., marine derived nutrient levels), and in others it is necessary to know something about pre-removal variation (e.g. abundance and fluctuations in wildlife populations). The opportunity to study the effects of dam removal is limited – once the dams are removed there is no “going back”. Studies of the effects of dam removal on ecosystem processes are particularly lacking. Babbitt (2002:658) put it this way, “The lack of studies (of dam removal effects) cries out for new research and peer-reviewed papers by experts in social, economic, and ecological fields.”

Scientists from many disciplines are keenly interested in studying responses of the Elwha ecosystem to dam removal, particularly because 83% of the Elwha River watershed occurs within the boundaries of Olympic National Park and is, therefore, “pristine”. Consequently, we convened a workshop to stimulate creative thinking about research needs and to “capture” essential biological questions, hypotheses, and monitoring issues related to dam removal. We used three working groups: vegetation/ecosystem processes, fisheries/aquatic science, and wildlife. Each group was composed of 6-8 scientists (see appendix 1 for a list of participants). Objectives assigned to each working group included:

1. Create a list of research and/or monitoring questions, couched as research hypotheses.
2. Rank hypotheses in priority order.
3. For the highest priorities (in each workgroup), prepare a pre-proposal including,
   - Hypothesis
   - Short summary of proposed research/monitoring – what, why, where
   - Linkages with other research components
   - Time-line
   - Tentative budget
   - Outline potential funding sources – be specific
   - Suggest scientists who will (should) take the lead in obtaining funding.

Here, we present workshop results as hypotheses with a supporting rationale and assumptions. As with all workshops, participants presented numerous ideas and thoughts that did not lead to “clean” research questions. We have necessarily done some editing of ideas to present a clearer picture. We include an approach for obtaining funding (Appendix 2) and creation of a Research Natural Area (Appendix 4) provided by one workshop participant (D. L. Peterson) .

A conceptual framework

The Elwha River can logically be divided into 3 distinct reaches (Figure 4). The predicted variation of how the reaches will respond to dam removal was used to provide a framework for testing research hypotheses and monitoring changes over time (Figures 5 and 6). For example,

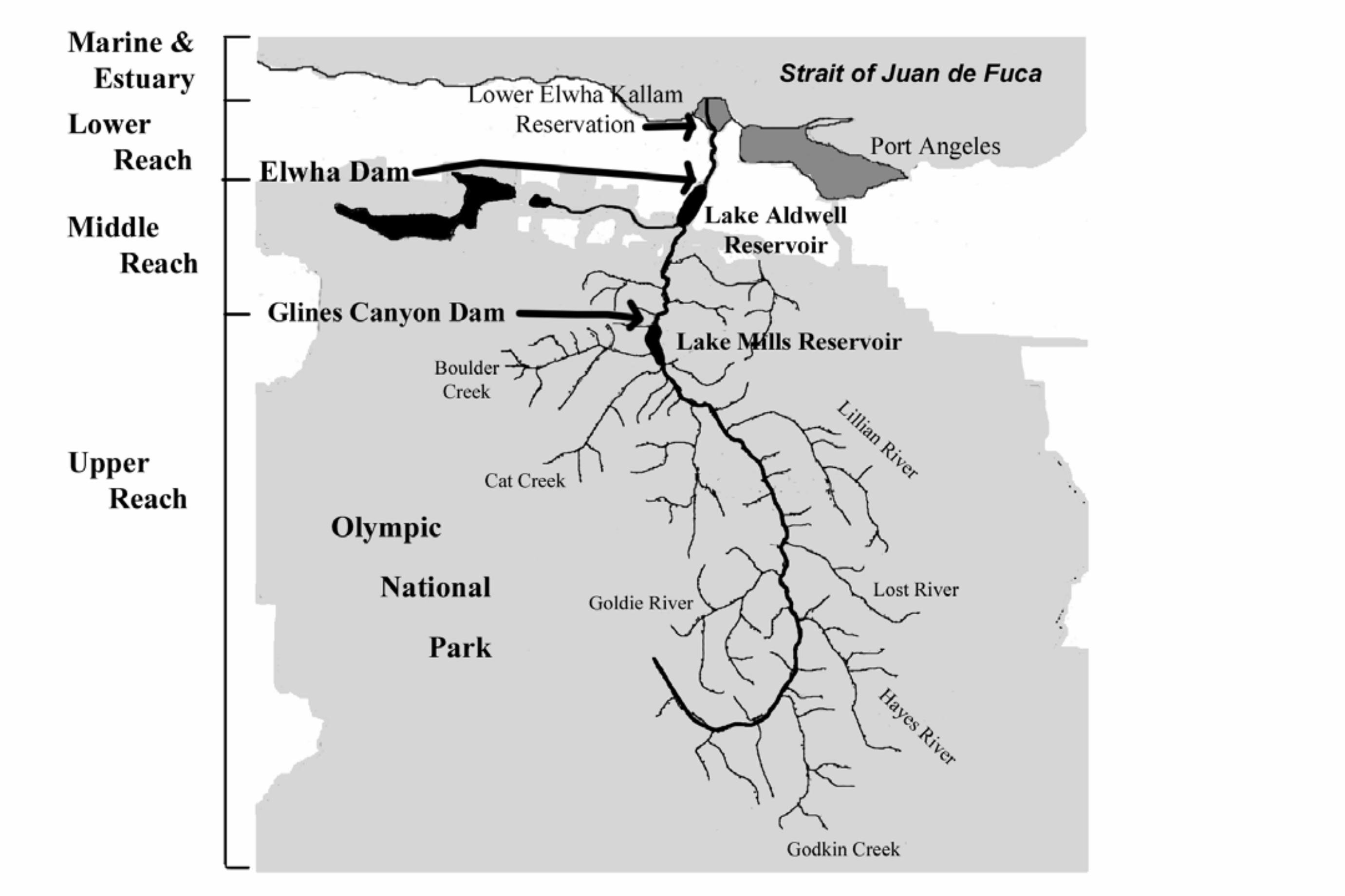

Figure 4. The Elwha River Basin showing river reaches.

the trophic structure of the ecosystem upstream of both dams (the upper reach) is likely to change because the return of anadromous fish will add a food source, nutrients, and restore aquatic predators to the system (the anadromous fish). There is also potential for trophic structure changes in the lower reach of the river of the river (downstream of Elwha Dam) but this may be more difficult to demonstrate biologically because this area has been used by anadromous fish continuously since dam construction. The greatest changes in the middle and lower reaches will initially be caused by downriver transport of sediments and woody debris released from beneath the reservoirs. Once spawning gravels have been restored, this area will also be affected by the return of anadromous fish. The areas currently beneath both reservoirs will provide an opportunity to study plant successional patterns, methods of ecosystem restoration, and how fluvial processes shape the newly exposed surface.

In addition to research and monitoring ideas that fit into the conceptual framework, participants noted that there was a need to establish specific baselines of biotic and physical components of the Elwha River. These ideas and notes are presented first because they apply generally to the drainage.

