The Watershed Program Research Plan

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National Marine Fisheries Service
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Mission

The Watershed Program conducts research on physical and biological processes that influence aquatic ecosystems in the Pacific Northwest, effects of land management on those ecosystems, and ensuing effects on the health and productivity of anadromous fish populations. Program scientists provide technical support to National Marine Fisheries Service (NMFS) policy makers and regulatory staff, and collaborate with other agencies, tribes, and educational institutions on research and education related to the management of Pacific salmon (*Oncorhynchus* spp.).

Program Description

The Watershed Program staff includes scientists with skills in fish biology, aquatic and riparian ecology, geomorphology, hydrology, chemistry, spatial analysis, and statistics. Our research focuses on natural processes that form and maintain aquatic ecosystems, and on land uses and restoration actions that can alter these ecosystems and affect salmon populations. We link land uses to habitat conditions by examining the processes that form and sustain riparian, riverine, and estuarine environments, including such processes as the routing of sediment, water, and organic material from hillslopes and riparian areas to streams. All of our research is ultimately related to the health and productivity of anadromous fish populations, as we seek to understand how watershed condition affects aquatic ecosystems, habitat conditions, and fish communities.

Our research findings are used by NMFS and other natural resources managers to develop actions and policies that protect and recover aquatic ecosystems and salmon populations. The Watershed Program also provides NMFS policy makers and regulatory staff with scientific information and assists in evaluating the consequences of proposed management actions. In addition to conducting scientific research, Watershed Program scientists hold affiliate faculty positions at University of Washington, University of British Columbia, and Seattle University. Watershed Program scientists also hold positions on the Center for Streamside Studies advisory board and work on interagency technical teams.

Program Research

The Watershed Program focuses on three primary research themes:

1) quantify fish responses to changes in watershed, habitat, or ecosystem conditions,
2) quantify the effects of natural or human disturbance on watershed processes and habitat conditions, and
3) evaluate the effectiveness of various habitat and watershed restoration strategies or techniques.

The first theme responds to the lack of comprehensive habitat-based production models for most salmonids. Without such models we cannot predict population responses to watershed or habitat changes (including restoration actions). The second theme addresses the continuing need to quantify how land uses affect watershed processes and aquatic habitats, and ultimately alter salmonid production. Similarly, the effectiveness of various restoration strategies and techniques (the third theme) must be evaluated to understand how each approach affects watershed processes, aquatic habitat, and salmonid abundance and survival.

Research approach
Watershed Program research is organized around a conceptual model of watershed function (Figure 1). In this model, habitat conditions in streams and estuaries link landscape and land use characteristics to fish abundance and survival. We distinguish between research on habitat-forming processes and habitat-based fish production models so that we can study habitat processes that influence riverine and estuarine ecosystems independent from the species that use those habitats. We can then relate abundance, growth, fitness, and survival of any species to this single suite of habitat or ecosystem metrics. Program research often spans all segments of the conceptual model, and this larger picture clarifies relationships between our various research activities.

Landscape and ecosystem processes operate at a wide variety of space and time scales (Figure 2). Therefore, we recognize that spatial and temporal scales of assessment vary depending on the relationships under study. For example, we might use coarse resolution remote sensing data to investigate broad regional patterns in relationships among geologic or climatic variables and ecosystem conditions or salmon populations. By contrast, we use detailed field data to investigate how different riparian buffer treatments affect light regimes and primary productivity in specific stream reaches. As a general rule, insights gained from larger scale assessments lead to investigation of specific cause and effect linkages at smaller spatial scales.

With this research structure the Watershed Program can strategically address research topics that are important in the near term, and initiate key in-depth studies that will provide answers to difficult questions in the long term. By maintaining process-based linkages between research elements, we can more cost-effectively integrate results into a comprehensive understanding of watershed and ecosystem function, which ultimately will allow NMFS to better administer habitat protection under the Endangered Species Act (ESA) and the essential fish habitat (EFH) component of the Magnuson-Stevens Fishery Conservation and Management Act. For near-term ESA recovery planning (e.g., Technical Recovery Teams), we also use this conceptual model to help identify appropriate simplifying assumptions that can answer management needs sooner. Simpler models such as the salmonid watershed analysis model (SWAM) allow us to estimate answers to specific management questions quicker than through the more detailed studies in our research plan.

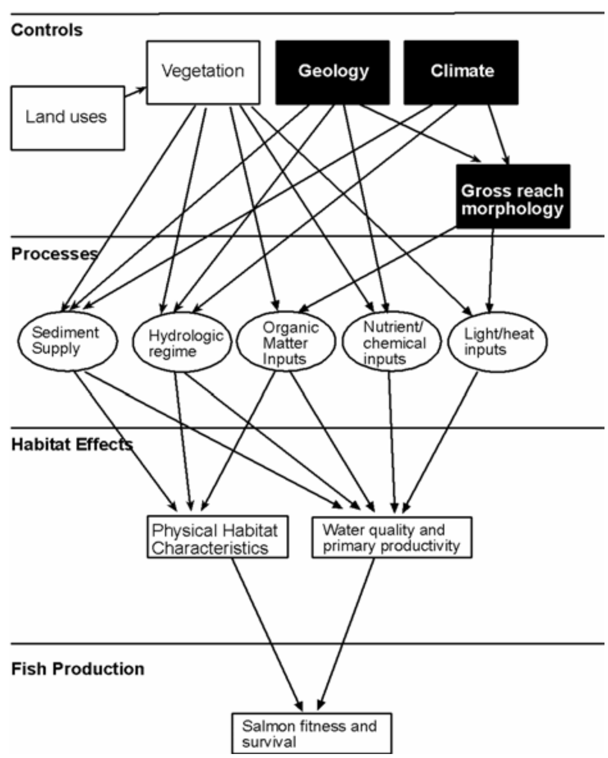

Figure 1. Schematic diagram of relationships between landscape and land use controls on habitat characteristics (via habitat forming processes), and between habitat characteristics and salmon fitness and survival.

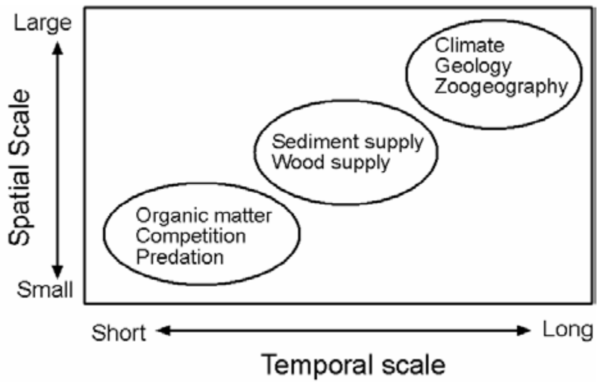

Figure 2. Spatial and temporal scales of factors that control habitat conditions and fish production in streams (adapted from Naiman et al. 1992).

Research theme 1: quantify fish responses to changes in watershed, habitat, or ecosystem conditions.

In order to predict responses of fish populations to watershed and habitat changes (ultimately what NMFS needs to conserve and recover salmon populations), we must understand how fishes utilize stream and estuary habitats. There are relatively few studies that quantify abundance, survival, and fitness of salmonids in these habitats (coho salmon *O. kisutch* are a well-studied exception), especially in large rivers where chinook salmon (*O. tshawystcha*) and steelhead trout (*O. mykiss*) are dominant species. Without such studies we are unable to develop life-stage models to help us evaluate potential effects of freshwater and estuarine habitat changes on most fish populations. Our research plan includes formalizing the structure of life-stage models for salmon, as well as collection of critical data required to parameterize and run the models. Developing these models will allow us to estimate responses of salmon populations to changes in watershed or ecosystem conditions.