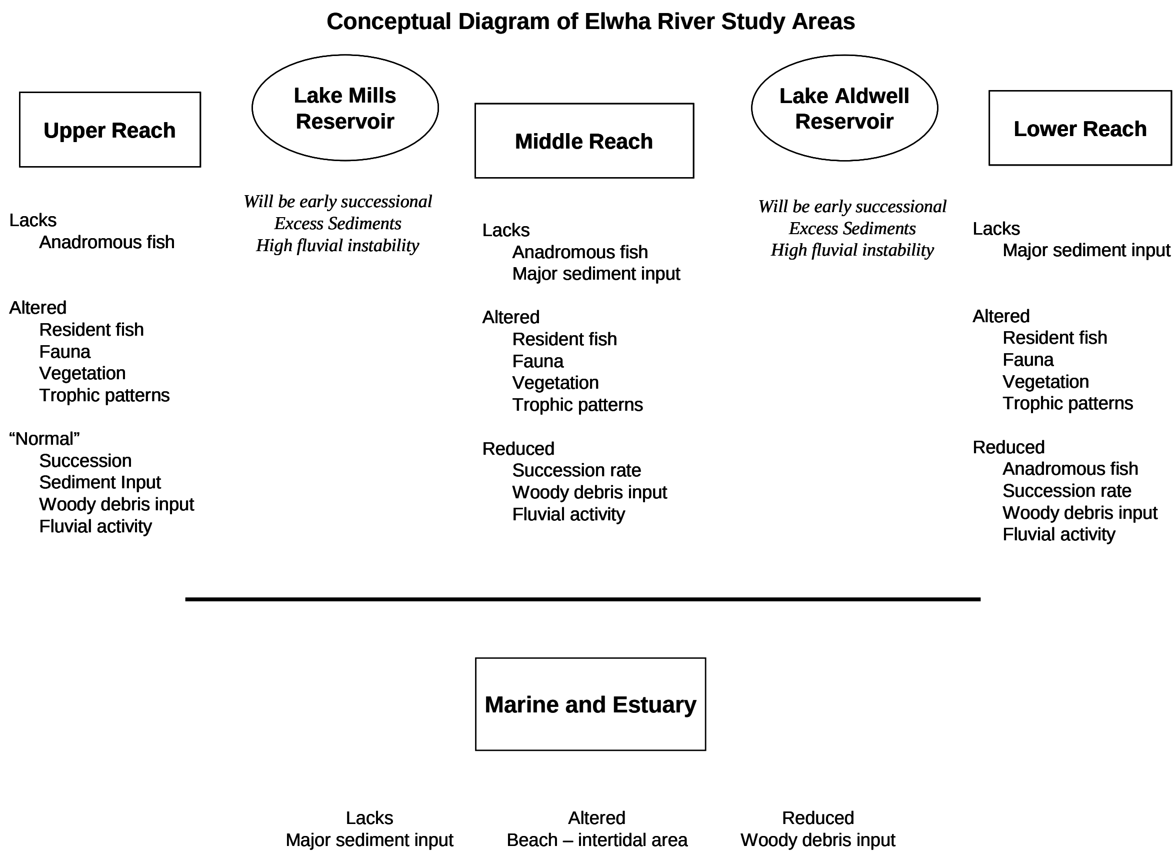

Figure5. Elwha River reaches and expected effects of dam removal.

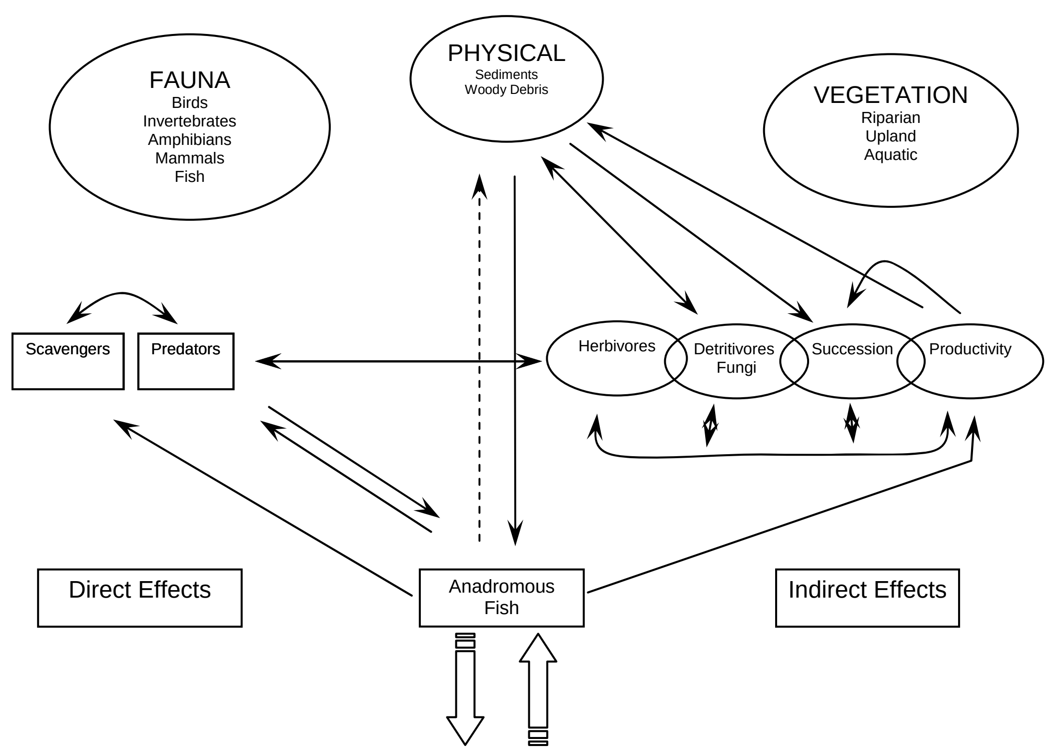

Figure 6. . General Elwha River ecosystem conceptual diagram illustrating direct and indirect effects from the reintroduction of anadromous fish.

General and Baseline Monitoring Suggestions

Genetic Baseline Data

Adequate genetic baselines on fish are required to understand and identify changes associated with dam removal. We need genetic profiles for hatchery and wild populations of all salmonid species. Micro-satellite profiles seem to be state of the art now; however, molecular genetics has been evolving rapidly, and other genetic markers (including new microsatellite loci) may be available in the future. Given this uncertainty, a prudent course of action may be to archive tissue from current populations. These tissues could be assayed in the future when needed for comparison with future collections using the state-of-the-art methodology. The current high cost of genetic profiling would be postponed probably reduced due to improved technology. Some of the genetic profiles may need to be developed now to provide information on population structure or guide efforts to evaluate management options (see below).

Hatchery releases for restoring populations

Releases of hatchery fish are a major component of the fish restoration plan. It is important to document the extent to which the hatchery-mediated reintroductions vs. uncontrolled straying lead to restoration. In addition, evaluating the efficacy of releasing salmonids at alternative life stages (adult, egg, swim-up fry, fed fry, smolt) received little consideration. A reasonable answer may be provided to both questions by a program of genetic marking of all fish released in the Elwha River other than at the hatcheries (e.g., fish or eggs transported via pack stock, helicopters, etc.). The hope is that micro-satellite-based grand-parentage analysis may be sufficient to test the null hypothesis of no difference in the contribution to F2 and subsequent generations from "equivalent" releases of hatchery fish at different life stages .