We will develop fish production models at a variety of scales to meet different management needs. Landscape-scale models will illustrate broad relationships among landscape characteristics, land use, and salmon abundance. Such models can assist managers in locating areas with relatively high potential abundance and areas with relatively high restoration potential. However, they do not indicate which restoration actions are needed, or how different restoration actions will affect salmon populations. More detailed life-stage models for salmonids will provide greater insight into the effects of specific habitat changes and restoration actions. These models are based on extensive field data of fish use and survival in different habitat types, and under different ecosystem conditions or management regimes. Where possible, we will use experiments to clarify the results of our field studies, and to gain greater resolution on the degree to which different habitat or ecosystem characteristics affect anadromous fish populations.

Research theme 2: quantify the effects of natural and human disturbance on watershed processes and habitat conditions.

Immutable landscape variables (e.g., geology, valley form, and drainage network configuration) are unaffected by land use practices. They determine the range of potential habitat conditions that a specific site can exhibit, the underlying physical potential of different locations within and among watersheds. Mutable landscape and land use variables (e.g., riparian forest modification, increased landsliding) then determine the habitat characteristics expressed at a site at any point in time. Understanding these relationships is a critical step in understanding the "habitat potential" of different areas, which can be used to help identify areas where habitat protection or restoration are most likely to provide significant benefits for salmon production.

At the river basin scale ($\geq 10^4$ km^2) we rely primarily on analysis of relationships among underlying landscape characteristics, existing management regimes, and habitat conditions. Coarse resolution geospatial data sets are adequate for determining large-scale influences of such factors as geology, landforms, precipitation regimes, and land use practices on stream and river habitats and food webs. At the reach scale we require field data in order to accurately assess influences of such factors as valley form, channel morphology, riparian management regime, and water quality on physical and biological processes, and habitat characteristics. Manipulative experiments to isolate effects of individual landscape or land use characteristics on specific aspects of stream habitat or productivity are more feasible at the reach scale (~10^2 m). These experiments will help resolve ambiguities emerging from our analyses at the river basin scale.

Research theme 3:evaluate the effectiveness of watershed and habitat restoration strategies and techniques.

Many approaches and techniques for restoring salmon habitats are used in watershed management plans or as components of a salmon recovery strategy. However, it is often unclear how watershed-level or site-specific restoration actions might contribute to recovery of salmon stocks. This stems in part from limited information on the effectiveness of various habitat restoration and enhancement techniques. Unfortunately, few watershed and stream habitat restoration techniques (e.g., instream structure placement, riparian planting, road restoration, reconnection of isolated habitats, etc.) have been adequately evaluated, and there is considerable debate within the scientific community about the effectiveness of various techniques. Drawing statistically significant conclusions about the biological effectiveness of various techniques has been difficult, and this has hampered efforts to provide scientific guidance on restoration activities.

Despite these limitations, we have a reasonable understanding of the processes that affect channel morphology and create fish habitat. For example, in the coastal Pacific Northwest, the delivery of organic matter (e.g., woody debris, leaf litter, etc.), water, and sediment are major processes dictating channel morphology and the formation of salmon habitat. In the 1990s, it became widely accepted that restoring such watershed processes is the key to restoring watershed health and improving fish habitat, and many studies have described restoration strategies that emphasize on restoring these physical and biological processes. However, such strategies (e.g., road restoration, culvert removal, riparian and upslope restoration) occur at the site or reach level and a method that places site-specific restoration within a watershed context is needed to assist in prioritizing and implementing restoration.

We are and will continue to work collaboratively with other agencies to conduct and monitor watershed-wide experiments where specific land use practices are altered in an attempt to improve watershed processes, habitat characteristics, or water quality. By carefully managing the application of restoration actions (e.g., making sure that road restoration is focused so that we have control and treatment watersheds), we can evaluate the effectiveness of techniques for restoring habitat conditions, water quality, or fish populations. These results will help identify:

1) which types of restoration actions are effective at restoring salmon habitats and contributing to recovery of salmon populations, and
2) where restoration actions will have the greatest long-term benefits for salmon populations.

The information gained in understanding salmonid responses to restoration actions will inform the previous two research themes. That is, restoration actions can be treated as experimental manipulations of land uses or habitat characteristics, which can improve our understanding of the linkages among watershed process, aquatic ecosystem conditions, and salmon abundance and survival.

Research Teams

The Watershed Program is organized into three research teams, each focusing on one of the three key research themes. The three teams are:

1) Fish and Habitat Relationships Team
2) Watershed Processes and Human Disturbance Team
3) Restoration Team

Each team has identified high priority research objectives (questions) to help coordinate future research efforts, and build off our existing research. Following are the research objectives and future research areas for each team.

Fish and habitat relationships team

Successful management of Pacific salmon in the Pacific Northwest and recovery of listed species depends in part on our ability to quantify the effects of land uses on habitat and salmon populations, as well as the benefits of restoration activities on salmon survival and fitness. Our research approaches this problem along two main avenues. First, regional assessments of landscape and land use effects on salmonid populations will be used to evaluate correlations among landscape and land use attributes and fish population responses. These studies establish linkages between land uses and population responses. The development of such linkages is an important component of technical recovery planning efforts.

Second, detailed life-cycle modeling will advance our ability to predict population responses to habitat change. These models will provide scientific and data-based tools for evaluating the likely outcomes of changes in land use practices or of salmon habitat restoration efforts in the region. Because each model is driven by habitat condition (both amount and quality), we will be able to link our watershed process studies to instream habitat conditions and to fish population performance. Moreover, construction of such a model will help us evaluate a wide range of management scenarios because it relies on understanding the fundamental processes linking aquatic habitats to salmon populations.

Our field research over the next five years will focus on estimating the habitat capacity and survival for each life stage of ESA listed chinook salmon. A number of cooperative studies are near completion or in progress, including effects of flooding on freshwater survival, effects of riprap on use of mainstem river habitats by juveniles, and use of estuary habitat types by juveniles. Each provides answers to questions of immediate concern, as well as crucial data for development of the life-cycle model. Future studies must include the more detailed and difficult studies required to estimate survival in rivers and estuaries as a function of habitat type and quality. Near-term research objectives include the following:

1. *Broad-scale relationships among land uses and fish populations*. Regional salmon recovery planning efforts require the ability to rapidly evaluate impacts of various land uses on salmon habitat and populations across entire Evolutionarily Significant Units (ESUs). Two main factors inhibit detailed analyses across such large areas: field data on habitats and populations are not available across the region, and mechanisms linking land uses to populations effects are not well understood. An alternative approach is to systematically assess correlations among landscape or land use attributes and fish populations (e.g., SWAM). These studies help identify major land use factors affecting salmon populations and quantify uncertainties in the relationships.

2. *Development of a habitat-based salmon life-cycle model.* We will develop a life-cycle model that can integrate effects of different habitat changes on salmon populations. This model will be habitat-based and will have a relatively simple structure (Figure 3). We have three research goals for development of this initial model. First, produce a life-cycle model for Puget Sound chinook salmon that can form the basis for future efforts. This model will be adequate for first approximations of effects of habitat change on chinook