Biotic and Physical/ nutrient status parameters

- Determine nutrient, sediment, thermal, and large woody debris (LWD) budgets and compare among different reaches of river and establish reference “chemical signatures” for each tributary stream. Determine residence time of nutrients. Compare terrestrial (allochthonous) vs. marine derived nutrients (MDN). Measure algae and allochthonous inputs. Requires a before and after sampling approach at selected sites.

- Soil chemistry baseline and monitoring.

- Aquatic chemistry parameters will be important to track at relatively high precision (ppb?). Dissolved organic carbon, N, P, track with development and maturation of riparian vegetation.

Vegetation

A vegetation monitoring program is necessary to characterize the response of the ecosystem to dam removal and re-introduction of anadromous fish. The program must be cost-efficient yet robust enough to handle a dynamic environment. A nested design was suggested ranging from large spatial and temporal scales down to specific question-oriented monitoring at smaller scales. Remote sensing may be a cost-effective approach to establishing vegetation and landform baselines above and below the dams. Suggested remote sensing techniques included LIDAR, hyperspectral imagery, digital video, and thematic mapping imagery.

Parameters suggested for measurement included:

- Vegetation structure
- Sediments
- Large woody debris
- Topography and landform, channel evolution
- Nutrients

Potential study areas and controls

- Upland ~ exposed lakebed slopes & terraces, both reservoirs
- Floodplain
  - exposed lakebed slopes (site selection could be accomplished using hyperspectral imagery)
  - non-inundated reaches between dams (hyperspectral site selection)
- Reference reaches
  - Geyser Valley (Elwha River above Lake Mills)
  - Quinault River (above/below Lake Quinault)
  - Lyre River (above and below falls)
  - Other Olympic Peninsula Rivers.

The Upper Reach -- Above Lake Mills

Since 83% of the Elwha basin lies within Olympic National Park, restoration of anadromous fish will provide a unique opportunity to examine nutrient linkages between aquatic and terrestrial ecosystems. The upper and middle reach of the river have been without anadromous fish for about 90 years. In the pre-dam Elwha, salmon and trout brought nutrients from the sea as biomass distributed all along the river and its tributaries. The nutrients, absorbed by aquatic plants and animals, formed the base for an in-stream food chain which fed, among others, the juvenile salmon and trout. We also know from experimental work, (Cederholm et al. 1989) that adult salmon carcasses are fed on by at least 22 species of birds and mammals on the Olympic Peninsula. This food source is especially important during the late fall and winter when other food is scarce.

Phosphorus and nitrogen often limit biological productivity in Northwest streams. Wild salmon and steelhead are expected to increase by almost 400,000 adult fish following full restoration (NPS 1996). This translates to an addition of approximately 298,000 kg of nitrogen to the system (Munn et al. 1999) during years pink salmon spawn.

Assumptions:

- **The return of anadromous fish to the upper reaches of the Elwha River will bring an influx of nutrients, food, and restore native predators (the anadromous fish) to the ecosystem**. This will likely alter the ecosystem (See Figure 5) including associated wildlife species, aquatic organisms, vegetation, and soils.

- **The upper reach of the Elwha River will serve as a baseline** for several physical processes that will change in the middle and lower reaches of the river following dam removal. Consequently, measurements of water temperature and chemistry, rates of sediment and woody debris movement, and level of floodplain activity (fluvial processes, perhaps LIDAR) in the upper river are considered key to understanding effects of dam removal on the middle and lower reaches of the river.

Primary Hypotheses

H1: Carbon, nitrogen, and phosphorus will accumulate in the floodplain and adjacent uplands as direct and indirect results of inputs from anadromous fish.

H2: Trophic pathways will be restructured with effects cascading throughout the ecosystem.

H3: Productivity of the aquatic ecosystem will increase following dam removal.

H4: Resident fish already utilizing the upper river will compete with re-introduced anadromous fish for space and food.

H5*:* Fish species will recolonize the upper river at different rates. (i.e., natural barriers will influence recolonization rates of species throughout basin)

H6 Hatchery and wild populations of anadromous fish will interbreed and may compete with one another for space and food.

Elaboration

H1: *Returning salmonids will contribute additional carbon, nitrogen, phosphorous and other nutrients to the floodplain and adjacent upland ecosystems in the upper reach of the Elwha River.* A corollary null hypothesis would be that even if nutrients are added to the system, there will be no measurable changes on vegetation development in terms of productivity or plant succession. The fundamental question is whether or not the addition of marine-derived nutrients matters to floodplain vegetation.

Research Suggestions

1) This hypothesis can be tested using an experimental approach outside the Elwha drainage by adding carbon and/or nutrients at different levels to different habitats, and examine vegetation growth response and competitive hierarchies. This could involve a series of pot studies and field studies where nutrients are added to pots using Elwha-type soils (Jenny Pot tests) or adding nutrients to intact floodplain systems (mainly alder) that have no anadromous fish.

2) Field tests of vegetative changes in the upper reaches of the Elwha River system depend on long-term studies. Changes are likely to be slow and extend far beyond the time frame of typical funding sources such as the National Science Foundation (usually 3-5 years?). The measurement of multiple stable isotopes such as ^{13}C, ^{15}N, ^{34}S, and $^{87/86}Sr$ (new surfaces) was suggested.

3) To isolate a "fish" effect, research must focus on *nutrient sources* to determine whether or not anadromous fish were responsible for transporting nutrients to the upper reach of the Elwha ecosystem. Understanding aquatic and terrestrial nutrient retention mechanisms and transport vectors is vital. Suggested areas of study include: fish, alder, upland litter, soil carbon, nitrogen and phosphorous, and atmospheric deposition. It has also been suggested that other, suitable "control" sites would be useful if not crucial to the research. Two examples of rivers without anadromous fish include the upper Sol Duc and upper Dosewallips; both these rivers have substantial natural barriers to anadromous fish.

4) An experimental approach could be used to supplement Elwha River studies. This might include planting alder, removing litter, and adding fish or excluding fish from field areas not in the Elwha system or using pots.

H2: *As a major influx of nutrients is returned to this system in the form of anadromous fish, there will be a restructuring of trophic pathways.* This is one of the biggest unknowns and includes a suite of sub-questions and hypotheses. These are listed in general order of priority as determined by the wildlife group. The group phrased their ideas in the form of a list of parameters and high priority organisms to be measured and monitored over time.

Research/monitoring suggestions

1) Measure relative abundance before and after dam removal of those species known to be strong interactors with salmon in PNW river systems (e.g., bears, otter, osprey, eagles, mink, crows, ravens, jays).
   - Consider measuring presence/absence of other species (while doing above).
   - Measure relative use of marine derived nutrients, using isotopic analysis – in conjunction with DNA analysis (used for abundance studies).

2) Measure the use of fish by those species known to be strong interactors with salmon in PNW river systems (bears, otter, osprey, eagles, mink, and birds - concentrating on members of the corvidae family).

3) Measure the direct and indirect effects of changes in bear distribution and abundance.
   - Determine effects of bear predation of fish on recovery of salmon.
   - Measure effects of bear predation on deer and elk population.
   - Measure changes in herbivory on understory structure/composition.