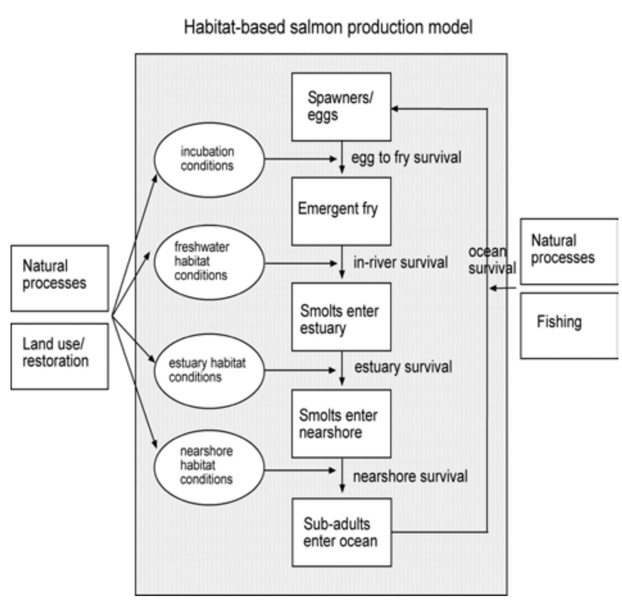

Figure 3. Schematic diagram of the simplified salmon life-cycle model.

populations. Second, collect and analyze field data needed to parameterize and update this model, including estimates of survival from life stage to life stage. These updates will increase reliability of the basic model. Third, design additional model elements that incorporate biological processes and life-history patterns. At each step we will evaluate whether increasing the complexity of the model results in increased accuracy or sensitivity.

3. *Quantifying stage-to-stage survivals for salmonids in freshwater and estuaries*. This is the greatest data gap in virtually all salmon modeling efforts at present (with the possible exception of coho salmon). This task may require adaptation or development of marking techniques for small juvenile salmon, evaluations of statistical methods suitable for estimating survival rates, studies of migration patterns and cues at different life stages, and potential refinement of capture techniques.

4. *Influence of spatial structure (habitat and population) on population responses to habitat change*. We are initially concerned with three aspects of habitat use by salmonids and their effects on population dynamics: spatial structure of salmon populations and their habitats, habitat-specific density dependence, and habitat selection by salmon. Initial investigations will employ a combination of life-cycle modeling and field data. Field studies and experiments will later be required to understand mechanisms and processes that explain observed patterns and their effects on the dynamics of salmon populations.

5. *Effects of changes in habitat quality on salmonid abundance and survival*. Research will focus on effects of changes in habitat quality (e.g., stream productivity, stream temperature) on salmonid abundance and survival. Studies will include research on sub lethal effects and delayed mortality. Field studies and experiments to systematically address influences of productivity and stream food web structure on growth and survival of salmonids are currently underway.

6. *Climate change effects.* Models of global climate change predict lower precipitation and higher temperature regimes in the Pacific Northwest, and therefore higher stream temperatures and increased freshwater eutrophication. As these influences can have significant effects on Pacific salmon and their competitors, we will initiate studies to evaluate impacts of large-scale environmental change on the long-term performance of salmon populations.

7. *Analysis of fish density data.* Nearly all studies of habitat use by salmonids require analysis of data on fish density. These data often have a random denominator (e.g., pool area) as well as a random numerator (e.g., number of fish). In addition, there are often many more zero observations than one might expect for common statistical distributions. Interpretation of such data requires careful consideration of underlying assumptions. Research is underway to assess the best methods of analyzing fish density data and the implications of a range of biological and ecological assumptions.

Ecosystem processes and human disturbance team

The Pacific Northwest is a highly dynamic landscape where natural processes such as debris flows, floodplain development, and organic matter export vary in space and time. Pacific salmon adapted to and thrived in this landscape. However, land use activities such as logging, farming, and urban development have significantly affected these processes. As a result, a large proportion of the freshwater habitat that Pacific salmon depend upon is degraded. Little is known, however, regarding how natural processes affect the formation and maintenance of salmonid habitat, and ultimately the distribution, abundance, growth and survival of Pacific salmon. We also know little about how subsystems within a watershed interact, effect downstream reaches, or the cumulative effects of various activities throughout watershed or basin.

Our research focuses on understanding how natural processes within a watershed (from headwaters to nearshore) affect the formation of salmonid habitat, the growth and survival of Pacific salmon, and how land use activities affect these response variables. We will link our research directly with the life cycle model being developed by the Fish and Habitat Relationships Team. Specifically, the life cycle model will provide hypotheses for subsequent studies by our team, the results of which will then be used to further refine models. Hence, we envision a tight coupling between field studies, experiments, and mathematical models. This approach will allow us to develop tools to evaluate and predict the effects of different land uses on habitat, productivity, and ultimately biota.

We have several ongoing projects including: examining riparian buffers, landscape attributes of riparian vegetation and ecosystem function, timber harvest and stream functionality, effects of urbanization on nearshore and estuarine conditions and biota, function of headwater streams, and effects of floodplain development on physical and biological characteristics of rivers. In addition to these studies, over the next five years, we will focus on the following key research questions:

1. *Watershed-scale management practices*. Cumulative effects of multiple land use practices within a watershed impact streams in different ways, depending on the type, frequency, and spatial distribution of such activities. By analyzing watershed patterns of land use (e.g., road density, forest age distribution) and patterns

of natural features (e.g., geology, geomorphology, precipitation) and comparing them with stream habitat conditions, we can gain insights into the types of spatial and temporal patterns of land use activities that are compatible with high quality conditions.

2. *Urban stream systems*. Perhaps nowhere are the natural processes that contribute to the formation of freshwater habitat disrupted more profoundly and irrevocably than in urban basins where forested landscapes are replaced with roads, rooftops, and other impervious surfaces. Despite the fact that urban sprawl is increasing across the Pacific Northwest, there has been very little study of urban streams from an ecological perspective. In order to craft effective restoration and conservation strategies, we need greater knowledge of what species (native and non-native) live in these systems, how they interact within the heavily modified stream environment, and how biota respond to urbanization and the specific stressors that accompany such change. In particular, two arenas in which greater research would be particularly valuable are the role of riparian corridors in urban landscapes and the relationships between biological indicators of stream health and specific measures of habitat alteration. This will be linked to our ongoing research examining the effects of urbanization on estuarine and nearshore habitats.

3. *Lowland river ecology*. Most of the research on stream salmonids has occurred in relatively high elevation forested watersheds. In contrast, little is known about how natural processes affect habitat formation and salmonids in lowland river reaches. This discrepancy is problematic, as most fish production occurs in low elevation rivers. In addition, these regions are impacted by a variety of land uses (primarily agricultural and urban), and very little is known about the impacts of farming or urbanization on natural processes. For this research, we will begin to collect baseline information on natural processes, habitat, and salmonids in large river systems areas in relatively pristine areas and on lands impacted by land uses. We are initiating several projects to investigate large river processes, including the transport of nitrogen from farms into surface waters, morphological controls on the dynamics of floodplain ecosystems, and food web dynamics associated with logjams.

4. *Influence of nutrients and light on stream food webs and salmonid growth and survival* Although much is known regarding physical habitat and fish abundance, there is relatively little known about how nutrients or light regime affect salmon populations or how these abiotic resources interact with habitat to affect salmonids. In this research, we will use a combination of natural gradients (e.g., gradients in nitrogen concentration in natural streams), field experiments, and mesocosm experiments to examine how resources and habitat interact to affect the growth and survival of stream salmonids. We will use models developed by the Fish and Habitat Relationships Team to help in formulation of hypotheses; the design of these experiments; the types of data to collect; and interpretation of results. Similarly, we will work with the Restoration Team to examine how addition of organic and inorganic nutrients, such as salmon carcasses can alter stream productivity. Data from these studies can then be used to further refine life cycle models developed by the Fish and Habitat Relations Team. Existing studies include examining how riparian buffers affect stream ecosystems, and landscape attributes of riparian vegetation and stream ecosystem structure and function.