4) Measure changes in aquatic macroinvertebrate populations and the effect on vertebrate species utilizing macroinvertebrates as food. Consider avian species such as harlequin

ducks, dippers, willow flycatchers, swallows, and mammalian predators such as water shrews.

5) Determine relative changes in abundance and distribution of elk and deer upstream and downstream of the dams, including their influence on restoring former reservoir vegetation.

6) Measure species diversity and proportion of early and late successional-associated species.

Sub hypotheses

Direct Effects:

1) Some animal populations will show increased marine-derived nutrient utilization.

2) The abundance of mammalian predators (otter, mink, raccoon, skunks, bears) will increase.

3) The abundance of avian predators of fish (crows, ravens, eagles, herons, mergansers, kingfisher, and osprey) will increase.

4) There will be an increase in secondary producers, especially macroinvertebrates .

Indirect Effects:

The use of marine-derived nutrients by animal populations will result in transport of marine nutrients into upland terrestrial ecosystems, with a possible increase in terrestrial plant community productivity.

Bears

a. There will be a change in population distribution, as bears increase their use of riparian areas.
b. Bear population will increase.
c. Increased bear population will result in an increase in predation on neonatal elk/deer.
d. Increased predation will decrease deer and elk populations.
e. Decreased deer and elk populations will change understory vegetation composition and biomass (from a decrease in herbivory).

Corvids

a. Population of corvids (ravens, crows, jays) will increase due to increased scavenging opportunities
b. Increased corvid population will increase predation on breeding bird populations

Spotted Skunks, Raccoons, Bobcats

a. Population and health of spotted skunks, raccoons, and bobcats will increase due to increased scavenging opportunities.

b. If the population of spotted skunks or raccoons increases, an increase in the predation on birds (primarily ground nesting) may occur. Increased populations of bobcats could have indirect effects on deer (young preyed upon by bobcats).

Otter and Mink:

a. An increase in otter and mink, and subsequent predation on fish, will affect fish production/population.

Macroinvertebrates:

a. An increase in available nutrients from salmon carcasses will change the diversity and abundance of macroinvertebrates in the river system.
b. If populations of macroinvertebrates increase, an increase in avian predators of aquatic insects will occur. (e.g. harlequin ducks, dippers, willow flycatchers, swallows, and/or mammalian invertebrate predators such as water shrews) .
c. Measure biomass of macroinvertebrates by trophic guild (community structure, distribution, and function). Need to address energy transfer among trophic levels (e.g. certain insects may play stronger role in determining trophic levels than others [keystone species]). These keystone species may have more influence than their biomass would otherwise indicate. This should be conducted in a functional context.
d. Monitor guilds of aquatic invertebrates, and understand community structure, distribution, and function. Track availability of food resources (e.g. macroinvertebrate) during dam removal. Requires a before and after approach to sampling
e. Monitor dynamics of scour on floodplain features in relation to invertebrate communities and western toads

Observation: Timing and retention of fish carcasses will have a great influence on stream productivity with a fall pulse in a high-energy system. However, this may mean that most nutrients are washed out of the system during winter high water flows. If carcasses are retained in the system or deposited in the spring, this will potentially increase algae production and macroinvertebrate populations with different effects on the trophic structure of the system. Major runs of pink salmon occur in alternating years which will also have a major influence on the timing of any changes in stream productivity.

H3: *Productivity of the aquatic ecosystem will increase following dam removal because nutrients will be added to the system from carcasses.* This hypothesis was primarily focused on invertebrates and fish, but equally applies to aquatic plants and the terrestrial system as described in **H1** and **H2.** The primary approach suggested here is to establish baseline conditions prior to dam removal and should include:

- current distribution of resident fish species
- life history patterns of fish species
- relative abundance of species
- genetic baseline sampling
- Seasonal distribution and movement of selected species among habitats.

1) Stream "productivity" is highest in the lower portion of the watershed. Look at productivity in different stream reaches (upper, lower, etc) before and after dam removal, to gauge the characteristics of change.

2) Is primary production limited by nutrients in streams (N, P)? Need to address C and N (isotope ratios) before and after dam removal. Requires a before and after sampling approach at selected sites.

3) Is the upper river going to become a source or a sink for nutrients?

H4: *Resident fish already utilizing the upper river will compete with re-introduced anadromous fish for food and space*. In particular, resident rainbow trout will compete with re-introduced steelhead. This will also apply to bull trout, cutthroat trout, and sculpins.

Do life history patterns of salmonids and other fish species differ before and after dam removal and how are patterns influenced by changes in habitat?

H5*: Fish species will recolonize the upper river at different rates.* (i.e., natural barriers will influence recolonization rates of species throughout basin)

Suggested methods include isotopic analysis, radio telemetry, mark-recapture studies, otolith microchemistry, and trapping.

Related questions and ideas:

1) Could we predict anadromous fish (by species) re-occupation of rates based on habitat pre-surveys of ? Does current technology allow us to predict recolonization?

2) What is the relative importance of tributaries to fish species among different reaches of the river?

3) Natural barriers will influence recolonization rates of each species.

4) Determine the extent and magnitude of Atlantic salmon invasion into Elwha River Basin

H6 *Hatchery and wild populations of anadromous fish will interbreed and may compete with one another.* This assumes that fish of hatchery origin will be introduced during the first few years following dam removal and that some "stray" wild fish will colonize the river.

The Middle and Lower Reaches

Dam removal will result in the release of several million cubic yards of sediment from beneath Lake Mills and Lake Aldwell. Sediments released from the two reservoir areas will initially dominate the post dam-removal ecosystem. At first, fine sediments will predominate with gravels, cobbles and possibly woody debris playing a larger role over time. Fluvial processes will be in a state of flux for some years. A number of research and monitoring questions center around fluvial dynamics.

Anadromous fish have been absent from the middle reach of the Elwha River for more than 90 years. Relatively small numbers of primarily hatchery fish still use the lower reach. Returning fish are expected to colonize the middle reach and to increase their use of the lower reach following dam removals. Because of the mass-spawning nature of pink salmon and their expected numbers at full restoration, the number of fish using the middle and lower reaches of the River will vastly exceed the number of fish using the upper reach. Several, if not most of the hypotheses that apply to the upper reach also apply to the middle and lower reaches and will not be repeated here. However, it should be noted that the middle and lower reaches of the river differ from the upper reach in key ways that will affect research and monitoring:

1. The middle and lower reaches are not "pristine" in the sense that only a portion of the middle reach contains old-growth forests with the remainder being second growth.
2. The middle and lower reaches have been relatively heavily used by humans and hence wildlife abundance and species composition has been altered by consumptive and non-consumptive uses.
3. There will be a lag between dam removal and re-establishment of suitable spawning habitat for anadromous fish.
4. The middle and lower reaches will be subject to high levels of sediment instability in comparison to the upper reach.

Assumptions:

- **The middle and lower reaches have been "starved" of major sediment inputs for approximately 80-90 years.** Sediment additions to the middle and lower reaches will dominate fluvial processes until a new equilibrium is established with inputs to the system from above the former Lake Mills area.

- **Anadromous fish colonization of the middle and lower reaches of the river will occur slower than in the upper river** because the release of sediments from the reservoirs will reduce egg survival**.**

- **The number of anadromous fish utilizing the middle and lower reaches of the Elwha River will exceed the number of fish utilizing the upper reach** because of the amount of available habitat below Rica Canyon to the river mouth for pink salmon and chum salmon.

- **The return of anadromous fish to the middle reach of the Elwha River and increased use of the lower reach will bring a potentially large influx of nutrients, food, and restore native aquatic predators to the ecosystem**.

- **Anadromous fish spawning and rearing in the middle and lower reaches of the Elwha River will occur primarily in the main channel** (including secondary and off-channel habitat) because few tributaries exist in these reaches.

- **Species abundance and composition will shift over time as quality of spawning habitat evolves.**

Primary Hypotheses

H1**:**: Post-dam removal floodplains will move toward a dynamic equilibrium that is characteristic of the natural condition of the Elwha River ecosystem.

H2: As fluvial processes are restored to the lower reaches of the river (below Rica Canyon) physical and vegetative changes will affect wildlife communities.

H3*:* Nonnative eastern brook trout will not pose a threat to native char.

H4: Sediment additions from dam removal will temporarily destroy or severely alter macroinvertebrate populations downstream of the dams.

H5: A wild run of sockeye salmon will be re-established from the existing stock of Lake Sutherland kokanee.

H6: Stream productivity is highest in the lower portion of the watershed. Estimating productivity of different stream reaches before and after dam removal will help gauge the characteristics of change. Determine the limitations to primary productivity (N?, P?). Also need to address the C and N (isotope ratios) before and after dam removal. Requires a before and after sampling approach at selected sites.

H7: Sediment discharge from the two reservoirs will alter the behavior and dynamics of existing fish populations downstream of the dams.

Elaboration

H1: *Post-dam removal floodplains will move toward a dynamic equilibrium that is characteristic of the pre-dam condition of the Elwha River ecosystem.*

Riparian vegetation structure is typically a mosaic of patchy forest and landform types in various stages of succession. The rate of succession and distribution of landforms and associated forests are a function of the frequency and severity of fluvial disturbance, supply and movement of sediment and woody debris, and life history characteristics of colonizing plant species. Fluvial disturbance is influenced by the existing forest and the presence of large woody debris jams within the active channel.

There will be several areas that can studied to compare vegetation patterns and processes as affected by dam removal: 1) the upper reach which will serve as a control, 2) the middle reach between Glines Canyon Dam and the upper part of Lake Aldwell which will be affected by sediments from Lake Mills; 3) the lower reach (below Elwha Dam which will be subject to sediment additions from both reservoirs) 4) the newly exposed reservoir bottoms, and 4) the delta at the river mouth. Initially, the areas inundated by Lakes Mills and Aldwell will have a highly skewed distribution of vegetation-free landforms, and for a number of years will be dominated by early-successional vegetation. By contrast, patch types and landforms between and below the dams will be dominated by mid- and late-successional patch types. The river delta will increase in size over time with increased sediment delivery.

Research/Monitoring ideas and sub hypotheses

1. There will be an increase in topographic complexity, and a concurrent increase in vegetation, soil and habitat heterogeneity.

2. There will be an increase in functional diversity of biogeochemical cycles as physical and biological heterogeneity increases.

3. Once the dams are removed, the spatial and temporal distribution of habitats downstream of the dams will change in response to sediment evacuation and accumulation, large woody debris, and discharge. A habitat classification scheme can be implemented to determine how the distribution of habitats changes through time. Transport of sediments and large woody debris should be monitored. One might expect three additional sources of LWD following dam removal: upper reach, reservoir areas, and from increased lateral channel migration downstream of the dams as the River stabilizes with the release of sediments from the reservoirs.

    a. Determine the sources and fate of wood debris due to lateral channel migration by using remote sensing tools augmented with ground surveys to characterize physical/channel complexes.

4. The influx of large wood and fine sediments will result in creation of new floodplain surfaces and recruitment of riparian vegetation.

5. Reservoir sediments contain abundant large wood that will be mobilized after dam removal – this will strongly affect the quality of aquatic and riparian habitats.

6. Examine sediment flux and response of alluvial aquifer. Using remote sensing tools augmented with ground surveys to characterize physical/channel complexes.

7. How long will it take for different reaches to produce suitable habitat? The spatial distribution of habitat will change as a function of inputs of sediments and wood, and this will be a function of the geomorphic context.

Additional Notes/Comments

- By quantifying the heterogeneity and frequency distributions of landforms and vegetation patches in the upper reach of the river, the success of recovery in the middle and lower reaches of the river can be evaluated (i.e., use the upper reach as a control).
- Other watersheds on the Olympic Peninsula can be used to model the frequency distribution of floodplains and vegetation patches as related to drivers/inputs such as rainfall and terrain. This model could then applied to the upper reach of the Elwha River to test the model and to predict the expected equilibrium frequency distribution for the middle and lower reaches of the of the river.

Suggested Monitoring parameters:

- Vegetation type
- Stem density
- Species diversity
- Canopy height
- High-resolution topographic relief of the floodplain
- Stream channel geometry and morphology
- Flood frequency curves; floodplain flood duration and extent
- Stream flow
- Water chemistry
- Sediment soil texture
- Extensive temperature measurements (thermal refugia, productivity hotspots)
- Water table elevations

H2: *As fluvial processes are restored to the middle and lower reach of the river physical and vegetative changes will affect wildlife communities*. Participants commented that while interesting, results of lower river changes are relatively predictable, and changes influence a smaller area and proportion of ecosystem – hence hypotheses were not elaborated to the same extent as those in the upper river. However, as noted above, there may be greater additions of salmon carcasses to these reaches of the river than to the upper reach. We will not repeat the hypotheses and specifics outlined in the section on the upper reach, but these all apply to the middle and lower reaches. Obviously, there will be strong interactions between the influx of sediments and wildlife communities, especially those dependent on stream channel characteristics.

Sub Hypotheses

1. Beaver/muskrat distribution and abundance will change.
2. Abundance of toads and red legged frogs (and possibly long-toed, northwest salamander, or snakes) will increase.

3. Increased availability of early seral plant communities will affect wildlife distribution and abundance.
4. We will see an increase in early seral dependent birds (e.g. willow flycatchers) as new gravel bars are established and vegetation colonizes new substrates (equally applicable to areas exposed by draining the reservoirs).
5. Currently, elk are dominant in the upper reach and deer dominate the downstream reaches. Elk and deer population distribution will change as elk habitat increases, especially with respect to expected new floodplain surfaces exposed by draining Lake Mills and perhaps Lake Aldwell.

Suggested Measures

- Measure changes in relative abundances of aquatic species such as beaver, toads, red-legged frogs that may benefit from changes in stream channel characteristics (e.g., more river side-channels, sloughs).

- Measure relative abundance of breeding birds, small mammals, elk, and deer that are expected to change in response to changing successional dynamics related to changes in fluvial processes.

H3*: Nonnative eastern brook trout will not pose a threat to native char.* The existence of introduced brook trout, especially in the middle reach of the river may provide a source for invasion of this species into the upper reach once the dams have been breached. There is the potential for this species to compete with native bull trout. Eastern brook trout are also known to compete with native cutthroat trout in other regions.