5. *Linkages between physical and biological diversity*. In the Pacific Northwest, salmon have adapted to a highly dynamic landscape where stochastic processes form and sustain their habitats. However, these processes and their effects on biological diversity are poorly understood. For example, recent studies have shown that mainstem habitat is more diverse (e.g., higher substrate heterogeneity) downstream of tributary junctions compared to upstream. Biological diversity can also be higher downstream of these junctions, as a result of higher physical diversity. However, land use activities such as logging, farming, and urban development have significantly affected these linkages. This research area will systematically examine linkages between physical diversity, biological diversity, and fish production, and how land use alters these linkages.

The goal of each of these five research areas is to advance our understanding of linkages among natural processes, habitat, and salmon growth and survival. Although we know a tremendous amount about how salmon use different types of habitat, we know almost nothing about the mechanisms driving these patterns or how survival is related to habitat quantity or quality. We also know very little about the natural rates of variation in the processes that create, maintain, and ultimately degrade stream habitat, or how long it takes for streams in degraded watersheds to return to properly functioning conditions under various management strategies. Hence, our long-term goal is to fill many of these gaps.

Restoration Team

Our research focuses on understanding how site-specific and watershed-wide restoration actions affect watershed processes, stream productivity, the formation and maintenance of habitat, and the growth and survival of salmonids. We will link our research directly with the life cycle model being developed by the Fish and Habitat Relationships Team and the work done by the Ecosystem Processes and Human Disturbance Team. This approach will allow us to evaluate the effects of different restoration activities on stream productivity and salmonid response, identify which types of restoration actions are effective, and where restoration will have the greatest long-term benefits in salmon production.

Our general goal is to identify how stream and salmonid productivity is influenced by site-specific and watershed-scale habitat restoration efforts. Currently, we have a number of key research projects ongoing that address linkages between watershed restoration activities, stream structure and function, and fish response. We will use the salmon life cycle models developed by the Fish and Habitat Relationships Team in the design of these projects. Biological data from preceding studies can be used to help fill the gaps of knowledge in such life cycle models. Over the next five years, we will continue to address these linkages and focus on the following key research questions:

1. *Small stream restoration: effects of wood and boulder placement on primary productivity and fish in small streams.* The restoration of freshwater habitat through the placement of wood and boulders has become a common method for restoring salmon habitat. Unfortunately, comprehensive evaluation of these projects is lacking. The objective of this project is to evaluate the biotic responses to the placement of wood and boulders in small streams in the Pacific Northwest. While our ongoing studies have examined changes in abundance associated with restoration activities, our future research will focus on examining the effects of restoration on both fish movements and survival; the ultimate measures of restoration effectiveness. These estimates of survival will be used in the salmon life cycle models being developed by the Fish and Habitat Relationships Team.

2. *Restoration of large rivers: Influence of engineered logjams in large rivers on primary productivity and fish response.* The restoration of freshwater habitat in larger river systems through the placement of large logjams is becoming a larger component of bank protection and salmon habitat restoration efforts. We will evaluate how these large logjams redistribute adult salmon, and how they affect juvenile salmon use and growth rates, and macroinvertebrate response. Similar to the project on small streams, we will also examine fish movements and survival among in rivers with a and without engineered logjams.

3. *Floodplain restoration: comparison of natural to constructed floodplain channels.* The loss of important off-channel rearing habitat in large and small alluvial rivers has lead to increased emphasis on reconnecting isolated habitats and constructing off-channel ponds. The objective of this project is to evaluate the effectiveness of reconnected and artificially created off-channel ponds and assess their contribution to basin-wide salmon production. This study in combination with a study on floodplain dynamics will be used to develop comprehensive guidelines for floodplain restoration.

4. *Dam removal: effects of changing sediment supply on habitat formation and biological response.* Despite long-standing concerns about effects of increased sediment supplies on salmonid rearing habitats, there have been no direct measurements of reach-level effects of altered sediment supply on rearing habitat formation. Our study will capitalize on alteration of sediment supply before and after removal of the Elwha River dams in order to assess effects of changing sediment supplies on rearing habitat. The study sites downstream of the dam include reaches with and without wood in order to quantify the interactive effects of sediment and wood on habitat formation.