H4: *Sediment additions from dam removal will temporarily destroy or severely alter macroinvertebrate populations below the dams*. The release of fine sediments from beneath reservoirs may suffocate aquatic organisms, particularly invertebrates, for a number of years. This would temporarily alter trophic structure since invertebrates play key roles as both food and predators for fish and amphibians. This monitoring and research requires a before and after dam-removal approach to sampling. Suggested research and monitoring includes:

- Monitor guilds of aquatic invertebrates, and understand community structure, distribution, and function. This may include use of an Index of Biological Integrity (IBI) and offers an excellent opportunity to determine how responsive this approach is to changes in aquatic conditions.

- Track availability of food resources for fish (e.g. macroinvertebrate) during dam removal.

- Measure biomass of macroinvertebrates by trophic guild (community structure, distribution, and function). This work should address energy transfer among trophic levels (e.g. certain insects may play stronger role in determining trophic levels than others (keystone species). These keystone species may have more influence than their biomass would otherwise indicate. This should be conducted in a functional context.

- Studies need to be related to the dynamics of scour on floodplain features and how this influences invertebrate communities and other aquatic organisms such as western toads.

H5: *A wild run of sockeye salmon will be re-established from the existing stock of Lake Sutherland kokanee.* Landlocked sockeye salmon (kokanee) presently exist in Lake Sutherland, to the west of the Elwha River, smolts have been captured exiting the lake, and sockeye salmon adults are often observed in the lower river during spawning season. It is possible that these fish will return as sockeye salmon adults to Lake Sutherland once the dams have been removed.

H6: *Stream productivity is highest in the lower reach of the watershed.* Aquatic ecosystems in general tend to be more productive further down a river system than in the headwaters. In addition, the lowest reach of the Elwha River still has anadromous fish so higher productivity could result from the addition of salmon carcasses. This hypothesis was not fleshed out but obviously links to hypotheses concerning salmon additions to the upper river and should also include the terrestrial ecosystem. The basic ideas here describe the need examine productivity of different stream segments before and after dam removal to gauge the characteristics of change. Specifically there is a need to determine the limitations to primary productivity (nitrogen and/or phosphorous) and to address the C and N isotope ratios before and after dam removal.

- How do biotic and chemical elements respond to sediment at different geomorphic reaches? Is there localized nutrient retention and will that influence affect primary and secondary production?

H7: *Sediment discharge from the two reservoirs will alter the behavior and dynamics of fish populations below the dams*. This hypothesis has obvious linkages with H1 which looks primarily at the dynamics of the fluvial processes as the river responds to sediment discharge from the reservoirs and comes into a "normal" equilibrium with upper river.

Research/monitoring ideas and sub hypotheses

1. The recovery time of salmonids in side channels with large woody debris will occur more rapidly than in those areas without LWD

2. Especially downstream of Elwha Dam, determine location(s) of river aggradation and response of fish species to changes in distribution of sediments

3. Determine how adult and juvenile fish respond to sediment discharge (pulses) using remote sensing, particularly LIDAR.

4. Will changes in habitat (boulders; flow barriers; gradient barriers) influence fish passage? Will this impinge on recovery of native salmon and trout?

5. What are current life history strategies of fish species below dams? Determine the distribution, abundance, and overall productivity of each species below dams.

6. Fish restoration will be aided by natural strays. We need to monitor effectiveness of hatchery broodstock in restoration.

7. Do the life history patterns of juvenile chinook differ before and after dam removal and how does that relate to habitat diversity (e.g. wood, sediment). We also need to know this for the other salmon species.

Surfaces exposed by draining of the Reservoirs.

Surfaces exposed by draining the two reservoirs present numerous challenges and opportunities to scientists and managers. Here, we expect the surface to be dominated by lake-bottom silts and that the process of river incision and re-establishment of vegetation and a "normal" floodplain to require years. No one is quite sure just how fast this process will proceed. We have included just one hypothesis with accompanying elaboration (H1). The remaining hypotheses are simply listed.

Hypotheses, research ideas, and monitoring suggestions

H1: Plant life history characteristics will interact with environmental factors to influence successional pathways and rates of change.

H2: Stable floodplain surfaces will form where accumulations of large wood deflect flows and facilitate deposition of fine sediments.

H2: Herbivory by native ungulates will decrease the density and growth of woody vegetation colonizing floodplains.

H3: Townsend's vole and mountain beaver will increase due to a large quantity of herbaceous plants in recovering lakebeds – this will adversely affect restoration of woody plant species.

H4: Recovery of soil microbial diversity and function will vary with texture, aeration, and volume of litter inputs from the surrounding forest.

H5: Gradients in nutrient availability due to longitudinal patterns of hyporrheic transfer will only develop after channel and floodplain complexity develops in response to wood jams.

H6: Marine-derived nutrients will be transferred to riparian and upland vegetation as soon as anadromous fish colonize former reservoir areas.

H7: Transfer of nutrients from upland slope soils to riparian and aquatic ecosystems will only occur after hydrologic connectivity has been restored

H8: The topography of the de-watered reservoirs surface will change dramatically as dams are gradually removed and delta deposits are distributed throughout former pool areas. After dam removal is complete, most topographic change will occur within the river's meander zone.

H9: Prior to recruitment of sufficient large wood into channels to create jams, the river channel will change position primarily through incremental migration rather than through evulsion.

H10: By the time de-watering is complete, mixing of sediments from reservoir deltas and lake beds will be so complete that substrate texture will be homogeneous throughout.

H11: Where tributaries enter the former reservoir pools, considerable incision into sediments and erosion will occur.

H12: De-watering of sediments in the newly exposed upland areas will require two to three years, with the rate modified by sediment texture and insolation as determined by topography.

H13: Longitudinal gradients (primarily sediment texture) will be maintained by hydraulic and fluvial dynamics within the unconstrained reaches.

Elaboration:

- **H1:** *Plant life history characteristics will interact with environmental factors to influence successional pathways and rates of change.* Studies of the role of initial colonizers on pathways of primary and secondary succession. Different life history attributes of species pool will influence the course of succession.

The initial colonizers of disturbed landscapes are derived from a regional pool of native and exotic plant species. These species differ in life history attributes that determine their relative rate of finding suitable environmental conditions for germination, growth and establishment. Numerous studies have shown that the pre-emptive occupancy of space by initial colonizers influence subsequent establishment by other species. Thus, it is important to know the range of variation of life history attributes amongst the regional pool of plant species (both native and exotic) to predict the pattern and process of plant succession. Critical life history and environmental attributes that will influence succession and restoration include:

1. Reproductive attributes
    a. Time of seed dispersal (spring, summer, fall, year-round)
    b. Number of seeds produced (few, many)
    c. Dispersal vectors (wind, water, animal)
    d. Seed dormancy or lack thereof
    e. Seed bank attributes
    f. Age of reproductive maturation/generation time (young vs older)

2. Environmental characteristics or attributes
    a. Seedling microsite parameters
        i. Soil (organic vs. mineral, rough vs. smooth surfaces)
        ii. Moisture (wet vs. moist vs. dry)
        iii. Light (high vs. low)
        iv. Nutrients (higher vs. lower)
        v. Mycorrhizal associations

    b. Inherent rates of growth
        i. Rapid rate of growth (ruderals & competitors)
        ii. Slower rate of growth (stress tolerators)
        iii. Palatability to herbivory (insect to ungulates)
        iv. Susceptibility to pathogens, insects

3. Stochastic of Environmental Conditions
    a. El Nino cycle of cool, wet to moist to warmer, drier growing seasons
    b. Herbivory ~ timing of herbivory and size of populations
    c. Extreme winter & storm-related conditions
    d. Rain on snow events
    e. Debris and landslides

Specific additional study questions and hypotheses applicable to floodplain and upland areas:

1. How do initial colonists influence successional pathways?
2. Are exotic (annual vs. perennial, deciduous vs. evergreen) species more effective colonists of primary successional environments?
3. Are native (annual vs. perennial, deciduous vs. evergreen) species more effective colonists of primary & secondary succession (floodplains only) environments?
4. What life history attributes will be critical in selection of plant stock?
5. How will herbivory influence rates and patterns of plant succession?
    a. What species are preferred over others (i.e. cottonwood vs. alder)?
    b. How does time of year influence grazing patterns?
6. Are rates of succession enhanced by planting of native stock?
7. Are soils stabilized more rapidly by herbaceous than woody species?
8. How does large woody debris influence rates and patterns of plant succession on floodplain environments?
9. How does substrate texture (upland & floodplain) influence rates and patterns of plant succession?
10. How does variation in the temporal and spatial availability of nutrients influence the composition and growth rates of colonizing species?
11. How does variation in the temporal and spatial availability of water influence the composition and growth rates of colonizing species?
12. How does variation in the temporal and spatial availability of light influence the composition and growth rates of colonizing species?

13. Cover and density of colonizing vascular plants will be greatest on substrates of optimal texture (sandy loam?).

Vegetation Group Suggested Timeline and additional thoughts

BEFORE dam removal

- Determine what factors that respond to restoration would influence plant growth in these areas (water, nutrients, soil carbon)
- What are baseline / background isotopic signatures in Elwha and adjacent basins?
- Identify intersection of good salmon and terrestrial habitat for MDN sources and movement

AFTER dam removal

- What are physical / chemical characteristics of soils in recovering areas both longitudinally and laterally?
- Initiate of experiments to isolate contributions of nutrient sources (e.g. exclosures, fertilization)

LONG TERM:

- Most characteristics don't need to be measured annually.
- Recognize that initial change is more rapid (e.g. channel development, succession, nutrient accumulation) than long-term changes.
- Fit into the "glue" of a remote sensing plan. This will need ground truthing, tie into that program
- Measure parameters that are integrative over time – e.g. isotopes or vegetation composition. Parameters that respond weekly or seasonally are not useful
- Measure parameters that are integrative over space – e.g. stream chemistry of small basins.
- Think extensive, not intensive

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Appendix 1. Workshop Participants and Coordinators

Workshop Coordinators/Facilitators — Brian Winter, Olympic National Park
Ed Schreiner, USGS – FRESC
Dave Woodson, USGS – Western Regional Office

Sponsors — NPS, Olympic National Park
USGS, Western Regional Office
USGS, FRESC

Name/Session	Expertise	Affiliation
Fish/Aquatics		
Steve Ralph	session facilitator	EPA – Seattle, WA
Sam Brenkman	session recorder	Olympic National Park
Reg Reisenbichler	fish/genetics	USGS - WFRC
Michael Adams	amphibians	USGS - FRESC
Judith Li	invertebrates	Oregon State University, Corvallis, OR
George Pess	fish	NMFS-Seattle
Jack Stanford	floodplain ecology	Flathead Lake Biological Station
Jana Compton	nutrient cycling	EPA - Corvallis, OR
Loveday Conquest	sampling design	University of Washington, Quantitative Sciences
Tim Randle	sediment transport	US Bureau of Reclamation, Denver, CO
Wildlife		
Cat Hoffman	session facilitator	Olympic National Park
Bill Baccus	session recorder	Olympic National Park
Kurt Jenkins	ungulates	USGS – FRESC
Doug Houston	ungulates	USGS – FRESC, Retired
Steve West	small mammals, bats	University of Washington, College of Forest Resources
Patti Happe	wildlife	Olympic National Park
Ed Starkey	wildlife	USGS – FRESC
Scott Mills	population ecology	University of Montana
Charlie Robbins	wildlife	Washington State University, School of Veterinary Medicine
Vegetation/Ecosystem Processes		
Steve Acker	session facilitator	Olympic National Park
John Boetsch	session recorder	Olympic National Park
Bob Bilby	MDN	NMFS, Seattle
Bob Edmonds	soils	University of Washington,

		College of Forest Resources
Steven Perakis	nutrients	USGS – FRESC
Jeff Braatne	riparian vegetation	University of Idaho
Dave Peterson	forest vegetation	USFS – Fire and Environmental Sciences Lab
Martin Liermann	sampling design	NMFS
Rick Edwards	hyporheic zone	USFS, Juneau, AK
Lee Case	landscape change	USGS NW Geographic Science Center
Bill Jackson	sediment transport	NPS – Water Resources Division, Denver, CO
Others		
Marijke van Heeswijk	watersheds	USGS, Washington Water Science Center, Tacoma
Marianna Alexandersdottir	biometrics	Northwest Indian Fisheries Commission
Pat Crain.	Fisheries	Clallam County (formerly Lower Elwha Klallam Tribe
Larry Ward	Fisheries	Lower Elwha Klallam Tribe
Mike McHenry	Fisheries	Lower Elwha Klallam Tribe

Appendix 2. Elwha Restoration Funding Opportunities by David L. Peterson

Given the uncertainties of both internal (hard) and external (soft) funding for research, a diverse approach to developing a financial base for a scientific program is needed. Multiple potential sources of funding also provide the possibilities of cost sharing, leveraging, and interdisciplinary partnerships. A fundamental base of funding from the National Park Service is needed to demonstrate agency commitment to restoration science. Sufficient NPS funding is needed to provide at least a small administrative and oversight infrastructure for a long-term scientific program.

The Elwha restoration team is encouraged to develop a small scientific cadre that is committed to work together to develop opportunities for research funding. This is a significant investment of time and energy and will require coordination between NPS, other federal agencies, universities, and potential contractors. The scientific cadre should emphasize and market dynamic interactions and applications rather than a laundry list of projects.

Potential Sources of Funding:

Foundations
These are several foundations that support natural resource research and are capable of large, long-term commitments. Examples include: Canon, Bullitt, Mellon, Packard, etc. A focus on conservation and restoration can be readily marketed, and the national park and Native American connection to the Elwha will be attractive.

Federal agencies
The most likely supporters of Elwha research are the National Park Service (NPS), U.S. Geological Survey (USGS), National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), USDA Forest Service (USFS), and U.S. Army Corps of Engineers (ACE). The mainstay for NPS research is the National Resources Preservation Program, in cooperation with USGS. This program provided significant funding for high-profile issues, although some internal NPS lobbying may be needed to ensure that restoration is an NRPP priority.

USGS is the primary research arm of the Department of Interior. USGS has organizational and scientific ties with NPS, including former NPS scientists. A joint USGS-NPS research program can be developed among Olympic NP, the Cascades monitoring cluster, USGS-FRESC, and USGS-NFRC. The latter two centers have the option of prioritizing Elwha restoration research and can quickly involve a large group of scientists. USGS also has the capability of multidisciplinary research through its four divisions (biology, geology, water, mapping).

NMFS and USFWS have a primary focus on fisheries and aquatic systems. However, the importance of aquatic-terrestrial interactions in the Elwha, and the expanding mission of NMFA and USFWS toward large-scale ecosystem and landscape issues make it imperative for these agencies to be involved. NMFS and USFWS also provide expertise on regulatory issues that may be relevant to Elwha restoration.

The ACE has an increasing interest in dam removal and ecological restoration, replacing its traditional focus on dam construction and maintenance. The Elwha program provides a rare opportunity for the ACE to learn about ecosystem recovery after dam removal, thereby accumulating knowledge and principles useful for future dam removal projects.

The USFS PNW Research Station and other USFS research stations have considerable expertise in restoration ecology. They have most of the expertise in forest management and silvicultural that is needed for addressing restoration targets. USFS contributions may be in-kind rather than financial.

National Science Foundation

The Elwha program is an ideal situation for an LTER-like ecosystem study, and would be a good complement to existing LTER research. A viable NSF proposal will require: (1) a set of clear scientific questions, (2) an initial dataset on which to base hypotheses and experiments, (3) a high-profile university scientist(s) as lead PI(s). The collection of data prior to dam removal will be critical for justifying future research. Significant university involvement and graduate student participation will be required.

Prior to developing an NSF proposal, inquires should be made with NSF program directors regarding their receptiveness to a major Elwha scientific program. The possibility of using the Elwha as a "restoration LTER site" could also be pursued with the LTER network office and director.

Many scientific activities proposed for the Elwha can be done at relatively low cost, through cost-share and in-kind contributions, and through partnerships. For example, the 400-acre drawdown area of Lake Mills could be completely reforested for about $200,000 (@$500/ac). Participation by Peninsula residents, students, and NGO's can reduce costs as well as develop public support.

Several near-term efforts could raise the profile of an incipient long-term research program:

(1) Workshop on Elwha research that develops a consensus formal research template and agenda. Involve stakeholders.
(2) National Academy of Science panel that develops a formal research template and agenda. This could also be done by a Society for Ecological Restoration panel
(3) Invite Congressional staff for field trips and briefings.
(4) Implement a scientific "pulse" for data collection as a base for future research.

Time is of the essence in order to develop a credible research plan and viable mechanisms for funding prior to dam removal.

Appendix 3. Suggested fish studies in the estuarine and marine environments

1) What are juvenile migratory patterns of salmonids in Straits of Juan de Fuca? What is the survivorship of juvenile chinook?

2) *Ho*=The important role of the Elwha estuary for juvenile rearing will increase after dam removal. How best might we understand this?

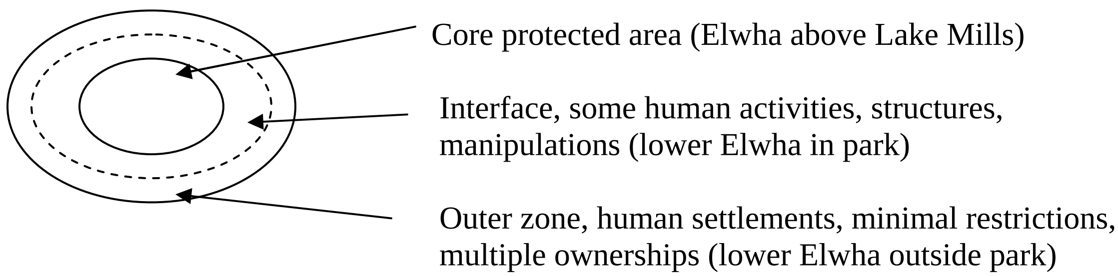
- Methods=Conduct fish inventories along nearshore of Straits throughout the entire year. Analyze otolith microchemistry.

3) *Ho*=The estuary will be more productive after dam removal.

Appendix 4 Elwha Research National Area – David L. Peterson

The removal of dams and restoration of terrestrial and aquatic ecosystems in the lower Elwha River drainage provides an excellent opportunity for a long-term research and monitoring effort to benefit understanding and management of natural resources in Olympic National Park. The Park and the National Park Service in general have a long history of supporting research and monitoring in support of objectives in research management plans. In a broader sense, national parks also serve as national laboratories for resource management on all public and private lands. In this case, knowledge from a large-scale restoration effort will be invaluable as other agencies and society contemplate dam removals at other locations in North America.

As a Biosphere Reserve, Olympic NP can use the Biosphere Reserve concert (per UNESCO criteria) as a framework for research and monitoring along the Elwha.



The <u>core protected area</u> can serve as a reference for restoration targets and trajectories. For example, the spatial distribution, disturbance history, and demography of forests can be quantified and serve as a conceptual model for restoration of forest structure throughout the lower Elwha.

The <u>interface</u> encompasses the Lake Mills area extending northward to the park boundary and is the area subject to the biggest effects of dam removal. It is also the area where restoration activities will be focused. Per Biosphere Reserve principles, a high level of scientific research and monitoring is appropriate.

The <u>outer zone</u> includes national forest, tribal and private lands outside the park. Intensive and extensive management activities, experiments, manipulations, and human intervention occur here, with the greatest focus on the Lake Aldwell drawdown area.

Biosphere Reserve Zone	Research and Monitoring Activities
Core protected zone	Forest inventory, vegetation description Reconstruction of disturbance history Landform-vegetation interactions Herbivore effects on vegetation Seed pool, regeneration Biogeochemical and soil characterization
Interface	The above topics plus: Planting of native tees and shrubs Dispersal of propagules (seeds, spores) Movement of woody debris Slope stabilization Limited use of fertilizers and herbicide
Outer Zone	The above topics plus: Planting and dispersal of some exotic species Use of large equipment for land grading Isotope, tracer studies Large-scale soil amendments Involvement of local communities in research and monitoring Traditional ecological knowledge Intensive trials Placement of monitoring equipment, greenhouses, etc.

Scientific activities in the Elwha RNA will be coordinated within and between each Biosphere zone. These activities will be guided by the Elwha Research Plan within the context of the Elwha Ecosystem Restoration Plan and other relevant documents. A "research czar" and/or an oversight panel will ensure that scientific work is focused on specific projects that enhance the Elwha restoration program. Multidisciplinary, interdisciplinary, and team-based research will be especially encouraged.

The Elwha restoration program and accompanying research effort can serve as a prototype for dam removal proposals being considered throughout North America. Having a conceptual framework and administrative infrastructure to support a major research and monitoring effort over the next few decades will be a magnet for attracting scientific expertise from around the world, and will provide opportunities to leverage considerable outside funding. Other national parks, such as Redwood, Channel Islands, Everglades, and Big Cypress have established restoration programs and can provide expertise and ideas for a the Elwha program. Scientific activities that are relatively intrusive and visually disruptive compared to "traditional" national park research may be necessary, at least in the short term, to adequately understand ecosystem processes and inform science-based management decisions.